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Abstract: Customer co-creation, the practice of involving the customer in a firm's new product development, has received increasing attention. We develop a unique analytical model to study co-creation and examine the conditions under which co-creation is economically beneficial for both the customer and the firm. In our model, the customer and the firm determine (simultaneously or sequentially) their innovation share in the co-created product, directly affecting their share in the development costs and the final co-created product quality. The firm decides the product price (affecting customer demand, firm revenues and customer purchasing costs) and its level of manufacturing flexibility (affecting its unit production cost and fixed investment). Our model generates new and important insights. We show that when the consumer surplus and firm profit are both positive, both the customer and firm want to "engage" in co-creation, and when either the customer or the firm obtains a negative economic value from co-creation they prefer to avoid co-creation. We find that co-creation thrives when customers are more sensitive to quality and less sensitive to price, the environment is less investment intensive, and demand for the product is high. Under these conditions, the co-created product quality and the firm's flexibility increase. How innovation efforts are shared between the customer and the firm is an important instrument to guide the co-creation process. When the customer is first to contribute to co-creation, our results show that both the customer's share in the innovation effort and the final co-created product quality increase.

Keywords: customer co-creation; flexibility; product development effort

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1 Introduction

Customer co-creation, also called "co-design" or "co-development", is a product development approach in which customers actively take part in the design of their product (Prahalad and Ramaswamy, 2004; Wallace, 2010). Firms have turned to co-creation to better identify and fulfill customer needs, increasing new product success (Franke et al., 2009; Randall et al., 2007; Zhang and Chen, 2008). Several success stories of business-to-consumer (B2C) co-creation exist, such as MiAdidas and NIKEiD, in which customers can design their personalized shoes online using a variety of materials and colors; Threadless, which markets customer-designed T-shirts; and Lego Ideas, in which customers can suggest new Lego sets online (Piller et al., 2012; Schreier et al., 2012).

A wealth of research has discussed the advantages of co-creation, assuming that co-creation creates value for both the customer and the producer (Leclercq et al., 2016; Mahr et al., 2014; Payne et al., 2008). However, little research attention has been devoted to the case when co-creation becomes unfavorable for either the customer or the firm (Gemser and Perks, 2015; Weber and Van der Laan, 2014). In some companies, co-creation does not deliver the desired outcome (e.g., the failure of Mattel's My Design Barbie program). Therefore, in this article, we answer the following main question: Under which conditions is co-creation beneficial for both the firm and customer? Specifically, we examine when co-creation is no longer economically beneficial for either the customer or the firm or both? (i.e., leads to a negative consumer surplus or a negative firm profit), in which environments co-creation thrives (i.e., the likelihood of mutually beneficial co-creation and the co-created product quality increase)? and how innovation efforts should be shared between the customer and the firm?

To answer these questions, we develop a unique analytical model. We model a firm collaborating with its customer for the development of a new product (i.e., a B2C setting). We consider the consumer surplus and firm profit - two well-accepted economic measurements, embedded in welfare economics (Hausman, 1981; Willig, 1976) - to measure the economic benefit or gain after collaboration of the customer and firm respectively (these measurements are also used in, for instance, the work of Syam and Pazgal (2013), Syam et al. (2005) and Baldwin et al. (2006)). We calculate the consumer surplus as the difference between the customer's willingness to pay and the price, for different quantities of a product, based on the (aggregate) demand curve, minus the development costs, while we calculate the firm's profit, seen as the producer surplus, as their revenues minus the production, fixed investment, and development costs.

On the one hand, the customer and firm decide (either simultaneously or sequentially) *their innovation or (R&D) development share* in the co-created product, affecting the final product quality and how development costs are shared. For example, at Lego Ideas, a well-known co-creation initiative, the customer builds a prototype for a new Lego set, while the firm takes care of the later stages of design if the set is accepted for commercialization (Lego, 2018). At Adidas, customers are only involved in the later stage of the innovation cycle in which they can choose from a predefined range of options to customize their shoe, referred to as mass customization (Alptekinoğlu and Corbett, 2008; Fogliatto et al., 2012; Piller, 2007). Note that not only the sequence of who contributes first to the product development changes over different co-creation initiatives, but also the intensity of the customer's innovation contribution can range from being a source of information to being a real co-developer or creator (i.e., the customer innovation share can be small or large) (Cui and Wu, 2016; Hoyer et al., 2010).

On the other hand, the firm individually decides its level of *manufacturing flexibility* and the *price* charged for the product. The former affects the firm's variable production cost and fixed investment, while the latter affects the firm's revenues and the customer's purchasing cost. As an example of a manufacturing flexibility decision, Adidas has invested significantly in its Speedfactories to obtain a flexible automated digital manufacturing process to efficiently produce customized shoes (Kim, 2018). Note that in our model we consider an endogenous demand and a monopolistic firm.

Our analytical B2C co-creation model is an important contribution to the literature. It answers the call of Syam and Pazgal (2013) for more economic models on co-creation, as conventionally co-creation has been studied using experimental methods, case studies, surveys, or conceptual frameworks, and has been looked at from a business-to-business perspective (Gemser and Perks, 2015; Leclercq et al., 2016). Our model is also the first to include firm flexibility. It allows to study co-creation from a general perspective, and it forms a reference base for future co-creation studies.

Our results contribute to the literature in three ways. First, we examine the conditions under which co-creation is beneficial for both the co-creating customer and the firm. We partition the firm's manufacturing flexibility–joint co-created product quality space in different regions where co-creation is mutually beneficial, where both the customer and the firm want to escape co-creation (i.e., both parties obtain a negative economic value from co-creating), and where either the customer or the firm wants to escape co-creation (one of the parties obtains a negative value from co-creating). We show the boundary conditions for co-creation to be mutually beneficial and find that there is both a minimum and maximum level of manufacturing flexibility, that there is a minimum demand needed, and that the co-created product quality is limited by both the customer and the firm.

Second, we discuss the co-created product quality and the firm's operational flexibility levels as an outcome of the co-creation process, and discuss the business settings where the likelihood for a mutually beneficial co-creation increases. We find that co-creation thrives for initiatives in environments in which customers are sensitive to quality and not to price, customer demand for the product is high, and investment intensity is low. Moreover, we find that the co-created product quality is higher when the customer is the first to contribute to the co-creation, rather than the firm.

Third, we also discuss how sharing the innovation effort between the customer and the firm is an instrument to guide the co-creation process. We find that the customer's innovation share in the co-created product increases when the customer, rather than the firm, is first to contribute to the co-creation. This effect is further intensified in environments in which co-creation thrives (see second contribution).

Our model stems from a managerial need to explain co-creation success or failure and to identify when co-creation is beneficial for the customer and firm. Our insights help (1) explain and predict the co-creation success or failure of different co-creation initiatives (e.g., see the discussion in the "Managerial Insights" section), (2) advise companies in which environments co-creation initiatives are best launched, and (3) suggest how innovation efforts in the co-created product should be shared. Overall, our intention is to help companies and their customers gain insights into their co-creation process and to offer an analytical co-creation model on which future co-creation research can build.

2 Relevant Literature

Our work mainly contributes to the streams of literature on co-creation, mass customization, flexibility, and (joint) new product development, in which research is scattered across the fields of management, marketing, innovation, and operations.

Co-creation has received increasing attention from researchers and practitioners over the past years (see the reviews of Bendapudi and Leone (2003), Alves et al. (2016) and Gemser and Perks (2015)). Following the service dominant logic, co-creation implies that customers are not just recipients of a good, but actively engage in the customer-supplier relationship and innovation process, and are actual co-creators of value (Grönroos, 2011; Lusch and Vargo, 2006; Payne et al., 2008; Prahalad and Ramaswamy, 2000; Vargo and Lusch, 2004).

Value co-creation can refer to different types of value (e.g., monetary gains or social benefits for the firm or customer), different processes (e.g., co-creating firms or a firm co-creating with its customer), and different actors (e.g., lead users, a crowd of customers, communities, ...)(Franke et al., 2008; Jeppesen, 2005; Saarijärvi et al., 2013). In user innovation literature, lead users are well-known to have a higher competence and engagement to co-create, and a larger potential to develop more innovative and radically new products (Hamdi-Kidar et al., 2019; Vernette and Kidar, 2013). Moreover, some studies have also considered the impact of the network organization and externalities. For instance, Syam and Pazgal (2013) find that a centralized pattern of externalities among customers (with an expert lead user in the center) positively affects firm co-creation profit, and Baldwin et al. (2006) consider a redundancy reduction thanks to communities.

All these studies have contributed to our knowledge on co-creation, however, there is still a lot to learn on how firms and customers engage in the co-creation process and manage the co-creation of value (Payne et al., 2008; Ulaga, 2003).

While majority of co-creation studies emphasize the benefits of co-creation (Alves et al., 2016; Gemser and Perks, 2015), they ignore situations when co-creation is not beneficial, a gap we aim to fill. The few studies that do consider downsides of co-creation mainly focus on the costs related to finding and interacting with customers (e.g., by setting up information systems to communicate with customers) (Franke and Piller, 2004; Mahr et al., 2014; Syam and Pazgal, 2013), the risk of disappointed customers if the co-designed product fails to meet their expectations (Heidenreich et al., 2015), or value co-destruction (Plé and Chumpitaz Cáceres, 2010).

In this article, we develop an analytical model (thereby answering the call of Syam and

Pazgal (2013) for more economic co-creation models) to assess the conditions that drive co-creation to be economically beneficial for either the collaborating customer or the firm or both.

While certain studies consider 'subjective and social' co-creation value (such as an increased customer status, joy, accomplishment, social esteem and knowledge, or firm reputation) (Franke and Schreier, 2010; Fuchs and Schreier, 2011; Nambisan and Baron, 2009), or consider value as the customer's value-in-use related to the customer's longitudinal experience during consumption and usage (Grönroos and Voima, 2013; Ranjan and Read, 2016); our analytical model compels the focus on (modelable and measurable) economic gains of the customer and firm (measured through consumer surplus and profit respectively). The focus on economic benefits is in line with the work of, for instance, Ueda et al. (2008), Grönroos (2011), Baldwin et al. (2006) and Syam and Pazgal (2013). Ueda et al. (2008) present a value-creation model, including the producer's profit and the consumers' utility gain, to study provided, adapted and co-creative value; Grönroos (2011) develops a framework to measure mutually created value by considering jointly created productivity gains; Baldwin et al. (2006) model the pathway of how user innovations become commercialized products, using consumer surplus and firm profit; and Syam and Pazgal (2013) study the effect of production externalities on co-creation depending on the network organization, also including consumer surplus and firm profit in their model.

Although flexibility can play a primary role in co-creation (Syam and Pazgal, 2013; Zhang et al., 2011), to the best of our knowledge, we are the first to model the relationship between a firm's manufacturing flexibility decision and the success of co-creation analytically. This operational lens contributes to current co-creation literature, which has mainly taken a marketing or innovation perspective (Gemser and Perks, 2015).

