

# COMPANY-CUSTOMER INTERACTION IN MASS CUSTOMIZATION

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*To Emma and Max*



*I will not choose what many men desire,  
Because I will not jump with common spirits*  
– W. Shakespeare, *The Merchant of Venice*



# Abstract

Advances in manufacturing and information technologies have made it possible for firms to satisfy consumers' increasing demand for unique products. Although, the mass customization of products is prevalent in almost all industries today, firms' optimal mass customization strategy is still not that clear. The initial attempt to mass customization of a number of firms failed, because it proved to be unprofitable, while others have successfully established mass customization as a product strategy. The optimal degree of mass customization solves two decision problems: first, firms' trade-off between the coverage of consumers' preferences to charge a premium price and cost-efficient production; second, consumers' trade-off between tailoring a product to their needs and interaction costs. In an attempt to facilitate managerial decision making, this thesis studies a firm's mass customization decision in a game-theoretical model that combines the decision problems faced by each player in the interaction. Based on this model of company-customer interaction, novel insights into the optimal mass customization strategy of firms depending on their market and competitive environment are gained.





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# List of Variables

|                             |  |
|-----------------------------|--|
| $\theta \in [0, 1]$         | Consumer type                                    |
| $i = \{A, B\}$              | Type of the firm                                 |
| $x_i = \{0, 1\}$            | Location of firm $i$                             |
| $y_i \in [0, 1]$            | Distance of type- $\theta$ consumer to firm $i$  |
| $t \in [0, 1]$              | Sensitivity to product differences               |
| $r$                         | Reservation price                                |
| $d_i \in [0, 1]$            | Complexity of the interaction process            |
| $e_\theta \in [0, 1]$       | Effort level                                     |
| $p_i$                       | Price  |
| $U_i$                       | Consumer utility                                 |
| $\pi_i$                     | Firm $i$ 's profit                               |
| CS                          | Consumer surplus                                 |
| $k_i \in [0, 1]$            | Degree of mass customization                     |
| $a$                         | Variable production costs for a standard product |
| $b_i \geq a$                | Variable costs for mass customized production    |
| $c_i = a + (b_i - a) k_i^2$ | Variable production costs                        |
| $z_i$                       | Discount   |

Note: The subscript  $i$  is omitted in the monopoly model.



# Chapter 1

## Introduction

### 1.1 Motivation

What used to be within the realms of possibility for professional athletes like football star David Beckham, suddenly became feasible for every customer when Adidas<sup>1</sup> launched its mi adidas (my individual adidas) program in 2001: mass customized sports shoes. Consumers can customize the fit (size and width), performance (insole, cushioning, outsole characteristics), and design (colors, embroidery) of the shoes on the internet as well as in mi Innovation Centers of selected stores<sup>2</sup>. A mass customized shoe costs about 30 percent more than the standard alternative (see company's website). While mi adidas allows the company to meet customer preferences, the production of a mass customized shoe is more costly and complex than that of the standard alternative. To offer mass customized shoes cost efficiently, all mi adidas models are based on an existing inline shoe (Moser et al. 2006). From the consumer's perspective, customizing shoes at mi adidas is a whole new buying experience. Consumers have to define and select their preferences via a virtual product configurator online while a trained sales expert, called product trainer, performs all customization stages with the customer in a store.

Years before Adidas launched its mi adidas program, Levi Strauss<sup>3</sup> (Levi's) introduced its mass customization concept Original Spin at its retail locations. Original Spin allows customers to select their preferred type of jeans (classic, low-cut, relaxed), the color (for example stonewashed or black), the leg opening (for example straight or boot cut), and the fly (zip or button), and to fit the jeans to three body measurements (hip, waist, and inseam) with the help of a salesperson. All options are entered into the computer and sent to a Levi's factory. To offer mass customized jeans cost efficiently, jeans created in the Original Spin program are not made to measure but

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<sup>1</sup>German-based Adidas AG is the largest sportswear manufacturer in Europe and the second biggest worldwide. In 2015, the company made revenues of €16.9 billion and operated 1,484 adidas branded stores and an online store with 55,555 employees (Adidas Group 2015).

<sup>2</sup>Today there are around ten permanent shops featuring mi Innovation Centers around the world, including the flagship stores in Paris and San Francisco (Boër and Dulio 2007).

<sup>3</sup>Levi Strauss & Co. is an American clothing company with 2,800 company-operated stores worldwide. The company also operates an online store. In 2014, the company made sales of \$4.8 billion with approximately 15,000 employees (Levi Strauss & Co. 2014).

on a prototype that as closely as possible matches a consumer's proportions (Levi Strauss & Co. 1999). The price of a mass customized jeans is about 35 percent more than that of a standard Levi's pair (Levi Strauss & Co. 1999).

Other interesting examples include Procter & Gamble<sup>4</sup> (P&G) and Ferrero<sup>5</sup>. P&G started Reflect.com in 1999, a website allowing women to create their own beauty products. Using Reflect.com, consumers can customize the product color, packaging, and delivery of hair care, skin care, cosmetics, and fragrances online and at two Reflect stores. All products are priced above mass merchandise (Tode 2005). Quite recently, in 2014, Ferrero started a temporary promotion to personalize the labels of Nutella jars. Using the unique code from the lid of a purchased jar, consumers can personalize the label with a name or message online that is then sent to the customer in the post.

What do these examples have in common? All of the examples have tried to turn consumer heterogeneity into an opportunity to create value rather than minimizing it in so called one-size fits all solutions by interacting with consumers. However, not all of them actually created value. While Adidas and Ferrero have expanded their mass customization businesses, Reflect.com was shut down and Levi's is in its second attempt to mass customization. The mi adidas program has become an integral part of Adidas' overall business (Stoetzel 2012). Next to Adidas' customization offerings for sport shoes (mi adidas), the company introduced customizable uniforms for sport teams (mi team), sneakers that can be individualized as a fashion product (mi originals), as well as a personalized online training program (mi coach). Ferrero spread the personalization of Nutella jars to many countries worldwide and already repeated its promotional periods in some countries. Reflect.com, on the other hand, was closed down after six years, because consumers did not participate in the mass customization of Reflect products strong enough to sustain the company (Iyer and Zelikovsky 2011). This was partly caused by complaints about the length of the questionnaires that had to be answered to customize Reflect products (Tode 2005). At first, Levi's Original Spin seemed like a huge success, but in 2003 the company had to shut down its mass customization operations. The crucial problem was that the company did not reach that many customers. Custom jeans were only sold in selected stores, because it was labor-intensive to sell them (Flynn and Vencat 2012). In 2010, Levi's introduced its new mass customization program Curve ID that allows consumers to customize a pair of jeans online in fewer steps. Recently, the company unveiled a new range of mass customization services at Levi's Tailor Shops, where customers can put a personal stamp on their favorite denim pieces. The service includes, for example, length alteration, monogramming, patches, studs, and rips.

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<sup>4</sup>Procter & Gamble Co. is an American multinational consumer goods company. In 2015, the company reported net sales of \$76,279 million and operated a portfolio of 65 brands with 110,000 employees (Procter & Gamble 2015).

<sup>5</sup>Ferrero SpA is an Italian manufacturer of branded chocolate products and the third biggest chocolate producer in the world. The Ferrero Group had a turnover of €8,412 million and employed 27,485 people in 2014 (Ferrero Group 2014).

What are the characteristics of a successful mass customization strategy? While Adidas integrates its consumers in the fabrication phase of its production process, customization at Ferrero is done after the production and consumers have to personalize the jar themselves after the purchase. Although, integrating their consumers to quite a different extent into the production process, both firms are successful with their mass customization strategies. The two examples highlight that there exists not the optimal degree of mass customization. Instead, the failed mass customization strategies of P&G and Levi's point to the importance of determining a company-specific degree of mass customization. In the company's first attempt to mass customization, Levi's integrated its consumers early in the production of the mass customized product, which proved to be unsuccessful. The company's new mass customization program Curve ID provides less options for consumers and seems to be successful<sup>6</sup>. The examples further show that the interaction process with the customer is key for a successful mass customization strategy. Integrating consumers into a firm's production process results in an active role for the consumer. During the customization process, a customer has to define her preferences and select the options that best match these preferences by either interacting with a salesperson or an online configurator. In case of Reflect.com, the lengthy questionnaires seem to have discouraged customers from customizing the products, partly causing the shut down of the mass customization service. Levi's has learned from its first mass customization attempt. The company's Curve ID program demonstrates a great simplification for consumers. Instead of having to run through a detailed mass customization process with a salesman in selected stores, consumers can now customize jeans in fewer steps online.

## 1.2 Aims and methodological approach

The examples illustrate that mass customization has been trickier to implement than first anticipated as mass customization leads to both benefits and costs on the supply as well as on the demand side. Firms can charge a higher price for mass customized products than for the standard alternatives while the production process becomes more costly and complex. What is the optimal degree of mass customization that balances this trade-off? And how is this degree affected by market conditions? By analyzing these questions, the thesis extends current research on mass customization. On the demand side, mass customization allows consumers to tailor a product to their preferences, but at the same time involves costs for running through the configuration process with the firm. How much effort do consumers put in the customization process when effort is costly? And how is this effort influenced by the interaction process with the firm? This dissertation project contributes to a better understanding of the decision problems consumers face during the interaction with the firm on a theoretical basis since the research that incorporates the strategic role of the consumer in mass customization is of experimental and

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<sup>6</sup>According to Flynn and Vencat (2012), Levi's second attempt in customization seems to be working with revenue up nine percent in the third quarter of 2011, credited in large parts to the success of Curve ID.

qualitative nature.

With these issues in mind, the dissertation project develops and analyzes a game theoretical model that combines the decision problems faced by firms and consumers in mass customization. Both a monopoly and a duopoly model are studied under various assumptions. While the methodological approach used throughout the thesis does not provide a single, precise answer to the complex topic described above, it offers several advantages. By considering only the most relevant factors, it reduces the scope of the research questions and, thereby, enables the analytical derivation of results. The analytical results offer perspectives on how players might act under various circumstances. Hence, the findings can be applied to a multitude of products, firms, and industries. Further, it provides valuable information for managers' decision making and may explain companies' actions.

### 1.3 Structure of the thesis

The thesis evolves as follows. First, it reviews and evaluates existing research (Chapter 2). The development and analysis of the monopoly model (Chapter 3) and duopoly model (Chapter 4) are followed by a discussion of the findings (Chapter 5). Chapter 6 concludes.

The analysis of the literature in Chapter 2 discusses the most important conceptual, empirical, experimental, and theoretical studies that relate to this thesis. It begins with a summary of how industrial markets evolved from mass production to mass customization (Section 2.1), specifically highlighting the key drivers of mass customization (Subsection 2.1.1) and the role of the consumer (Subsection 2.1.2). In Section 2.2, the economics of mass customization in terms of costs and benefits of the supply (Subsection 2.2.1) and demand (Subsection 2.2.2) side are analyzed. Balancing firms' and consumers' costs and benefits arising from mass customization results in the optimal degree of mass customization (Subsection 2.2.3). Section 2.3 addresses the question of how to model the decision problem. A conceptual overview (Subsection 2.3.1) helps to understand how different mass customization strategies can be defined and classified before related game-theoretical studies in product differentiation literature (Subsection 2.3.2), operations management literature (Subsection 2.3.3), and product customization literature (Subsection 2.3.4) are presented. The literature analysis concludes with an evaluation of the presented work to identify the gap in the literature that is the topic of this dissertation (Section 2.4).

The model derived in Chapter 3 analyzes the optimal degree of mass customization in a horizontally differentiated monopoly. The model is based on the assumption that consumers, heterogeneous in their taste, are uniformly distributed along a line of unit length with the monopolist's standard product located at the center of this line. The deeper consumers' integration into the production process of the firm, the more consumer preferences can be covered, but the higher the dis-economies of scale. When making the purchasing decision, consumers choose the effort they want to exert during the product configuration of a mass customized product, which leads



to interaction costs. Next to the pricing decision, the monopolist determines the degree of mass customization (see Section 3.2). The equilibrium analysis of the model (Section 3.3) studies the benchmark model (Subsection 3.3.1), in which consumers face no effort choice, and the model with consumers' choice of effort (Subsection 3.3.2). A comparative analysis highlights the effect of integrating consumer effort into the monopoly model (Subsection 3.3.3). The model is extended to cover the effect of consumers' valuation for uniqueness on the degree of mass customization (Subsection 3.4.1) and the monopolist's incentive to offer both a lower-priced standard product and a mass customized product (Subsection 3.4.2). Section 3.5 summarizes and interprets the results from the monopoly model.

Chapter 4 examines the optimal degree of mass customization in a horizontally differentiated competitive setting. The model is based on the assumption that firms are located at the opposite ends of the unit line and actively compete for consumer demand. Consumers decide from which firm to buy and choose their effort level, resulting in interaction costs. Firms simultaneously set prices, the degree of mass customization, and choose their product strategy (see Section 4.2). Section 4.3 analyzes the equilibrium solutions for the benchmark model (Subsection 4.3.1), in which consumers face no effort decision, and for the model with consumer effort (Subsection 4.3.2) in case no firm mass customizes, one firm mass customizes, and both firms mass customize. Subsection 4.3.3 compares the results and illustrates the effect of integrating consumers' choice of effort into the duopoly model. In Section 4.4, four extensions are analyzed: first, asymmetries in firms' production and interaction processes (Subsection 4.4.1); second, consumers' valuation for uniqueness (Subsection 4.4.2); third, firms' incentive to offer a lower-priced standard and a mass customized product (Subsection 4.4.3); and fourth, firms' location choice (Subsection 4.4.4). The chapter is concluded by a summary of the results in Section 4.5.

Chapter 5 discusses the novel insights from the monopoly and duopoly model to identify the contribution of this dissertation to the current state of research (Subsection 5.1). Subsection 5.2 derives managerial implications from these insights. Finally, the limitations of the monopoly and duopoly model are addressed that give rise to future research (Subsection 5.3). Limitations include the cost structure of the firm (Subsection 5.3.1), consumers' utility function (Subsection 5.3.2), product line design (Subsection 5.3.3), pricing (Subsection 5.3.4), and the periodicity of the game (Subsection 5.3.5). The last chapter of the thesis (Chapter 6) concludes.



## Chapter 2

# Literature analysis

Determining the optimal degree of mass customization is key for a successful mass customization strategy. Thereby, not only a firm's trade-off between tailoring a product to consumers' needs and dis-economies of scale, but also each consumer's trade-off between fitting the product to her needs and interaction costs need to be taken into account. For that reason, the model developed in this dissertation integrates the decision problems faced by firms and consumers. The literature analysis introduces the reader to the concept of mass customization and reviews the current state of experimental, empirical, conceptual, and game-theoretical research.

The first part of the literature analysis (Section 2.1) briefly summarizes the concept of mass customization, highlighting the key drivers for the evolution of mass customization (Subsection 2.1.1) and the role of the consumer (Subsection 2.1.2). In the second part (Section 2.2), costs and benefits of mass customization on the supply (Subsection 2.2.1) and demand (Subsection 2.2.2) side are discussed. The third part (Section 2.3) presents different streams of literature that contribute to the modeling approach of this dissertation. Finally (Section 2.4), the current state of research is evaluated to identify important aspects of mass customization that theoretical literature has not yet covered.

### 2.1 The evolution of mass customization

Davis (1987) firstly introduced the notion of mass customization, a term that was later popularized by Pine (1993a). According to Pine (1993a, p. 47) mass customization is the "developing, producing, marketing and delivering of affordable goods and services with enough variety and customization that nearly everyone finds exactly what they want". In the past century, the production of goods evolved from craft production over mass production to mass customization. Craft production was the common manufacturing technique in the pre-industrialized world. Craft production refers to the manufacturing of unique products for an individual customer by hand. Craft produced goods, however, are labor intensive and of inconsistent quality with a limited distribution. With the beginning of the Industrial Revolution in the nineteenth century, mass

production, the production of large quantities of standardized goods, emerged (Duguay et al. 1997). Due to the wide distribution and low costs of mass produced products, mass produced goods are available for everyone at a reasonable price. To meet consumers' preferences, firms increasingly started to offer more product variants. As stated in *The Economist*<sup>1</sup>, according to the Food Marketing Institute, the number of items in an average American supermarket increased by more than five times from 1975 to 2010. More specifically, while today Coca-Cola offers more than 20 types of Coke, for example Coca-Cola Zero, Coca-Cola Life, and Coca-Cola Vanilla, the company sold only one type, the regular coke, from when the first Coke was launched in 1886 to 1982 (see company's website). In the 21st century, mass customization emerged. Mass customization enables companies to offer unlimited choices at reasonable costs to meet consumers' preferences with high-quality, unique products. Staying with the example of Coca-Cola, the company recently introduced Coca-Cola Freestyle, a soda machine that allows consumers to select from mixtures of Coca-Cola branded products and custom flavors which are then dispensed for an individual consumer. Figure 2.1 illustrates the evolution of industrial markets from local crafted markets over undifferentiated mass markets to the future of industrial markets - mass customization.

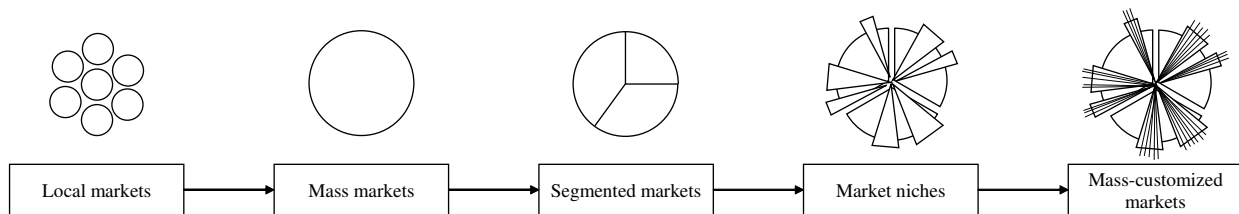


Figure 2.1 Market development by Davis (1987)

### 2.1.1 Key drivers of mass customization

This subsection identifies the key drivers - namely consumers' growing need for uniqueness, technological advancements, and changing consumer markets - for the evolution of mass customization.

#### Growing need for uniqueness

While mass production provides low-cost products through large scale manufacturing, the number of varieties offered is limited. Ford's Model T is commonly considered the most popular and successful example of a mass produced good. The statement from Ford and Crowther (1923, p. 72) emphasizes the essential principle of mass production: "Any customer can have a car painted any color that he wants so long as it is black." The 20th century was all about homogeneity. Companies offered so-called one-size fits all solutions and the media told consumers which clothing

<sup>1</sup>You choose (2010, December). *The Economist*. Retrieved from <http://www.economist.com/node/17723028> on 10.01.2016.

brands were cool and which food healthy. The prevailing culture emphasized the need to fit in and be like everyone else.

With the advent of the internet and the widespread use of social media, this intended homogeneity crumbled. Consumers were no longer satisfied with one-size fits all solutions that made mass production so successful, but felt the need for uniqueness. According to social theorists, people seek to see themselves as being different from others since they find high similarity to other people undesirable (Fromkin 1970,7, Snyder and Fromkin 1977, 2012). It is commonly argued that consumers purchase and display products for the purpose of feeling differentiated, i.e. to satisfy the need for uniqueness (Grubb and Grathwohl 1967, Michel et al. 2009, Snyder 1992, Tian et al. 2001). Tian et al. (2001, p. 52) define consumers' need for uniqueness as "the trait of pursuing differentness relative to others through the acquisition, utilization, and disposition of consumer goods for the purpose of developing and enhancing one's self-image and social image". This may explain why companies started to increase the offered variety. As shown with the example of Coca-Cola, the company first increased its Coke offering from one type to more than 20 and recently introduced a soft-drink machine that offers almost unlimited choice. Research indeed reveals that consumers believe that they are judged by the products they buy and display (Reed 2002, Wan et al. 2001) and that there exists a positive relationship between the need for uniqueness and the desire for unique products (Lynn 1991). Mass customized products help consumers to be unique. Consumers can actively influence and participate in the design of the product to express their individualism (Cox and Alm 1998, Firat and Shultz 1997, Hu 2013, Pine 1993b). Mass customization campaigns frequently feature slogans like "Create your own" (Adidas) or "Create your taste" (McDonald's). No matter how extravagant or off-beat a consumer's self-image might be, mass customized products can help consumers to create this self-image. The need for uniqueness is now aspired more than ever in society and can be seen as one of the key drivers of mass customization.

### **Technological advancements**

While mass production requires the production of large volumes of standardized goods, mass customization demands the production of small volumes of individualized products. Interchangeability, moving assembly lines, and the division of labor were the main technological enablers of mass production (Duguay et al. 1997, Hu 2013), but proved no longer suitable for mass customization. Advances in two technologies, namely information and manufacturing technologies, paved the way for mass customization.

Mass customization critically depends on the interaction between a firm and its consumers and is hence, compared to mass-production, characterized by a high intensity of information as consumer-specific information is needed in order to design and produce a consumer-specific product (Fogliatto et al. 2012, Piller and Möslin 2002, Tseng and Hu 2014). Information technologies provide the mean to mass customization in order to define a catalog of options offered to consumers, collect and store information on customers' choices, transfer the gathered data to

the manufacturer, and translate individual choices into product design features (Da Silveira et al. 2001). Before the rapid dissemination of the internet, salesmen interacted with consumers in order to elicit consumers' preferences (Berman 2002). Today, most companies offer their consumers mass customized products on the internet via web-based systems (Fogliatto et al. 2012). However, mass customizing a product online comes with several challenges as some consumers may find it difficult and complex to individualize the product. A key advancement in information technologies is, hence, the use of interaction systems that guide the customer through the configuration process and visualize the customized good, including product configurators, choice boards, and toolkits (Berman 2002, Tseng and Hu 2014). Adidas, for example, makes use of an online configurator that visualizes the selected options on a virtual sneaker.

Consumer information is then translated into product variants. Addressing consumers' unique preferences, however, increases manufacturing costs. In an effort to meet the challenge of offering individualized products cost-effectively, firms started to view their related products as a family that share components, sub-assemblies, and production steps (Gupta and Krishnan 1998, Lee and Tang 1997, Robertson and Ulrich 1998, Sanderson and Uzumeri 1997, Tseng and Hu 2014). Based on independently designed modules, a high number of assembly combinations/product variants can be created to satisfy consumers' needs (Fisher et al. 1999, Tseng and Hu 2014). The underlying idea is not new. In 1914, an automotive engineer already requested the standardization of automobile subassemblies, such as axes and wheels, to facilitate a mix and match of components in order to reduce costs (Fixson 2007). Based on modularity, product families with a common platform, consisting of all common modules that are shared within a product family, can be produced (Da Cunha et al. 2007, Halman et al. 2003, Lee and Tang 1997, Van Hoek 2001). Platform sharing reduces the number of different components, thereby, improving economies of scale, reducing development time and systemic complexity (Fisher et al. 1999, Moon 2008, Muffatto 1999, Robertson and Ulrich 1998). However, introducing too much commonality can reduce differentiation (?). Therefore, it is key to balance modularity and commonality (Robertson and Ulrich 1998, Tseng and Hu 2014).

To manage high uncertainty and variety in manufacturing, firms employ the concept of postponement or delayed differentiation, meaning that some activities in the supply chain are delayed until customers' orders are received (Ernst and Kamrad 2000, Mikkola and Gassmann 2003, Van Hoek 2001). Companies can then finalize the product in accordance with customer preferences (Van Hoek 2001). Postponement can occur along the entire supply chain, from sourcing to final distribution. Delaying the point when the product attains its uniqueness reduces costs and complexity of manufacturing and enhances a company's flexibility/responsiveness (Aviv and Federgruen 2001, Da Cunha et al. 2007, Ernst and Kamrad 2000, Ko and Jack Hu 2008, Lee and Tang 1997, Van Hoek 2001). However, the standardization of upstream activities and postponement of downstream activities also leads to modularity and commonality issues (Van Hoek 2001).

### Changing consumer markets

The change of consumer markets, especially the shortening of product life cycles and increased global competition from low-wage economies, is seen as one of the main driving forces for companies to adopt mass customization.

Empirical evidence, for example Bloom et al. (2011), shows that the share of imports in the EU and the US from low-wage<sup>2</sup> countries has risen from below five percent in 1980 to above 15 percent in 2007. Several empirical studies reach the general consensus that competition from low-wage countries is the driver of innovation in high-wage countries. Schott (2008) shows that firms in high-wage countries tend to produce better qualities when faced with competition from low-wage countries. In an empirical study, Bloom et al. (2011) find that firms increasingly invest in new technology, human capital, and customized design in the threat of competition from low-wage countries. The authors infer that the growth of competition from low-wage countries leads to lower opportunity costs of innovation for firms in high-wage countries. Hence, when competition from low-wage countries intensified price competition, firms in high-wage countries adopted mass customization to mitigate price competition. According to a survey of the MIT Smart Customization Group, it is indeed observable that roughly 85 percent of mass customizing companies in the survey launched their mass customization business between 2006 and the study in 2011 (Walcher and Piller 2011).

Moreover, consumer markets are characterized by the shortening of product life cycles (Da Silveira et al. 2001, Pine 1993a). More severe global competition and fashion trends as well as consumers' growing need for variety lead to the shortening of product life cycles in many industries (Van Iwaarden and Van der Wiele 2012). Ahlström and Westbrook (1999) find that 72 percent of the surveyed companies indicated the market lifetime of their products was less now than five years ago. On average, these companies estimated the lifetime had shrunk by 25 percent. Long product development cycles and long product life cycles are key features of mass produced goods while mass customization is related with short product development cycles and short product life cycles (Pine 1993a). Hence, mass customized products are advantageous in the current business environment.

To resume, changing consumer markets increased the need for production strategies that focus on individual customers to fight price wars (Ahlström and Westbrook 1999, Berman 2002).

#### 2.1.2 The role of the consumer

Mass produced products are designed by manufacturers with only limited input from their customers. The individual is standardized in order to be able to standardize manufacturing, i.e. the standardization of taste allows for the standardization of design that allows for mechanized mass production, resulting in the standardization of products that allows for mass distribution

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<sup>2</sup>Bloom et al. (2011) define low-wage countries as countries with below five percent GDP per capita relative to the US in 1972-2001.