A vast body of literature has examined operational flexibility (for a review, see Yu et al. (2015)), defined as the ability to change or react with little penalty in time, effort, costs, or performance (Upton, 1994) and to deal with risk (Sreedevi and Saranga, 2017). We argue that a firm's manufacturing flexibility is driven by the fixed investments therein and that it leads to an easier (i.e., less costly) derivation of a new product in production. This follows a similar logic to that of Van den Broeke et al. (2018), who argue that flexibility (in platforms) increases fixed investments but reduces the unit cost to obtain a product. That study fits in the broader literature stream of product development (for a review of that literature, see Krishnan and Ulrich (2001)).

We draw inspiration from the product development literature to model the different costs involved in product design. For example, similar to the innovation sharing model of Bhaskaran and Krishnan (2009) and the platform evaluation model of Krishnan and Gupta (2001), we consider product quality as an indicator of innovation. In our model, we distinguish between the consumer surplus and the firm profit, something that is also common in the literature on collaborative product development, R&D collaborations, and investment sharing. For example, Bhaskaran and Krishnan (2009) examine investment, revenue, and innovation sharing as inter–firm mechanisms to manage risk and uncertainty in joint new product development (e.g., in a B2C environment in which a biotech and pharmaceutical company work together). While some studies focus on the impact of contractual structures on the R&D partnership's success (Bhattacharya et al., 2014; Savva and Scholtes, 2014), in our analysis, we examine how sharing development efforts between the customer and the firm serves as an instrument to guide the co-creation success.

3 The Model

In this section, we develop an analytical B2C model with recourse to a firm (f) collaborating with its customer (c) for the development of a new product. We assume a development collaboration with only one customer (or a group of customers with similar characteristics, so that they appear as one customer), a monopolistic firm (i.e., we do not consider competition), and assume that both the customer and the firm are risk neutral. In our main model, to avoid unnecessary complexity, we do not explicitly consider the network context, a simplification also applied in the work of Grönroos (2011) and Grönroos and Voima (2013). However, in Appendix, we do present an extension of our main model in case other customers buy the co-created product (seen as a positive externality), or multiple customers contribute to the co-creation.

Our model includes the consumer surplus (CS) and the profit of the firm (Π_f) to assess the benefits from co-creation for the customer and the firm.

First, the consumer surplus is positively driven by the difference between its *willingness to pay* and the *price* for the product, and its product *demand*. Demand D is modeled endogenously, using the demand curve $D = \alpha - \beta P + \gamma\theta$ (based on Banker et al. (1998)), with α the intrinsic demand potential for the firm, β the sensitivity to the unit product price P, and γ the sensitivity to the product quality θ. Derived from the demand curve, the value for the customer obtained from buying the product is given by the consumer surplus (see Hicks (1939) and Moorthy (1984)), and in our model equals $\left(\frac{\alpha+\gamma\theta}{\beta} - P\right) * \frac{D}{2}$. The firm's *revenues* from selling the product increases with a higher demand and selling price, and is simply given by $P * D$.

Second, the customer and the firm each decide on their effort in the new product development (i.e., their innovation share in the co-created product innovation); represented by θ_c and θ_f, respectively. For reasons of simplicity and ease of interpretation, in our main model, we do not consider a difference in quality appreciation γ between the innovation contribution of the firm θ_f and the customer θ_c, and assume γ to be positive. In Appendix, we present an extension of our main model where we allow the customer to have a different quality sensitivity for the firm's and customer's innovation effort, denoted by γ_f and γ_c respectively, leading to the following demand $D = \alpha - \beta P + \gamma_c\theta_c + \gamma_f\theta_f$. While some studies have argued a higher quality appreciation for products that are self- or user-designed (i.e., $\gamma_c > \gamma_f$) (Franke and Schreier, 2010; Schreier et al., 2012), others have argued that for certain product categories, such as luxury fashion brands, there is a negative effect of user-design (i.e., $\gamma_f > \gamma_c$, where

γ_f can be higher than for mainstream fashion brands and γ_c can even be negative) (Fuchs et al., 2013).

In our analysis, we consider three scenarios: one where the customer and the firm simultaneously decide their development effort, and the two scenarios where either the customer or the firm is first to determine its development effort (i.e., sequential decision making). The customer's and firm's development effort θ_c and θ_f affect the final co-creation outcome, that is, the product quality θ, with $\theta = \theta_c + \theta_f$. The customer's and firm's share in the final co-created product are given by $1 - \lambda$ and λ respectively, with $\theta_c = (1 - \lambda)\theta$, $\theta_f = \lambda\theta$, and $\lambda \in [0, 1]$. Note that in product development literature, product quality is commonly used to represent the level of innovation and the products' functionalities and features (see Tatikonda and Montoya-Weiss (2001), Bhaskaran and Krishnan (2009) and Heese and Swaminathan (2006)).

In line with the innovation sharing model of Bhaskaran and Krishnan (2009), *development costs* in our model are given by the polynomial function $I_d\theta_c^2$ and $I_d\theta_f^2$ for the customer and the firm respectively, with I_d equal to the investment parameter for product development (i.e., a higher I_d means a more investment–intensive environment for product development). In Appendix, we also extend our main model and analyze what happens if the development cost for the customer would differ from that of the firm, denoted respectively by I_d^c and I_d^f. The development cost of the customer might decrease (and be lower than that of the firm, with $I_d^c < I_d^f$), e.g., when involving a lead user in the co-creation, rather than an ordinary customer (Hamdi-Kidar et al., 2019).

For simplicity, and without loss of generality, we do not model interaction costs (see Bhaskaran and Krishnan (2009) who model an interaction cost that is increasing in the level of innovation undertaken by both parties). This assumption implicitly creates a benefit of co-creation in our model, since our total development costs, given by $I_d\theta_f^2 + I_d\theta_c^2 = I_d\lambda^2\theta^2 + I_d(1-\lambda)^2\theta^2 = I_d\theta^2(2\lambda^2+1-2\lambda)$, are always equal or smaller than the development costs if either the customer or firm develops the product alone, given by $I_d\theta^2$ (since $2\lambda^2+1-2\lambda$

with $\lambda \in [0,1]$ is always smaller than 1). Including interaction costs, analogous to Bhaskaran and Krishnan (2009), would change the total development costs to $(I_d + K)(\theta_f^2 + \theta_c^2) = (I_d + K)\theta^2(2\lambda^2 - 2\lambda + 1)$, which is not necessarily smaller than $I_d\theta^2$ if K is sufficiently high. The co-creation benefit we assume is realistic because of collaboration and specialization benefits, or because of economies of integration (Piller et al., 2004).

While the co-creation benefit for the customer is driven by the valuation of the product, and the purchasing and development costs, the firm's profit is driven by revenues and development costs, but also by the production cost and fixed operational investment, both of which depend on the firm's manufacturing flexibility decision. As we assume that production occurs in-house, the production cost and investment in operations are not shared with the customer.

Achieving a higher level of flexibility requires that the firm invests more up front (e.g., in its facilities). Given the natural assumption of decreasing marginal returns from investments (Van Mieghem, 2007), the *firm's investment in flexibility* equals $\frac{I_p}{C_p}$, where I_p indicates the investment parameter for operational flexibility and a lower C_p indicates a higher level of flexibility (i.e., the smaller C_p, the higher is the level of flexibility, and the faster is the increase of investment therein). We assume that the firm's unit production cost C_p decreases as the firm's level of operational flexibility increases. In a similar vein, Van den Broeke et al. (2018) assume that a higher level of (platform) flexibility increases fixed investment, but lowers the variable production cost to obtain a product. The *firm's production cost* is simply given by $C_p * D$.

As a result, the consumer surplus (CS) and the profit of the firm (Π_f) are given by

$$CS = \left(\frac{\alpha + \gamma\theta}{\beta} - P\right)\frac{D}{2} - I_d\theta_c^2, \tag{1}$$

$$\Pi_f = (P - C_p)\,D - \frac{I_p}{C_p} - I_d\theta_f^2. \tag{2}$$

The sequence of decisions in the co-creation process between the customer and the firm

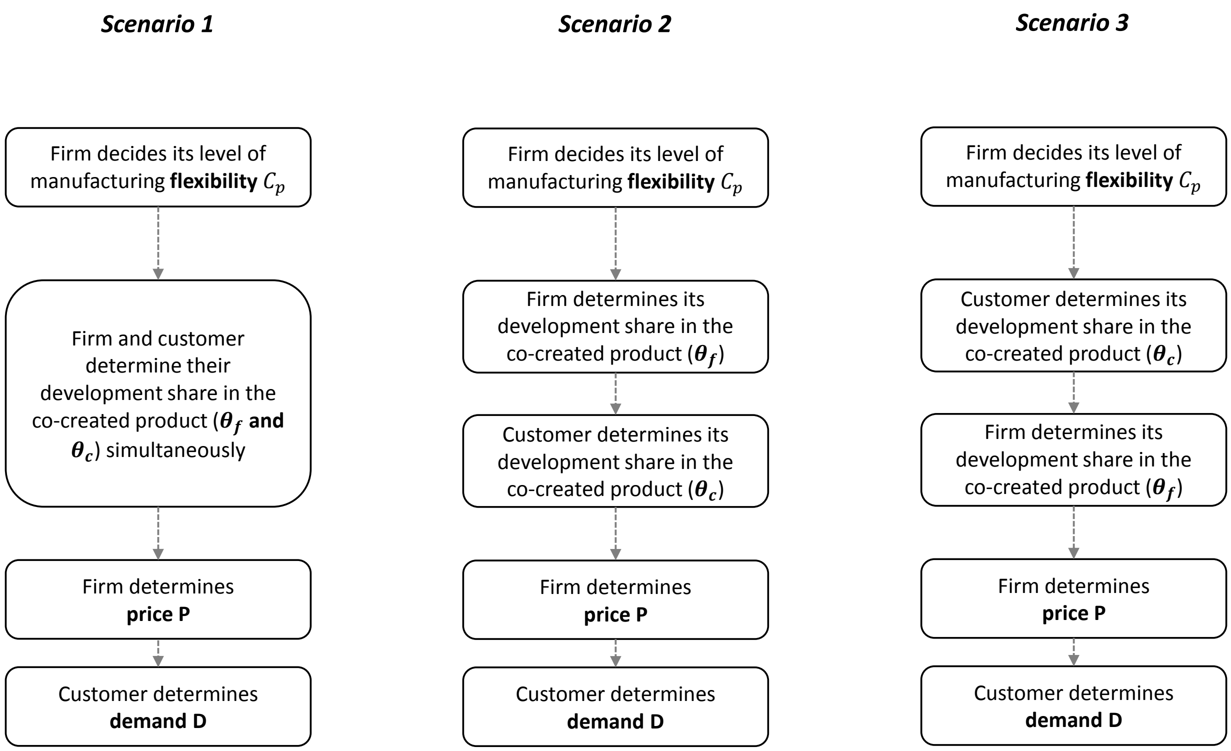

Figure 1: Decision timeline of the co-creation process.

is shown in Figure 1. At first, the firm decides its level of manufacturing flexibility C_p. This is a long term decision, which is more difficult to change. The firm and customer then co-create (i.e., share development efforts θ_c and θ_f in the final product θ), either simultaneously (scenario 1) or sequentially (scenario 2 and 3). Subsequently the firm decides price P and the customer responds with its product demand D.