(Lampel and Mintzberg 1996). This standardization is emphasized by Giedion (1948, p. 704) "Over a period of years of experience with builders and architects, as well as home-owners, we have found that the five-foot tub is on the average an adequate size bathtub for the average size person." In the process of value creation of mass produced goods, value is created inside the firm while consumers are outside the firm (Prahalad and Ramaswamy 2004). The concept of the value chain by Porter (1980) emphasizes the unilateral role of the firm in creating value. Thus, the interaction between companies and customers is not seen as source of value creation in mass production (Normann and Ramirez 1994, Wikström 1996).

However, consumers themselves can be highly innovative. Research reveals that in many industries, consumers are the initiators of new products, prototypes, or processes (Von Hippel 2005). Up to 30 percent of surveyed consumers indicate that they have developed a product for personal use in the past (Von Hippel 2005). This supports the idea to outsource certain tasks in the process of designing new products to the consumer (Schreier 2006).

While mass production focuses on the standardized consumer, the individual consumer is in the focus of mass customization. In mass customization, the locus of control when it comes to designing products lies with the individual customer (Wind and Rangaswamy 2001). Using web-based interaction systems like product configurators, consumers can convert their innovative ideas and preferences into products, which are then produced by the firm (Schreier 2006). The integration of consumers into a firm's value chain can be seen as the most distinctive feature of mass customization. Consumers are seen as partners in the value creation of a firm (Piller et al. 2004) and "now take part in activities and processes which used to be seen as the domain of the companies" (Wikström 1996, p. 361). While traditional cereal companies select the ingredients for the muesli mixtures themselves, consumers of mymuesli take part in the value creation and mix the ingredients themselves. Another obvious example is Adidas. While Adidas used to design sneakers that matched the preferences of most consumers, today consumers create the design of the sneakers themselves. This demonstrates that consumers overtake activities in the value chain that used to be the domain of the firm. However, value creation in mass customization is bilateral. In order to translate a consumer's individual preferences into a product configuration that meets a consumer's needs, the consumer and the firm have to interact. The interaction between companies and consumers is, hence, seen as a source of value creation in mass customization.

## 2.2 The economics of mass customization

This section briefly describes the major costs and benefits that arise through the adoption of mass customization on both the supply and the demand side and highlights that a successful mass customization strategy needs to balance the trade-offs of firms and consumers.



### 2.2.1 Firms' trade-off

In economics, it is assumed that firms seek to maximize profits. When making decisions, firms try to maximize revenues and minimize costs. Hence, a firm finds it profitable to adopt mass customization if mass customized products result in either increased demand or higher prices, or lower costs. This subsection provides a non-exhaustive overview of the effect of mass customization on a firm's revenue drivers and costs.

#### Revenue drivers

Practical examples and experimental research have proven that mass customized products allow firms to charge higher prices since they lead to an increase in consumers' willingness to pay. Adidas and Nike, for example, charge approximately 30 percent<sup>3</sup> more for a mass customized sports shoe than for its standard alternative. Several researchers experimentally prove these practical findings and show that consumers are willing to pay a price premium for a mass customized product. Franke and Piller (2004) analyze the value created by product configurators that allow customers to create their own products, which are then produced by the manufacturer. Particularly, participants in the experiment create their own watches via a product configurator. The authors find that consumers' willingness-to-pay for a self-designed watch exceeds the willingness-to-pay for the standard alternative by 100 percent on average, even when the quality is the same. Schreier (2006) empirically tries to generalize the findings from Franke and Piller (2004). He finds that customers' average willingness-to-pay increases by more than 100 percent for self-designed cell phone covers, t-shirts, and scarves. The author attributes these benefits to the following sources: first, closer fit between individual needs and product characteristics; second, extra value from the perceived uniqueness of the self-designed product; third, value from the do-it yourself effect as the customer takes on the role of an active designer. Next to allowing firms to charge a premium price, mass customized products also enable firms to capture individual differences in the willingness-to-pay between different customers as firms can price differentiate on the level of a specific customer design (Piller 2004b). The breakfast cereals manufacturer mymuesli, for example, allows customers to create their own cereal mixture. Consumers can choose the cereal base and additional ingredients like fruits or nuts. Each cereal base as well as each additional ingredient has an individual price so that the total price of a customized muesli differs from mixture to mixture. This enables mymuesli to capture individual differences in the willingness-to-pay between its customers.

According to Berman (2002), the reduction of inventory holding costs is one of the major benefits of mass customization. Mass customization requires only a low inventory of finished products since goods are produced to order, not to stock. Products are customized after the company

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<sup>3</sup>Depending on the model. A standard Nike Free RN running shoe is priced at €110 while its customizable alternative the Nike Free RN iD costs €145 - 32 percent more (see the retailer's website). A comparable running shoe, the Adidas Pure Boost, is priced at €119.95 while its customizable alternative, the mi Pure Boost, costs €159.95 - 33 percent more (see the retailer's website).

has received the customer order. Hence, companies know the exact quantity and configuration required leading to lower losses from overage. Dell Computer is an example for cost savings from lower inventory levels. Hersch (1998) finds that when Dell was the only mass customizing computer manufacturer, the time of materials staying in inventory was seven hours compared to 78 days of its non-customizing competitor Compaq. This substantially lower inventory holding time resulted into a six percent increase in net profits, because of lower inventory holding costs and fewer losses from overage (Hersch 1998). Also other industries can benefit from lower inventory costs. Agrawal et al. (2001) estimate that inventory savings from making cars build-to-order instead of build-to-stock could be approximately \$3,600 per car for Nissan Motors and \$65 to \$85 billion per year for the entire car industry.

Further, firms can benefit from integrating their consumers into the production process as this gives firms access to detailed customer information and more precise market knowledge (Piller et al. 2004, Piller and Möslein 2002). For example, the customer information P&G accumulated with Reflect.com proved priceless (Tode 2005). Selling cosmetic products online was a learning experience for P&G and the information the firm accumulated with the lengthy questionnaire about consumers' preferences could be channeled into its beauty care brands. Another benefit from customer integration is the building up of stable relationships between firms and consumers as satisfaction with mass customized products increases loyalty and the probability of a re-purchase. A commonly mentioned reason for Levi's Original Spin failure is the company's inability to build relationships with its customers. As customers' information was not saved in an online database, re-orders of mass customized jeans were difficult (Piller 2004a) and no market knowledge was gained. However, in the company's new mass customization attempt, customers' customization settings are saved in their online account so that they can easily re-order their customized jeans.

### Costs

From a firm's perspective, the major cost driver of mass customization lies in manufacturing. Compared to mass produced goods, mass customized goods are produced one by one. Consequently, economies of scale realized in mass production are lost when products are mass customized. This implies substantially higher unit production costs. In the Original Spin program of Levi's, mass customized jeans were sewn virtually on scratch one pair at a time while mass produced jeans could be cut and sewn in batches of 30 (Levi Strauss & Co. 1999). To produce mass customized products more cost efficiently, Adidas, for example, makes use of an existing inline shoe for all mass customized configurations (Moser et al. 2006). The example of Levi's also emphasizes the need for qualified labor to produce mass customized products, leading to an increase in personnel costs.

Next to variable production costs, mass customization also increases fixed costs. In order to produce unique products in large volumes, investments in flexible machinery and production technologies are needed. Moreover, a more complex and detailed quality control and complex

manufacturing planning increase the overall cost level (Agrawal et al. 2001, Zipkin 2001). Next to production costs, firms also compete with delivery times (Da Cunha et al. 2007). As some activities are postponed until customers' orders are received, the lead time for mass customized products is longer than for the immediately available standard product. For example, the standard delivery of a pair of Adidas sneakers takes two workdays while a customer has to wait four to six weeks for her customized mi adidas sneakers. Therefore, Adidas has already implemented the fast customization option, including the personalization of sneakers via a name or number, that shortens the delivery time to four workdays.

Another cost driver is the process of elicitation as it requires an elaborated system for eliciting customers' preferences and transferring these to the firm (Piller and Möslin 2002, Zipkin 2001). Because the customer is integrated into the production process, the firm has to minimize consumers' burdens to customize a product. This can be done by investing in customer service centers, configuration systems, and promotion activities (Piller and Möslin 2002). A prominent example for minimizing consumers' costs of customization is the Adidas mi Innovation Center. Latest technology collects a customer's individual running characteristics and transfers the data into a matching individual shoe as well as enables the customer to see the customized shoe on her own foot via a virtual mirror.

### **2.2.2 Consumers' trade-off**

When making a purchasing decision, consumers buy the product that maximizes their utility or do not buy at all if buying a product leads to disutility. Hence, the decision whether to buy a mass customized product or the best available standard product is basically the result of a simple economic equation (Franke and Piller 2003): If the perceived benefits from the mass customized product compared to the standard product outweigh its perceived relative costs, i.e. the mass customized product maximizes utility, the consumer will buy the mass customized product and vice versa. This subsection provides a non-exhaustive overview of the effect of mass customization on a consumer's benefits and costs.

#### **Benefits**

Benefits from purchasing a mass customized product are twofold: first, the increment utility from buying a product that better fits to a consumer's aesthetic and functional preferences than the best available standard product; second, perceived value from configuring a mass customized product (Novak et al. 2000). "Mass customization may increase the value for the customer through the development of differentiated, unique products and services" (Fiore et al. 2004, p. 836). Therefore, when the best standard product attainable does not match a consumer's individual preferences, firms can generate additional value for this customer by allowing her to customize the product according to her needs. This value can be highlighted with the example of mass customizing jeans at Levi's. Since not every consumer has the "ideal" figure, customizing

the fit of Levi's jeans allows customers to match their body measurements. A good fitting jeans tremendously increases the utility consumers derive from purchasing the jeans.

The perceived uniqueness of a product is the extent to which this product differs from other products from a customer's point of view (Tian et al. 2001). Using empirical analysis, Schreier (2006) finds that next to a closer fit between individual needs and product characteristics, there exist additional value from the perceived uniqueness of the self-designed product and from the do-it-yourself effect as the customer takes on the role of an active designer. By asking students how much they would pay for a watch that would be unique, Schreier (2003) reveals that the average willingness to pay increases by 64 percent when the item is unique. Since mass customization may provide an endless number of product configurations, mass customized products can be seen as highly unique. This finding is reinforced by the experimental studies of Franke and Schreier (2008) and Franke et al. (2010), who show that perceived uniqueness and the do-it-yourself effect create additional value for consumers independent of the improved aesthetic and functional fit. The perceived uniqueness significantly increases a consumer's willingness to pay (Franke and Schreier 2008) and accounts for the perceived value increase of a mass customized product of 70 percent of participants (Franke et al. 2010). Furthermore, several empirical studies (Fiore et al. 2004, Michel et al. 2009) find that customers that value uniqueness are more likely to mass customize a product.

### Costs

Mass customization also involves costs for the consumer. The direct cost of mass customization is the price premium of a mass customized product compared to its standardized alternative charged by mass customizing firms (Piller et al. 2004). As previously explained, mass customization allows firms to charge a higher price as consumers' willingness to pay is increased. Adidas and Nike, for example, charge approximately 30 percent more for a mass customized pair of trainers than for their standard alternative.

In addition, customers may perceive cognitive costs from the process of customizing a product. While co-design activities may increase consumers' perceived value of the product, they are also a major driver for complexity, effort, and perceived risks (Piller et al. 2005). Pine (1993a) uses the term mass confusion for describing consumers' burdens and drawbacks from mass customizing a product. The examples of Reflect.com (P&G) and Original Spin (Levi's) show that the profitability of a mass customization strategy critically depends on the complexity of the mass customization process. Original Spin failed due to its complexity, but Levi's new, less complex attempt to mass customization seems to be profitable. In case of Reflect.com, the lengthy questionnaire seems to have discouraged customers from customizing the products, partly causing the shut down of the customization service. Customers often have trouble deciding what they want and then communicating or acting on their decisions (Zipkin 2001). In an experiment, Franke and Schreier (2010) show that next to the perceived benefits of the mass customization process, consumers' effort put into the product configuration can have a negative impact on the

perceived value of the self-designed product. Consumer effort results from the perception of complexity from excess variety (Franke and Piller 2004, Huffman and Kahn 1998, Kamali and Loker 2002). Consumers might be overwhelmed by the number of customizable options resulting in an unmanageable information overload due to limited information processing capacities. Even a rather simple product like a pair of sneakers becomes complex if one has to decide between different widths, colors, and patterns (Piller et al. 2005). In addition, customers often lack knowledge about their individual needs and preferences (Dellaert and Stremersch 2005, Huffman and Kahn 1998). Especially in consumer markets, customers often have insufficient knowledge when defining product specifications that should match their ideal product (Huffman and Kahn 1998, Liechty et al. 2001). In their experimental study, Dellaert and Stremersch (2005) show that mass customization affects consumers' perception of complexity. Although, there is a perceived value of mass customized products, complexity negatively affects consumers' utility from buying a mass customized product. Interestingly, the authors find that consumers with a better product knowledge perceive the configuration process as less complex and, hence, derive a lower negative utility from complexity. Therefore, in order to specify the variety of options to ones preferences, consumers need to exert effort. Consequently, consumers might not choose to specify all options or even purchase the standard alternative.

In addition to these costs, lead times for mass customized products are much longer as highlighted with the mi adidas example. Consumers have to wait two workdays for a standard pair of sneakers while mass customized trainers have a lead time of four to six weeks. Thus, customers need to wait for custom orders whereas a standard product is immediately available. This leads to waiting costs for consumers. Furthermore, as the configuration process may take a while, time gets diverted from other activities, creating opportunity costs.

### **2.2.3 Determining the optimal degree of mass customization**

The introductory examples emphasize that implementing mass customization successfully has proven to be more difficult for firms that initially anticipated. Next to P&G and Levi's, there exist a number of examples of large companies and start-ups that have failed to profitably offer its customers mass customized products. A recent international study on mass customization finds that 17 percent of companies experienced mass customization as more complicated than anticipated and that 20 percent of the companies in the study went out of business during twelve months of data gathering (Walcher and Piller 2012). While some companies find the implementation of mass customization challenging and difficult, some examples show that a successful implementation of mass customization is indeed feasible (Salvador et al. 2009). As previously described, Adidas launched its mass customization business, mi adidas, in 2001 and has since then expanded its customizable product portfolio. Interviews with managers from the mi adidas business unit confirm that the mass customization business has become an integral part of Adidas' overall business (Stoetzel 2012). Stoetzel (2012) further discovers that mi adidas is mentioned in the Adidas Group's annual report from 2011 as important lever to achieve the strategic

business plan.

Recent articles, for example Fletcher and Wolfe (2004) and Spaulding and Perry (2013), recognize the level of mass customization as critical strategic decision variable of firms. That the degree of mass customization is indeed an important decision variable for firms shows the case of two firms that implemented mass customization in the footwear industry. The German company Creo Shoes and American-based Customatix launched their mass customization business in 2000. Both companies offered mass customized shoes that could be personalized via an on-line configurator. While consumers at Creo were confronted with a low number of base shoe models and a low quantity of possible customizable configurations, Customatix offered hundred of different models that could be mass customized to billions of possible combinations. Both companies went out of business. While Creo failed because of a relatively low degree of mass customization, Customatix failed because of too much choice (Boër and Dulio 2007). The key of profiting from mass customization is to see it not as replacement of mass production, but rather to view mass customization and mass production as poles of a continuum of real-world strategies (Lampel and Mintzberg 1996). Hence, in order to profit from mass customizing products, firms have to carefully balance the costs and benefits of mass customization. But, as proven in this section, mass customization does not only invoke a trade-off for firms. Mass customization might not only be beneficial for consumers, but leads to costs, directly from a price increase and indirectly due to consumer effort. This implies that when firms balance the costs and benefits from mass customization in order to determine the optimal degree of mass customization, they also have to consider how consumers react to changes in the degree of mass customization. To conclude, the optimal degree of mass customization has to jointly balance a firm's trade-offs and consumers' trade-offs.

### 2.3 Modeling the decision problem

The modeling approach of this dissertation mainly draws upon the literature of product customization examining whether firms should mass customize or mass produce. The work on product customization is related to studies dealing with the design and positioning of product lines, covered by the product differentiation literature. The theory of product differentiation is primarily based on two works: Chamberlin's work on monopolistic competition (Chamberlin et al. 1933) and Hotelling's work on spatial competition (Hotelling 1929). Since the model developed in this dissertation is based on the spatial competition model of Hotelling (1929), this section gives a brief, non-exhaustive, overview of the evolution of product differentiation literature building on the model of Hotelling (1929). Thereafter, studies more closely related to the model of this dissertation, namely studies on product customization and work on operations management that focuses on strategies that enable the production of high variety are examined in detail. To begin with, this section identifies conceptual approaches that classify firms' mass

customization approaches based on empirical observations.

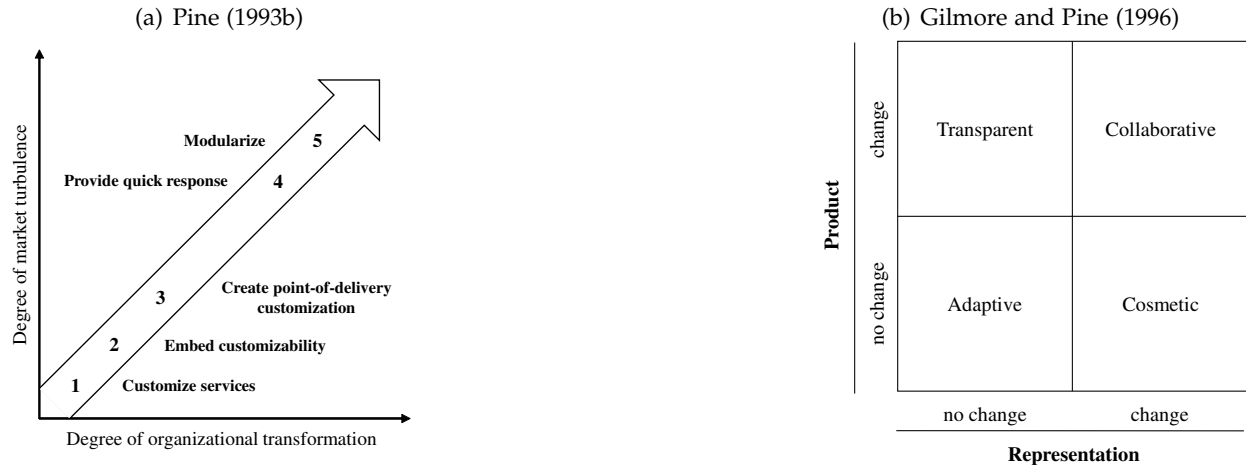
### 2.3.1 Conceptual overview

Since the emergence of mass customization, many researchers have focused on how to classify firms' diverse mass customization strategies in order to help managers determine the type of customization they should pursue.

Pine (1993b) identifies five basic methods for mass customizing products and services based on practical experiences and prior research, which are illustrated in Figure 2.2 (a). The rank order of the proposed methods is in terms of their increased value to consumers and by the ease of implementation. The first method is to customize services around existing standardized products or services. The mass production of customized services or products that customers can easily adapt to their individual needs constitutes the second method. Method three aims at moving the production to the customer to provide point-of-delivery customization. The fourth method is to provide quick response. Particularly, reducing time throughout a firm's value chain accelerates, among other things, new product development so that changing customer needs can be more closely and rapidly satisfied. The last method builds upon the idea to modularize components in order to customize end products and services. Modular components are produced that can be configured into a wide variety of end products and services in order to provide each customer with a product or service that meets her needs. The author's framework shall help firms to shift from mass production to mass customization throughout their key value-added activities.

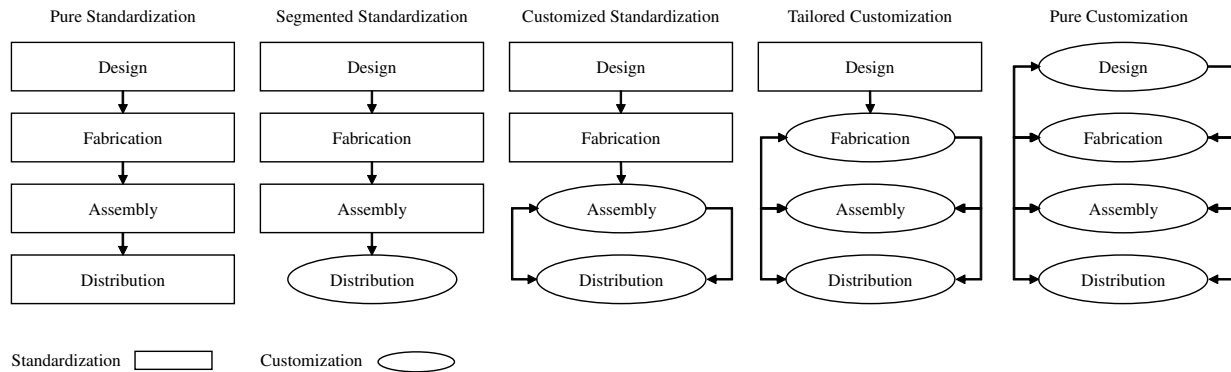
Based on empirical observations, Gilmore and Pine (1996) identify four customization strategies, illustrated in Figure 2.2 (b), which are collaborative, adaptive, cosmetic, and transparent. These four strategies differ in two dimensions, namely whether or not the product itself is changed and whether or not the representation of the product is changed. A cosmetic mass customization strategy only changes the representation of the product, for example the packaging. A firm that follows the adaptive approach neither changes the product nor the representation for the individual customer, but provides her with the ability to adapt the product's functionality and representation to her particular needs. Thus, a standard good is created that can easily be tailored to individual needs by the consumer herself without interacting with the company. When using the transparent mass customization approach, the firm changes the product for consumers in such a way that they don't know the product has been customized. Therefore, instead of requiring consumers to take time to describe their preferences, companies observe consumers' behavior over time to predict their needs. In the collaborative strategy, firms need to interact with their customers in order to be able to translate their needs into customized products.

Lampel and Mintzberg (1996) define a continuum of mass customization strategies. The authors separate the firm's value chain in four stages, namely design, fabrication, assembly, and distribution, and define customization as point of customer integration into the value chain. Customization strategies include pure standardization, segmented standardization, customized



**Figure 2.2** Stages of mass customization by Pine (1993b) and the four approaches to customization by Gilmore and Pine (1996)

standardization, tailored customization, and pure customization. Figure 2.3 illustrates this classification of mass customization strategies.



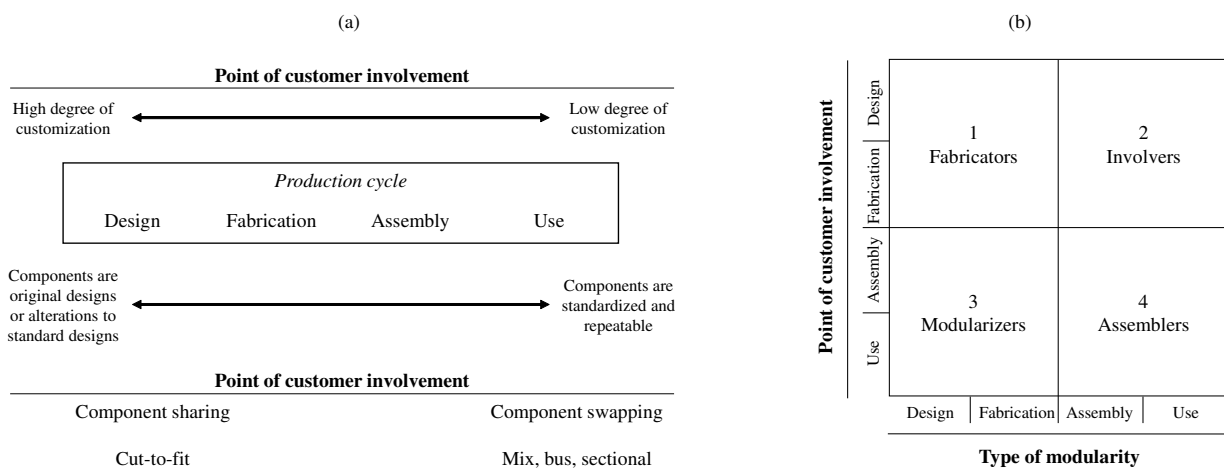
**Figure 2.3** A continuum of strategies by Lampel and Mintzberg (1996)

Pure standardization is based on a dominant design targeted to the largest possible group of consumers. Under this strategy, there are no distinctions between different customers. Under segmented standardization, firms respond to the needs of different consumer clusters. Particularly, a basic product is modified to cover various product dimensions, but not at the request of individual buyers. This strategy increases the choices for consumers, but individual consumer preferences still not influence the product. Customized standardization means that products are made to order from standardized components, i.e. the assembly is customized. Each component is designed and mass produced for the aggregate market, but each consumer can create her own configuration out of the available components. Under tailored customization, a product prototype with a standard design is offered to consumers, which can be modified to meet consumers' needs. With pure customization, products are made to order. Thus, the product is customized to



consumers' preferences in every stage of the supply chain. Lampel and Mintzberg (1996) argue that the key of profiting from mass customization is to see it not as replacement of mass production, but rather to view mass customization and mass production as poles of a continuum of real-world strategies. Managers should not replace the one extreme with the other, but rather locate their strategy along this proposed continuum.

Duray et al. (2000) identify and classify mass customizers according to the ways they achieve mass customization. The proposed distinct mass customization configurations are empirically validated. According to the authors, mass customizers can be identified and classified by two dimensions: the point in the value chain where the customer gets involved and the type of product modularity involved.