The customer and the firm make their decisions (D, P, θ_c, θ_f and C_p) to maximize their benefit (i.e., CS and Π_f respectively). Note that we assume that the customer and the firm will only engage in co-creation when CS and Π_f are positive.

Filling in the demand curve $D = \alpha - \beta P + \gamma\theta$, (1) and (2) become:

$$CS = \left(\frac{\alpha + \gamma\theta}{\beta} - P\right)\frac{(\alpha - \beta P + \gamma\theta)}{2} - I_d\theta_c^2, \tag{3}$$

$$\Pi_f = (P - C_p)(\alpha - \beta P + \gamma\theta) - \frac{I_p}{C_p} - I_d\theta_f^2. \tag{4}$$

The first-order condition characterizing price that maximizes firm profit (4) is $\frac{\partial \Pi_f}{\partial P} = \alpha - 2\beta P + \gamma\theta + \beta C_p = 0$. Since $\frac{\partial^2 \Pi_f}{\partial P^2} = -2\beta < 0$, the profit function is concave in price. This leads to the following price decision by the monopolistic firm:

$$P^* = \frac{\alpha + \gamma\theta + \beta C_p}{2\beta}. \tag{5}$$

The corresponding CS and Π_f, after inserting P^* back into (3) and (4) are:

$$CS = \frac{1}{8\beta}(\alpha + \gamma\theta - \beta C_p)^2 - I_d\theta_c^2, \tag{6}$$

$$\Pi_f = \frac{1}{4\beta}(\alpha + \gamma\theta - \beta C_p)^2 - \frac{I_p}{C_p} - I_d\theta_f^2. \tag{7}$$

In the next section we assess under which conditions co-creation is mutually beneficial and determine the co-created product quality, flexibility, and innovation share of the customer and the firm under the three scenarios discussed in Figure 1.

4 Analysis

4.1 Boundaries for mutually beneficial Co-creation

From the expressions (6) and (7), we can derive the boundary levels of the jointly co-created product quality θ in function of the firm's flexibility C_p so that both the customer c and firm f economically benefit (i.e., CS and $\Pi_f \geq 0$):

Following the proof in Appendix, we propose:

Proposition 1. *Co-creation is beneficial for both the customer and the firm when* $\theta \in [\underline{\theta^c}, \overline{\theta^c}] \cap [\underline{\theta^f}, \overline{\theta^f}]$*; otherwise either the customer or the firm or both want to "escape" co-*

creation rather than engaging in it. We refer to expressions (19) *and* (20) *in Appendix for the calculations of these boundaries.*

Proposition 1 confirms that co-creation does not always lead to a positive value for both the firm and the customer. It also follows that

Corollary 1. *There is a minimum and maximum level of flexibility ($\underline{C_p}, \overline{C_p}$) for mutually beneficial co-creation.*

Corollary 2. *There is a minimum level of demand ($\underline{\alpha}$) for mutually beneficial co-creation.*

Corollary 3. *Both the customer and firm limit the co-created product quality ($\overline{\theta^c}$ and $\overline{\theta^f}$).*

Note that the condition in Corollary 2 (see expression (21)) becomes more stringent for higher price sensitivity β, lower quality sensitivity γ, and higher investment in product development and flexibility (I_d and I_p). This can be an important insight in practice because it means that for firms that deal with customers that are sensitive to price rather than to quality (e.g., firms focusing on a low-end rather than a high-end customer segment) or for firms that are in an investment intensive environment in terms of development and manufacturing (e.g., companies in electronics), customer co-creation is less likely to be mutually profitable, unless the co-created product can elicit higher demand. In extreme cases, if the base demand for a product α is lower, and if the users negatively appreciate co-development efforts of other users (e.g., luxury fashion brands), involving customers in product development might not be optimal (as illustrated by Fuchs et al. (2013)).

In Figure 2, we visualize the intervals of Proposition 1 in the "product quality–flexibility " space, in which higher θ refers to a higher quality of the co-created product, and lower C_p refers to higher (operational) firm flexibility. We show the region Ω_b where both the surplus of the customer and the profit of the firm are positive (leading to an incentive for both to engage in co-creation), the regions where either the customer or the firm obtains a negative value and therefore want to escape co-creation (resp. Ω_f and Ω_c), and regions where neither partner has a benefit and both want to escape co-creation (i.e., regions Ω_n). We treat the

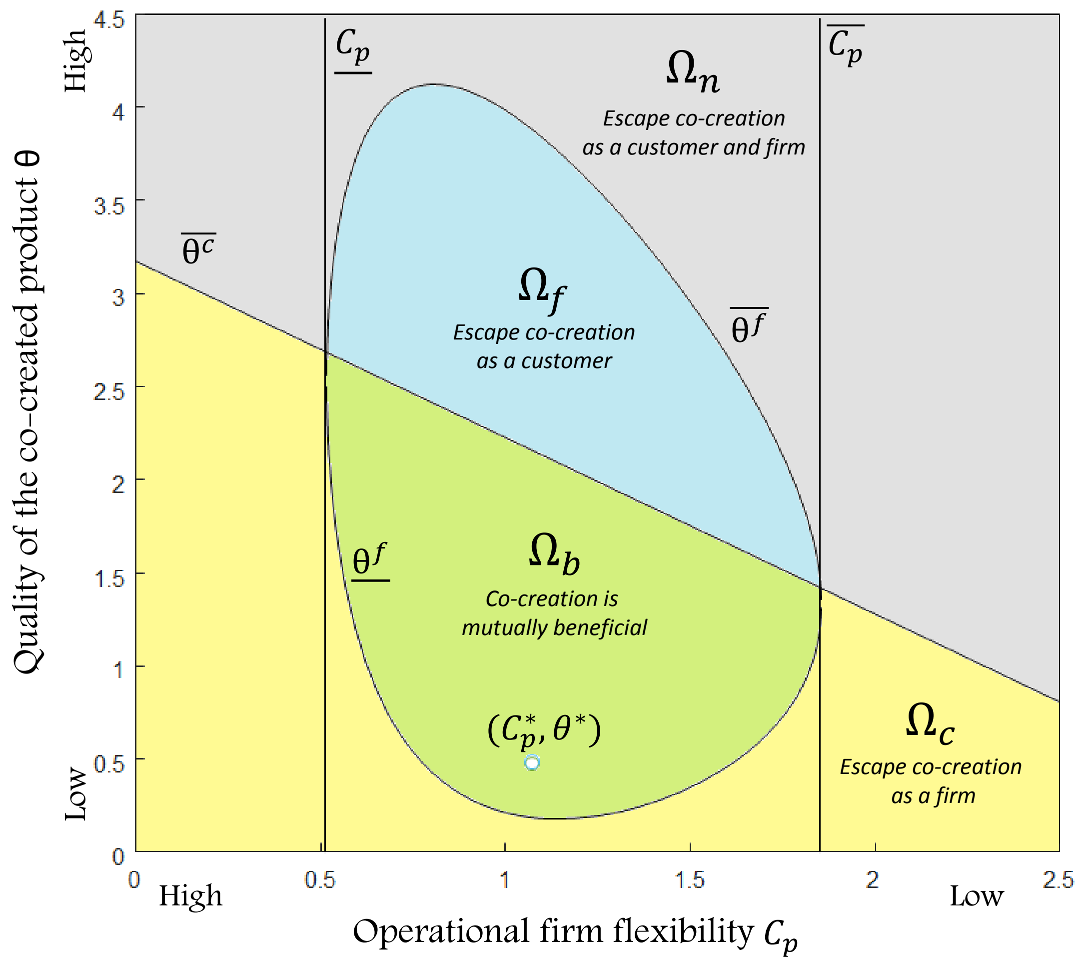

Figure 2: The firm's flexibility and the co-created product quality determine whether co-creation is beneficial for both the customer and the firm (i.e., in the region Ω_b). We also indicate the optimal levels of flexibility and product quality (C_p^*, θ^*). The figure is constructed given $\beta = 2$, $\gamma = 1$, $I_d = 2$, $I_p = 3$, $\alpha = 6.7$, and $\lambda = 0.45$.

size of Ω_b as the likelihood of co-creation: the larger the region, the higher is the probability that co-creation will occur. Note that (looking at Figure 3), similar to our discussion earlier on the requirements of $\underline{\alpha}$, we find that mutually beneficial co-creation is more likely (i.e., the size of Ω_b increases) in quality sensitive environments with low investment intensity.

In Figure 2 we also indicate the final levels of flexibility and product quality (C_p^* and θ^*) resulting from the co-creation. Note that, following Figure 1, there exists three different results of (C_p^*, θ^*), but that for the setting in Figure 2 they are very similar (i.e., explaining why we can visualize them with one dot). The levels of product quality and flexibility will

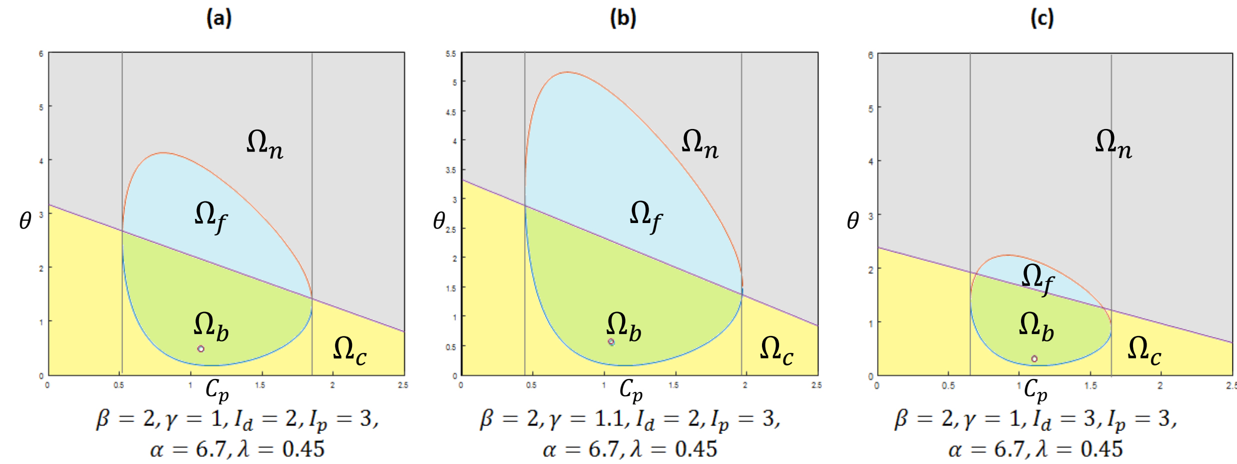

Figure 3: Panel (a) visualizes the same environment as in Figure 2, while panel (b) and (c) illustrate that an increase in quality sensitivity γ and an increase in product development investment I_d, increase and decrease the size of Ω_b (i.e., the region where co-creation is mutually beneficial) respectively.

be further discussed in the next section.