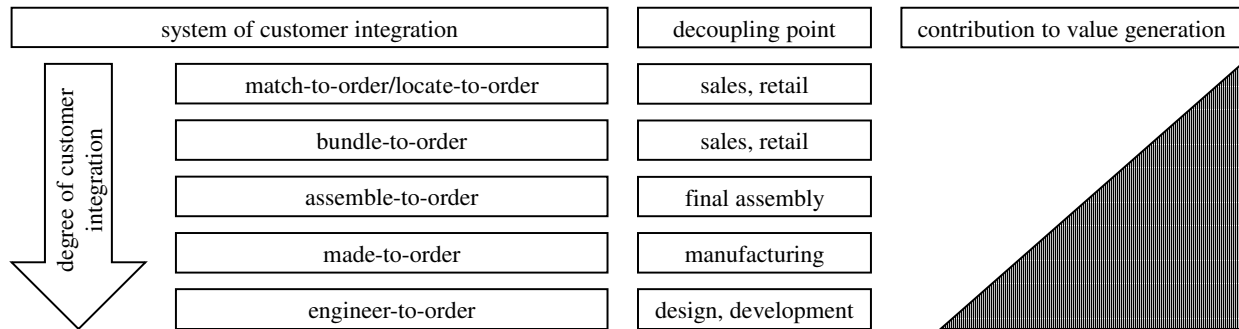


**Figure 2.4** Matrix grouping of mass customization configurations and customer involvement and modularity in the production cycle by Duray et al. (2000)

As there exist various types of modularity, the authors consider the typology initially introduced by Ulrich and Tung (1991). These types of modularity define how common modules can be combined to a unique product and include, for example, component-sharing and component-swapping. Duray et al. (2000) integrate this typology of modularity into the production cycle of a firm, as illustrated in Figure 2.4 (a), in order to assign the different types of modularity to a specific phase of the production cycle. For example, component-sharing modularity takes place during the design and fabrication stages. In order to fully realize mass customization in practice, customer involvement in the production process and modularity types are combined. While customer involvement provides the customization, modularity restricts the range of choice. Duray et al. (2000), thereby, build upon the idea of Lampel and Mintzberg (1996) that mass customization can be defined by the degree of customer involvement. This classification based on customer involvement and modularity allows the authors to identify four groups of mass customizers, depicted in Figure 2.4 (b): fabricators, who closely resemble pure customizers as they involve the customer early in the process; involvers, who involve a customer early in the production process, but do not fabricate any new modules for this customer; modularizers, who develop modularity

in the design and fabrication stage with customers specifying their unique preferences not until the assembly and use stage; assemblers, who closely resemble mass producers, however, involve customers into the specification of the product.

Piller et al. (2004) classify several archetypes of customization by combining the degree of company-customer interaction with the degree of postponement and illustrate these by case examples. The approaches to customization, illustrated in Figure 2.5, build upon the classifications of Lampel and Mintzberg (1996) and Duray et al. (2000).



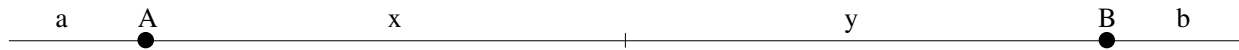
**Figure 2.5** Archetypes of mass customization by Piller et al. (2004); simplified illustration

In a match-, locate-, and bundle-to-order system, for example, customization is delayed to sales and retail activities with little customer integration and, thus, little contribution to the value generation done by the customer. In the made-to-order customization system, the customer is integrated in the manufacturing process already and, therefore, contributes a lot to the value generation. The authors argue that only those mass customization systems will be successful in the long run that can balance the benefits and costs of customer integration.

### 2.3.2 Product differentiation literature

Hotelling (1929) introduces the idea of spatial competition, i.e. that firms compete not only on price but also on location. Identical firms, Firm  $A$  and Firm  $B$ , compete in a linear market of length  $l$ . Consumers are uniformly distributed over this line and are heterogeneous in their taste for products. Individual consumer demand is inelastic. Each consumer purchases one unit of the product and incurs transportation costs that are a linear function of the distance between her location and that of the firm. Which product a consumer purchases depends on the price and location of a firm's product relative to the price and location of the competitor's product. Firm  $A$  is located  $a$  units away from the left end of the line and Firm  $B$  is located  $b$  units away from the right end of the line. Hence, all consumers in segment  $a$  buy from Firm  $A$  while all consumers in segment  $b$  buy Firm  $B$ 's product. The segment between Firm  $A$ 's and Firm  $B$ 's location is divided by the marginal consumer, to whom both products provide the same costs (in terms of price and transportation costs). All consumers located in segment  $x$ , between Firm  $A$ 's location and the location of the marginal consumer, buy Firm  $A$ 's product while all consumers located in segment  $y$ , between the location of the marginal consumer and Firm  $B$ , buy from Firm  $B$ . Hence,

the market of a firm is a connected segment on the line with the firm's location somewhere in this segment. Figure 2.6 illustrates the set-up of the classic Hotelling (1929) model.



**Figure 2.6** Model set-up after Hotelling (1929).

Hotelling (1929) finds that firms have an incentive to locate at the center of the market, i.e. firms' products are alike. If firms are not located close to each other, then one firm has an incentive to move closer to the other in order to increase its market share. This tendency is called the principle of minimum differentiation. Since Hotelling (1929), literature has focused on competitive positioning questions, thereby extending and refining the work of Hotelling (1929). d'Aspremont et al. (1979) show that the proposed principle of minimum differentiation is not an equilibrium if firms are allowed to undercut the price of their competitor. Modifying the linear transportation costs considered in Hotelling (1929) to quadratic transportation costs, the authors find that firms tend to locate at the ends of the unit line, i.e. choose maximum differentiation. Graitson (1982) reviews the main extensions to the Hotelling (1929) model, including the number of firms, the shape of the demand curve, and the type of space. Smithies (1941), for example, introduces a price elastic demand curve. The case of more than two firms is considered by Eaton and Lipsey (1975). Prescott and Visscher (1977) extend the Hotelling (1929) model to analyze the sequential location of firms. Shaked and Sutton (1982) examine a three-stage process to find a locational equilibrium. The case without boundary effects is analyzed, among others, by Salop (1979) and Economides (1984) on a circular model, where firms are located on a circle of perimeter 1, equidistant from each other. Hauser (1988) examines how an existing brand should respond to competitive new entry. The main finding of spatial competition models is that a firm's optimal location is determined by two effects: first, firms have an incentive to differentiate to mitigate price competition; second, firms have an incentive to move towards the center to position where consumers' preferences are. Gabszewicz and Thisse (1979) consider competition in vertically differentiated consumer markets. Consumers have uniform tastes for product attributes but are heterogeneous in their income level/willingness to pay. By contrast, products are vertically differentiated when there exists a ranking of products, i.e. every consumer prefers the same product but not every consumer can/wants to afford it, while products cannot be ranked when they are horizontally differentiated, i.e. every consumer prefers a different product.<sup>4</sup> Many studies, for example Neven and Thisse (1989), have extended the one-dimensional space to a two-dimensional space to combine horizontal and vertical differentiation. In Neven and Thisse (1989), the horizontal axis represents the different product designs while the vertical axis represents the quality of the product. Generally, the authors find that firms choose maximum differentiation along one axis and minimum differentiation along the other.

<sup>4</sup>See Tirole (1988) for a literature review on vertical differentiation.

During the era of mass production, product differentiation literature mainly focused on single product competition.<sup>5</sup> As competition intensified, firms started to offer a higher variety of products. Since then, studies on product differentiated have considered multi-product competition.<sup>6</sup> Brander and Eaton (1984) are the first to analyze product line selection between multi-product firms in a duopoly. In their model, firms can choose different product constellation, i.e. firms can choose to produce product pairs that are close substitutes or pairs that are more distant substitutes. The authors find that competing firms are likely to develop products that are close substitutes to their existing products, leading to less intense price and output competition. However, in the threat of entry, firms will develop products that are distant substitutes, because the intensified competition deters entry. Martinez-Giralt and Neven (1988) analyze whether firms have an incentive to establish a couple of outlet stores. Outlet store locations are modeled as points on the Salop (1979) circle. The authors find that firms choose to operate only one outlet, because multiple outlets intensify price competition. Klemperer (1992) extends the model by considering two firms that produce  $n$  products that are represented as points on the circle to explain why competing firms may choose similar product lines. Mussa and Rosen (1978) and Moorthy (1984) consider the issue of a multi-product monopolist in a quality differentiated market and show that consumer self-selection induces competition within the monopolist's own product line. Champsaur and Rochet (1989) analyze multi-product competition in a vertically differentiated market and show that the quality decision is affected by two opposing forces: first, firms have an incentive to offer a broad range of qualities to discriminate among consumers with different characteristics; second, firms have an incentive to differentiate their products from their competitors' products to mitigate price competition. Canoy and Peitz (1997) study a model of multi-product competition in which products are differentiated in two dimensions, quality and horizontal attributes, and highlight the role of strategic effects. Desai (2001) analyzes the effect of cannibalization on price and quality choice in an oligopoly. There exist conditions under which only the high-valuation segment gets its preferred quality due to cannibalization concerns. Generally, literature on product variety mostly focuses on balancing the revenue gain from greater variety against lower unit production costs from lower variety. It is assumed that consumers are heterogeneous, firms can increase profits by producing greater variety, and firms can mitigate price competition by differentiating their products from their competitors' products (Lancaster 1990).

### 2.3.3 Operations management literature

The literature in operations management that is presented here focuses on manufacturing strategies that enable high variety cost efficiently. Specifically, this subsection non-exhaustively reviews studies that deal with platform sharing and postponement.

Several studies explore the trade-off between cost savings from common components and prod-

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<sup>5</sup>See Lancaster (1990) for an extensive literature review on product differentiation.

<sup>6</sup>See ? for a review on multi-product firms and product differentiation.

uct differentiation arising from unique components when firms employ platform sharing. Particularly, literature in this field analyzes whether a firm should use common components, i.e. a product platform, across its products in a vertically differentiated market with two consumer segments that differ in their valuation for quality. Customers purchase the product that maximizes their utility, which is increasing in quality. Unit manufacturing costs increase in the quality level of the components. Common components, i.e. the product platform, lead to cost savings due to economies of scale. Generally speaking, the trade-off between cost savings and diminishing product differentiation resulting from platform sharing is analyzed. In Kim and Chhajed (2000), the monopolist can choose to produce a single product for one consumer segment or both segments or to produce a product for each segment. If the firm decides to produce two products, it can decide whether or not to use a common platform. The firm chooses the quality level of the common platform as well as the quality levels of the products catering to the low and high consumer segment. While the common platform results in a valuation premium for the low-end product, it leads to a valuation discount for the high-end product. The authors find that while commonality leads to cost savings, it reduces the perceived quality difference at the same time. Krishnan and Gupta (2001) extend the work of Kim and Chhajed (2000) by accounting for additional costs and benefits of modular products. Next to economies of scale resulting from producing the platform in larger volumes, integration benefits of platforms arise, i.e. the platform has a more cost-efficient design. When the platform is applied to the low-end product, over design costs emerge while under design costs are the result of a platform applied to the high-end product. Krishnan and Gupta (2001) find that the platform-based development of products becomes more profitable than the independent development as integration benefits increase and over-design costs decrease. The authors show that the differentiation between the two products is higher in the presence of platforms than in their absence, leading to reduced cannibalization, and conclude that the platform approach is not optimal when market diversity is either too low or too high. They further analyze the effect of sequential product introduction and find that simultaneous product introduction is more attractive when the platform approach is used. Different to Kim and Chhajed (2000) and Krishnan and Gupta (2001), who model the product platform as shared quality level, Desai et al. (2001) analyze whether a firm should make the low- or high-quality component of a pair of two-component products common. Hence, the firm can produce a unique pair of products or products that share a component. Unit manufacturing costs are increasing in product quality while investments in design effort can reduce manufacturing costs. When components are common, cost savings due to design effort and economies of scale are greater. However, commonality decreases product differentiation, which hinders a firm's ability to extract premium prices. The authors show that the profitability of a common-component design improves as the relative size and quality valuation of the low consumer segment increase. Further, as the importance for quality increases, the loss in product differentiation due to a common design has a greater adverse impact on the firm's profit. Heese and Swaminathan (2006) generalize the model of Desai et al. (2001). Particularly, the authors

assume that each product is composed of a finite number of components and use a more general relation between effort and quality-related costs to capture potential interactions. In contrast to the conventional paradigm that the loss of product differentiation under commonality leads to less attractive product lines, Heese and Swaminathan (2006) find that in the presence of interaction between quality and effort decisions, commonality might lead to more attractive product lines and higher profits. Kim et al. (2013) extend the above research by considering the case of a non-dominating preference structure where each consumer segment has an attribute it values more than the other segment. The authors find that the effect of a commonality strategy is even more diverse when the preference structure is non-dominating and that it can improve a firm's profit as the firm is able to better design product lines with common components and attributes. Most interesting, they show that commonality can relieve cannibalization in the product line.

Ghosh and Morita (2008) extend the research on platform sharing to a competitive setting. The authors model platform sharing by introducing a product differentiation parameter that decreases under platform sharing. The authors investigate both whether or not a monopolist should use a common platform for its two products and whether two firms, each producing one product, should share a common platform in a duopoly. The continuum of consumers with identical preferences is captured by the representative consumer. By using a common platform, fixed costs for product development are reduced. At the same time, using a common platform reduces the differentiation between the two products. Both platform sharing under horizontal and vertical product differentiation are analyzed. The authors find that platform sharing across firms benefits consumers, because it intensifies competition in the horizontal differentiation model and increases the quality of the lower-quality product in the vertical differentiation model.

Ghosh and Morita (2006) pick up the trade-off between commonality of components and the degree of product differentiation and transfer it to manufacturer-supplier relationships. In a model with two manufacturers and free entry of suppliers, the manufacturers decide whether or not to use common components in the first stage of the game. In a second stage, there is free entry of suppliers. If the two manufacturers chose not to share a platform in the previous stage, each supplier must determine whether or not to specialize in part 1 or part 2 - one cannot produce both parts. Lastly, each manufacturer independently chooses a set of suppliers with which it communicates. Communication is costly. Platform sharing reduces the degree of product differentiation, which in turn intensifies price competition. However, under platform sharing, each manufacturer can choose a supplier from a larger number of potential suppliers, which lowers its expected price for procurement. The authors find that the manufacturers will share a platform if the reduction of product differentiation due to platform sharing and the communicating costs are relatively small. Ghosh and Morita (2006) further argue that the IT revolution can substantially reduce communication costs and suggest that this phenomenon could be the reason for the recent prevalence of platform sharing.

Bourreau and Dogan (2010) incorporate the trade-off between commonality of components and the degree of product differentiation in a framework for cooperation in product development

between competitors. Firms jointly decide how much of the product components to develop together, i.e. firms jointly decide on the degree of cooperation in product development. Firms share the development costs of jointly developed components equally. The degree of differentiation between firms' products, however, decreases in the degree of commonly developed components. The authors find that firms will choose a higher degree of commonality if the competition effect is mild relative to the development cost effect. They argue that commonality might, thus, be high in markets where product differentiation is not an important determinant of competition.

Next to platform sharing, the cost-efficient supply of high variety can be reached by postponement. Several studies examine the optimal decoupling point, i.e. the point in the supply chain where products become differentiated.<sup>7</sup> Particularly, literature in this field analyzes whether a firm's products should run through distinct or common production processes. Each product passes through a finite number of production processes. While products become more differentiated when operations are distinct, distinct operations also involve higher costs. In Lee and Tang (1997), distinct operations involve investment costs and additional processing costs, but lower buffer inventories and the complexity of the manufacturing process. The firm can delay product differentiation by deferring the common operation. The authors find that delayed product differentiation enables the firm to improve the service level and to reduce inventories. While Lee and Tang (1997) consider only one point of differentiation between products, Garg and Tang (1997) extend the research to product lines with multiple differentiating features. The production process has three manufacturing stages and two differentiating attributes, thus, two points of differentiation. Garg and Tang (1997) consider a centralized and decentralized inventory model. The authors show that demand variability, correlation, and the relative magnitude of lead times play an important role in determining which point of differentiation should be delayed. When inventory is centralized, early and late postponement lead to a reduction in inventory and late postponement becomes superior as negative correlation between product demand across a family increases. When inventory is decentralized, the point of differentiation that has a lower lead time becomes preferable. In an attempt to quantify the value of postponement, Anand and Mendelson (1998) study a firm's operational performance under early and delayed product differentiation. The monopolist sells two related products in two distinct product markets with demand uncertainty. Along their way down the supply chain, products pass through a production facility, a distribution center, and two retail outlets, one for each market. Under early differentiation, products are already segmented in the production facility, resulting in non-substitutable intermediate goods. Under delayed differentiation, manufacturing is common to the two products, which are customized in the distribution center. Delayed differentiation might result in higher production costs or the costs of restructuring the supply chain. The authors find that the value of postponement is largely driven by the degree of demand uncertainty and the correlation across markets

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<sup>7</sup>For a comprehensive literature review on postponement under monopoly settings please refer to Anand and Mendelson (1998) and Swaminathan and Lee (2003).

or products. Anand and Girotra (2007) extend the monopoly model of Anand and Mendelson (1998) by examining the value of delayed differentiation in a competitive market. Each firm chooses between two different supply chain configurations: early or delayed differentiation. The authors show that while the risk-pooling benefits, i.e. demand variance and market correlation, favor delayed differentiation in the monopoly case, the strategic premium, i.e. market size, favors early differentiation in the competitive setting. Anand and Girotra (2007) find that both entry threats and competition can significantly diminish the value of delayed differentiation. Even under cost parity with delayed differentiation, early differentiation is the dominant strategy for firms.

The above presented studies show that production postponement can be a strategy to reduce manufacturer's uncertainty about demand. Gavirneni and Tayur (1999) compare the value of production postponement and information sharing to reduce a firm's demand uncertainty under exogenous prices. Building upon their work, Cavusoglu et al. (2012) compare the value of and interaction between the two strategies in a one-level and two-level supply chain with endogenously determined wholesale and retail prices. In the one-level supply chain, the manufacturer produces a product and sells it directly to customers whereas in the two-level supply chain, the manufacturer sells the product to a retailer who then sells it to customers. In the postponement strategy, the demand is uncertain when the firm makes its pricing decision, but is resolved when it makes the production decision. In the information sharing strategy, the demand is known before making any decision. If the firm does not postpone production, it incurs inventory holding costs on the entire production quantity. If the firm postpones production, inventory holding costs are eliminated, but unit production costs increase. Information sharing does not affect inventory holding costs nor production costs. The authors find that while information sharing is always valuable, production postponement can sometimes be detrimental from the manufacturer's perspective, both in single-level and two-level supply chains. The two strategies may substitute, complement, or conflict with each other depending on the extent of the increase in the unit production cost when production is postponed.

### **2.3.4 Product customization literature**

While the presented literature on product differentiation primarily focuses on distinct product variants that are modeled as points on the Hotelling (1929) line or Salop (1979) circle, studies concerning product customization assume that all product varieties can be produced. The below studies model consumer demand as follows. Customers are uniformly distributed along the the Hotelling (1929) line or Salop (1979) circle and have heterogeneous preferences for product attributes. Their location on the unit line presents their ideal product configuration. Customers incur a disutility if the offered product does not match their preferred product. Particularly, they incur transportation costs for the distance between their location and the purchased product. These transportation costs are assumed to be zero when customers buy the mass customized product. Customers buy the product that is utility maximizing, i.e. with the lowest price plus



transportation costs. Individual demand is assumed to be inelastic.

Although, not directly linked to the topic of mass customization, the modeling approach of Balasubramanian (1998) adds to the models of mass customization. Balasubramanian (1998) models the competition between retail firms and a direct marketer. Purchasing from retailers involves transportation costs while buying from the direct marketer eliminates transportation costs. The direct marketer can, thus, be seen as a mass customizing firm. A key insight is that retailers pre-dominantly compete against the direct marketer not against neighboring retailers. This kind of competition is picked up in the literature of product customization. In an attempt to compare the profitability of a mass customization and a mass production strategy, Alptekinoglu and Corbett (2008) model the competition between a mass customizing and a mass producing firm. While the mass customizing firm offers every possible product variety in the product space, the mass producing firm offers a discrete set of standard products (modeled as points on the unit line). Firms differ in their fixed costs for entry and unit variable costs. In addition, the mass producing firm incurs fixed costs for each product that it can reduce by investing in flexibility. The authors find several interesting results. If the fixed costs for entry of the mass customizing firm are sufficiently high and those of the mass producing firm are sufficiently low, the mass producer will operate as a monopolist. When both firms enter the market, the mass producer chooses to be less flexible and offers lower variety than in a monopoly. This is due to the fact that a higher variety leads to increased price competition in a duopoly. The mass customizing firm is able to charge a higher price and gains a larger market share relative to the mass producing firm. However, both firms can profitably co-exist unless the cost disadvantage of the mass producer is too high.

The competition between a mass producing and a mass customizing firm when firms are asymmetric in their product qualities is analyzed by Loginova and Wang (2008). Firms can choose whether to adopt mass customization or to sell a standard product. The authors extend the one-dimensional space to a two-dimensional space: the location on the horizontal axis represents a consumer's ideal product and the location on the vertical axis reflects a consumer's quality valuation. Mass customization affects horizontal but not vertical differentiation. Firms face no variable production costs, but adopting mass customization requires a fixed cost. The authors show that when quality differences are small, no firm adopts mass customization. When quality differences are sufficiently large, one or both firms mass customize. The low-quality firm, however, never mass customizes alone. Loginova and Wang (2011) extend the study of Loginova and Wang (2008) and analyze the endogenous choice of quality as well as price differentiation. They find that firms choose to be either substantially differentiated in quality or non differentiated. Moreover, the main conclusions continue to hold when price differentiation is allowed. Loginova and Wang (2013) complement the study by Loginova and Wang (2011) with endogenously determined entry. The authors find that compared to simultaneous entry, endogenous timing yields Pareto superior outcomes as it avoids price wars. Further, there exist market conditions under

which the low quality firm finds it profitable to become the first and only firm to adopt mass customization.

Mendelson and Parlaktürk (2008b) extend the analysis of the competition between a mass customizing firm, which can produce any variety in the product space, and a mass producing firm, which can produce a discrete set of product varieties, to study the effect of inventory holding costs, lead time, and consumers' waiting costs. Customers are sensitive to delay and incur waiting costs for a mass customized product or a back-ordered standard product. The mass customizing firm customizes to order and does not carry inventory. Customization times depend on the ease of mass customization and the firm's mass customization capacity. The mass producing firm outsources to a supplier with a certain lead time and incurs inventory holding costs. While the unit costs of the mass producer exhibit economies of scale, those of the mass customizing firm do not. The most important finding of Mendelson and Parlaktürk (2008b) is that the profitability of the firms as well as the market outcome in terms of product variety and the customizing firm's ideal market size crucially depend on the unit cost differential of the two firms. As the cost disadvantage of the mass customizing firm compared to the mass producing firm increases, the ideal market size decreases. Due to strategic effects, shorter customization and lead times can hurt firms' profits, unless a firm's cost advantage is sufficiently high, since customization and lead times differentiate the firms' products, thereby weakening price competition. The effect of lead times on the profitability of mass customization and mass production in a competitive setting is picked up by Xia and Rajagopalan (2009) in a two-dimensional product space. Consumers are heterogeneous in both firm preference and product attributes. A consumer's location on the horizontal axis represents the preference for a firm and on the vertical axis its preference for product attributes. Firms can either adopt mass customization and produce every possible product variety or mass production and produce a discrete number of product varieties. A standard product is immediately available while it takes a certain lead time to produce the customized product. Next to transportation costs and the price, consumers incur disutility for lead time. Firms incur a fixed cost for every standard variety and custom products incur an additional cost that is decreasing in the lead time that can be chosen by a customizing firm. Xia and Rajagopalan (2009) show that symmetric firms are most likely to choose symmetric product strategies. Whether mass customization or mass production is more profitable depends on the relative costs of mass customization and its attractiveness to consumers. Increasing variety or decreasing lead time increases market share and margin, but leads to higher costs. Different to existing studies, the authors find that increasing variety will not intensify the price competition if firms are sufficiently differentiated. Furthermore, the reputation of a firm does not impact its product strategy but leads to greater product variety, shorter lead times, and higher prices. Parlaktürk (2009) extends the discussion by examining the value of mass customization depending on a firm's competitive position in a one-dimensional product space. Firms incur unit production costs, adopting mass customization, however, only entails a fixed cost and does not affect marginal costs. Firms differ in their cost efficiency and perceived quality, which de-

termines their competitive positions, i.e. leads to a difference in marginal costs and consumers' reservation value. The author considers two scenarios with regard to a mass customizing firm's pricing, namely uniform pricing and price differentiation. Parlaktürk (2009) finds that the value of mass customization depends on the competitive position of a firm. A firm with an overall quality/cost disadvantage never adopts mass customization while it is suitable for a firm with an overall advantage. Moreover, the ability to price differentiate leads to a broader adoption of mass customization.

Next to studies that focus on operational considerations of mass customization like lead times, several studies exist that analyze mass customization by focusing on the consumer side. Loginova and Wang (2009) study the effect of perceived uniqueness of a mass customized product on a firm's decision to mass customize in a competitive setting. Particularly, consumers derive additional utility from the perceived uniqueness of a customized product depending on their valuation for uniqueness. A consumer's most preferred product is represented on the horizontal axis, her value for uniqueness on the vertical axis. Adopting mass customization requires fixed costs. Marginal costs for both product types are normalized to zero. The authors find that only when consumer preferences for uniqueness are sufficiently high, firms choose to mass customize. While mass customization lowers differentiation between firms in the horizontal dimension, firms become vertically differentiated through uniqueness. The impact of customers' brand familiarity on a firm's decision to mass customize is analyzed in Loginova (2010). In particular, consumers' heterogeneity for product attributes is reflected by their location on the horizontal axis while their heterogeneity in brand knowledge is represented by their location on the vertical axis. Consumers familiar with a brand can easily transfer their preferences into appropriate characteristics of this brand while consumers unfamiliar with a brand have difficulties. Therefore, transportation costs will only be eliminated by buying a customized product if the consumer knows the particular brand. Firms that adopt mass customization incur fixed costs. Marginal costs are assumed to be zero. The authors find that while mass customization leads to less differentiation between firms, consumers' imperfect knowledge relaxes price competition. In equilibrium, only one firm adopts mass customization.

All of the above studies model mass customization on the basis of the Hotelling (1929) or Salop (1979) model. In these studies, consumers incur so-called *misfit costs* that result from the distance between the product offered and their ideal product configuration. Such costs are eliminated when a consumer purchases a mass customized product as a mass customizing firm produces any possible product variety in the product space and is, thus, always able to exactly meet each consumer's ideal product configuration.<sup>8</sup> However, as discussed in subsection 2.3.1, there exists a continuum of mass customization strategies between pure standardization and pure customization. The introductory examples show that firms adopt diverse mass customization strategies. In

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<sup>8</sup>Apart from Loginova (2010), who assume that consumers need brand knowledge to be able to specify their preferences.

order to implement mass customization profitably, the vast majority of firms determines their optimal degree of mass customization on a continuum of strategies between pure standardization and pure customization by balancing the costs and benefits associated with the mass customization strategy. Therefore, not every consumer's preferences will be met if a firm adopts a strategy between the two extremes. As the level of mass customization is not a decision variable in the studies presented above, they do not shed much light on the optimal degree of mass customization chosen by firms and how this degree is affected by market characteristics. The following studies integrate a firm's decision about the degree of mass customization into their modeling approaches.

Although, not analyzing the optimal degree of mass customization from a continuum of strategies, Syam et al. (2005) examine whether a manufacturer should customize one or two attributes of a product in a competitive setting. Firms produce a product with two attributes that they can either standardize or customize. Consumers are heterogeneous in their preferences for the two attributes and are represented as a point in the two-dimensional attribute space. Firms are located at the opposite ends of this square. If an attribute is customized, then it exactly matches a consumer's preference for this attribute. The authors incorporate consumers' effort as an exogenously given cost of interaction that is increasing in the number of customized attributes. The authors show that customization of both attributes is no equilibrium solution as it leads to intensified price competition. The same is true for customizing different attributes. If firms customize different attributes, more consumers are indifferent between the two firms resulting in intensified price competition. In equilibrium, firms choose to customize only one of the two attributes and each firm chooses the same attribute. Syam et al. (2005) show that consumers are better off with customization, but firms offer only partial mass customization.

The following studies incorporate the degree of mass customization as a decision variable of firms. Dewan et al. (2000) examine the optimal scope of mass customization in a competitive Salop (1979) setting. Consumers are uniformly distributed along the circle. A firm may choose to produce a standard product or a range of mass customized products. If it produces a range of mass customized products, it can decide about the length of the mass customization scope. When the firm produces a standard product it is represented as a point on the circle and has marginal costs of zero. When the firm produces a range of mass customized products, it is represented as an arc on the circle and incurs fixed costs that are increasing in the length of the arc. Consumers within the mass customization scope can buy a product tailored to their needs while customers outside the scope can buy the standard products at the ends of the scope. A firm that sells a standard product charges a uniform price while a firm that sells mass customized products sets a price for each product configuration, i.e. it can price differentiate. The authors find that when only one firm adopts mass customization, it gains market share and profits at the expense of the firm that produces a standard product. However, in equilibrium, both firms excessively invest in mass customization. This results in less product differentiation, leading to intensified

price competition and, thus, lower profits. Dewan et al. (2000) draw the conclusion that mass customization leads to a prisoner's dilemma. Consumer surplus, however, is greater with mass customization. Dewan et al. (2003) extend the model of Dewan et al. (2000) to cover sequential entry. The authors find that when firms face a fixed entry cost and adopt mass customization sequentially, there is a first mover advantage. Furthermore, the first entrant may be able to deter entry by strategically choosing its mass customization scope. Similarly to Dewan et al. (2000), the authors find that consumer surplus is greater with mass customization. Following the modeling approach of Dewan et al. (2000,0), Hsu et al. (2014) examine the effect of competition on mass customization with  $n$  firms. The authors find that price competition for mass customized products is not as intense as price competition for standard products and that the share of sales for mass customized products increases as competition increases. The authors empirically test their analytic predictions and find evidence that firms that face increased competition tend to sell relatively more mass customized products. Contrary to Dewan et al. (2000,0) and Hsu et al. (2014), Syam and Kumar (2006) do not interpret the degree of mass customization as a scope on the Salop (1979) circle but as a reduction of misfit costs, i.e. the degree of mass customization is incorporated by assuming that each consumer's transportation cost is decreasing in the degree of mass customization chosen by the firm. Firms can choose to offer mass customized products in addition to their standard products. Consumers are heterogeneous in their preferences for product attributes and segmented into two groups with respect to their intensity of preference, i.e. the two groups differ in their transportation cost parameter. The firms' standard products are located at the ends of the Hotelling (1929) line. If a firm decides to additionally offer a mass customized product, it also decides on the degree of mass customization. Adopting mass customization requires a fixed cost. Further, marginal costs are increasing in the degree of mass customization. Contrary to Dewan et al. (2000,0), the authors find that firms can increase their profits by offering mass customization in a competitive environment. They show that when a firm offers a mass customized product, it also offers a standard product. Furthermore, the authors find that the degree of mass customization is lower when both firms offer mass customization compared to when only one firm offers a mass customized product. Because the intensity of competition is increasing in the degree of mass customization, firms choose partial mass customization. Syam and Kumar (2006) extent their setting and allow firms to price differentiate. However, the main findings are not sensitive to this change in firms' pricing policy. The model of Syam and Kumar (2006) is extended by Mendelson and Parlaktürk (2008a) to cover the case of asymmetric firms. Different to Syam and Kumar (2006), firms either offer mass customized or standard products. Firms are asymmetric in their competitive position. Specifically, they differ in their cost efficiency and perceived quality. Mendelson and Parlaktürk (2008a) consider the case of uniform and differentiated pricing. Similar to Loginova and Wang (2008) and Parlaktürk (2009), the authors find that the value of mass customization critically depends on a firm's competitive position. A firm with a cost and quality disadvantage never adopts mass customization alone. When firms can price differentiate, they are more likely to adopt mass customization than under uniform pricing.

However, the degree of mass customization chosen by a firm in equilibrium is higher when firms set uniform prices. Mendelson and Parlaktürk (2008a) suggest that a firm should first place its effort into improving its competitive position and then adopt mass customization.

Although, not directly linked to the topic of mass customization, the modeling approach of Alexandrov (2008) adds to the topic of mass customization. The author develops a model of firms, which can offer adjustable (fat) products in a one-dimensional spatial model. Adjustable products are modeled as interval-long products following the setup of Salop (1979). The main finding is that market differentiation might lower firms' profits, because firms have an incentive to make their products more flexible, i.e. increase the length of the interval. However, more flexibility increases costs without increasing revenues. The analysis of a leader in setting price and product length shows that high development costs force the leader into accommodating the follower, thereby gaining less market share and lower profits than the follower.

While Dewan et al. (2000,0) and Syam and Kumar (2006) analyze which degree of mass customization is optimal for firms, Cavusoglu et al. (2007) additionally examine whether it is optimal for firms to adopt product proliferation (discrete product varieties), mass customization (every possible product variant within the customization scope), or targeted mass customization (multiple customization scopes). Competition is modeled on the Salop (1979) circle. Similar to Dewan et al. (2000) and Dewan et al. (2003), the costs for mass customization are increasing in the length of the mass customization scope. The main findings are as follows. Mass customization is not optimal if the costs are sufficiently high. When competing firms mass customize, they choose targeted mass customization. The authors show that firms' profits are the highest when firms choose to offer only a single product, unless the cost of mass customization is low enough. Similar to the other studies, consumers are on average better off with mass customization.

While the above presented studies assume that consumers are horizontally differentiated<sup>9</sup> and have heterogeneous preferences for product attributes, Wong and Lesmono (2013) analyze the optimal degree of mass customization in a vertically differentiated monopoly market. Different to the above presented studies, the authors define the degree of mass customization as degree of customer involvement in a firm's value chain. Consumers are segmented into two groups: for one group, lead time is more important while for the other, mass customization is more important. Consumers' reservation price increases in the degree of mass customization chosen by the monopolist. The firm can either produce one or two products. If the firm decides to offer two products with different levels of mass customization, it incurs a fixed cost for setting up an additional product line. Marginal costs and lead time are increasing in the degree of mass customization. Using numerical analysis, the authors show that the two product strategy is the most profitable in the majority of cases. Moreover, the highest degree of mass customization is chosen when the firm chooses to offer one product targeted at the high-cost segment.

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<sup>9</sup>Either in a one-dimensional or two-dimensional product space.

## 2.4 Evaluation of presented work and research gap

This section briefly evaluates the contributions and limitations of the conceptual, theoretical, empirical, and experimental literature previously discussed. The aim of this subsection is to identify the research gap and to explain how the models developed in the next sections will contribute to filling this gap.

Several approaches have been undertaken to analyze whether mass customization is a profitable strategy for firms. The majority of mass customization models are, however, limited in their assumption regarding the firm's decision scope. Alptekinoglu and Corbett (2008), Mendelson and Parlaktürk (2008b), and Xia and Rajagopalan (2009), among others, assume that when a firm implements mass customization, it offers full mass customization, meaning that it can produce every possible variant in the product space. Hence, each consumer can buy her preferred product configuration and does not incur misfit costs. This assumption might simplify the game theoretical analysis but neglects the degree of mass customization as key strategic decision variable of firms. To profit from mass customization, companies need to position their mass customization strategy between pure standardization and pure customization as already discussed in previous sections. The analysis of this key strategic decision variable is subject of the monopoly and duopoly model developed in the next sections.

A few theoretical studies integrate a firm's decision about the degree of mass customization in their models. Dewan et al. (2000,0) assume that when a firm adopts mass customization, it can produce a range of products, represented as an arc of the circle. In the models of Syam and Kumar (2006) and Mendelson and Parlaktürk (2008a), consumers' misfit costs are reduced by the degree of mass customization. The model of this dissertation adopts the modeling approach of Dewan et al. (2000,0) since this approach allows the assumption that a firm adopting partial mass customization is able to sell some consumers their preferred product configuration while others can reduce their misfit costs when buying the mass customized product closest to their location. This dissertation will contribute to the ongoing debate about a firm's optimal degree of mass customization.

Within the scope of conceptual mass customization literature, the definition of mass customization strategies has been broadly discussed. Theoretical models adopt different definitions of mass customization. Wong and Lesmono (2013) agree with Lampel and Mintzberg (1996) and Duray et al. (2000) and define mass customization by the degree of customer involvement in the production process. In the models of Syam and Kumar (2006) and Mendelson and Parlaktürk (2008a), the degree of mass customization represents the fraction of product attributes that can be mass customized. Dewan et al. (2000,0) adopt the view that the degree of mass customization measures a firm's manufacturing flexibility. The monopoly and duopoly model developed in the next sections define the degree of mass customization as degree of customer involvement in the production process similar to Wong and Lesmono (2013) since this view abstracts from the number of product variants and allows the strategic analysis of a firm's and consumers' strategic benefits and costs of early or late involvement in the production process.

Experimental and empirical research has been illuminating the strategic role of the customer as well as the strategic interaction between firms and consumers in the configuration process and the value creation of a mass customized product. Customers become co-producers and take part in the value creation of a firm (Piller et al. 2004). However, consumers' co-design activities are complex and involve effort (Piller et al. 2005). Using experimental studies, Dellaert and Stremersch (2005) show that complexity in customizing a product leads to a negative utility for consumers and Franke and Schreier (2010) find that the effort consumers exert during the configuration process can have a negative impact on the perceived value of the mass customized product. Consequently, consumers might choose not to exert full effort when configuring a mass customized product. Despite the evidence of consumers' strategic role in mass customization, theoretical models have not yet concentrated on this issue. Existing theoretical models assume that consumers benefit from mass customization without having to exert effort and do not incur effort costs from interacting with the firm. Only Syam et al. (2005) take these interaction costs into account. Their model assumes exogenously given interaction costs that cannot be influenced by the consumer. The consumer cannot choose how much effort to exert. Existing studies have neglected the strategic role of the consumer and the strategic interaction between firms and consumers in their modeling approaches. This dissertation is the first to incorporate the strategic role of the consumer and the strategic interaction between firms and consumers into the analysis of mass customization.

With the help of laboratory experiments, different factors of consumers' valuation for mass customized products have been identified. Next to a closer fit between individual preferences and product characteristics, additional value from the perceived uniqueness of a mass customized product and the do-it-yourself effect exist (Franke and Schreier 2008, Franke et al. 2010, Schreier 2006). Similar to Loginova and Wang (2009) and Wong and Lesmono (2013), the models of this dissertation study the effect of consumers' perceived uniqueness of a mass customized product on a firm's mass customization decision.

While the majority of operations management studies assume a vertically differentiated market with two consumer segments, the mass customization literature mainly examines spatial competition. Although, the monopoly and duopoly model developed in the next sections concentrate on horizontally differentiated product markets, the operations management literature contributes to the models of this dissertation. The operations management literature presented earlier focuses on whether two products should share a common platform or not and whether products should share common operations or not. As discussed earlier, most companies implement mass customization by applying the concept of modularity. Hence, the higher the degree of mass customization, the less common components are shared by the end products and the lower the degree of common operations. The operations management literature contains several implications of cost savings arising from the use of common parts that particularly contribute to the mass customization literature. Operations management studies, for example Kim and Chhajed (2000), Desai et al. (2001), and Krishnan and Gupta (2001), find that unique product components



lead to dis-economies of scale while common parts lower the differentiation between firms and intensify price competition. Several mass customization studies highlight the intensified competition between firms' products due to mass customization, for example Dewan et al. (2000,0), who find that mass customization leads to a prisoner's dilemma. Some work, for example Dewan et al. (2000,0), Syam and Kumar (2006), Alptekinoglu and Corbett (2008), and Mendelson and Parlaktürk (2008a), include fixed costs for implementing mass customization and/or unit costs that are increasing in the degree of mass customization. However, not much light has yet been shed on how dis-economies of scale resulting from unique product operations affect the optimal degree of mass customization. This dissertation adopts the view that all production stages that do not involve the consumer are run commonly for all products. Common product parts compose the product platform and can be pre-produced. All production stages that involve the consumer are run distinctively. Unique product parts involve dis-economies of scale and are produced after customer-specific information has been received.

Several theoretical models consider the effect of a firm's competitive positioning on the mass customization decision. Loginova and Wang (2008) study the decision to adopt mass customization when firms are asymmetric in their product qualities and Parlaktürk (2009) analyzes the value of mass customization depending on a firm's competitive position in terms of efficiency and perceived quality, i.e. firms are different in marginal costs and consumers' reservation value. Mendelson and Parlaktürk (2008a) study the effect of asymmetric firms on the optimal degree of customization when firms differ in their margin. As so far no theoretical study exists that takes into account the interaction between a firm and its consumers, the effect of differing interaction processes on the optimal degree of mass customization and the profitability of mass customization has not yet been discussed. The duopoly model of this dissertation shall capture firms' asymmetries in the interaction process next to cost differences in producing customized products.

Product differentiation literature that examines the optimal number of product variants and their positioning is exhaustive and only briefly discussed in this literature review. The vast majority of theoretical mass customization studies assumes that the mass customizing firm can produce any product configuration while the mass producing firm produces discrete standardized product variants. So far, only Syam and Kumar (2006) analyze whether or not firms find it profitable to offer mass customized products next to their standard products in case firms can choose the degree of mass customization. The monopoly and duopoly model pick up on this question and analyzes a firm's decision to offer a lower-priced standard product next to its mass customizable offer and vice versa. Moreover, the effect of offering two products (one standard product and one mass customized product) on the optimal degree of mass customization is analyzed. The majority of mass customization studies assumes that firms are located at the ends of the Hotelling (1929) line or equidistant along the Salop (1979) circle, i.e. it is assumed that firms choose maximum differentiation. The duopoly model of this dissertation is extended to examine a firm's location choice in a competitive setting.

The next sections develop a monopoly and duopoly model of strategic company-customer interaction in mass customization in an attempt to extend the literature and fill the gaps in research previously discussed. The contribution of the models to existing literature is threefold: first, the models add to product differentiation literature by analyzing a firm's optimal product line and positioning strategy by allowing firms to consider mass customization as an alternative choice to standardization; second, the models capture the idea of platform sharing and postponed differentiation that enable cost-efficient mass customization, thereby adding to the literature in operations management; third, the models are an important extension to the existing models of mass customization by incorporating the strategic role of the consumer and interaction between firms and consumers in mass customization. The modeling approach covers a firm's trade-off between tailoring a product to consumers' needs and dis-economies of scale as well as each consumers' trade-off between achieving a better product fit and and interaction costs. The models are extended in four ways: first, the effect of consumers' valuation for uniqueness on the optimal degree of mass customization is examined; second, a firm's incentive to offer a lower-priced standard product next to its mass customizable offer and vice versa as well as the impact of offering a standard product and a mass customized product on the optimal degree of mass customization is analyzed; third, asymmetries in firms' production and interaction processes are evaluated; lastly, the assumption of maximal differentiated firms is analyzed by examining whether firms have an incentive to move towards each other.<sup>10</sup> The theoretical framework developed in this dissertation aims to validate some observations made by academics and practitioners alike, to derive several novel insights regarding mass customization as product strategy in a monopoly and duopoly market, and to investigate the implications of these insights for managerial decision-making.

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<sup>10</sup>Extensions three and four are analyzed in a competitive setting only.

## Chapter 3

# Monopoly model

### 3.1 Motivation

The literature review emphasizes the importance of determining the optimal mass customization strategy for firms. In order to profit from mass customization, firms have to carefully choose their mass customization strategy on a continuum of strategies between pure standardization and pure customization. What is a firm's optimal degree of mass customization? Which market factors increase or decrease the optimal degree of mass customization? Are there conditions under which a firm chooses the end poles of the continuum? The monopoly model of this chapter builds upon previous work and analyzes a firm's optimal degree of mass customization.

Analysis of the literature reveals that extant game-theoretical research on mass customization has neglected the strategic role of the consumer in their modeling approaches. In order to benefit from mass customization, the consumer has to specify her preferences and communicate them to the firm. Consequently, the consumer and the firm have to interact. How much effort do consumers exert during the configuration of the mass customized product? How is the optimal effort level affected by market conditions? How does a consumer's effort level affect the optimal degree of mass customization? Do choices interact? In particular, the monopoly model of this chapter analyzes a consumer's optimal effort level and studies its effect on a firm's optimal degree of mass customization.

Platform sharing has been identified as one of the key drivers that enable mass customized production cost efficiently. Running through production steps separately for each individual customer induces dis-economies of scale, leading to higher per unit production costs. To lower production costs of a mass customized product, the firm may choose to build a product platform that is mass customizable in the final production stages. How do dis-economies of scale affect the optimal degree of mass customization? Several studies in the operations management literature analytically explore the trade-off between costs and benefits of unique components and/or common components. The monopoly model developed in this chapter picks up on this literature to include the concept of a product platform into the modeling of mass customization.

Literature has revealed that next to an improved aesthetic and functional fit, mass customized

products provide additional value for a consumer due to the perceived uniqueness of the product. So far no theoretical study exists that analyzes the effect of consumers' valuation for uniqueness on the optimal degree of mass customization. Is the optimal degree of mass customization increasing in consumers' valuation for uniqueness? Is mass customization the dominant strategy even when consumers do not value the perceived uniqueness of a mass customized product? Subsection 3.4.1 analyzes the effect of consumers' valuation for uniqueness on the optimal degree of mass customization.

Real life examples show that firms often sell both a standard and a mass customized product. Is it always profitable to sell both products? Under which market conditions might it be profitable to sell only one product? How is the optimal degree of mass customization affected by the one or two product strategy? Subsection 3.4.2 picks up on existing literature and analyzes whether a firm has an incentive to offer a mass customized product in addition to its standard product and vice versa. Additionally, the subsection examines the effect of selling both products on the optimal degree of mass customization.

## 3.2 Model framework

The model adopts the Hotelling (1929) model and its assumptions.

### 3.2.1 Modeling assumptions

#### The geographical space and consumer preferences

In this model of horizontal differentiation, one firm serves a market of consumers with heterogeneous preferences for product attributes. The firm is located at the center of a line of unit length  $[0, 1]$ , i.e.  $x = \frac{1}{2}$ . Consumers are uniformly distributed on this line of unit length and have a total mass of 1. Each consumer is identified by a point  $\theta \in [0, 1]$  that represents her ideal product configuration and has a common reservation price of  $r$ . Each consumer purchases at most one product. When the offered product does not match a consumer's ideal product configuration, she incurs a disutility of  $t(|\theta - x|)^2$ , the misfit costs, where  $t$  measures consumers' sensitivity to product differences, i.e. the importance of purchasing the ideal product configuration, and  $|\theta - x|$  denotes the distance between a consumer's ideal product configuration and the product offered by the firm.<sup>1</sup> When a type- $\theta$  customer buys the firm's product at price  $p$ , her utility is equal to

$$U = r - t(|\theta - x|)^2 - p \quad (3.1)$$

For any given  $p$  consumers located at  $\theta \in [0, \frac{1}{2}]$  will purchase the firm's product iff

<sup>1</sup>Please note that when consumers face linear transportation costs, each consumer chooses the same effort during the configuration process, i.e. the effort level is not dependent on a consumer's distance to the offered product. As this assumption is not realistic, quadratic transportation costs are used.

$$U_{\theta \leq \frac{1}{2}} \geq 0$$

The left-hand side of the above inequality denotes the net utility from purchasing the product and the right-hand side that from choosing not to buy at all. Given this choice rule, consumers located at  $\underline{\theta}$  are indifferent to either buying or not buying. Hence, consumers located at  $\theta \in [\underline{\theta}, \frac{1}{2}]$  purchase the product while those located at  $\theta \in [0, \underline{\theta}]$  do not purchase the product.

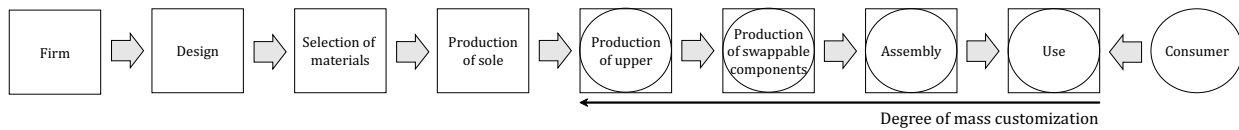
Similarly, consumers located at  $\theta \in [\frac{1}{2}, 1]$  will purchase the firm's product iff

$$U_{\theta > \frac{1}{2}} \geq 0$$

Given this choice rule, consumers located at  $\bar{\theta}$  are indifferent to either buying or not. Hence, consumers located at  $\theta \in [\frac{1}{2}, \bar{\theta}]$  purchase the product while those located at  $\theta \in [\bar{\theta}, 1]$  do not purchase the product. This leads to a total demand of  $D = \bar{\theta} - \underline{\theta}$ .

### The strategy space and firm's production process

The monopolist chooses the degree of mass customization  $k \in [0, 1]$ , which is defined as the degree of customer integration into the production process. When the firm chooses  $k = 0$ , it only sells one standard product and is represented as a point on the unit line. When the firm chooses  $k > 0$ , it is represented as a line of length  $k$  around its location on the unit line.<sup>2</sup> The higher  $k$ , the greater the integration of consumers into the production process. Figure 3.1 illustrates the possibilities of customer integration in a simplified production process. When the firm offers a high degree of mass customization, customers are integrated early in the production process, for example may select the materials. When the firm offers a low degree of mass customization, customers are integrated into the final stages of the production process and may, for instance, personalize the assembly of the product.



**Figure 3.1** This figure shows the simplified production process of a sneaker. The higher  $k$ , the greater the integration of consumers into the production process.

By integrating consumers into the production process, the firm is able to better match consumers' preferences since they can adjust the product to their preferences in these stages. Thus, the integration of consumers into the production process allows the firm to reduce consumers' misfit costs by approaching their ideal product configurations. Therefore, the higher  $k$ , the higher the number of consumers who can buy their ideal product. When the firm chooses  $k = 1$ , each

<sup>2</sup>This representation of a firm adopting mass customization is similar to Dewan et al. (2000) and Dewan et al. (2003), who study competition between a mass customizing and a standard firm on the Salop (1979) circle.

consumer is offered her ideal product. The motivation behind such a setting is that the firm observes consumers' preferences by interacting with its customers during the production process, e.g. via an online product configurator, and can tailor products for all consumers whose ideal product configuration can be approached within the scope of this interaction. When consumers are involved in the final stages of the production process, only consumers with a high initial preference fit can adjust the product to perfectly match their preferences while other consumers with a low initial preference fit incur reduced misfit costs. When consumers are involved in the early stages of the production process, even consumers with a low initial preference fit can adjust the product to perfectly match their preferences.

The production process is separated into two parts. In the first part, the firm pre-manufactures the product platform  $(1 - k)$ , i.e. commonly runs through the stages of the production process that does not involve the consumer. In the second part, the firm observes consumers' preferences and distinctively runs through the stages of the production process that integrates the consumer ( $k$ ). Unit manufacturing costs for a standard product are denoted by  $a$ . The firm bears additional variable costs for mass customization.<sup>3</sup> These variable costs  $b$  ( $b > a$ ) depend on the degree of customer involvement in the production process and are given by

$$c = a + (b - a)k^2 \quad (3.2)$$

Unit manufacturing costs for the standardized product platform  $a$  are normalized to zero. It is assumed that unit variable costs for mass customized production are quadratic in the degree of mass customization, representing dis-economies of scale. Dis-economies of scale are, thus, realized when the firm chooses  $k > 0$ . The higher the degree of customer involvement in the production process, i.e. the higher  $k$ , the higher the share of distinct production stages, and, therefore, the greater the dis-economies of scale. The motivation behind such a set up is that mass customizing products becomes more costly the earlier consumers are involved in the production process since early production stages are more complex. Therefore, when choosing the optimal degree of mass customization, the firm trades off the coverage of consumers' preferences with dis-economies of scale.