4.2 Levels of Product Quality and Operational Flexibility

Before deciding on the price, both the customer and the firm take part in creating the new product (see Figure 1). Depending on the type of co-creation approach, the customer and firm simultaneously determine their product development input θ_c and θ_f, or either of the two parties initiates the co-creation, followed by the other getting involved in the co-creation. For example, for the IT-platform-enabled crowdsourcing example of Lego Ideas (Schlagwein and Bjorn-Andersen, 2014) and for the user-innovation example of Rodeo Kayaking (Baldwin et al., 2006), the customer is first to develop part of the product, while at MiAddidas, the firm takes the first step in the (R&D) product development. Remark that Lego is first to invest in the platform where product ideas can be suggested, but that we consider a real change in the product design to determine innovation effort, hence used to determine which party is first to invest in the co-creation (i.e., which scenario we consider in Figure 1). At MiAddidas, the firm makes the first step in product development, by developing different configuration and customization possibilities for the customer.

We find that (for the proof, see the Appendix):

Proposition 2. *Under the three different scenarios in Figure 1, the total created product quality is:*

Scenario 1:

$$\theta_1^* = \frac{3\gamma(\alpha - \beta C_p)}{8\beta I_d - 3\gamma^2}, \tag{8}$$

Scenario 2:

$$\theta_2^* = \frac{\gamma(24\beta I_d - \gamma^2)\,(\alpha - \beta C_p)}{(8\beta I_d - \gamma^2)^2 - 16\beta I_d \gamma^2}, \tag{9}$$

Scenario 3:

$$\theta_3^* = \frac{\gamma\,(6\beta I_d - \gamma^2)\,(\alpha - \beta C_p)}{(4\beta I_d - \gamma^2)^2 - 2\beta I_d \gamma^2}. \tag{10}$$

Comparing the product qualities under the different scenarios, it always holds that:

$$\theta_1^* < \theta_2^* < \theta_3^*. \tag{11}$$

We can thus state that:

Corollary 4. *The co-creation process where the customer is first to contribute to the product development (i.e., scenario 3) leads to the highest co-created product quality θ.*

From Proposition (2), we also find that:

Corollary 5. *The co-created product quality θ increases with higher flexibility (i.e., lower C_p).*

We now discuss the optimal level of C_p (for the proof, see Appendix):

Proposition 3. *Under the three different scenarios in Figure 1, the flexibility level C_p is:*

$$
\begin{aligned}
C_p^* = {} & \frac{1}{2\beta}\left(-1+i\sqrt{3}\right)\left(\frac{\alpha^3}{27}-\frac{I_p\beta}{4z_a}-\sqrt{\left(\frac{I_p\beta}{4z_a}\right)\left(-\frac{2\alpha^3}{27}+\frac{I_p\beta}{4z_a}\right)}\right)^{\frac{1}{3}} \\
& +\frac{1}{2\beta}\left(-1-i\sqrt{3}\right)\left(\frac{\alpha^3}{27}-\frac{I_p\beta}{4z_a}+\sqrt{\left(\frac{I_p\beta}{4z_a}\right)\left(-\frac{2\alpha^3}{27}+\frac{I_p\beta}{4z_a}\right)}\right)^{\frac{1}{3}}+\frac{\alpha}{3\beta},
\end{aligned}
\tag{12}
$$

with z_a for the different scenarios of the co-creation process given by:

Scenario 1:

$$z_a = \frac{16\beta I_d^2 - 4I_d\gamma^2}{\left(8\beta I_d - 3\gamma^2\right)^2},$$

Scenario 2:

$$z_a = \frac{16\beta I_d^2}{\left(8\beta I_d - \gamma^2\right)^2 - 16\gamma^2\beta I_d},$$

Scenario 3:

$$z_a = \frac{I_d\left(4\beta I_d - \gamma^2\right)^3}{\left(\left(4\beta I_d - \gamma^2\right)^2 - 2\beta\gamma^2 I_d\right)^2}.$$

From Proposition (2) and (3), and based on partial derivatives (see the discussion in Appendix), we find that:

Corollary 6. *The co-created product quality and flexibility increase (i.e., θ increases and C_p decreases) with an increase of quality sensitivity γ and demand α,*

Corollary 7. *The co-created product quality and flexibility decrease (i.e., θ decreases and C_p increases) with higher investment in product development and flexibility (I_d and I_p) and price sensitivity β.*

This implies that the co-creation outcome θ is the highest when companies co-create with quality–sensitive customers with high product demand, who have a low sensitivity to price, and when they are in a low–investment–intensive environment (independent of the scenario of how the co-creation process takes place).

4.3 Sharing Product Development Effort to Guide Co-creation

An important instrument in the co-creation process is the distribution of the innovation effort in the co-created product. The different scenarios (see Figure 1) lead to different ways to share innovation efforts. Since $\frac{\theta_f}{\theta_c} = \frac{\lambda}{(1-\lambda)}$, we can derive λ (based on the results in Appendix when proving Proposition (2)):

Proposition 4. *Under the three different scenarios the innovation share of the co-created product carried by the firm is:*
Scenario 1:

$$\lambda_1 = \frac{2}{3}, \tag{13}$$

Scenario 2:

$$\lambda_2 = \frac{16\beta I_d}{24\beta I_d - \gamma^2}, \tag{14}$$

Scenario 3:

$$\lambda_3 = \frac{4\beta I_d - \gamma^2}{6\beta I_d - \gamma^2}. \tag{15}$$

This shows that a change of α or I_p does not affect the optimal innovation share of the customer and firm. It follows that when the customer is the first to contribute to the co-creation (i.e., scenario 3), the firm will have a smaller share in the co-created product compared to when simultaneously contributing to the co-creation (i.e., scenario 1) (since $\lambda_3 < \lambda_1$). We also find that, when the firm is the first to contribute to the co-creation (i.e., scenario 2), the firm will have a larger share in the co-created product compared to when simultaneously contributing to the co-creation (i.e., scenario 1) (since $\lambda_2 > \lambda_1$).

Hence, it follows that:

Corollary 8. *The customer's share in the co-created product is the highest when the customer is the first to contribute to the co-creation (i.e., scenario 3), while the firm's share is the* *highest when it is the first to contribute to the co-creation (i.e., scenario 2) (since it holds that $\lambda_3 < \lambda_1 < \lambda_2$).*

This is an important insight for companies. It shows that to get customers involved in the co-creation and let them increase their development efforts, it is better to let them first make development efforts, and thus involve them in the early stages of the co-creation process. Moreover, it positively impacts the co-creation outcome (see Corollary 4). This effect gets even stronger when dealing with quality–sensitive rather than price–sensitive customers (e.g., in a high-end segment) or when being in a low–investment–intensive environment in terms of investments in product development. The latter is based on the following Corrollary (derived from Proposition 4):

Corollary 9. *The share in the co-creation of the customer and the firm when the customer and the firm initiate the co-creation respectively (i.e., $1 - \lambda_3$ and λ_2 respectively) increases when the quality sensitivity γ increases, or the price sensitivity β and the product development investment I_d decrease.*

We refer to Appendix for an extension of these results in case $\gamma_c \neq \gamma_f$, $I_d^c \neq I_d^f$, and the product is sold to other users, or developed by a community of users.

5 Managerial Insights and Conclusion

Literature and business examples have mainly focused on the benefits of customer co-creation for both the customer and the firm. However, in this article we develop an analytical model that shows that either the firm or the customer or both might want to escape rather than engage in co-creation (see Proposition 1). We show (1) the conditions under which co-creation is mutually beneficial, (2) which conditions stimulate co-creation, and (3) how co-creation efforts should be shared. Table 1 (based on our propositions and corollaries) gives an overview of the impact of different parameters on the co-created product quality level, the firm's operational flexibility, the sharing of development effort, and the likelihood

Table 1: Impact of Different Parameters (Summary of Propositions and Corollaries)

Increase of different parameters	θ_1, θ_2, θ_3	$\frac{1}{C_{p1}}$, $\frac{1}{C_{p2}}$, $\frac{1}{C_{p3}}$	λ_2	λ_3	Ω_b
Customer's demand α	↑	↑	-	-	↑
Customer's quality sensitivity γ	↑	↑	↑	↑	↑
Customer's price sensitivity β	↓	↓	↓	↑	↓
Investment in operational flexibility I_p	↓	↓	-	-	↓
Investment in product development I_d	↓	↓	↓	↑	↓

of mutually profitable co-creation (i.e., the size of Ω_b), under the three co-creation process scenarios in Figure 1 (denoted by subscripts 1, 2 and 3 respectively).

A key finding of our study is that co-creation is not always beneficial for both the customer and the firm and that B2C co-creation seems to thrive (i.e., has a higher likelihood of being mutually beneficial with an increase of Ω_b and θ) in environments where the customer is quality sensitive rather than price sensitive, demand is high, and the investment intensity is low. Note that results might differ in business-to-business settings. There we found many examples of co-development (e.g., in high-tech and pharmaceutical industries) with the goal of sharing the high investment costs. Knowing the conditions under which co-creation is stimulated can help managers better target their co-creation initiatives. For instance, they can co-create together with their high-end rather than low-end customer segment and for products that require less development effort, and have a higher demand.

The extra analyses and extensions to our main model (provided in Appendix), further help to interpret our results. We find that when the innovation contribution of the firm (θ_f) is increasingly appreciated over the innovation contribution of the customer (θ_c) (i.e., η decreases, given $\gamma_c = \eta\gamma_f$), the optimal innovation share of the firm λ increases. In the extreme case, this can lead to co-creation no longer being optimal (i.e., $\lambda = 1$). This could explain why user-based design backfires in the context of luxury fashion brands (although they are high-end customers), where the user's input might be negatively perceived, leading to lower quality and a lower signal of high status (Fuchs et al., 2013). Moreover, a decrease in total development costs, for instance thanks to a lower development cost for customers (i.e., lower I_d^c) will increase the co-created product quality and co-creation likelihood. This decrease in development costs can come from involving lead users or communities of innovators in co-creation, as this might lead to less development effort and less search redundancy (Baldwin et al., 2006; Hamdi-Kidar et al., 2019). Although studied in a co-production setting (where the customer participates in the production process), Haumann et al. (2015) also found that the effort and time investment required by the customer should not be too high, or it might negatively impact the customer's satisfaction. In Appendix, we also consider having multiple customers buying the product or being involved in the co-creation process. This can have an impact on our main model's results. For instance, under scenario 1 (i.e., when the customer(s) and the firm simultaneously decide their innovation effort), having multiple customers increases the co-created product quality, but can lead to a larger share of the firm's innovation share when involving these customers in the co-creation process.

In the next paragraphs, we discuss several of our model findings and their managerial relevance using some business examples. We examine two textbook examples of co-creation initiatives at Lego and Adidas, and a co-creation project at a wood–processing company (see Table 2).

With Lego Ideas, a customer can submit an idea for a new Lego set by building a prototype, and if the idea receives more than 10,000 votes, it is potentially accepted for commercialization by Lego (Lego, 2018).

By contrast, MiAdidas, similar to NIKEiD, offers customers the possibility to design their personalized Adidas shoes online (Piller et al., 2012). Crucial for Adidas to co-create is its new, flexible manufacturing plant, which uses an automated digital manufacturing process (Financial Times, 2016). Note however, that in such a mass-customization environment,

Table 2: Overview of the different cases

Case	Company Description	Source of Information
A	Lego	Existing literature
B	Adidas	Existing literature
C	Wood company	Interview with the company's supply chain manager

flexibility is limited to a preset range of choices for the customer, and the customer is only involved in the last stage of development, after the firm (similar to scenario 2 in our analysis). Although Adidas presented their flexible 'Speedfactories' as its future, only four years after opening these factories (end 2019), they announced they would shut them down (Adidas, 2019). In the end the high investments did not deliver the flexibility they hoped for, resulting in a limited number of models they were able to make and co-create with the customer. For Adidas, the high investment to achieve the necessary flexibility (i.e., related to high I_p) were not worthwhile.

We also consider a wood–processing company, which is increasingly receiving specific customer requests (e.g., a tailored shelf for a closet). These requests are difficult for a company organized as a mass producer to handle. In the past, the company had occasionally produced customized products. However, the high cost of doing so was unprofitable for the firm. In 2018, the company bought an expensive laser–cutting machine (at almost €0.8 million), which allows it to cut all customized forms of wood, thus highly increasing its operational flexibility. A customer can now provide a desired product design, after which the wood–processing company transforms it into a digital design processed by the machine (i.e., product development effort is shared). Note that for this company, demand α per individualized product can be quite low and customers are quite price sensitive, reducing the potential for mutually beneficial co-creation.

These B2C co-creation examples show that successful co-creation goes hand in hand with a sufficiently flexible operations system at the firm, that is, a low C_p. This can explain why in certain settings without a sufficient level of flexibility, co-creating a personalized product is difficult to achieve. Another finding is that customer demand should be sufficiently high to ensure mutually profitable co-creation. For example, the voting threshold at Lego helps ensure a minimum level of demand ($\underline{\alpha}$) and interest for the product. Other means for a company to ensure a minimum demand could be contractual agreements. The benefit of Lego's voting system is that it also stimulates customer engagement and product publicity.

In the successful co-creation examples, the customer also shares part of the development effort. In our study, we show that the level of sharing development effort can be a useful instrument in the co-creation process. From Proposition 1 we also show that the optimal level of the co-created product quality (i.e., the level of innovation) should not be too high. This might explain the preset range of options for customization at Adidas or the design restrictions at Lego (e.g., the customer can only suggest ideas with a maximum of 3000 pieces, can only use existing molds, and cannot use licensed properties such as Star Wars, as this would increase development costs).

We also found that to get customers involved in the co-creation and let them increase their development efforts, it is better to let them first make development efforts. In practice, it means that, for example at LegoIdeas, where the customer is first to make development efforts, the firm will have to exert a lower share of the co-creation efforts than when it takes the first step in product development (e.g., such is the case at Miaddidas).

The successful co-creation examples were not necessarily successful from the start but oftentimes evolved into a success over time, proving that co-creation is a dynamic process (see Fuchs and Schreier (2011); Mahr et al. (2014)). From a model perspective, we consider a co-creation project successful if, in the co-created product quality–flexibility space, it is situated in or evolved over time into region Ω_b (i.e., the region where co-creation is mutually beneficial).

As shown with our results, our analytical model leads to interesting and new insights, and provides a general framework to discuss the co-creation process. Future research can further build on this model to include even more aspects of co-creation. Future research could examine how having multiple co-creating customers might affect co-creation benefits and when paying customers for a product design is beneficial (e.g., Threadless gives a cash reward for the design of a T-shirt). Moreover, herein we assume that there is no limitation on the communication mechanism for customers to express their product needs and that their sensitivity to quality and price is known, which is not always the case. Another fruitful avenue for research is to determine what happens when the customer or the firm is not always rational (i.e., not always profit driven), due to, for example, loyalty to a firm, power relations, or risk–averse behavior. Future research can also examine who gains most from the co-creation, and can take into account other gains than pure monetary ones (e.g., value-in-use for the customer). Last, future research should investigate co-creation over time (longitudinal studies), as we showed that it is an evolving process.

References

Adidas. 2019. Adidas is shutting down the robotic factories that were supposed to be its future. https://qz.com/1746152/adidas-is-shutting-down-its-speedfactories-in-germany-and-the-us/. [Online; accessed 30-06-2020].

Alptekinoğlu, Aydın, Charles J Corbett. 2008. Mass customization vs. mass production: Variety and price competition. *Manufacturing & Service Operations Management* **10**(2) 204–217.

Alves, Helena, Cristina Fernandes, Mário Raposo. 2016. Value co-creation: Concept and contexts of application and study. *Journal of Business Research* **69**(5) 1626–1633.

Baldwin, Carliss, Christoph Hienerth, Eric Von Hippel. 2006. How user innovations become commercial products: A theoretical investigation and case study. *Research policy* **35**(9) 1291–1313.

Banker, Rajiv D, Inder Khosla, Kingshuk K Sinha. 1998. Quality and competition. *Management science* **44**(9) 1179–1192.

Bendapudi, Neeli, Robert P Leone. 2003. Psychological implications of customer participation in co-production. *Journal of marketing* **67**(1) 14–28.

Bhaskaran, Sreekumar R, Vish Krishnan. 2009. Effort, revenue, and cost sharing mechanisms for collaborative new product development. *Management Science* **55**(7) 1152–1169.

Bhattacharya, Shantanu, Vibha Gaba, Sameer Hasija. 2014. A comparison of milestone-based and buyout options contracts for coordinating R&D partnerships. *Management Science* **61**(5) 963–978.

Cui, Anna S, Fang Wu. 2016. Utilizing customer knowledge in innovation: antecedents and impact of customer involvement on new product performance. *Journal of the Academy of Marketing Science* **44**(4) 516–538.

Financial Times. 2016. Robot revolution helps adidas bring shoemaking back to germany, by James Shotter and Lindsay Whipp. *June 8, 2016* .

Fogliatto, Flavio S, Giovani JC Da Silveira, Denis Borenstein. 2012. The mass customization decade: An updated review of the literature. *International Journal of Production Economics* **138**(1) 14–25.

Franke, Nikolaus, Peter Keinz, Martin Schreier. 2008. Complementing mass customization toolkits with user communities: How peer input improves customer self-design. *Journal of product innovation management* **25**(6) 546–559.

Franke, Nikolaus, Peter Keinz, Christoph J Steger. 2009. Testing the value of customization: when do customers really prefer products tailored to their preferences? *Journal of Marketing* **73**(5) 103–121.

Franke, Nikolaus, Frank Piller. 2004. Value creation by toolkits for user innovation and design: The case of the watch market. *Journal of Product Innovation Management* **21**(6) 401–415.

Franke, Nikolaus, Martin Schreier. 2010. Why customers value self-designed products: The importance of process effort and enjoyment. *Journal of product innovation management* **27**(7) 1020–1031.

Fuchs, Christoph, Emanuela Prandelli, Martin Schreier, Darren W Dahl. 2013. All that is users might not be gold: How labeling products as user designed backfires in the context of luxury fashion brands. *Journal of Marketing* **77**(5) 75–91.

Fuchs, Christoph, Martin Schreier. 2011. Customer empowerment in new product development. *Journal of Product Innovation Management* **28**(1) 17–32.

Gemser, Gerda, Helen Perks. 2015. Co-creation with customers: An evolving innovation research field. *Journal of Product Innovation Management* **32**(5) 660–665.

Grönroos, Christian. 2011. Value co-creation in service logic: A critical analysis. *Marketing theory* **11**(3) 279–301.

Grönroos, Christian, Päivi Voima. 2013. Critical service logic: making sense of value creation and co-creation. *Journal of the academy of marketing science* **41**(2) 133–150.

Hamdi-Kidar, Linda, Peter Keinz, Emmanuelle Le Nagard, Eric Vernette. 2019. Comparing lead users to emergent-nature consumers as sources of innovation at early stages of new product development. *Journal of Product Innovation Management* **36**(5) 616–631.

Haumann, Till, Pascal Güntürkün, Laura Marie Schons, Jan Wieseke. 2015. Engaging customers in coproduction processes: How value-enhancing and intensity-reducing communication strategies mitigate the negative effects of coproduction intensity. *Journal of Marketing* **79**(6) 17–33.

Hausman, Jerry A. 1981. Exact consumer's surplus and deadweight loss. *The American Economic Review* **71**(4) 662–676.

Heese, Hans Sebastian, Jayashankar M Swaminathan. 2006. Product line design with component commonality and cost-reduction effort. *Manufacturing & Service Operations Management* **8**(2) 206–219.

Heidenreich, Sven, Kristina Wittkowski, Matthias Handrich, Tomas Falk. 2015. The dark side of customer co-creation: exploring the consequences of failed co-created services. *Journal of the Academy of Marketing Science* **43**(3) 279–296.

Hicks, John R. 1939. The foundations of welfare economics. *The Economic Journal* **49**(196) 696–712.

Hoyer, Wayne D, Rajesh Chandy, Matilda Dorotic, Manfred Krafft, Siddharth S Singh. 2010. Consumer cocreation in new product development. *Journal of Service Research* **13**(3) 283–296.

Jeppesen, Lars Bo. 2005. User toolkits for innovation: Consumers support each other. *Journal of product innovation management* **22**(4) 347–362.

Kim, Allen. 2018. Adidas' vision for the future: Personalization, fast. `https://money.cnn.com/2018/07/06/technology/adidas-speedfactory/index.html`. [Online; accessed 23-08-2018].

Krishnan, Vish, Saurabh Gupta. 2001. Appropriateness and impact of platform-based product development. *Management Science* **47**(1) 52–68.

Krishnan, Viswanathan, Karl T Ulrich. 2001. Product development decisions: A review of the literature. *Management science* **47**(1) 1–21.

Leclercq, Thomas, Wafa Hammedi, Ingrid Poncin. 2016. Ten years of value cocreation: An integrative review. *Recherche et Applications en Marketing (English Edition)* **31**(3) 26–60.

Lego. 2018. `https://ideas.lego.com/`. [Online; accessed 09-07-2018].