The monopolist's profit function is given by

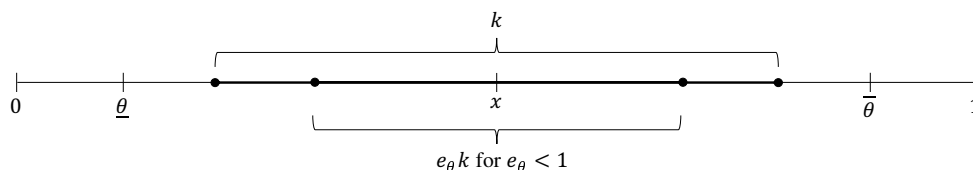
$$\pi = D(p - c) \quad (3.3)$$

### Consumer effort

When the firm chooses the degree of mass customization  $k$ , it determines the extent of customer involvement in the production process and, therewith, the upper bound of consumers who are

<sup>3</sup>Without the loss of accuracy, fixed costs for mass customization are normalized to zero.

able to buy their ideal product configuration. However, in order to benefit from the firm's mass customization offer, i.e. in order to reduce misfit costs, consumers need to actively participate in the co-design of the product. Consumers have to exert effort, e.g. choose colors or materials from the firm's options, in order to adapt the offered product to their preferences. In this model, each consumer chooses her individual effort level  $e_\theta \in [0, 1]$  to put into the configuration process of the product. By exerting effort, a consumer can pull the firm's product towards her own location  $\theta$  up to the pre-determined point  $k$  set by the firm, leading to reduced misfit costs. Specifically, it is assumed that the degree of mass customization  $k$  and consumer effort  $e_\theta$  are complementary. This means that mass customization is only utility increasing for consumers when they exert effort. On the other hand, exerting effort only increases consumer utility when the firm offers mass customization. Thus, the firm's choice and consumers' choices interact. By choosing an effort level of  $e_\theta = 0$ , a consumer purchases the firm's standard product. The higher  $e_\theta$ , the more of the firm's mass customization offer is used. When  $k < 1$ , consumers, whose preferences lie outside of  $k$ , can still pull the product closer to their preferences, but are not able to purchase their ideal product configuration, independent of their choice of  $e_\theta$ . Figure 3.2 illustrates this set-up.



**Figure 3.2** Set-up:  $k$  and  $e_\theta$  are complementary. The share of consumers, who are able to purchase their ideal product is given by  $e_\theta k$ .

Effort is assumed to be costly. Consumers incur a disutility of  $\frac{1}{2}de_\theta^2$  from co-designing the product, the cost of interaction, where  $d$  measures the complexity of the firm's interaction process. The complexity of the interaction process  $d$  can be illustrated by the example of Adidas. The company opened mi Innovation centers in selected stores that feature, for example, a virtual mirror enabling consumers to see their personalized shoe on their own foot. Compared to the online configurator, mi Innovation centers simplify the customization process for consumers and, therefore, exhibit a lower  $d$ . The motivation behind introducing consumer effort as a decision variable is that, in reality, consumers observe the firm's standard product and its mass customizable offer and then decide how much of this offer to use. In order to mass customize a certain option, the consumer needs to define her preferences and interact with the firm, for example via an online configurator, which requires time and the knowledge of preferences. Thus, interacting with the firm in order to co-design product attributes is costly in terms of opportunity costs and cognitive burden. Therefore, when choosing the optimal effort level, each consumer trades off the reduction of misfit costs with interaction costs.

Similar to Loginova and Wang (2009) and Wong and Lesmono (2013), it is assumed that the reser-

vation price  $r$  is increasing in the degree of mass customization offered by the firm. When the firm offers a mass customized product, the perceived uniqueness of the product increases consumers' willingness to pay. As stated earlier in the literature review, this phenomenon has been observed in experimental studies such as Schreier (2006), Franke and Schreier (2008), Franke and Schreier (2010), and Franke et al. (2010). Thus, the adoption of mass customization resembles a quality increase.

Formally, consumers' utility function is given by

$$U = r(1+k) - t \left( \max \left\{ 0, |\theta - x| - e_\theta \frac{k}{2} \right\} \right)^2 - \frac{1}{2} de_\theta^2 - p \quad (3.4)$$

The utility function given by Equation 3.4 is an extended version of the Hotelling (1929) utility function with quadratic transportation costs stated in Equation 3.1. Compared to the standard utility, consumers' reservation price is increasing in the degree of mass customization  $k$ . Further, given the firm adopts mass customization, consumers can reduce their misfit costs, i.e. the distance to the firm  $|\theta - x|$ , by exerting effort  $e_\theta$ . Note that misfit costs cannot be negative. The exerted effort leads to interaction costs of  $\frac{1}{2} de_\theta^2$ .

### Pricing

This model analyzes the situation where the mass customizing firm charges the same price for mass customized products even if consumers choose different effort levels.<sup>4</sup> This is a common marketing practice in horizontally differentiated product markets. Adidas, for example, charges the same price for a certain pair of customizable sneakers independent of how much and which product attributes the customer individualizes. If the firm does not price differentiate, the infra-marginal consumers will derive a positive utility from a purchase. If the firm price differentiated, it would exploit consumer surplus of these infra-marginal consumers, leaving them indifferent between purchasing the product or not. The individual price of each consumer would, thus, be the uniform price plus her reduction of misfit costs. Since an increase in the degree of mass customization leads to lower misfit costs, the monopolist would increase the integration of consumers into the production process. However, increasing the integration of consumers into the production process leads to an increase in dis-economies of scale. Therefore, price differentiation induces the same trade-off already addressed in this model.

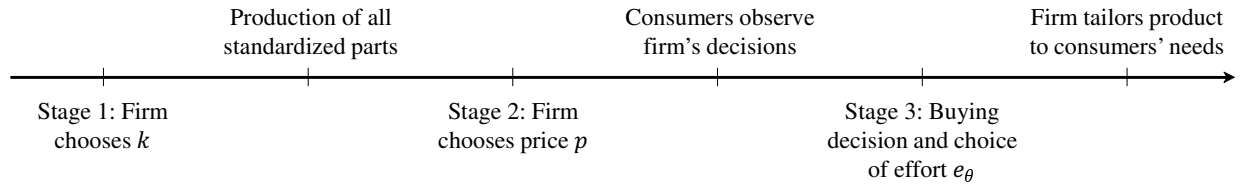
### 3.2.2 Timing of the game

The interaction between the firm and consumers is formalized as a three-stage game. In the first stage, the firm chooses the degree of mass customization  $k \in [0, 1]$ . The firm runs through the standardized production stages and pre-produce the product platform  $1 - k$ . Given the first

<sup>4</sup>This assumption is similar to Syam and Kumar (2006), who examine the situation where firms charge the same price for all customized products in their base model.



stage decision, the firm sets its price  $p$  in the second stage. After having observed the firm's mass customizing and pricing decisions, consumers make their purchasing decision in the third stage of the game. Particularly, consumers decide whether or not to buy the product and how much effort  $e_\theta$  they exert when co-designing the product. Having received consumer specific information, the firm tailors the product to fit consumers' needs. At last, payoffs are realized. Figure 3.3 illustrates the timing of the game.



**Figure 3.3** The three-stage game is solved via backward induction.

### 3.3 Equilibrium analysis of the model

This section derives the equilibrium solutions for the case when consumers benefit from mass customization without exerting effort (Subsection 3.3.1) and the case with consumers' choice of effort (Subsection 3.3.2), for both a covered and an uncovered market. The equilibrium solutions are compared and the value of integrating consumer effort and resulting interactions costs into the model is assessed.

To provide a benchmark for the analysis, the following facts are mentioned.<sup>5</sup> When the monopolist sells a standard product, it

- faces a demand of  $D = 2\sqrt{\frac{1}{t}(r-p)} \in [0, 1]$ ;
- charges a prices of  $p = \frac{2}{3}r$  when the market is uncovered and  $p = r - \frac{1}{4}t$  when the market is covered;
- makes a profit of  $\pi = \sqrt{\frac{16r^3}{27t}}$  when the market is uncovered and  $\pi = r - \frac{1}{4}t$  when the market is covered.
- This leads to a consumer surplus of  $CS = \sqrt{\frac{16r^3}{243t}}$  when the market is uncovered and  $CS = \frac{1}{6}t$  when the market is covered.

#### 3.3.1 Model without consumer effort

This subsection derives the equilibrium solutions for the model without consumer effort. It is assumed that consumers benefit from mass customization without exerting effort. In this case,

<sup>5</sup>The derivation of results can be found in Appendix A Monopoly model.

consumer utility reduces to<sup>6</sup>

$$U = r(1+k) - t \left( \max \left\{ 0, \left| \theta - \frac{1}{2} \right| - \frac{k}{2} \right\} \right)^2 - p \quad (3.5)$$

Compared to consumer utility with quadratic transportation costs when firm  $i$  offers a standard product, given by Equation 3.1, offering a mass customized product leads to an increase in consumers' reservation price due to perceived uniqueness and a reduction of misfit costs.

A type- $\theta$  consumer purchases the firm's mass customized product iff

$$U \geq 0$$

$$r(1+k) - t \left( \max \left\{ 0, \left| \theta - \frac{1}{2} \right| - \frac{k}{2} \right\} \right)^2 - p \geq 0$$

The left-hand side of the above inequality denotes the net utility from purchasing the firm's mass customized product and the right-hand side that from choosing not to buy at all. Solving the inequality with respect to  $\theta$ , yields the consumer who is indifferent between buying or not, which is denoted by  $\underline{\theta}$  (left from the firm) and  $\bar{\theta}$  (right from the firm)

$$\underline{\theta} = \frac{1-k}{2} - \sqrt{\frac{1}{t}(r(1+k) - p)}$$

$$\bar{\theta} = \frac{1+k}{2} + \sqrt{\frac{1}{t}(r(1+k) - p)} \quad (3.6)$$

Consumers located at  $\theta \in [\underline{\theta}, \bar{\theta}]$  purchase the product while those located at  $\theta \in [0, \underline{\theta}]$  and  $\theta \in [\bar{\theta}, 1]$  do not buy. The demand is defined as

$$D = \bar{\theta} - \underline{\theta} = 2\sqrt{\frac{1}{t}(r - p + kr)} + k \quad (3.7)$$

In the second stage of the interaction, the firm sets the price in order to optimize its profit given by Equation 3.3 under the constraint of  $D \leq 1$ . The firm's optimization problem is given by

$$\mathcal{L}(p, \lambda) = D(p - c) + \lambda(D - 1) \quad (3.8)$$

---

<sup>6</sup>It can be shown that  $\left( \left| \theta - \frac{1}{2} \right| - \frac{k}{2} \right)$  maximizes the misfit costs for  $\underline{\theta}$  and  $\bar{\theta}$ . Please see Appendix A.1 Model without consumer effort for the proof.

**Lemma 1** *In equilibrium, the monopolist sets a price  $p^*$  of*

$$p^* = \begin{cases} \frac{1}{18} \left( 12r(1+k) + 6bk^2 - tk^2 + k\sqrt{t(tk^2 + 12r(1+k) - 12bk^2)} \right) & \text{when } \lambda = 0 \\ r(1+k) - \frac{t}{4}(k-1)^2 & \text{when } \lambda > 0 \end{cases}$$

The monopolist's optimal price is increasing in the degree of mass customization  $k^7$  and consumers' reservation price  $r$ . The higher consumers' reservation price and the higher the degree of mass customization, the higher consumer utility and, therefore, the higher the price the firm can charge. In a covered market,  $\lambda > 0$ , the price is decreasing in consumers' sensitivity to product differences  $t$  since an increase in  $t$  leads to higher misfit costs and reduces consumers' utility. Since the firm's optimal price is unaffected by the firm's variable cost of producing a mass customized product  $b$ , the firm does not transfer an increase in its variable cost to the consumer. In an uncovered market,  $\lambda = 0$ , the monopolist transfers parts of its variable cost of producing a mass customized product  $b$  to the consumers, i.e. the optimal price is increasing in  $b$ .<sup>8</sup> As consumers' sensitivity to product differences  $t$  increases, the optimal price of the monopolist increases. This is due to the fact that as  $t$  increases, it becomes more important for consumers to buy their ideal product and misfit costs increase. Hence, consumers are willing to pay more for a product that matches their preferences. As the firm does not serve every consumer, it can charge a higher price.<sup>9</sup>

The firm chooses the degree of mass customization in the first stage.<sup>10</sup>

**Lemma 2** *For  $\lambda > 0$ , the equilibrium degree of mass customization when  $b$  is sufficiently large is given by*

$$k^* = \frac{2r+t}{4b+t} \in (0,1)$$

*When  $b$  is small enough, the optimal degree of mass customization becomes*

$$k^* = 1$$

When the monopolist integrates its consumers into the production process, it can charge a higher price, i.e. the price is increasing in the degree of mass customization. However, mass customized production steps are more costly, leading to dis-economies of scale. If these costs are sufficiently

<sup>7</sup>While the optimal price is strictly increasing in  $k$  for  $\lambda > 0$ , for  $\lambda = 0$  the optimal price increases in  $k$  if  $b$  is sufficiently low.

<sup>8</sup>For a reasonable range of  $b$ .

<sup>9</sup>Please refer to the Proof of Lemma 1 for the analytical derivation of the sensitivities.

<sup>10</sup>Please find the numerical solution for the case when  $\lambda = 0$  in the Proof of Lemma 2.

small, the firm will integrate its consumers as much as possible into the production process and sets  $k^* = 1$ . If these costs are sufficiently high, the firm will trade off the price increase with the cost increase. The monopolist, therefore, increases the degree of mass customization until marginal benefits from the price increase equal marginal costs from dis-economies of scale<sup>11</sup>

$$\begin{aligned} \frac{\partial}{\partial k} p &= \frac{\partial}{\partial k} c \\ \frac{\partial}{\partial k} \left( r(1+k) - \frac{t}{4}(k-1)^2 \right) &= \frac{\partial}{\partial k} (bk^2) \\ r + \frac{1}{2}t(1-k) &= 2bk \\ k &= \frac{2r+t}{4b+t} \end{aligned}$$

Figure 3.4 illustrates the trade-off. Therefore, the higher the variable cost of producing a mass customized product  $b$ , the lower the degree of mass customization offered by the firm. The monopolist always chooses to mass customize, i.e. sets  $k^* > 0$ , since consumers' reservation price  $r$  in a covered market needs to be sufficiently high so that all consumers buy. The degree of mass customization is increasing in consumers' reservation price  $r$  since the perceived uniqueness of a mass customized product increases in  $r$ . Given the variable cost of producing a mass customized product is such that the monopolist offers partial mass customization, the degree of mass customization is increasing in consumers' sensitivity to product differences  $t$ . The more important it is for consumers that the purchased product matches their ideal product, the higher the total amount of misfit costs reduction for a given change in  $k$ . Figure 3.4 depicts the optimal degree of mass customization with respect to the variable cost of producing a mass customized product  $b$ , consumers' reservation price  $r$ , and consumers' sensitivity to product differences  $t$ .

Finally, payoffs are realized.

**Lemma 3** *In equilibrium, the monopolist's optimal profit and consumer surplus are given by*

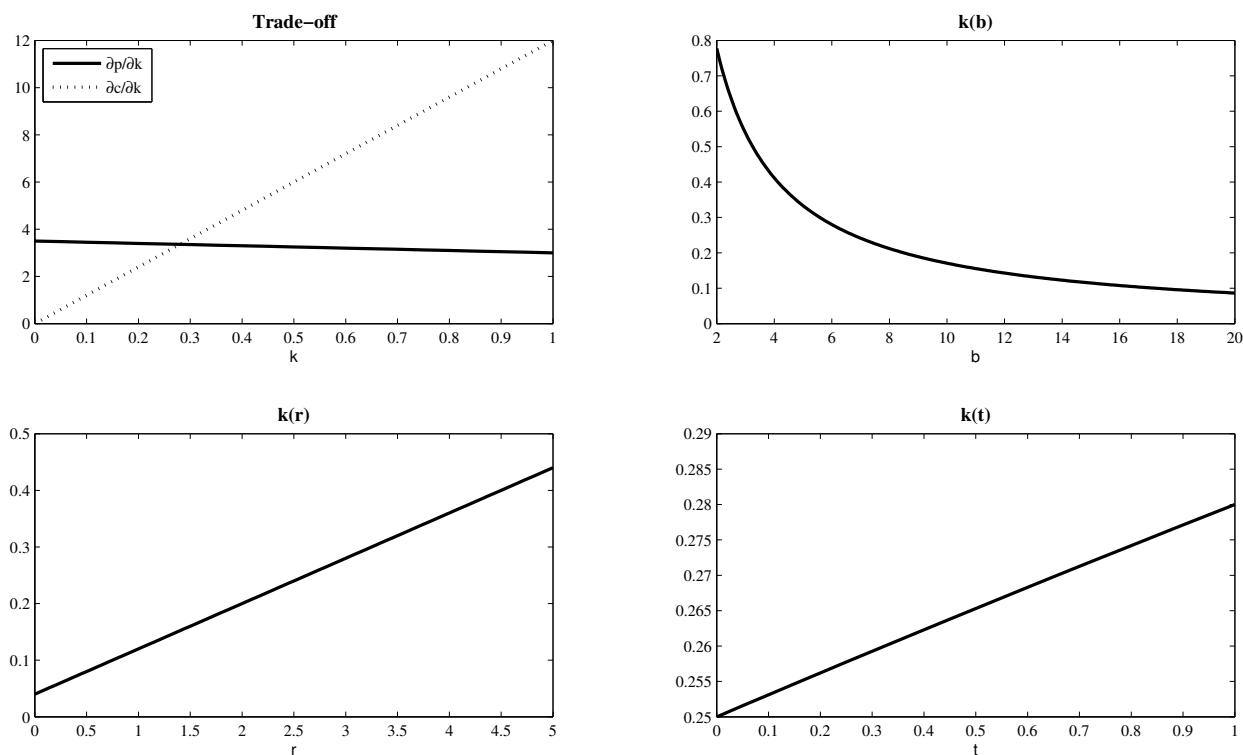
$$\pi^*(k^*, p^*) = \begin{cases} \left( 2\sqrt{\frac{1}{t}(r(1+k^*) - p^*)} + k^* \right) (p^* - bk^{*2}) & \text{when } \lambda = 0 \\ \frac{4br - bt + 2rt + r^2}{4b+t} & \text{when } \lambda > 0 \end{cases}$$

$$CS(k^*, p^*) = \begin{cases} \frac{3k^* + 4\sqrt{\frac{1}{t}(r(1+k^*) - p^*)}}{3} (r(1+k^*) - p^*) & \text{when } \lambda = 0 \\ t(2b-r)^2 \frac{8b+2r+3t}{3(4b+t)^3} & \text{when } \lambda > 0 \end{cases}$$

where

<sup>11</sup>The trade-off is exemplary shown for the case of a covered market.

$$p^* = \frac{1}{18} \left( 12r(1+k^*) + 6bk^{*2} - tk^{*2} + k^* \sqrt{t(tk^{*2} + 12r(1+k^*) - 12bk^{*2})} \right)$$



**Figure 3.4** The monopolist's trade-off and the optimal degree of mass customization in a covered market are shown for  $t = 1$ ,  $b = 6$ , and  $r = 3$ .

When the firm mass customizes in a covered market, its profit is decreasing in the variable cost of producing a mass customized product  $b$  since the firm does not transfer an increase in its costs to the consumer. As consumers' reservation price  $r$  increases, so does the firm's profit since it can charge a higher price. When the firm partially mass customizes, its profit is decreasing in consumers' sensitivity to product differences  $t$ . This is due to the fact that an increase in  $t$  leads to higher misfit costs and, therewith, lowers the price the firm can charge. Consumer surplus is decreasing in the degree of mass customization in a covered market. For  $k^* = 1$ , consumer surplus is zero. When the monopolist partially mass customizes, consumer surplus is increasing in the variable cost of producing a mass customized product  $b$  and consumers' sensitivity for product differences  $t$  while it is decreasing in consumers' reservation price  $r$ . As  $b$  and  $t$  increase, the optimal degree of mass customization decreases, leading to a lower price and, hence, a higher consumer surplus. As  $r$  increases, so does the optimal degree of mass customization and the firm's price, leading to a lower consumer surplus. In an uncovered market, numerical analysis reveals that the monopolist's profit as well as consumer surplus have an optimal  $k$ .<sup>12</sup>

<sup>12</sup>Please refer to the Proof of Lemma 3 for an analytic derivation of the sensitivities in a covered market and a

### 3.3.2 Model with consumer effort

This section analyzes the equilibrium solutions for the case when consumers have to exert effort during the configuration process in order to benefit from mass customization and face costs for the exerted effort.

In the third stage of the interaction, each consumer chooses her optimal effort level.

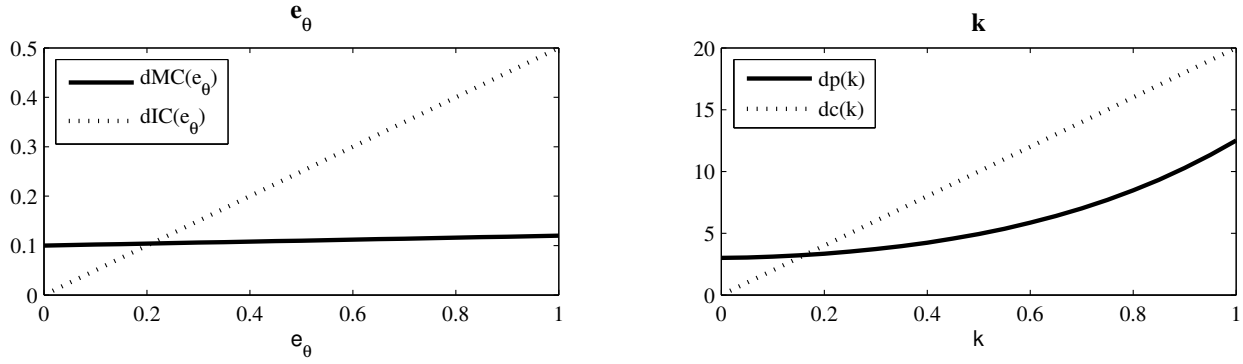
**Lemma 4** *In equilibrium, a type- $\theta$  customer chooses an effort level of  $e_\theta^* = \frac{2tk|\theta - \frac{1}{2}|}{tk^2 + 2d} \in [0, 1]$  when  $d$  is sufficiently high and  $e_\theta^* = 1$  when  $d$  is low enough.*

To include each consumer's trade-off of tailoring a product to her needs and interaction costs, it is assumed that the complexity of the interaction process  $d$  is high enough so that  $e_\theta^*$  is such that  $e_\theta^* \in [0, 1]$ . When choosing the effort level to put into the product configuration, consumers trade-off the reduction of misfit costs with interaction costs. The higher the effort level consumers put into the co-design of the product configuration, the better the functional and aesthetic fit between the purchased product and their ideal product, leading to lower misfit costs (MC). However, the higher the effort level, the greater the interaction with the firm when co-designing the product, leading to higher interaction costs (IC). Consumers, therefore, increase their effort level until the marginal benefits from lower misfit costs equal the marginal costs from interacting with the firm

$$\begin{aligned} \frac{\partial}{\partial e_\theta} MC &= \frac{\partial}{\partial e_\theta} IC \\ \frac{\partial}{\partial e_\theta} \left( t \left( \theta - \frac{1 - e_\theta k}{2} \right)^2 \right) &= \frac{\partial}{\partial e_\theta} \left( \frac{1}{2} d e_\theta^2 \right) \\ tk \left| \theta - \frac{1}{2} \right| - e_\theta \frac{tk^2}{2} &= d e_\theta \\ e_\theta^* &= \frac{2tk \left| \theta - \frac{1}{2} \right|}{tk^2 + 2d} \end{aligned}$$

Figure 3.5 illustrates the trade-off. When the complexity of the interaction, measured by  $d$ , is sufficiently high, consumers choose not to provide full effort. Hence, as the complexity of the interaction process  $d$  increases, interaction costs increase, lowering the optimal effort level. This finding is consistent with literature suggesting that consumers might not customize all options when the complexity of the configuration process is too high. The closer a consumer's ideal product configuration to the offered product, i.e. the better the initial aesthetic and functional fit, the lower the effort level as less effort is needed to approach the ideal product configuration. The consumer, whose preferences are already perfectly met by the standard product, chooses an effort level of  $e_\theta^* = 0$ . Consequently, a consumer's effort level is increasing in the distance between her ideal product configuration and the standard product offered by the firm,  $|\theta - \frac{1}{2}|$ . The effort level

numerical depiction of the firm's profit and consumer surplus in an uncovered market.



**Figure 3.5** Trade-offs: The trade-offs on the consumer side ( $e_\theta$ ) and on the firm side ( $k$ ) are shown for  $\theta = 0.1$ ,  $k = 0.2$ ,  $t = 1$ ,  $d = 0.5$ ,  $b = 10$ , and  $r = 3$ . Consumers' trade-off is depicted in absolute values

is increasing in the degree of mass customization  $k$  if  $k$  is sufficiently small, because the effort becomes more efficient in reducing the misfit costs while it is decreasing in  $k$  for large values of  $k$  since less effort is needed to reduce misfit costs in the same amount. When the firm sets  $k = 0$ , consumers optimal response is to provide zero effort, i.e.  $e_\theta^* = 0$ . The results show that the effort level is increasing in consumers' sensitivity to product differences  $t$ . As  $t$  increases, misfit costs are reduced to a greater amount for a given change in  $e_\theta$ , i.e. the more important it is for consumers that the product matches their ideal product configurations, the higher the effort level.<sup>13</sup> Figure 3.6 provides a graphical summary of the effort level with respect to the model parameters.