Lusch, Robert F, Stephen L Vargo. 2006. Service-dominant logic: reactions, reflections and refinements. *Marketing theory* **6**(3) 281–288.

Mahr, Dominik, Annouk Lievens, Vera Blazevic. 2014. The value of customer cocreated knowledge during the innovation process. *Journal of Product Innovation Management* **31**(3) 599–615.

Moorthy, K Sridhar. 1984. Market segmentation, self-selection, and product line design. *Marketing Science* **3**(4) 288–307.

Nambisan, Satish, Robert A Baron. 2009. Virtual customer environments: testing a model of voluntary participation in value co-creation activities. *Journal of product innovation management* **26**(4) 388–406.

Payne, Adrian F, Kaj Storbacka, Pennie Frow. 2008. Managing the co-creation of value. *Journal of the Academy of Marketing Science* **36**(1) 83–96.

Piller, Frank T. 2007. Observations on the present and future of mass customization. *International Journal of Flexible Manufacturing Systems* **19**(4) 630–636.

Piller, Frank T, Evalotte Lindgens, Frank Steiner. 2012. Mass customization at adidas: Three strategic capabilities to implement mass customization. *Available at SSRN: https://ssrn.com/abstract=1994981* .

Piller, Frank T, Kathrin Moeslein, Christof M Stotko. 2004. Does mass customization pay? an economic approach to evaluate customer integration. *Production planning & control* **15**(4) 435–444.

Plé, Loïc, Rubén Chumpitaz Cáceres. 2010. Not always co-creation: introducing interactional co-destruction of value in service-dominant logic. *Journal of Services Marketing* **24**(6) 430–437.

Prahalad, Coimbatore K, Venkat Ramaswamy. 2004. Co-creation experiences: The next practice in value creation. *Journal of Interactive Marketing* **18**(3) 5–14.

Prahalad, Coimbatore K, Venkatram Ramaswamy. 2000. Co-opting customer competence. *Harvard business review* **78**(1) 79–90.

Randall, Taylor, Christian Terwiesch, Karl T Ulrich. 2007. Research note: User design of customized products. *Marketing Science* **26**(2) 268–280.

Ranjan, Kumar Rakesh, Stuart Read. 2016. Value co-creation: concept and measurement. *Journal of the Academy of Marketing Science* **44**(3) 290–315.

Saarijärvi, Hannu, PK Kannan, Hannu Kuusela. 2013. Value co-creation: theoretical approaches and practical implications. *European business review* .

Savva, Nicos, Stefan Scholtes. 2014. Opt-out options in new product co-development partnerships. *Production and Operations Management* **23**(8) 1370–1386.

Schlagwein, Daniel, Niels Bjorn-Andersen. 2014. Organizational learning with crowdsourcing: The revelatory case of lego. *Journal of the Association for Information Systems* **15**(11) 3.

Schreier, Martin, Christoph Fuchs, Darren W Dahl. 2012. The innovation effect of user design: Exploring consumers' innovation perceptions of firms selling products designed by users. *Journal of Marketing* **76**(5) 18–32.

Sreedevi, R, Haritha Saranga. 2017. Uncertainty and supply chain risk: The moderating role of supply chain flexibility in risk mitigation. *International Journal of Production Economics* **193** 332–342.

Syam, Niladri B, Amit Pazgal. 2013. Co-creation with production externalities. *Marketing Science* **32**(5) 805–820.

Syam, Niladri B, Ranran Ruan, James D Hess. 2005. Customized products: A competitive analysis. *Marketing Science* **24**(4) 569–584.

Tatikonda, Mohan V, Mitzi M Montoya-Weiss. 2001. Integrating operations and marketing perspectives of product innovation: The influence of organizational process factors and capabilities on development performance. *Management science* **47**(1) 151–172.

Ueda, Kanji, Takeshi Takenaka, Kousuke Fujita. 2008. Toward value co-creation in manufacturing and servicing. *CIRP Journal of Manufacturing Science and Technology* **1**(1) 53–58.

Ulaga, Wolfgang. 2003. Capturing value creation in business relationships: A customer perspective. *Industrial marketing management* **32**(8) 677–693.

Upton, David M. 1994. The management of manufacturing flexibility. *California management review* **36**(2) 72–89.

Van den Broeke, Maud M, Robert N Boute, Jan A Van Mieghem. 2018. Platform flexibility strategies: R&D investment versus production customization tradeoff. *European Journal of Operational Research* **270**(2) 475–486.

Van Mieghem, Jan A. 2007. Risk mitigation in newsvendor networks: Resource diversification, flexibility, sharing, and hedging. *Management Science* **53**(8) 1269–1288.

Vargo, Stephen L, Robert F Lusch. 2004. Evolving to a new dominant logic for marketing. *Journal of marketing* **68**(1) 1–17.

Vernette, Eric, Linda Hamdi Kidar. 2013. Co-creation with consumers: Who has the competence and wants to cooperate? *International Journal of Market Research* **55**(4) 539–561.

Wallace, M. 2010. Putting customers in charge of design. `http://www.nytimes.com/2010/05/16/business/16proto.html`. [Online; accessed 07-12-2017].

Weber, Marcel EA, Dirk H Van der Laan. 2014. Does customer co-creation really pay off? an investigation into the firm's benefits from customer involvement in new product and service development. *Proceedings of the 7th World Conference on Mass Customization, Personalization, and Co-Creation (MCPC 2014), Aalborg, Denmark, February 4th-7th, 2014*. Springer, 145–157.

Willig, Robert D. 1976. Consumer's surplus without apology. *The American Economic Review* **66**(4) 589–597.

Yu, Kangkang, Jack Cadeaux, Ben Nanfeng Luo. 2015. Operational flexibility: Review and meta-analysis. *International Journal of Production Economics* **169** 190–202.

Zhang, Xiang, Rongqiu Chen. 2008. Examining the mechanism of the value co-creation with customers. *International Journal of Production Economics* **116**(2) 242–250.

Zhang, Xiang, Chen Ye, Rongqiu Chen, Zhaohua Wang. 2011. Multi-focused strategy in value co-creation with customers: Examining cumulative development pattern with new capabilities. *International Journal of Production Economics* **132**(1) 122–130.

Appendix

Proof of Proposition 1

From the model, it holds that $\theta = \theta_f + \theta_c$, with $\theta_f = \lambda\theta$ and $\theta_c = (1-\lambda)\theta$ (with $\lambda \in [0,1]$). A positive consumer surplus (6) and firm profit (7) are then given by:

$$CS = \frac{1}{8\beta}\left[(\alpha - \beta C_p)^2 + 2\gamma\theta(\alpha - \beta C_p) + \gamma^2\theta^2\right] - I_d(1-\lambda)^2\theta^2 \geq 0. \tag{16}$$

$$\Pi_f = \frac{1}{4\beta}\left[(\alpha - \beta C_p)^2 + 2\gamma\theta(\alpha - \beta C_p) + \gamma^2\theta^2\right] - \frac{I_p}{C_p} - I_d\lambda^2\theta^2 \geq 0. \tag{17}$$

Based on the second derivative, both (16) and (17) are concave quadratic in θ, under the condition that $0 \leq \frac{\gamma}{\sqrt{4\beta I_d}} < \lambda < 1 - \frac{\gamma}{\sqrt{8\beta I_d}} \leq 1$. This means it should also hold that:

$$\gamma < \frac{\sqrt{8\beta I_d}}{1+\sqrt{2}}. \tag{18}$$

Applying the quadratic formula, this results in the following limits, in terms of the total co-created product quality θ, for CS to be positive:

$$[\underline{\theta^c}, \overline{\theta^c}] = \left[(\alpha - \beta C_p)\left(\frac{\gamma - \sqrt{8\beta I_d(1-\lambda)^2}}{8\beta I_d(1-\lambda)^2 - \gamma^2}\right), (\alpha - \beta C_p)\left(\frac{\gamma + \sqrt{8\beta I_d(1-\lambda)^2}}{8\beta I_d(1-\lambda)^2 - \gamma^2}\right)\right], \tag{19}$$

and the following limits for Π_f to be positive:

$$[\underline{\theta^f}, \overline{\theta^f}] = \left[\frac{\gamma(\alpha - \beta C_p) - \sqrt{4\beta I_d\lambda^2(\alpha - \beta C_p)^2 + \left(\frac{4\beta I_p}{C_p}\right)(\gamma^2 - 4\beta I_d\lambda^2)}}{(4\beta I_d\lambda^2 - \gamma^2)}, \frac{\gamma(\alpha - \beta C_p) + \sqrt{4\beta I_d\lambda^2(\alpha - \beta C_p)^2 + \left(\frac{4\beta I_p}{C_p}\right)(\gamma^2 - 4\beta I_d\lambda^2)}}{(4\beta I_d\lambda^2 - \gamma^2)}\right]. \tag{20}$$

For the discriminant in the above expression to be positive, it needs to hold that there is a minimum base demand α required for the product:

$$\underline{\alpha} > \sqrt{\frac{I_p(4\beta I_d\lambda^2 - \gamma^2)}{C_p I_d\lambda^2}} + \beta C_p. \tag{21}$$

Proof of Proposition 2 (scenario 1)

The first-order conditions for the maximization of the consumer surplus CS (6) and the firm profit Π_f (7) when simultaneously optimizing the innovation input of the customer and the firm (θ_c and θ_f) are:

$$\frac{\partial CS}{\partial \theta_c} = \frac{\gamma}{4\beta}\left(\alpha - \beta C_p + \gamma\left(\theta_f + \theta_c\right)\right) - 2I_d\theta_c = 0 \tag{22}$$

$$\frac{\partial \Pi_f}{\partial \theta_f} = \frac{\gamma}{2\beta}\left(\alpha - \beta C_p + \gamma\left(\theta_f + \theta_c\right)\right) - 2I_d\theta_f = 0 \tag{23}$$

This leads to:

$$\theta_c = \frac{\left(\alpha - \beta C_p\right)\gamma + \gamma^2\theta_f}{8\beta I_d - \gamma^2}, \tag{24}$$

$$\theta_f = \frac{\left(\alpha - \beta C_p\right)\gamma + \gamma^2\theta_c}{4\beta I_d - \gamma^2}. \tag{25}$$

Simultaneously solving these, we find:

$$\theta_c^* = \frac{\gamma\left(\alpha - \beta C_p\right)}{\left(8\beta I_d - 3\gamma^2\right)}, \tag{26}$$

$$\theta_f^* = \frac{2\gamma\left(\alpha - \beta C_p\right)}{\left(8\beta I_d - 3\gamma^2\right)}. \tag{27}$$

Since $\theta = \theta_f + \theta_c$, it follows that:

$$\theta^* = \frac{3\gamma\left(\alpha - \beta C_p\right)}{8\beta I_d - 3\gamma^2}. \tag{28}$$

Proof of Proposition 2 (scenario 2)

In scenario 2, the customer determines θ_c (given by (24)) after the firm has set its development share θ_f. After filling in (24) in Π_f (given by (7)),we get:

$$\Pi_f = \frac{16\beta I_d^2}{\left(8\beta I_d - \gamma^2\right)^2}\left((\alpha - \beta C_p) + \gamma\theta_f\right)^2 - \frac{I_p}{C_p} - I_d\theta_f^2. \tag{29}$$

Based on the first order derivative, we find that:

$$\theta_f^* = \frac{16\gamma\beta I_d\left(\alpha - \beta C_p\right)}{\left(\left(8\beta I_d - \gamma^2\right)^2 - 16\beta I_d\gamma^2\right)}. \tag{30}$$

Inserting (30) into (24), it follows that θ_c equals:

$$\theta_c^* = \frac{\gamma\left(8\beta I_d - \gamma^2\right)\left(\alpha - \beta C_p\right)}{\left(8\beta I_d - \gamma^2\right)^2 - 16\beta I_d\gamma^2}. \tag{31}$$

Since $\theta = \theta_f + \theta_c$, it follows that:

$$\theta^* = \frac{\gamma\left(24\beta I_d - \gamma^2\right)\left(\alpha - \beta C_p\right)}{\left(8\beta I_d - \gamma^2\right)^2 - 16\gamma^2\beta I_d}. \tag{32}$$

Proof of Proposition 2 (scenario 3)

In scenario 3, the firm determines θ_f (given by (25)) after the customer has set its development share θ_c. After filling in (25) in CS (given by (6)),we get:

$$CS = \frac{2\beta I_d^2}{\left(4\beta I_d - \gamma^2\right)^2}\left((\alpha - \beta C_p) + \gamma\theta_c\right)^2 - I_d\theta_c^2, \tag{33}$$

Based on the first order derivative, we find:

$$\theta_c^* = \frac{2\beta\gamma I_d\left(\alpha - \beta C_p\right)}{\left(4\beta I_d - \gamma^2\right)^2 - 2\beta\gamma^2 I_d}. \tag{34}$$

Inserting (34) into (25), it follows that θ_f equals:

$$\theta_f^* = \frac{(4\beta I_d - \gamma^2)\,\gamma\,(\alpha - \beta C_p)}{(4\beta I_d - \gamma^2)^2 - 2\beta\gamma^2 I_d}. \tag{35}$$

Since $\theta = \theta_f + \theta_c$, it follows that:

$$\theta^* = \frac{\gamma\,(6\beta I_d - \gamma^2)\,(\alpha - \beta C_p)}{(4\beta I_d - \gamma^2)^2 - 2\beta\gamma^2 I_d}. \tag{36}$$

Proof of Proposition 3

To simplify the proof and to make it generalizable for all scenarios in Proposition (2) we introduce the notations z_c, z_f and z_t. For example, for scenario 1 in Proposition (2), we simplify the expressions to $\theta_c = z_c(\alpha - \beta C_p)$, $\theta_f = z_f(\alpha - \beta C_p)$, and $\theta = z_t(\alpha - \beta C_p)$, with $z_c = \frac{\gamma}{8\beta I_d - 3\gamma^2}$, $z_f = \frac{2\gamma}{8\beta I_d - 3\gamma^2}$ and $z_t = \frac{3\gamma}{8\beta I_d - 3\gamma^2}$. A similar reasoning can be applied for scenario 2 and 3. After deriving the optimal C_p we will replace these constants by their actual value.

To determine the optimal C_p, the firm looks at its profit (7), which can be expressed as:

$$\Pi_f = (\alpha - \beta C_p)^2 \left[\frac{(1 + \gamma z_t)^2}{4\beta} - I_d z_f^2\right] - \frac{I_p}{C_p}. \tag{37}$$

We replace $\left[\frac{(1+\gamma z_t)^2}{4\beta} - I_d z_f^2\right]$ by the notation z_a.

Based on the first order derivative, it needs to hold that:

$$\frac{\partial \Pi_f}{\partial C_p} = -2\beta z_a(\alpha - \beta C_p) + \frac{I_p}{C_p^2} = 0 \tag{38}$$

This means that it should hold that:

$$C_p^3 - \frac{\alpha}{\beta} C_p^2 + \frac{I_p}{2\beta^2 z_a} = 0 \tag{39}$$

To obtain the depressed form of this cubic equation, following Cardano's formula, we replace C_p by $y + \frac{\alpha}{3\beta}$ and the condition becomes:

$$y^3 - \frac{\alpha^2}{3\beta^2}y - \frac{2\alpha^3}{27\beta^3} + \frac{I_p}{2\beta^2 z_a} = 0. \tag{40}$$

Now, we replace $\frac{2\alpha^3}{27\beta^3} - \frac{I_p}{2\beta^2 z_a}$ by z_b, and y by $u + v$, so that (40) becomes:

$$(u+v)^3 - \frac{\alpha^2}{3\beta^2}(u+v) - z_b = 0, \tag{41}$$

or

$$u^3 + v^3 + \left(3uv - \frac{\alpha^2}{3\beta^2}\right)(u+v) - z_b = 0. \tag{42}$$

Setting $3uv - \frac{\alpha^2}{3\beta^2} = 0$ and $u^3 + v^3 = z_b$, $v = \frac{\alpha^2}{9u\beta^2}$ and $u^3 + \left(\frac{\alpha^2}{9u\beta^2}\right)^3 = z_b$. Transformed this becomes $u^6 - z_b u^3 + \left(\frac{\alpha^2}{9\beta^2}\right)^3 = 0$ This means that $u^3 = \frac{z_b \pm \sqrt{z_b^2 - 4\left(\frac{\alpha^2}{9\beta^2}\right)^3}}{2}$. Thus, it holds that:

$$u^3 = \frac{z_b - \sqrt{z_b^2 - 4\left(\frac{\alpha^2}{9\beta^2}\right)^3}}{2}, \tag{43}$$

$$v^3 = \frac{z_b + \sqrt{z_b^2 - 4\left(\frac{\alpha^2}{9\beta^2}\right)^3}}{2}. \tag{44}$$

Replacing the values of u and v (based on (43) and (44)) in $y = u + v$, and inserting this value of y in $C_p = y + \frac{\alpha}{3\beta}$: the first real root solution for C_p is:

$$C_{p_1} = \left(\frac{z_b - \sqrt{z_b^2 - 4\left(\frac{\alpha^2}{9\beta^2}\right)^3}}{2}\right)^{(1/3)} + \left(\frac{z_b + \sqrt{z_b^2 - 4\left(\frac{\alpha^2}{9\beta^2}\right)^3}}{2}\right)^{(1/3)} + \frac{\alpha}{3\beta} \tag{45}$$

.

When replacing z_b this becomes:

$$C_{p_1}=\frac{1}{\beta}\left(\frac{\alpha^3}{27}-\frac{I_p\beta}{4z_a}-\sqrt{\left(\frac{I_p\beta}{4z_a}\right)\left(-\frac{2\alpha^3}{27}+\frac{I_p\beta}{4z_a}\right)}\right)^{\frac{1}{3}} + \frac{1}{\beta}\left(\frac{\alpha^3}{27}-\frac{I_p\beta}{4z_a}+\sqrt{\left(\frac{I_p\beta}{4z_a}\right)\left(-\frac{2\alpha^3}{27}+\frac{I_p\beta}{4z_a}\right)}\right)^{\frac{1}{3}}+\frac{\alpha}{3\beta}.. \tag{46}$$

This result can also be easily obtained with the cubic formula. As a cubic equation always has three roots, the other roots are given by:

$$C_{p_2}=\frac{1}{2\beta}\left(-1+i\sqrt{3}\right)\left(\frac{\alpha^3}{27}-\frac{I_p\beta}{4z_a}-\sqrt{\left(\frac{I_p\beta}{4z_a}\right)\left(-\frac{2\alpha^3}{27}+\frac{I_p\beta}{4z_a}\right)}\right)^{\frac{1}{3}} + \frac{1}{2\beta}\left(-1-i\sqrt{3}\right)\left(\frac{\alpha^3}{27}-\frac{I_p\beta}{4z_a}+\sqrt{\left(\frac{I_p\beta}{4z_a}\right)\left(-\frac{2\alpha^3}{27}+\frac{I_p\beta}{4z_a}\right)}\right)^{\frac{1}{3}}+\frac{\alpha}{3\beta}. \tag{47}$$

$$C_{p_3}=\frac{1}{2\beta}\left(-1-i\sqrt{3}\right)\left(\frac{\alpha^3}{27}-\frac{I_p\beta}{4z_a}-\sqrt{\left(\frac{I_p\beta}{4z_a}\right)\left(-\frac{2\alpha^3}{27}+\frac{I_p\beta}{4z_a}\right)}\right)^{\frac{1}{3}} + \frac{1}{2\beta}\left(-1+i\sqrt{3}\right)\left(\frac{\alpha^3}{27}-\frac{I_p\beta}{4z_a}+\sqrt{\left(\frac{I_p\beta}{4z_a}\right)\left(-\frac{2\alpha^3}{27}+\frac{I_p\beta}{4z_a}\right)}\right)^{\frac{1}{3}}+\frac{\alpha}{3\beta}. \tag{48}$$

Note that complex numbers always come into play when applying the cubic formula. The discriminant of Equation (39) equals $\frac{I_p}{4z_a^2\beta^5}\left[8z_a\alpha^3-27I_p\beta\right]$. As this discriminant is larger than zero, three real solutions exist for C_p. From all suggested solutions for C_p (i.e.,$C_{p_1}, C_{p_2}, C_{p_3}$) only $C_{p_2}\in[\underline{C_p},\overline{C_p}]$ (i.e., lies in the region Ω_b in Figure 2, hence why this is the optimal solution for C_p^*.)

The values of z_a for the different scenarios of the co-creation process can be expressed as:

Scenario 1:

$$z_a=\frac{4I_d\left[4\beta I_d-\gamma^2\right]}{\left(8\beta I_d-3\gamma^2\right)^2}, \tag{49}$$

Scenario 2:

$$z_a=\frac{16\beta I_d^2}{\left(\left(8\beta I_d-\gamma^2\right)^2-16\gamma^2\beta I_d\right)}, \tag{50}$$

Scenario 3:

$$z_a=\frac{I_d\left(4\beta I_d-\gamma^2\right)^3}{\left(\left(4\beta I_d-\gamma^2\right)^2-2\beta\gamma^2 I_d\right)^2}. \tag{51}$$

Impact of different parameters on C_p and θ

Replacing $\frac{\alpha}{3\beta}$ by x_1 and $\frac{I_p}{4\beta^2 z_a}$ by x_2, C_p^* becomes:

$$\begin{aligned} C_p^* = \frac{1}{2}\left(-1+i\sqrt{3}\right)\left(x_1^3 - x_2 - \sqrt{-x_2\left(2x_1^3 - x_2\right)}\right)^{\frac{1}{3}} \\ -\frac{1}{2}\left(1+i\sqrt{3}\right)\left(x_1^3 - x_2 + \sqrt{-x_2\left(2x_1^3 - x_2\right)}\right)^{\frac{1}{3}} + x_1. \end{aligned} \tag{52}$$

Given that $x_1^3 > x_2$ it holds that C_p increases if x_1 decreases and x_2 increases.