Given the optimal choice of effort  $e_\theta^*$ , consumers' utility function is given by<sup>14</sup>

$$U = r(1+k) - \frac{2dt}{tk^2 + 2d} \left( \theta - \frac{1}{2} \right)^2 - p \quad (3.9)$$

Compared to consumer utility with quadratic transportation costs when the monopolist offers a standard product, given by Equation 3.1, offering a mass customized product leads to an increase in consumers' reservation price and a reduction of misfit costs since  $\frac{2dt}{tk^2 + 2d} < t$  for  $k > 0$ . A type- $\theta$  consumer purchases the firm's mass customized product iff

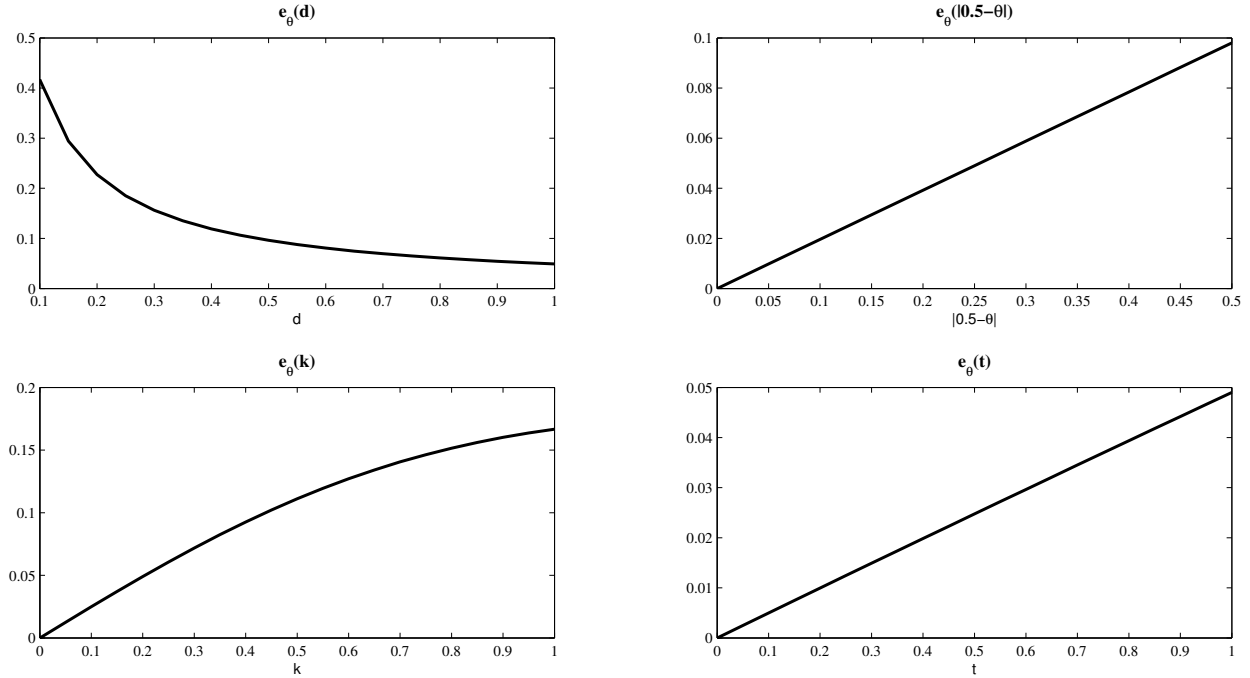
$$U \geq 0$$

$$r(1+k) - \frac{2dt}{tk^2 + 2d} \left( \theta - \frac{1}{2} \right)^2 - p \geq 0$$

The left-hand side of the above inequality denotes the net utility from purchasing the firm's mass customized product and the right-hand side that from choosing not to buy at all. Solving the

<sup>13</sup>Please refer to the Proof of Lemma 4 for the analytical derivation of the sensitivities.

<sup>14</sup>It can be shown that the term  $(|\theta - x| - e_\theta^* \frac{k}{2})$  maximizes the distance between a type- $\theta$  consumer and the firm's product located at  $x = \frac{1}{2}$ . Please see the Proof of Lemma 4 for the proof.



**Figure 3.6** Effort level: The effort level with respect to the model parameters is shown for  $|\frac{1}{2} - \theta| = 0.25$ ,  $k = 0.2$ ,  $t = 1$ , and  $d = 1$ .

inequality with respect to  $\theta$ , yields the consumer who is indifferent between buying or not, which is denoted by  $\underline{\theta}$  (left from the firm) and  $\bar{\theta}$  (right from the firm)

$$\begin{aligned}\underline{\theta} &= \frac{1}{2} - \sqrt{\frac{1}{2dt} (2d + tk^2) (r + rk - p)} \\ \bar{\theta} &= \frac{1}{2} + \sqrt{\frac{1}{2dt} (2d + tk^2) (r + rk - p)}\end{aligned}\quad (3.10)$$

Consumers located at  $\theta \in [\underline{\theta}, \bar{\theta}]$  purchase the product while those located at  $\theta \in [0, \underline{\theta}]$  and  $\theta \in [\bar{\theta}, 1]$  do not buy. The demand is defined as

$$D = \bar{\theta} - \underline{\theta} = \sqrt{\frac{2}{dt} (tk^2 + 2d) (r + rk - p)}\quad (3.11)$$

In the second stage of the interaction, the firm sets the price in order to optimize its profit given by Equation 3.3 under the constraint of  $D \leq 1$ . The firm's optimization problem is given by

$$\mathcal{L}(p, \lambda) = D(p - c) + \lambda(D - 1)\quad (3.12)$$

**Lemma 5** *In equilibrium, the monopolist sets a price  $p^*$  of*



$$p^* = \begin{cases} \frac{1}{3} (2r + 2rk + bk^2) & \text{when } \lambda = 0 \\ r(1+k) - \frac{dt}{2tk^2+4d} & \text{when } \lambda > 0 \end{cases}$$

The monopolist's optimal price is increasing in the degree of mass customization  $k$  and consumers' reservation price  $r$  in both a covered and an uncovered market. An increase in these parameters increases consumer gross utility and, subsequently, the price the firm can charge. In an uncovered market, the firm partly transfers an increase of the variable cost of producing a mass customized product  $b$  to its consumers. Hence, an increase in  $b$  leads to a higher price. In a fully covered market, the optimal price decreases in consumers' sensitivity for product differences  $t$  and the complexity of the interaction process  $d$  since both parameters decrease consumer utility.<sup>15</sup>

The firm chooses the degree of mass customization in the first stage.

**Lemma 6** *The monopolist chooses partial mass customization,  $k^* \in (0, 1)$ , when the unit production cost  $b$  is sufficiently large and full mass customization,  $k^* = 1$ , when  $b$  is small enough.*

Formally, when unit production costs  $b$  are sufficiently small, the degree of mass customization in an uncovered market,  $\lambda = 0$ , is given by

$$k^* = \frac{5r}{24b} + \frac{x}{\sqrt[3]{\sqrt{y^2 - x^3} + y}} + \sqrt[3]{\sqrt{y^2 - x^3} + y}$$

where

$$x = \frac{1}{12b}r - \frac{1}{2} \frac{d}{t} + \frac{25}{576b^2}r^2$$

$$y = \frac{5}{192b^2}r^2 + \frac{125}{13824b^3}r^3 + \frac{7}{32b} \frac{d^2}{t}$$

while in a fully covered market,  $\lambda > 0$ , the degree of mass customization when  $b$  is sufficiently high is defined by

$$(tk^2 + 2d)^2 (r - 2bk) + dkt^2 = 0$$

Analogous to the case without consumer effort, integrating the consumer into the production process decreases consumers' misfit costs and increases consumers' reservation price, leading to an increase in the utility consumers derive from a purchase. This allows the firm to charge a higher price and extract greater surplus from its consumers. However, integrating consumers

<sup>15</sup>Please refer to the Proof of Lemma 5 for an analytic derivation of the sensitivities.

into the production process leads to dis-economies of scale. Thus, the higher the integration, the higher the unit production costs. If integrating consumers into the production process is not too costly for the firm, it will integrate its consumers as much as possible into the production process. If this integration is, however, sufficiently costly, the firm trades off the price premium with higher manufacturing costs in order to find the optimal degree of mass customization. The firm, therefore, increases its degree of mass customization until the marginal benefits from a higher price equal the marginal costs from dis-economies of scale<sup>16</sup>

$$\begin{aligned} \frac{\partial}{\partial k} p &= \frac{\partial}{\partial k} c \\ \frac{\partial}{\partial k} \left( r(1+k) - \frac{dt}{2tk^2 + 4d} \right) &= \frac{\partial}{\partial k} (bk^2) \\ \frac{1}{(tk^2 + 2d)^2} \left( 4rd^2 + 4rdk^2t + dkt^2 + rk^4t^2 \right) &= 2bk \\ (2d + k^2t)^2 (r - 2bk) + dkt^2 &= 0 \end{aligned}$$

Figure 3.5 illustrates the trade-off. Results show that the monopolist always adopts mass customization, i.e. sets  $k^* > 0$ . The degree of mass customization realized in equilibrium is decreasing in the costs of customization  $b$ . The greater the dis-economies of scale from offering mass customization, the lower the degree of mass customization offered by the firm. Further, the degree of mass customization is increasing in consumers' reservation price  $r$  since an increase in  $r$  increases consumers' valuation for uniqueness. Further, the higher consumers' sensitivity to product differences  $t$ , the greater the degree of mass customization chosen by the monopolist. The higher  $t$ , the higher the total amount of misfit costs' reduction for a given change in  $k$ . The degree of mass customization is decreasing in the complexity of interaction process  $d$ .<sup>17</sup> When  $d$  increases, consumers lower their effort level. Hence, for a given  $k$ , consumer utility is enhanced to a lower degree while the firm's cost for mass customization is unchanged.<sup>18</sup>

Finally, payoffs are realized.

**Lemma 7** *In equilibrium, the monopolist's optimal profit and consumer surplus are given by*

$$\begin{aligned} \pi^*(k^*) &= \begin{cases} \sqrt{\frac{8}{27dt} (r(1+k^*) - bk^{*2})^3 (tk^{*2} + 2d)} & \text{when } \lambda = 0 \\ r(1+k^*) - \frac{dt}{2tk^{*2} + 4d} - bk^{*2} & \text{when } \lambda > 0 \end{cases} \\ CS(k^*) &= \begin{cases} \sqrt{\frac{8}{243dt} (tk^{*2} + 2d) (r(1+k) - bk^{*2})^3} & \text{when } \lambda = 0 \\ \frac{2dt}{6tk^{*2} + 12d} & \text{when } \lambda > 0 \end{cases} \end{aligned}$$

<sup>16</sup>The trade-off is exemplary shown for the case of a covered market.

<sup>17</sup>Given  $e_\theta^*$  is increasing in  $k$ .

<sup>18</sup>Please refer to the Proof of Lemma 6 for an analytic derivation of the sensitivities.

Given the optimal degree of mass customization, the firm's profit is increasing in consumers' reservation price  $r$  since an increase in  $r$  increases consumer utility. As unit variable costs  $b$  increase, the firm's profit decreases. The monopolist's profit is decreasing in consumers' sensitivity to product differences  $t$  and the complexity of the interaction process  $d$ . As consumers' sensitivity to product differences  $t$  increase and the complexity of the interaction process  $d$  increase, the disutility consumers' derive from purchasing a product that does not fit their preferences increases. Consequently, in a covered market, the firm has to lower its price, resulting in a profit decrease. Although, the price is unaffected by  $t$  and  $d$  in an uncovered market, an increase in these parameters lowers demand, leading to a lower profit.

Consumer surplus is decreasing in  $k^*$  in a covered market while it has a maximum at  $k^*$  when the market is uncovered. For  $k^* = 1$ , consumer surplus is positive in both a covered and an uncovered market. While consumer surplus in a covered market is increasing in consumers' sensitivity to product differences  $t$  and the complexity of the interaction process  $d$ , it is decreasing in these parameters when the market is uncovered. When the monopolist serves the whole market,  $t$  and  $d$  decrease consumer gross utility and lower the price the firm can charge. Although, an increase in  $t$  and  $d$  decrease consumer utility when the monopolist serves parts of the market, the price remains unchanged. Consequently, consumer surplus is reduced. In a covered market, consumer surplus is unaffected by consumers' reservation price  $r$  and the variable cost of producing a mass customized product  $b$ . The firm exploits any increase in  $r$  while it does not transfer a change in  $b$  to its consumers. When the market is uncovered, an increase in the variable cost of mass customization  $b$  decreases consumer surplus, because the higher  $b$  the higher the price while an increase in consumers' reservation price  $r$  leads to an increase in consumer surplus.<sup>19</sup>

### 3.3.3 Comparative analysis

This subsection compares the monopolist's mass customization and pricing decisions as well as the resulting profit and consumer surplus with<sup>20</sup> and without consumer effort to assess the value of integrating company-customer interaction into a model of mass customization.<sup>21</sup>

**Proposition 1** *The optimal degree of mass customization is lower when consumers' choice of effort and resulting interaction costs are integrated into the model.*

From Lemma 4 it follows that consumers choose not to provide full effort given that the complexity of the interaction process  $d$  is high enough. Hence, the degree of mass customization is not fully exploited. Consequently, for a given  $k$  consumers' misfit costs are smaller when consumers benefit directly from mass customization compared to the case when consumers exert effort. It follows that for a given  $k$  consumer gross utility is greater without than with consumer effort, enabling the firm to charge a higher price, while the monopolist's variable cost of producing a

<sup>19</sup>Please refer to the Proof of Lemma 7 for an analytic derivation of the sensitivities.

<sup>20</sup>For greater clarity, the superscript  $E$  is added to all decision variables in the model with consumer effort.

<sup>21</sup>Please note that for  $\lambda > 0$  results are derived analytically while results are mainly derived numerically for  $\lambda = 0$ .

mass customized product is unaffected by consumer effort. When the firm chooses the optimal degree of mass customization it balances the marginal benefit from an increased price due to mass customization and marginal costs of mass customized production. While a lower consumer utility from consumer effort decreases the marginal price benefit, the marginal cost remains unchanged. To determine the optimal degree of mass customization, the firm increases its degree of mass customization until marginal benefits equal marginal costs. As marginal benefits decrease, this point of intersection leads to a lower degree of mass customization when consumer effort is integrated into the model.

The necessary first-order condition  $\frac{\partial}{\partial k^E} \pi^E$  with consumer effort in a covered market is defined as

$$\frac{\partial}{\partial k^E} \pi^E = \tilde{\pi}^E : \frac{1}{(tk^{E2} + 2d)^2} \left( -8bd^2k^E + 4rd^2 - 8bdk^{E3}t + 4rdk^{E2}t + dk^E t^2 - 2bk^{E5}t^2 + rk^{E4}t^2 \right) = 0$$

while the necessary first-order condition  $\frac{\partial}{\partial k} \pi$  and the optimal degree of mass customization  $k^*$  without consumers' choice of effort in a covered market are given by

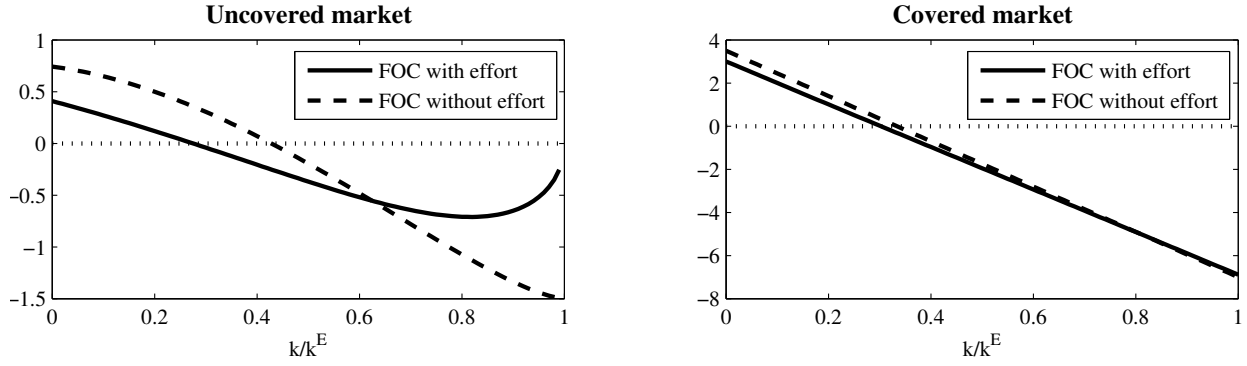
$$\begin{aligned} \frac{\partial}{\partial k} \pi &= \tilde{\pi} : r + \frac{1}{2}t - 2bk - \frac{1}{2}kt = 0 \\ k^* &= \frac{2r + t}{4b + t} \end{aligned}$$

For  $k^E = k = 0$ , the necessary first-order condition without consumer effort  $\tilde{\pi}$  is greater or equal than that with consumer effort  $\tilde{\pi}^E$  while for  $k^E = k = 1$ , the necessary first-order condition with consumer effort  $\tilde{\pi}^E$  is greater or equal than that without consumer effort  $\tilde{\pi}$ . It follows that the necessary first-order conditions intersect in  $k = k^E \in [0, 1]$ . Further,  $\tilde{\pi}$  and  $\tilde{\pi}^E$  are strictly decreasing in  $k$  and  $k^E$ , respectively.<sup>22</sup> Figure 3.7 illustrates the necessary first-order conditions for  $\lambda = 0$  and  $\lambda > 0$ .

Inserting the optimal degree of mass customization  $k^*$  without consumer effort into the necessary first-order condition with consumer effort  $\tilde{\pi}^E$  yields a negative value given the assumption of a sufficiently high  $d$  from Lemma 4 is satisfied, i.e.  $\tilde{\pi}^E(k^*) < 0$ . It follows that the optimal degree of mass customization when consumers exert effort  $k^{E*}$  is smaller or equal than the optimal degree of mass customization when consumers benefit from mass customization directly  $k^*$ . Hence, integrating consumers' choice of effort and resulting costs of interaction into a model of mass customization leads to a lower degree of mass customization chosen by the monopolist in a covered market.<sup>23</sup> Numerical analysis suggests that this finding is also true for  $\lambda = 0$ . Figure 3.7 shows that when the market is uncovered, the monopolist chooses a degree of mass cus-

<sup>22</sup> $\tilde{\pi}$  is linearly decreasing in  $k$  while  $\tilde{\pi}^E$  concavely decreases in  $k^E$  for small values of  $k^E$  and convexly decreases in  $k^E$  if  $k^E$  is sufficiently large.

<sup>23</sup>Please refer to the Proof of Proposition 1 for the analytic proof.



**Figure 3.7** This figure shows the necessary first-order condition of the profit with respect to  $k/k^E$  for  $b = 1, r = 0.5, t = 1, d = 1$  when  $\lambda = 0$ , and for  $b = 5, r = 3, t = 1, d = 1$  when  $\lambda > 0$ .

tomization with consumer effort that is smaller or equal relative to degree of mass customization without consumer effort.

**Proposition 2** *The monopolist can charge a higher price when it sells a mass customized product. The price increase from mass customization is lower when consumers have to exert effort in order to benefit from mass customization.*

Lemma 4 states that consumers choose not to provide full effort given that the complexity of the interaction process  $d$  is high enough. Hence, the degree of mass customization is not fully exploited. Consequently, mass customization is more effective in reducing consumers' misfit costs when consumers benefit directly from mass customization compared to the case when consumers exert effort and face interaction costs. Hence, for a given degree of mass customization misfit costs' are reduced less when consumers exert effort. Additionally, exerting effort is costly for consumers. It follows that for a given degree of mass customization, consumer gross utility from buying the mass customized product is lower with consumer effort than without. Therefore, when the market is covered, the firm must lower its price in order to serve the marginal consumers at zero and one.

In a covered market, the monopolist's price without consumer effort is given by

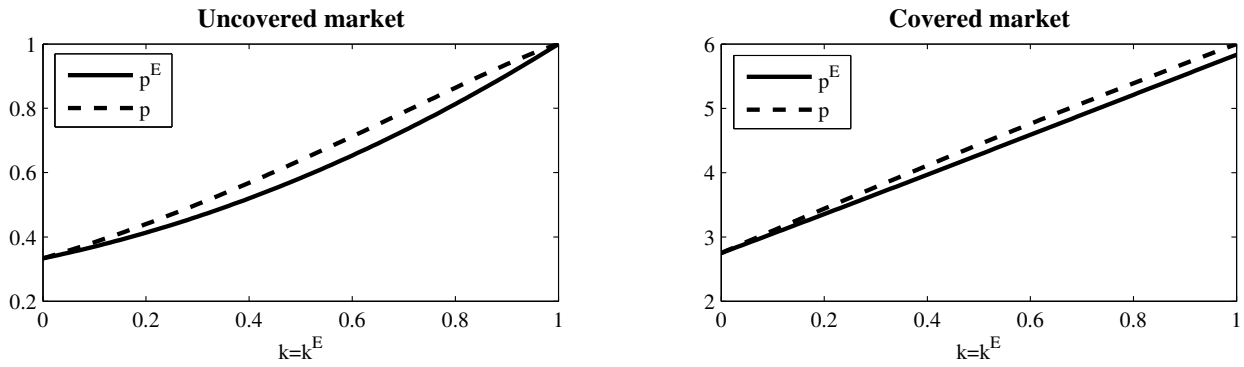
$$p = r(1 + k) - \frac{1}{4}t(k - 1)^2$$

Integrating consumer effort, the price becomes

$$p^E = r(1 + k^E) - \frac{dt}{2tk^{E2} + 4d}$$

For the boundary values of the domain of definition of the degree of mass customization  $k = k^E \in [0, 1]$ , the optimal price without consumer effort  $p$  is greater or equal than that with consumer effort  $p^E$ . For  $k = k^E = 0$ , prices are identical<sup>24</sup> while for  $k = k^E = 1$  the firm can charge a price without consumer effort that is greater or equal than that with consumer effort. The price functions are strictly increasing in  $k$  and  $k^E$ , respectively, and intersect at  $k = k^E = 0$  and  $k = k^E > 1$ . Hence, the optimal price without consumer effort  $p$  is greater or equal than with consumer effort  $p^E$  for a given  $k = k^E > 0$  and prices with mass customization are higher than without for any  $k = k^E > 0$ . Consequently,  $p^E(k^*)$  is smaller or equal than  $p(k^*)$ . From Proposition 1 it follows that  $k^{E*}$  is smaller or equal than  $k^*$ . Hence,  $p^E(k^{E*})$  must be smaller than  $p(k^*)$ . In an uncovered market, it can be shown that  $p \geq p^E$  for a given  $k$ .<sup>25</sup> Numerical analysis suggests that  $p(k^*) > p^E(k^{E*})$  is also true for  $\lambda = 0$ .

Figure 3.8 illustrates the monopolist's price with and without effort for  $\lambda = 0$  and  $\lambda > 0$ .



**Figure 3.8** This figure shows  $p$  and  $p^E$  when  $\lambda > 0$  for  $t = 1$ ,  $d = 1$ ,  $r = 3$ ,  $b = 5$ , and when  $\lambda = 0$  for  $t = 1$ ,  $d = 1$ ,  $r = 0.5$ ,  $b = 1$ , dependent on  $k/k^E$ .

**Proposition 3** *The profit increase from selling a mass customized product is lower when consumer effort and interaction costs are integrated into the model.*

In a covered market, the monopolist's margin without consumer effort is given by

$$m = r(1 + k) - \frac{1}{4}t(k - 1)^2 - bk^2$$

Integrating consumer effort, the margin becomes

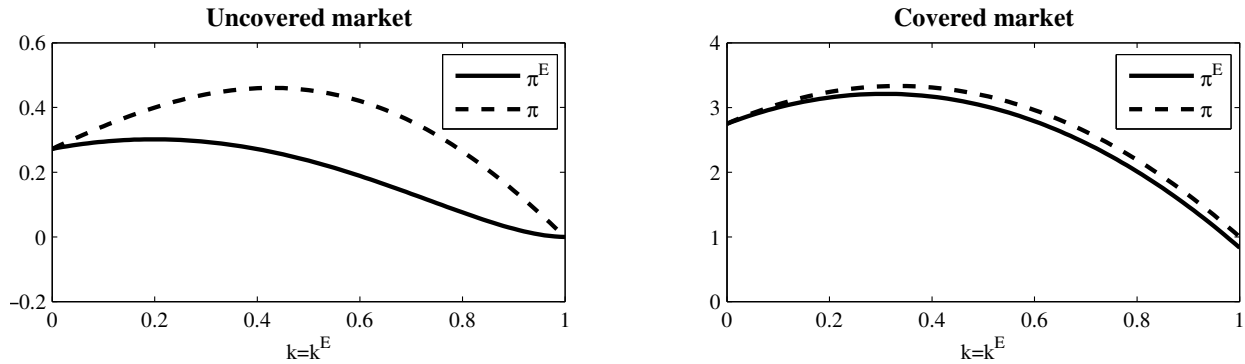
$$m^E = r(1 + k^E) - \frac{dt}{2tk^{E2} + 4d} - bk^{E2}$$

<sup>24</sup>Prices for  $k = k^E = 0$  are identical to the price when the firm only sells a standard product in a covered market, i.e.  $p = r - \frac{1}{4}t$ .

<sup>25</sup>Please refer to the Proof of Proposition 2 for the analytic proof.

For the boundary values of the domain of definition of the degree of mass customization  $k = k^E \in [0, 1]$ , the margin without consumer effort  $m$  is greater or equal than that with consumer effort  $m^E$ . For  $k = k^E = 0$ , margins are identical<sup>26</sup> while for  $k = k^E = 1$  the firm makes a margin without consumer effort that is greater or equal than that with consumer effort, i.e.  $m(k=1) \geq m^E(k^E=1)$ . The margin functions are strictly increasing in  $k$  and  $k^E$ , respectively, for  $k \in [0, k^*]$  and  $k^E \in [0, k^{E*}]$ , respectively, and intersect at  $k = k^E = 0$  and  $k = k^E > 1$ . Hence, the margin without consumer effort is greater than with consumer effort for a given  $k \in [0, k^*]$  and  $k^E \in [0, k^{E*}]$ , respectively, and the margin with mass customization is greater than the margin without for any  $k \in (0, k^*]$  and  $k^E \in (0, k^{E*}]$ , respectively. Consequently,  $m^E(k^*)$  is smaller or equal than  $m(k^*)$ . From Proposition 1 it follows that  $k^{E*}$  is smaller or equal than  $k^*$ . Hence,  $m^E(k^{E*})$  must be smaller than  $m(k^*)$ . Since for  $\lambda > 0$  the demand constraint is binding, i.e.  $D = 1$ , the profit of the monopolist is lower when consumer effort is integrated into the model relative to when consumer effort is neglected,  $\pi^E(k^{E*}) < \pi(k^*)$ . In an uncovered market, it can be shown that  $m \geq m^E$  and  $D \geq D^E$  for a given  $k$  since for a given  $k$  the distance of the firm to the consumer with a gross utility of zero is greater without than with consumer effort.<sup>27</sup> Numerical analysis suggests that  $\pi(k^*) > \pi^E(k^{E*})$  is also true for  $\lambda = 0$ .