A decrease of α and an increase of β lead to a decrease of x_1, and hence an increase of C_p.

Under the different scenarios (see Figure 1), x_2 becomes (based on Proposition 3 for the values):

Scenario 1: $x_2 = \frac{I_p\left(8\beta I_d - 3\gamma^2\right)^2}{16\beta^2 I_d[4\beta I_d - \gamma^2]}$

Scenario 2: $x_2 = \frac{I_p\left(\left(8\beta I_d - \gamma^2\right)^2 - 16\gamma^2\beta I_d\right)}{64\beta^3 I_d^2}$

Scenario 3: $x_2 = \frac{I_p\left(\left(4\beta I_d - \gamma^2\right)^2 - 2\beta\gamma^2 I_d\right)^2}{4\beta^2 I_d(4\beta I_d - \gamma^2)^3}$

It holds that in all scenarios, if I_p increases, x_2 increases, and hence C_p increases.

We show the impact of different parameters on x_2 (with partial derivatives) for scenario 1. A similar logic holds for scenario 2 and 3.

Note that x_2 decreases with an increase in β, so that C_p should decrease. This leads to opposite findings compared to the impact of β on x_1, and hence C_p. However, the general impact of an increase of β is an increase of C_p.

Given

$$\frac{\partial x_2}{\partial \gamma} = \frac{-2\gamma I_p\left(8\beta I_d - 3\gamma^2\right)}{16\beta^2 I_d}\frac{\left(16\beta I_d - 3\gamma^2\right)}{\left(4\beta I_d - \gamma^2\right)^2} < 0, \tag{53}$$

it follows that if γ increases, x_2 decreases, and hence C_p decreases.

Given

$$\frac{I_p\gamma^2\left(8\beta I_d - 3\gamma^2\right)}{16\beta^2}\left(\frac{16\beta I_d - 3\gamma^2}{I_d^2\left[4\beta I_d - \gamma^2\right]^2}\right) > 0, \tag{54}$$

it follows that if I_d increases, x_2 increases, and hence C_p increases.

Impact when γ_c differs from γ_f

Distinguishing between the quality sensitivity of the customer to the product innovation share of the customer and firm, demand changes to $D = \alpha - \beta P + \gamma_c\theta_c + \gamma_f\theta_f$. Consequently, the consumer surplus and firm profit (Equations (6) and (7)) change to:

$$CS = \frac{1}{8\beta}\left(\alpha - \beta C_p + \gamma_c\theta_c + \gamma_f\theta_f\right)^2 - I_d\theta_c^2, \tag{55}$$

$$\Pi_f = \frac{1}{4\beta}\left(\alpha - \beta C_p + \gamma_c\theta_c + \gamma_f\theta_f\right)^2 - \frac{I_p}{C_p} - I_d\theta_f^2. \tag{56}$$

Analogous to the proof of Proposition 2, we find the following co-created product quality θ and the innovation share of the firm λ, based on Equations (55) and (56), under the three scenarios in Figure 1:

- Scenario 1: $\theta = \frac{(\alpha-\beta C_p)(\gamma_c+2\gamma_f)}{8\beta I_d-2\gamma_f^2-\gamma_c^2}$, $\lambda = \frac{2\gamma_f}{\gamma_c+2\gamma_f}$,
- Scenario 2: $\theta = \frac{(\alpha-\beta C_p)(8\beta I_d(\gamma_c+2\gamma_f)-\gamma_c^3)}{(8\beta I_d-\gamma_c^2)^2-16\beta I_d\gamma_f^2}$, $\lambda = \frac{16\beta I_d\gamma_f}{8\beta I_d(\gamma_c+2\gamma_f)-\gamma_c^3}$,
- Scenario 3: $\theta = \frac{(\alpha-\beta C_p)(2\beta I_d(\gamma_c+2\gamma_f)-\gamma_f^3)}{(4\beta I_d-\gamma_f^2)^2-2\beta I_d\gamma_c^2}$, $\lambda = \frac{\gamma_f(4\beta I_d-\gamma_f^2)}{2\beta I_d(\gamma_c+2\gamma_f)-\gamma_f^3}$.

Let us denote $\frac{\gamma_c}{\gamma_f} = \eta$. As an illustration, for scenario 1, $\frac{\partial\theta}{\partial\gamma_f} = \frac{(\alpha-\beta C_p)(\eta+2)\left(8\beta I_d+\gamma_f^2(2+\eta^2)\right)}{(8\beta I_d-\gamma_f^2(2+\eta^2))^2}$. An increase of γ_f always leads to an increase of θ if $\eta = \frac{\gamma_c}{\gamma_f} > -2$ and to a decrease if $\eta = \frac{\gamma_c}{\gamma_f} < -2$. For the example of luxury fashion brands, where $\gamma_c < \gamma_f$ and γ_c can be negative, this implies that optimally, the development share of the firm $\lambda = \frac{2\gamma_f}{\gamma_c+2\gamma_f}$ should increase, and that if $\gamma_c \leq 0$, involving the customer in the co-creation process does not create any value.

Impact when I_d^c differs from I_d^f

Distinguishing between the development cost of the customer and the firm, the consumer surplus and firm profit (Equations (6) and (7)) change to:

$$CS = \frac{1}{8\beta}\left(\alpha - \beta C_p + \gamma\theta\right)^2 - I_d^c\theta_c^2, \tag{57}$$

$$\Pi_f = \frac{1}{4\beta}\left(\alpha - \beta C_p + \gamma\theta\right)^2 - \frac{I_p}{C_p} - I_d^f\theta_f^2. \tag{58}$$

Analogous to the proof of Proposition 2, we find the following co-created product quality θ and the innovation share of the firm λ, based on Equations (57) and (58), for scenario 1 (note that scenario 2 and 3 follow a similar logic): $\theta = \frac{(\alpha-\beta C_p)(2I_d^c+I_d^f)\gamma}{8\beta I_d^c I_d^f - \gamma^2(I_d^f+2I_d^c)}$ and $\lambda = \frac{2I_d^c}{I_d^f+2I_d^c}$.

Impact of multiple buyers or multiple co-creating customers

Let us consider a situation where there is a community/network of multiple customers. We consider a 'main' customer, who always participates in the co-creation with the firm, and N neighbors of this customer; the latter can either participate in the co-creation or not. Below, we try to give insights on the positive externalities in co-creation when being able to sell to or co-create the product with multiple customers. The final co-created product quality is given by $\theta = (N+1)\theta_c + \theta_f$ (with $\theta_f = \lambda\theta$ and $\theta_c = \frac{(1-\lambda)\theta}{(N+1)}$) when $N+1$ customers join the co-creation process, or $\theta = \theta_c + \theta_f$ (with $\theta_f = \lambda\theta$ and $\theta_c = (1-\lambda)\theta$) when they don't join the co-creation process. The total demand curve equals $D = (\alpha - \beta P + \gamma\theta)(N+1)$. The latter assumes there is no price discrimination between the main customer and its neighbors for the product, and that they have the same sensitivity to price and quality. Note that if $N = 0$, we fall back to the main model analyzed in the core of the paper.

Let us first consider the situation where the N neighbors buy the product, but do not join the co-creation process:

The consumer surplus (CS) and firm product (Π_f) (Equations (6) and (7)) change to:

$$CS = \left(\alpha + \gamma\theta - \beta C_p\right)^2 \frac{(N+1)}{8\beta} - I_d\theta_c^2, \tag{59}$$

$$\Pi_f = (\alpha + \gamma\theta - \beta C_p)^2 \frac{(N+1)}{4\beta} - \frac{I_p}{C_p} - I_d \theta_f^2. \tag{60}$$

Analogous to the proof of Proposition 2, we find the following co-created product quality θ and the innovation share of the firm λ, under the three scenarios in Figure 1:

- Scenario 1: $\theta = \frac{3\gamma(N+1)(\alpha-\beta C_p)}{8\beta I_d - 3\gamma^2(N+1)}$, $\lambda = \frac{2}{3}$,
- Scenario 2: $\theta = \frac{(\alpha-\beta C_p)\gamma(24\beta I_d - \gamma^2(N+1))}{(8\beta I_d-\gamma^2(N+1))^2 - 16\beta I_d \gamma^2(N+1)}$, $\lambda = \frac{16\beta I_d}{24\beta I_d - \gamma^2(N+1)}$,
- Scenario 3: $\theta = \frac{(\alpha-\beta C_p)(N+1)\gamma(6\beta I_d-\gamma^2(N+1))}{(4\beta I_d-\gamma^2(N+1))^2-2\beta I_d\gamma^2(N+1)}$, $\lambda = \frac{4\beta I_d - \gamma^2(N+1)}{6\beta I_d - (N+1)\gamma^2}$.

Next, we consider the situation where the N neighbors join in the co-creation process:

The consumer surplus (CS) and firm product (Π_f) (Equations (6) and (7)) change to:

$$CS = (\alpha + \gamma\theta - \beta C_p)^2 \frac{(N+1)}{8\beta} - I_d (N+1)^2 \theta_c^2, \tag{61}$$

$$\Pi_f = (\alpha + \gamma\theta - \beta C_p)^2 \frac{(N+1)}{4\beta} - \frac{I_p}{C_p} - I_d \theta_f^2. \tag{62}$$

Analogous to the proof of Proposition 2, we find the following co-created product quality θ and the innovation share of the firm λ, under the three scenarios in Figure 1:

- Scenario 1: $\theta = \frac{\gamma(N+1)(2N+3)(\alpha-\beta C_p)}{8\beta I_d(N+1) - 2\gamma^2(N+1)^2 - \gamma^2}$, $\lambda = \frac{2N+2}{2N+3}$,
- Scenario 2: $\theta = \frac{(\alpha-\beta C_p)(N+1)\gamma(16\beta I_d(N+1)^2 + 8\beta I_d(N+1) - \gamma^2)}{(8\beta I_d(N+1)-\gamma^2)^2 - 16\beta I_d\gamma^2(N+1)^3}$, $\lambda = \frac{16\beta I_d(N+1)^2}{8\beta I_d(N+1) - \gamma^2 + 16\beta I_d(N+1)^2}$,
- Scenario 3: $\theta = \frac{(\alpha-\beta C_p)\gamma(N+1)((N+1)(4\beta I_d-(N+1)\gamma^2)+2\beta I_d)}{(N+1)(4\beta I_d-(N+1)\gamma^2)^2 - 2\beta I_d\gamma^2}$, $\lambda = \frac{(N+1)(4\beta I_d - \gamma^2(N+1))}{2\beta I_d + (N+1)(4\beta I_d - (N+1)\gamma^2)}$.