Figure 3.9 illustrates the monopolist's profit with and without consumer effort for  $\lambda = 0$  and  $\lambda > 0$ .



**Figure 3.9** This figure shows  $\pi$  and  $\pi^E$  when  $\lambda > 0$  for  $t = 1$ ,  $d = 1$ ,  $r = 3$ ,  $b = 5$ , and when  $\lambda = 0$  for  $t = 1$ ,  $d = 1$ ,  $r = 0.5$ ,  $b = 1$ , dependent on  $k/k^E$ .

**Proposition 4** *Mass customization reduces consumer surplus. Integrating consumers' choice of effort and interaction costs into the model mitigates the loss in consumer surplus from mass customization.*

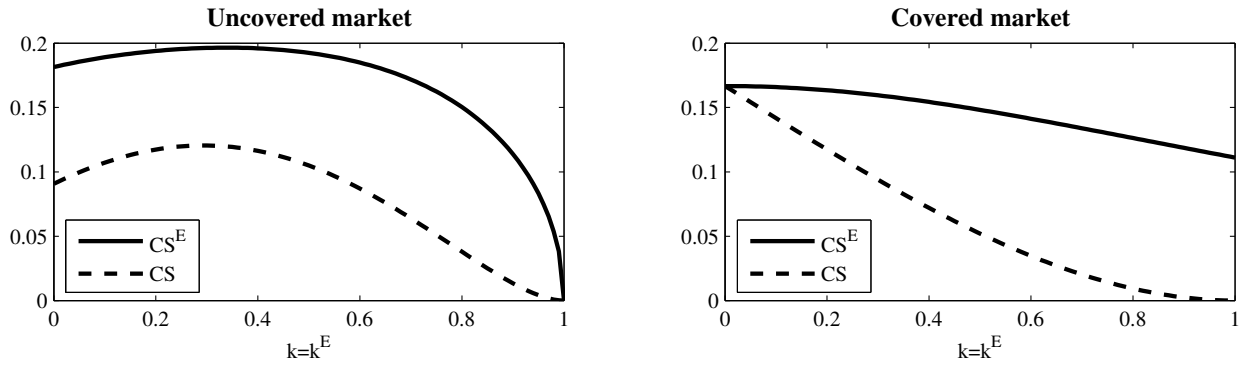
In a covered market, consumer surplus with consumer effort  $CS^E$  and consumer surplus without consumer effort  $CS$  are given by

<sup>26</sup>Note that the margins equal the margin when the firm only sells a standard product in a covered market,  $m = r - \frac{1}{4}t$ .

<sup>27</sup>Please refer to the Proof of Proposition 3 for the analytic proof.

$$CS^E = \frac{2dt}{6tk^{E2} + 12d}$$

$$CS = \frac{1}{12}t(k-1)^2(k+2)$$



**Figure 3.10** This figure shows consumer surplus for  $b = 1, r = 0.5, t = 1, d = 1$  when  $\lambda = 0$ , and for  $b = 5, r = 3, t = 1, d = 1$  when  $\lambda > 0$ , dependent on  $k/k^E$ .

For  $k = k^E = 0$ , consumer surplus with and without consumer effort are identical to consumer surplus when the firm only sells a standard product, i.e.  $CS = \frac{1}{6}t$ . Since consumer surplus is decreasing in  $k$  and  $k^E$ , respectively, and the monopolist chooses  $k^* = k^{E*} > 0$ , consumer surplus with mass customization is lower than when only a standard product is sold. When the monopolist fully mass customizes, consumer surplus without consumer effort is zero, i.e.  $CS(k = 1) = 0$ , since every consumer purchases her ideal product and misfit costs vanish. The monopolist charges a price that leaves every consumer indifferent to buying or not. With consumer effort, consumer surplus is positive for  $k^E = 1$ , i.e.  $CS^E(k^E = 1) > 0$ , since consumers choose to provide partial effort when the complexity of the interaction process  $d$  is sufficiently high and, consequently, misfit costs do not fully vanish. The monopolist charges a price that leaves the infra-marginal consumer with a positive utility. The difference in consumer surplus  $\Delta CS = CS^E - CS$  is increasing in the complexity of the interaction process  $d$  since an increase in  $d$  lowers consumer effort.  $\Delta CS$  is always positive given the assumption of a sufficiently high  $d$  from Lemma 4. Hence,  $CS^E(k^*) \geq CS(k^*)$ . Since consumer surplus is decreasing in  $k$  and  $k^* \geq k^{E*}$ , it follows that  $CS^E(k^{E*}) > CS(k^*)$ .<sup>28</sup> Numerical analysis suggests that  $CS^E(k^{E*}) > CS(k^*)$  holds true when the market is uncovered. Figure 3.10 illustrates consumer surplus with and without consumer effort for  $\lambda = 0$  and  $\lambda > 0$ .

<sup>28</sup>Please refer to the Proof of Proposition 4 for the analytic proof.



### 3.4 Extensions

This section extends the monopoly model in two ways: first, the effect of consumers' valuation for perceived uniqueness of mass customized products on the optimal degree of mass customization is studied; second, it is analyzed whether the monopolist has an incentive to offer both a lower-priced standard product and a mass customized product.

#### 3.4.1 Consumers' valuation for uniqueness

As observed by a variety of experimental studies<sup>29</sup>, mass customization leads to an increase in consumers' reservation price, because consumers attach additional value to mass customized products due to perceived uniqueness.<sup>30</sup> In this subsection, the effect of consumers' valuation for perceived uniqueness of mass customized products on the optimal degree of mass customization is analyzed. The reservation price for a mass customized product is given by

$$r(1 + \alpha k) \quad (3.13)$$

where  $\alpha \in [0, 1]$  measures consumers' valuation for perceived uniqueness. Thus, when  $\alpha = 0$ , consumers do not value uniqueness and do not exhibit an increase in their reservation price. When  $\alpha > 0$ , consumers appreciate uniqueness, resulting in an increase in their reservation price.

Including  $\alpha$  into the model leads to the following main results in a covered market

$$p^* = r(1 + \alpha k) - \frac{dt}{2tk^2 + 4d}$$

$$\frac{\partial}{\partial k} \pi : (2d + k^2t)^2 (r\alpha - 2bk) + dkt^2 = 0$$

In an uncovered market, the demand  $D$ , optimal price  $p^*$ , and degree of mass customization  $k^*$  are given by<sup>31</sup>

$$D = \sqrt{\frac{2}{dt} (tk^2 + 2d) (r(1 + \alpha k) - p)}$$

$$p^* = \frac{2r(1 + \alpha k) + bk^2}{3}$$

$$k^* = \sqrt[3]{\sqrt{y^2 - x^3} + y} + \frac{5}{24b}r + \frac{x}{\sqrt[3]{\sqrt{y^2 - x^3} + y}},$$

<sup>29</sup>For example Schreier (2006), Franke and Schreier (2008), and Franke et al. (2010).

<sup>30</sup>This assumption is similar to Loginova and Wang (2009) and Wong and Lesmono (2013).

<sup>31</sup>Please note that an analytical derivation of the results is omitted at this point and can be found in Appendix A.4 Consumers' valuation for uniqueness.

where

$$\begin{aligned} x &= \frac{1}{12b}r - \frac{1}{2}\frac{d}{t} + \frac{25}{576b^2}r^2\alpha^2 \\ y &= \frac{5}{192b^2}r^2\alpha + \frac{125}{13824b^3}r^3\alpha^3 + \frac{7}{32b}\frac{d}{t}r\alpha \end{aligned}$$

**Proposition 5** *The optimal degree of mass customization  $k^*$  is increasing in consumers' valuation for perceived uniqueness  $\alpha$ . When consumers do not value uniqueness, the firm finds it most profitable to set  $k^* = 0$  if the variable cost of mass customization  $b$  is sufficiently high.*

From the first derivative of  $k^*$  with respect to  $\alpha$  it follows that the optimal degree of mass customization  $k^*$  is increasing in consumers' valuation for uniqueness  $\alpha$

$$\frac{\partial}{\partial \alpha} \frac{\partial}{\partial k} \pi : \begin{cases} 5rtk^2 + 6dr \geq 0 & \text{when } \lambda = 0 \\ r(tk^2 + 2d)^2 \geq 0 & \text{when } \lambda > 0 \end{cases}$$

Independent of the assumption of a covered market,  $k^* = 0$  is the only solution that solves the first-order necessary conditions when  $\alpha = 0$  given  $b$  is sufficiently high.<sup>32</sup> While the variable production cost of producing a mass customized product is unaffected by consumers' valuation for perceived uniqueness  $\alpha$ , the firm needs to lower its price as  $\alpha$  decreases since consumers' reservation price declines.

$$\frac{\partial}{\partial \alpha} p : \begin{cases} \frac{2}{3}rk \geq 0 & \text{when } \lambda = 0 \\ rk \geq 0 & \text{when } \lambda > 0 \end{cases}$$

Consequently, when consumers do not value the uniqueness of mass customized products, the price charged by the firm may not capture unit manufacturing costs for mass customized products if these costs are sufficiently high. To determine the optimal degree of mass customization, the firm increases the degree of mass customization until marginal benefits equal marginal costs. Hence, when marginal benefits decline because the firm has to decrease its price, the point of intersection decreases, leading to a lower optimal degree of mass customization.

In an uncovered market, the firm loses consumer demand when it raises the price for the mass customized product in the presence of no valuation for uniqueness, because the increase in consumers' reservation price from mass customization is not sufficiently high.

$$\frac{\partial}{\partial \alpha} D : \left( \frac{1}{6}\sqrt{2} \right) kr \frac{2d + k^2t}{dt \sqrt{\frac{1}{dt}(2d + k^2t)} \left( \frac{1}{3}r - \frac{1}{3}bk^2 + \frac{1}{3}kr\alpha \right)} \geq 0$$

<sup>32</sup>Please refer to the Proof of Proposition 5 for the analytic derivation.

Therefore, the monopolist offers a standard product when consumers do not value the uniqueness of a mass customized product and the variable cost for mass customized production is sufficiently high.

### 3.4.2 Incentive to offer a standard and a mass customized product

This subsection analyzes the monopolist's incentive to offer (i) a lower-priced standard product in addition to its mass customized product and (ii) a mass customized product in addition to its standard product. The standard products  $x^S$  is located at  $x^S = \frac{1}{2}$ .

When the firm offers both a standard product  $x^S$  and a mass customized product  $x^C$ , the mass customized product is priced at  $p$  and the standard product is sold with a price discount of  $z$ . In this case, a type- $\theta$  consumer purchases the standard product  $x^S$  if her utility from buying the standard product  $U^S$  is greater or equal than the utility from buying the mass customized product  $U^C$

$$U^S \geq U^C$$

$$r - t \left( \theta - \frac{1}{2} \right)^2 - (p - z) \geq r(1 + k) - \frac{2dt}{tk^2 + 2d} \left( \theta - \frac{1}{2} \right)^2 - p$$

Hence, the consumer  $\underline{\theta}^S$  and  $\bar{\theta}^S$ , respectively, who is indifferent between buying the firm's standard or mass customized product, is located at

$$\underline{\theta}^S = \frac{1}{2} - \frac{1}{tk} \sqrt{(z - rk)(tk^2 + 2d)}$$

$$\bar{\theta}^S = \frac{1}{2} + \frac{1}{tk} \sqrt{(z - rk)(tk^2 + 2d)} \quad (3.14)$$

Recall from Subsection 3.3.2 that the consumer who is indifferent between buying the mass customized product and not buying at all is given by

$$\underline{\theta}^C = \frac{1}{2} - \sqrt{\frac{1}{2dt} (2d + k^2t) (-p + r + kr)}$$

$$\bar{\theta}^C = \frac{1}{2} + \sqrt{\frac{1}{2dt} (2d + k^2t) (-p + r + kr)} \quad (3.15)$$

Since consumers close to the firm buy the standard product and consumers distant to the firm buy the mass customized product<sup>33</sup>, the demand for the standard product  $D^S$  and for the mass customized product  $D^C$  are as follows

<sup>33</sup>Please refer to the Proof of A.4 Incentive to offer a standard and a mass customized product for the analytic proof.

$$\begin{aligned}
D^S &= \bar{\theta}^S - \underline{\theta}^S = \frac{2}{kt} \sqrt{(tk^2 + 2d)(z - kr)} \\
D^C &= \bar{\theta}^C - \underline{\theta}^C - D^S = \sqrt{\frac{2}{dt} (tk^2 + 2d)(r - p + kr)} - D^S
\end{aligned} \tag{3.16}$$

The firm bears costs of  $c^S = a$  for the standard product and costs of  $c^C = a + (b - a)k^2$  for the mass customized product, where  $a$  is normalized to zero. The firm's profit is given by

$$\begin{aligned}
\pi &= D^S (bk^2 - z) + D^C (p - bk^2) \\
&= (\bar{\theta}^S - \underline{\theta}^S) (p - z) + (\bar{\theta}^C - \underline{\theta}^C - (\bar{\theta}^S - \underline{\theta}^S)) (p - bk^2) \\
&= (\bar{\theta}^S - \underline{\theta}^S) (bk^2 - z) + (\bar{\theta}^C - \underline{\theta}^C) (p - bk^2) \\
&= \pi^S + \pi^C
\end{aligned} \tag{3.17}$$

To set the price for the mass customized product  $p$  and the discount  $z$ , the firm simultaneously maximizes its profit function with respect to  $p$  and  $z$  subject to the demand constraint  $D \leq 1$ . The firm's maximization problem is defined as

$$\mathcal{L}(p, z, \lambda) = D^S(z)(p - z) + (D^C(p, z) - D^S(z))(p - bk^2) + \lambda(D^C(p, z) - 1) \tag{3.18}$$

The profit maximizing price  $p^*$  and discount  $z^*$  are given by<sup>34</sup>

$$\begin{aligned}
p^* &= \begin{cases} \frac{2}{3}r(1+k) + \frac{1}{3}bk^2 & \text{when } \lambda = 0 \\ r(1+k) - \frac{dt}{2tk^2+4d} & \text{when } \lambda > 0 \end{cases} \\
z^* &= \begin{cases} \frac{1}{3}bk^2 + \frac{2}{3}kr & \text{when } \lambda = 0 \\ \frac{1}{3}bk^2 + \frac{2}{3}kr & \text{when } \lambda > 0 \end{cases}
\end{aligned}$$

**Proposition 6** *The monopolist firm has an incentive to additionally offer a lower-priced standard product when the variable cost of producing a mass customized product is greater or equal than the price discount for the standard product.*

As can be noticed from Equation 3.17, the profit of the firm when it offers both products is the additive profit of offering a mass customized product  $\pi^C$  (identical to the profit in Subsection 3.3.2) and a standard product  $\pi^S$ . The additional profit from offering a standard product  $\pi^S$  is greater or equal zero iff

<sup>34</sup>The derivation of  $p^*$  and  $z^*$  is omitted as results are derived as in previous sections.

$$\begin{aligned}
\pi^S &\geq 0 \\
D^S (bk^2 - z) &\geq 0 \\
bk^2 &\geq z \\
bk &\geq r
\end{aligned}$$

Hence, when the production costs savings from offering a standard product are greater than the price discount for the standard product, the firm has an incentive to offer a standard product in addition to its mass customized product. This is true if the marginal increase in production costs of the mass customized product is greater or equal than the marginal increase in consumers' reservation price due to the perceived uniqueness of the mass customized product. Subsequently, when there exists demand for the standard product, the firm has an incentive to offer the standard product.

**Proposition 7** *The monopolist firm has an incentive to offer a mass customized product in addition to its standard product if the variable cost for producing a mass customized product is sufficiently small. If this cost is so low that there is no demand for the standard product, the firm finds it most profitable to only offer the mass customized product.*

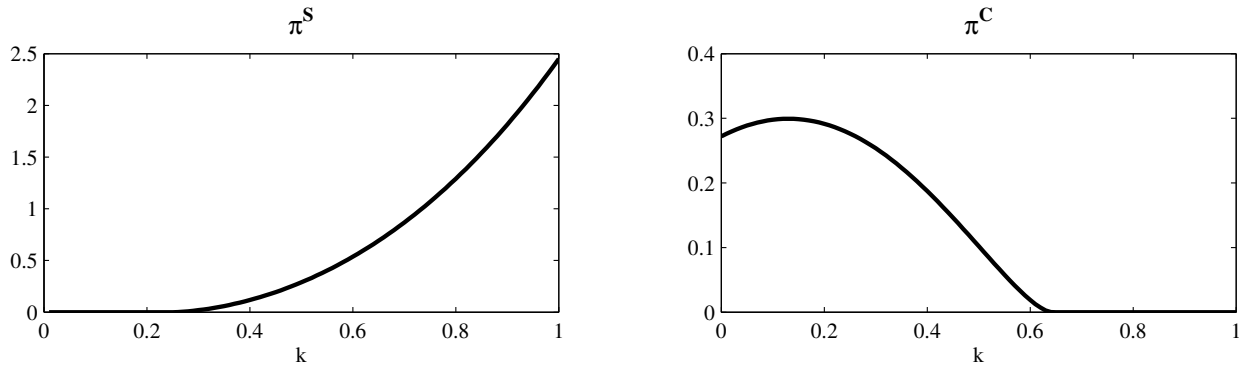
In an uncovered market, the margin for the standard product is unaffected when the firm additionally sells a mass customized product. The margin for the mass customized product is greater or equal than the margin for the standard product if the variable cost of producing a mass customized product is so low that only the mass customized product is sold ( $b < b'$ ). When the firm sells both products, the margin of the mass customized product is lower than the margin of the standard product. However, selling a mass customized product can increase demand if the variable cost of producing a mass customized product is sufficiently small ( $b \leq b''$ ). Given  $b \leq b''$ , the profit increase from the higher demand outweighs the margin loss in the cannibalized region. Hence the firm sells only the mass customized product for  $b < b'$ , both products for  $b' \leq b \leq b''$ , and only the standard product for  $b > b''$ .

When the market is covered, selling a mass customized product may increase the margin for the standard product if the variable cost of producing a mass customized product is sufficiently low ( $b \leq b'''$ ). The firm is able to sell the standard product at a higher price, because it serves the distant consumers with the mass customized product and exploits the willingness to pay of the consumers nearby with the standard product. When selling a mass customized product increases the margin for the standard product, the firm finds it most profitable to sell both products. When the variable cost of producing a mass customized product is so low that there is no demand for the standard product ( $b < b'$ ), the monopolist finds it most profitable to only sell the mass customized product. Since the demand constraint is binding for  $\lambda > 0$ , i.e.  $D = 1$ , the demand is unaffected by selling a mass customized product in addition to the standard product. Hence, the

firm only sells the mass customized product for  $b < b'$ , both products for  $b' \leq b \leq b''$ , and only the standard product for  $b > b''$ .

**Proposition 8** *When the monopolist has an incentive to offer both products, the optimal degree of mass customization is greater or equal than the optimal degree of mass customization when only the mass customized product is offered. This increase in  $k^*$  is convex.*

As can be noticed from Equation 3.17, the profit of the firm is the additive profit of offering a mass customized product  $\pi^C$  (as in Subsection 3.3.2) and the additional profit from offering a standard product  $\pi^S$ . Figure 3.11 illustrates the firm's profit from offering a customized product  $\pi^C$  and its additional profit from offering a standard product  $\pi^S$  when the market is uncovered.



**Figure 3.11** The profit is depicted for  $r = 0.5$ ,  $t = 1$ ,  $d = 1$ , and  $b = 2$  when  $\lambda = 0$ .

The optimal degree of mass customization when the firm only sells a mass customized product in a covered and uncovered market is analyzed in Subsection 3.3.2. Since the demand for the standard product  $D^S$  and discount  $z$  are independent of the assumption of a covered market, the effect of selling a standard product on the optimal degree of mass customization is identical for the two cases. The profit for the standard product  $\pi^S$  is increasing in  $k$  iff

$$\begin{aligned} \frac{\partial}{\partial k} \pi^S &\geq 0 \\ \frac{\partial}{\partial k} \left( \sqrt{\frac{16k}{27t^2} (tk^2 + 2d) (bk - r)^3} \right) &\geq 0 \\ -\frac{16}{27t^2} (r - bk)^2 (-6bt^2k^3 + 3rtk^2 - 8bdk + 2dr) &\geq 0 \\ \frac{1}{6k^3t + 8dk} (2dr + 3k^2rt) &\leq b \end{aligned}$$

Given there is demand for the standard product, this condition is always satisfied since  $\frac{r}{k} \geq \frac{1}{6k^3t + 8dk} (2dr + 3k^2rt)$ . Consequently, the optimal degree of mass customization when an additional standard product is offered is greater or equal than the optimal degree of mass customization when the firm sells only the mass customized product. From the second derivative of  $\pi^S$  it

follows that this increase is convex, i.e.  $\frac{\partial^2}{\partial k^2} \pi^S \geq 0$ .<sup>35</sup>

### 3.5 Summary of the results

The purchase of a mass customized product increases consumers' reservation price due to perceived uniqueness and reduces consumers' misfit costs due to a better aesthetic and functional product fit. Consequently, consumer gross utility increases. The monopolist exploits the increase in consumer gross utility and charges a higher price. However, mass customized products require more complex production processes and lead to dis-economies of scale, i.e. higher per unit production costs. In equilibrium, the monopolist always chooses to mass customize since mass customization is profit enhancing. The firm will fully mass customize if the costs from producing a mass customized product are sufficiently small. If these costs are, however, high enough, the firm will balance the marginal price benefit with the marginal production cost and offers partial mass customization. Next to unit production costs, the optimal degree of mass customization depends on consumers' reservation price, consumers' sensitivity to product differences and the complexity of the interaction process. The optimal degree of mass customization is increasing in consumers' reservation price and consumers' sensitivity to product differences while it is decreasing in the unit production cost and the complexity of the interaction process.

The introduction of consumers' choice of effort and resulting interaction costs lead to the following results. When the complexity of the interaction process is sufficiently high, consumers choose to exert partial effort. Hence, as the complexity of the interaction process increases, the exerted effort decreases since effort becomes more costly. The individual effort of a consumer is increasing in her distance to the firm, i.e. the lower the initial preference fit the higher the exerted effort and vice versa. The degree of mass customization affects the optimal effort level in two directions: first, the higher the degree of mass customization, the more effective the exerted effort; second, the higher the degree of mass customization, the less effort is needed to reduce misfit costs in the same amount. The first effect is predominant for low degrees of mass customization while the second effect is predominant for high degrees of mass customization. Consumers exert more effort, the higher consumers' sensitivity to product differences. For a given change in effort, misfit costs are reduced to a greater amount the higher consumers' sensitivity to product differences. Because consumers choose not to provide full effort given the assumption of a sufficiently complex interaction process, the misfit cost reduction potential of the given degree of mass customization is not fully exploited. While consumer gross utility decreases and, therewith, the price the firm can charge, the firm's variable production cost remains unchanged. Consequently, the firm sets a lower degree of mass customization. Although, selling a mass customized product is profitable for the firm, the profit increase from mass customization is alleviated by consumer effort. Mass customization is detrimental to consumer surplus, because the monopolist exploits the increase in consumer utility from reduced misfit costs and an increased reservation price. For

<sup>35</sup>Please refer to the Proof of Proposition 8 for the analytic proof.

the extreme case of full mass customization, consumer surplus is fully exploited by the firm in case of no consumer effort. Integrating consumer effort leads to a higher consumer surplus than when consumer effort is neglected, because the firm's pricing power vanishes.

The analysis of consumers' preferences for uniqueness on the optimal degree of mass customization reveals that the optimal degree of mass customization is increasing in consumers' valuation for uniqueness. When consumers do not value the uniqueness of a mass customized product, a sufficiently high variable production cost of a mass customized product may lead to the rejection of mass customization.

The firm may find it profitable to offer both a lower-priced standard product and a mass customized product dependent on the variable cost of producing a mass customized product. While offering a mass customized product in addition to the lower-priced standard product may enhance the margin of the standard product when the market is covered, demand may be increased when the market is uncovered. When the firm offers both products, the optimal degree of mass customization increases.



# Chapter 4

## Duopoly model

### 4.1 Motivation

The literature analysis reveals that strategic effects in a competitive setting essentially influence a firm's mass customization decision and the profitability of mass customization. However, existing theoretical research has neglected the strategic role of the consumer in mass customization. The following chapter transfers the monopoly model to a duopoly setting to cover the effect of competition on a firm's optimal degree of mass customization. Is it optimal for both firms to adopt mass customization? Is the adoption of mass customization strategically driven? How does the inclusion of strategic company-customer interaction affect a firm's optimal mass customization strategy? In particular, the duopoly model of this chapter analyzes firms' optimal pricing and mass customization decisions in case no firm, one firm, and both firms adopt mass customization and assesses the value of integrating consumers' strategic role into a model of mass customization.

The literature analysis emphasizes the importance of a firm's competitive positioning on the profitability of a mass customization strategy and the optimal degree of mass customization. Since past research does not integrate the strategic role of the consumer into the modeling of the decision problem, no light has yet been shed on the effect of a firm's disadvantage in interacting with its consumers. How does a disadvantage in interacting with consumers affect the optimal degree of mass customization? Are a disadvantage in interacting with consumers and in the competitive positioning identical in their effects on mass customization? May both firms be better off if one firm is at a disadvantage? Subsection 4.4.1 captures the case of asymmetric firms in order to examine the effect of both a disadvantage in producing mass customized products and a disadvantage in interacting with consumers.

Literature has revealed that next to an improved aesthetic and functional fit, mass customized products provide additional value for a consumer due to the perceived uniqueness of the product. So far no theoretical study exists that analyzes the effect of consumers' valuation for uniqueness on the optimal degree of mass customization. Is the optimal degree of mass customization increasing in consumers' valuation of uniqueness? Is mass customization the dominant strategy

even when consumers do not value the perceived uniqueness of a mass customized product? Subsection 4.4.2 analyzes the effect of consumers' valuation for uniqueness on the optimal degree of mass customization in a competitive setting.

Real life examples show that firms often sell both a standard and a mass customized product. Subsection 4.4.3 picks up on existing literature and analyzes whether competing firms have an incentive to offer a mass customized product in addition to their standard products and vice versa. Additionally, the subsection examines the effect of selling both products on the optimal degree of mass customization.

Most game-theoretical models that study mass customization in a competitive setting assume that firms are located at the ends of the unit line, i.e. are maximally differentiated. Subsection 4.4.4 examines if firms have an incentive to deviate from maximum differentiation.

## 4.2 Model framework

This model adopts the Hotelling (1929) model and its assumptions.

### 4.2.1 Modeling assumptions

#### The geographical space and consumer preferences

In this model of horizontal differentiation, two firms,  $A$  and  $B$ , compete to serve a market of consumers with heterogeneous preferences for product attributes. Firms are located at the ends of a line of unit length  $[0, 1]$ , with firm  $A$  located at zero and firm  $B$  located at one. Consumers are uniformly distributed on this line of unit length and have a total mass of 1. Each consumer is identified by a point  $\theta \in [0, 1]$  that represents her ideal product configuration and has a common reservation price of  $r$ . Each consumer purchases one product. When the offered product does not match a consumer's ideal product configuration, she incurs a disutility of  $ty_i^2$ , the misfit costs, where  $t$  measures consumers' sensitivity to product differences, i.e. the importance of purchasing the ideal product configuration.  $y_i \in [0, 1]$  denotes the distance between a consumer's ideal product configuration and the product offered by firm  $i$ ,  $i = \{A, B\}$ , with  $y_A = \theta$  and  $y_B = 1 - \theta$ .<sup>1</sup> When a type- $\theta$  customer buys firm  $i$ 's product at price  $p_i$ , her utility is equal to

$$U_i = r - ty_i^2 - p_i \quad (4.1)$$

For any given  $p_i$ , consumers will prefer firm  $i$ 's product over the product of the competing firm  $j$  iff

$$U_i \geq U_j$$

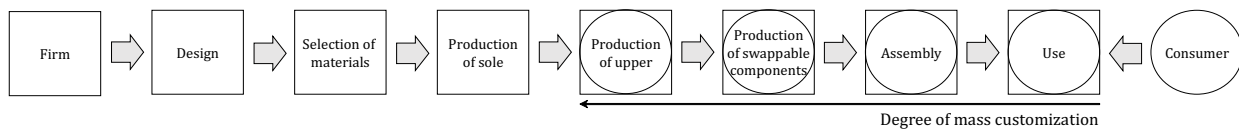
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<sup>1</sup>Please note that when consumers face linear transportation costs, each consumer chooses the same effort level during the configuration process, i.e. the effort level is not dependent on a consumer's distance to the offered product. As this assumption is not realistic, this model uses quadratic transportation costs.

The left hand side of the inequality denotes consumers' utility from purchasing firm  $i$ 's product and the right hand side that from buying from the competing firm  $j$ . Given this choice rule, the consumer who is indifferent between purchasing firm  $i$ 's product and the product of the competing firm  $j$ , denoted by  $\theta'$ , can be determined. It is assumed that the reservation price  $r$  is high enough so that all consumers are served at equilibrium and firms actively compete for the marginal consumers  $\theta'$ . The demand of firm  $A$  is given by  $D_A = \theta'$  and of firm  $B$  by  $D_B = 1 - \theta'$ .

### The strategy space and firm's production process

When firm  $i$  offers mass customization, it chooses the degree of mass customization  $k_i \in [0, 1]$ , which is defined as the degree of customer integration into the production process. When firm  $i$  chooses  $k_i = 0$ , it only sells one standard product and is represented as a point on the unit line. When firm  $i$  chooses  $k_i > 0$ , it is represented as a line of length  $k_i$  around its location on the unit line.<sup>2</sup> The higher  $k_i$ , the greater the integration of consumers into the production process. Figure 4.1 illustrates the possibilities of customer integration in a simplified production process. When firm  $i$  offers a high degree of mass customization, customers are integrated early in the production process, for example may select the materials. When firm  $i$  offers a low degree of mass customization, customers are integrated into the final stages of the production process and may, for instance, personalize the assembly of the product.



**Figure 4.1** This figure shows the simplified production process of a sneaker. The higher  $k$ , the greater the integration of consumers into the production process.

By integrating consumers into the production process, firm  $i$  is able to better match consumers' preferences since they can adjust the product to their preferences in these stages. Thus, the integration of consumers into the production process allows firms to reduce consumers' misfit costs by approaching their ideal product configurations. Therefore, the higher  $k_i$ , the higher the number of consumers who can buy their ideal product. When both firms choose  $k_i = 1$ , each consumer is offered her ideal product. The motivation behind such a setting is that firms observe consumers' preferences by interacting with their customers during the production process, e.g. via an online product configurator, and can tailor products for all consumers whose ideal product configuration can be approached within the scope of this interaction. When consumers are involved in the final stages of the production process, only consumers with a high initial preference fit can adjust the product to perfectly match their preferences while consumers with a low initial preference fit incur reduced misfit costs. When consumers are involved in the early stages of the production process, even consumers with a low initial preference fit can adjust the

<sup>2</sup>This representation of a firm adopting mass customization is similar to Dewan et al. (2000) and Dewan et al. (2003), who study competition between a mass customizing and a standard firm on the Salop (1979) circle.

product to perfectly match their preferences.

The production process is separated into two parts. In the first part, firm  $i$  pre-manufactures the product platform  $(1 - k_i)$ , i.e. commonly runs through the stages of the production process that do not involve the consumer. In the second part, firm  $i$  observes consumers' preferences and distinctively runs through the stages of the production process that integrate the consumer ( $k_i$ ). Unit manufacturing costs for a standard product are denoted by  $a$ . A firm bears additional variable costs for mass customization.<sup>3</sup> These variable costs  $b_i$  ( $b_i > a$ ) depend on the degree of customer involvement in the production process and are given by

$$c_i = a + (b_i - a) k_i^2 \quad (4.2)$$

Unit manufacturing costs for the standardized product platform  $a$  are normalized to zero. It is assumed that unit variable costs for mass customized production are quadratic in the degree of customization, representing dis-economies of scale from distinct operations. Dis-economies of scale are, thus, realized when firm  $i$  chooses  $k_i > 0$ . The higher the degree of customer involvement in the production process, i.e. the higher  $k_i$ , the higher the share of distinct production stages, and, therefore, the greater the dis-economies of scale. The motivation behind such a set up is that customizing products becomes more costly the earlier consumers are involved in the production process since early production stages are more complex. Therefore, when choosing the optimal degree of mass customization, firm  $i$  trades off the coverage of consumers' preferences with dis-economies of scale.

The profit of firm  $i$  is given by

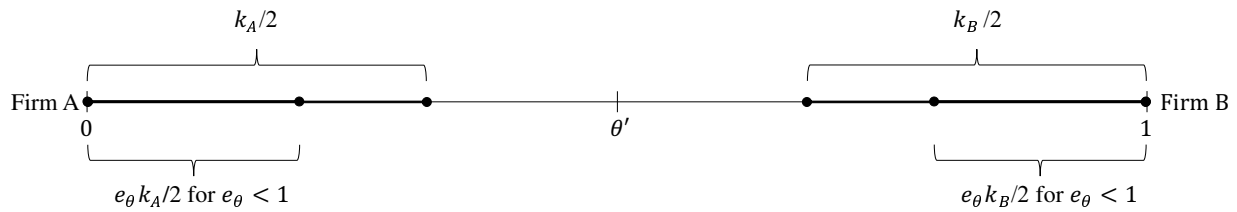
$$\pi_i = D_i (p_i - c_i) \quad (4.3)$$

### Consumer effort

When a firm chooses the degree of mass customization  $k_i$ , it determines the degree of customer involvement in the production process and, therewith, the upper bound of consumers who are able to buy their ideal product configuration. However, in order to benefit from the firm's mass customization offer, i.e. in order to reduce misfit costs, consumers need to actively participate in the co-design of the product. Consumers have to exert effort, e.g. choose colors or materials from firm  $i$ 's options, in order to adapt the offered product to their preferences. In this model, each consumer chooses her individual effort level  $e_\theta \in [0, 1]$  to put into the configuration process of the product. By exerting effort, a consumer can pull the firm's standard product towards her own location  $\theta$  up to the pre-determined point  $k_i$  set by the firm. Specifically, it is assumed that the degree of mass customization offered by firm  $i$  and consumer effort  $e_\theta$  are complementary.

<sup>3</sup>Without the loss of accuracy, fixed costs for mass customization are normalized to zero.

This means that mass customization is only utility increasing for consumers when they exert effort. On the other hand, exerting effort only increases consumer utility when the firm offers mass customization. Thus, firm  $i$ 's choice and consumers' choices interact. By choosing an effort level of  $e_\theta = 0$ , a consumer purchases firm  $i$ 's standard product. The higher  $e_\theta$ , the more of firm  $i$ 's mass customization offer is used. When  $k_i < 1$ , consumers, whose preferences lie outside of  $k_i$ , can still pull the product closer to their preferences, but are not able to purchase their ideal product configuration independent of their choice of  $e_\theta$ . Figure 4.2 illustrates this set-up.



**Figure 4.2** Set-up:  $k_i$  and  $e_\theta$  are complementary. The share of consumers, who are able to purchase their ideal product from firm  $i$  is given by  $e_\theta \frac{k_i}{2}$ .

Effort is assumed to be costly. Consumers incur a disutility of  $\frac{1}{2}d_i e_\theta^2$  from co-designing the product, where  $d_i$  measures the complexity of firm  $i$ 's interaction process. The complexity of the interaction process  $d_i$  can be illustrated by the example of Adidas. The company opened mi Innovation centers in selected stores that feature, for example, a virtual mirror enabling consumers to see their personalized shoe on their own foot. Compared to the online configurator, mi Innovation centers simplify the customization process for consumers and, therefore, exhibit a lower  $d_i$ . The motivation behind introducing consumer effort as a decision variable is that, in reality, consumers observe the firm's standard product and its customizable options and then decide how much of this offer to use. In order to customize a certain option, the consumer needs to define her preferences and interact with the firm, for example via an online configurator, which requires time and the knowledge of preferences. Thus, interacting with the firm in order to co-design product attributes is costly in terms of opportunity costs and cognitive burden. Therefore, when choosing the optimal effort level, each consumer trades off the reduction of misfit costs with interaction costs.

Similar to Loginova and Wang (2009) and Wong and Lesmono (2013), it is assumed that the reservation price  $r$  is increasing in the degree of mass customization. When firm  $i$  offers a mass customized product, the perceived uniqueness of the product increases consumers' willingness to pay. As stated earlier in the literature review, this phenomenon has been observed in experimental studies such as Schreier (2006), Franke and Schreier (2008), Franke and Schreier (2010), and Franke et al. (2010). Thus, the adoption of mass customization resembles a quality increase.

Formally, consumers' utility function is given by

$$U_i = r(1 + k_i) - t \left( \max \left\{ 0, y_i - e_\theta \frac{k_i}{2} \right\} \right)^2 - \frac{1}{2} d_i e_\theta^2 - p_i \quad (4.4)$$

The utility function given by Equation 4.4 is an extended version of the Hotelling (1929) utility function with quadratic transportation costs stated in Equation 4.1. Compared to the standard utility, consumers' reservation price is increasing in the degree of mass customization  $k_i$ . Further, given firm  $i$  adopts mass customization, consumers can reduce their misfit costs, i.e. the distance to firm  $i$   $y_i$ , by exerting effort  $e_\theta$ . Note that misfit costs cannot be negative. The exerted effort leads to interaction costs of  $\frac{1}{2} d_i e_\theta^2$ .

### Pricing

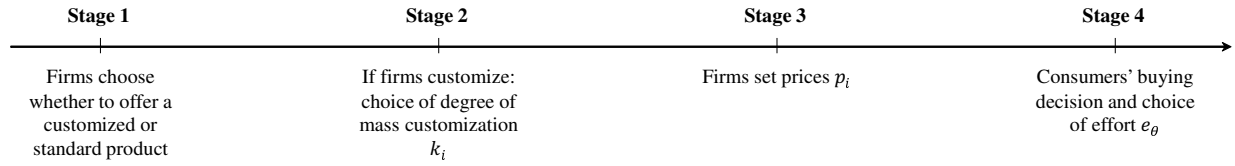
This model analyzes the situation where a mass customizing firm charges the same price for mass customized products even if consumers choose different effort levels.<sup>4</sup> This is a common marketing practice in horizontally differentiated product markets. Adidas, for example, charges the same price for a certain pair of customizable sneakers independent of how much and which product attributes the customer individualizes. If firms do not price differentiate, the infra-marginal consumers will derive a positive utility from a purchase. If firms price differentiated, they would exploit consumer surplus of these infra-marginal consumers, leaving them indifferent between purchasing the product or not. The individual price of each consumer would, thus, be the uniform price plus her reduction of misfit costs. Since an increase in the degree of mass customization leads to lower misfit costs, firms would increase the integration of consumers into the production process. However, increasing the integration of consumers into the production process leads to an increase in dis-economies of scale and less product differentiation between firms' products. Therefore, price differentiation induces the same trade-off already addressed in this model.

### 4.2.2 Timing of the game

The interaction between firms and consumers is formalized as a four-stage game. In the first stage, firms decide whether to offer a standard or mass customized product. In case firms choose to mass customize, firms set the degree of mass customization  $k_i \in [0, 1]$  in the second stage. Firms run through the standardized production stages and pre-produce the standard product or the product platform of a mass customized product  $1 - k_i$ . Given the first- and second-stage decisions, firms set prices  $p_i$  in the third stage. After having observed firms' product, customizing and pricing decisions, consumers make their purchasing decision in the fourth stage of the game. Particularly, consumers decide whether to buy from firm  $A$  or firm  $B$  and how much effort  $e_\theta$

<sup>4</sup>This assumption is similar to Syam and Kumar (2006), who examine the situation where firms charge the same price for all customized products in their base model.

they want exert when co-designing a mass customized product. In case firm  $i$  sells a mass customized product, the firm tailors the product to fit consumers' needs after having received consumer-specific information. At last, payoffs are realized. Figure 4.3 illustrates the timing of the game.



**Figure 4.3** The game is solve via backward induction.

### 4.3 Equilibrium analysis of the model

This section derives the equilibrium solutions for the case when consumers benefit from mass customization without exerting effort (Subsection 4.3.1) and the case with consumers' choice of effort and resulting interaction costs (Subsection 4.3.2). It is assumed that firm  $A$  and firm  $B$  are symmetric in their variable production costs for mass customized product parts,  $b_A = b_B = b$ , and the complexity of their interaction processes,  $d_A = d_B = d$ . Firms directly compete, i.e. consumers' reservation price  $r$  is high enough so that all consumers buy. The equilibrium solutions are compared and the value of integrating consumers' choice of effort and resulting interaction costs into the model is assessed.

#### 4.3.1 Model without consumer effort

The benchmark model assumes that consumers benefit from mass customization without having to exert effort. This subsection provides the equilibrium solutions for the benchmark model conditional on firms' first-stage decisions: both firms offer only a standard product (Subgame 1); one firm offers a mass customized product and its competitor offers a standard product (Subgame 2); both firms offer a mass customized product (Subgame 3); and, finally, firms cooperatively choose the degree of mass customization (Subgame 4).

When consumers benefit from mass customization without exerting effort, consumer utility reduces to<sup>5</sup>

$$U_i = r(1 + k_i) - t \left( \max \left\{ 0, y_i - \frac{k_i}{2} \right\} \right)^2 - p_i \quad (4.5)$$

<sup>5</sup>It can be shown that  $(y_i - \frac{k_i}{2})$  maximizes the distance between firm  $i$  and the marginal consumer  $\theta'$ . Please see the Appendix B.1 Model without consumer effort for the proof.

**Subgame 1: No firm mass customizes**

In case both firms decide to offer a standard product in the first stage of the game, consumer utility is given by Equation 4.1. A type- $\theta$  consumer purchases firm  $A$ 's product iff

$$\begin{aligned} U_A &\geq U_B \\ r - t\theta^2 - p_A &\geq r - t(1 - \theta)^2 - p_B \end{aligned}$$

The left-hand side of the above inequality denotes the net utility from purchasing firm  $A$ 's standard product and the right-hand side that from choosing to buy from firm  $B$ . Solving the inequality with respect to  $\theta$ , yields the consumer who is indifferent between buying from firm  $A$  or  $B$ , which is denoted by  $\theta'$

$$\theta' = \frac{1}{2} + \frac{1}{2t}(p_B - p_A) \quad (4.6)$$

The resulting demand functions are defined as  $D_A = \theta'$  and  $D_B = 1 - \theta'$ . Hence, consumers located at  $\theta \in [0, \theta']$  purchase from firm  $A$  while those located at  $\theta \in [\theta', 1]$  buy firm  $B$ 's standard product.

In the third stage of the interaction, firms set prices in order to optimize profits given by Equation 4.3.

**Lemma 8** *When both firms offer a standard product, the optimal price  $p_i^*$  is given by*

$$p_i^* = t$$

Firm  $i$ 's optimal price is increasing in consumers' sensitivity for product differences  $t$ . The higher  $t$ , the greater consumers' misfit costs from buying a product that does not fit their preferences, which increases differentiation between firms' products. Consequently, firms face less intense price competition and can charge higher prices. Note that when consumers are not sensitive to product differences, i.e.  $t = 0$ , firms price their products at marginal costs ( $a = 0$ ). Finally, payoffs are realized.

**Lemma 9** *In equilibrium, firm  $i$ 's profit  $\pi_i^*$  and consumer surplus  $CS$  are given by*

$$\begin{aligned} \pi_i^* &= \frac{1}{2}t \\ CS &= r - \frac{13}{12}t \end{aligned}$$



Firm  $i$ 's profit is increasing in consumers' sensitivity to product differences  $t$ . The higher  $t$ , the higher the price firm  $i$  can charge for its product. Consequently, firm  $i$ 's profit increases in  $t$ . Accordingly, the higher the price of firm  $i$ 's standard product, the lower consumer surplus. Consumer surplus is, thus, decreasing in  $t$ . Further, consumer surplus is increasing in consumers' reservation price  $r$ . While consumer utility is increasing in  $r$ , the price firm  $i$  can charge is unaffected by  $r$  due to competitive effects.<sup>6</sup>

### Subgame 2: One firm mass customizes

Given one firm, say firm  $A$ , decides to offer a mass customized product and its competitor (firm  $B$ ) decides to offer a standard product in the first stage of the game. Then, consumer utility from buying from firm  $A$  is defined in Equation 4.5 and from firm  $B$  in Equation 4.1. A type- $\theta$  consumer purchases firm  $A$ 's mass customized product iff

$$U_A \geq U_B$$

$$r(1+k_A) - t\left(\theta - \frac{k_A}{2}\right)^2 - p_A \geq r - t(1-\theta)^2 - p_B$$

The left-hand side of the above inequality denotes the net utility from purchasing firm  $A$ 's mass customized product and the right-hand side that from choosing to buy firm  $B$ 's standard product. Solving the inequality with respect to  $\theta$ , yields the consumer who is indifferent between buying from firm  $A$  or  $B$ , which is denoted by  $\theta'$

$$\theta' = \frac{1}{2} + \frac{p_B - p_A + k_A r}{t(2 - k_A)} + \frac{1}{4}k_A \quad (4.7)$$

The resulting demand functions are defined as  $D_A = \theta'$  and  $D_B = 1 - \theta'$ . Hence, consumers located at  $\theta \in [0, \theta']$  purchase from firm  $A$  while those located at  $\theta \in [\theta', 1]$  buy firm  $B$ 's standard product.

In the third stage of the game, firms set prices in order to maximize profits given by Equation 4.3.

**Lemma 10** *When only one firm (firm  $A$ ) offers a mass customized product while its competitor (firm  $B$ ) offers a standard product, then in equilibrium, prices are given by*

<sup>6</sup>Please refer to the Proof of Lemma 9 for an analytic derivation of the sensitivities.

$$p_A^* = \frac{1}{12} (12t + k_A^2 (8b - t) + 4k_A (r - t))$$

$$p_B^* = \frac{1}{12} (12t + k_A^2 (4b + t) - 4k_A (r + 2t))$$

The price of firm  $A$  is increasing in consumers' reservation price  $r$ , consumers' sensitivity to product differences  $t$  and the cost of producing a mass customized product  $b$ . Firm  $B$ 's optimal price is increasing in consumers' sensitivity to product differences  $t$  and the cost of producing a mass customized product  $b$  while it is decreasing in consumers' reservation price  $r$ . The higher  $t$ , the greater the differentiation between the firms' products, leading to less intense price competition. Since firms' products are not perfect substitutes for any  $k_A > 0$ , firm  $A$  can transfer parts of its variable production cost of producing a mass customized product  $b$  to its consumers. Subsequently, firm  $A$ 's price is increasing in  $b$ . An increase in  $p_A^*$  lowers the price pressure on firm  $B$ , leading to an increase in  $p_B^*$ . For any  $k_A > 0$ , firm  $A$ 's price is increasing in consumers' reservation price  $r$  since the firm can exploit consumers' valuation for uniqueness while firm  $B$  has to lower its price when  $r$  raises due to competitive effects. Selling a mass customized product enables firm  $A$  to charge a price that is greater or equal than the price of its competitor. This price difference is increasing in  $k_A$  since a mass customized product increases consumer utility in two ways: first, it increases the perceived uniqueness of the product and, therewith, consumers' reservation price; and second, it reduces misfit costs.<sup>7</sup>

Firm  $A$  chooses the degree of mass customization in the second stage of the game in order to optimize its profit.

**Lemma 11** *When  $b$  is sufficiently large, the equilibrium degree of mass customization chosen by firm  $A$  is given by*

$$k_A^* = \frac{2 \left( 8b + r + t - \sqrt{4b(16b - 8r + 7t) - 10rt + r^2 + 4t^2} \right)}{3(4b + t)} \in (0, 1)$$

*When  $b$  is small enough, the optimal degree of mass customization becomes*

$$k_A^* = 1$$

When mass customization is not too costly for firm  $A$ , it offers full mass customization, i.e. sets  $k_A^* = 1$ . However, when tailoring products to consumers' needs becomes sufficiently costly, the firm chooses partial mass customization and sets  $k_A^* \in (0, 1)$ . It follows that the optimal degree

<sup>7</sup>Please refer to the Proof of Lemma 10 for an analytic derivation of the sensitivities and price comparison.

of mass customization is decreasing in the variable production cost of mass customization  $b$ . In equilibrium, firm  $A$  always choose to offer mass customization, i.e.  $k_A^* > 0$ . Further, the higher consumers' reservation price  $r$ , the higher the optimal degree of mass customization set by the mass customizing firm. The degree of mass customization is decreasing in consumers' sensitivity to product differences  $t$  since an increase in  $t$  raises product differentiation between firms. Thus, increasing the degree of mass customization would intensify price competition.<sup>8</sup>

Finally, payoffs are realized.

**Lemma 12** *In equilibrium firm  $A$ 's profit  $\pi_A^*$ , firm  $B$ 's profit  $\pi_B^*$ , and consumer surplus  $CS$  are given by*

$$\begin{aligned}\pi_A^*(k_A^*) &= \frac{1}{144t(2-k_A^*)} \left(4k_A^*(bk_A^* - r + t) - 12t + tk_A^{*2}\right)^2 \\ \pi_B^*(k_A^*) &= \frac{1}{144t(2-k_A^*)} \left(4k_A^*(bk_A^* - r - 2t) + 12t + tk_A^{*2}\right)^2 \\ CS(k_A^*) &= r - \frac{13}{12}t + \frac{k_A^*(r - bk_A^*)}{2} + \frac{5tk_A^*}{8} + \frac{k_A^{*2}(r - bk_A^*)}{36} + \frac{k_A^{*2}t(11k_A^* - 34)}{288} - \frac{k_A^{*2}(r - bk_A^*)^2}{18t(k_A^* - 2)}\end{aligned}$$

The profit of the mass customizing firm, firm  $A$ , is higher compared to the profit of the firm that offers only a standard product, firm  $B$ . This is because firm  $A$  is able realize a higher margin than its competitor and gains market share at the expense of firm  $B$ .<sup>9</sup>

### Subgame 3: Both firms mass customize

When both firms decide to offer mass customized products in the first stage of the game, consumer utility is described by Equation 4.5. A type- $\theta$  consumer purchases firm  $A$ 's product iff

$$\begin{aligned}U_A &\geq U_B \\ r(1+k_A) - t\left(\theta - \frac{k_A}{2}\right)^2 - p_A &\geq r(1+k_B) - t\left(1-\theta - \frac{k_B}{2}\right)^2 - p_B\end{aligned}$$

The left-hand side of the above inequality denotes the net utility from purchasing firm  $A$ 's product and the right-hand side that from choosing to buy from firm  $B$ . Solving the inequality with respect to  $\theta$ , yields the consumer who is indifferent between buying from firm  $A$  or  $B$ , which is denoted by  $\theta'$

$$\theta' = \frac{1}{2} + \frac{2t - 4(p_A - p_B) + (k_A - k_B)(4r + 2t - tk_A - tk_B)}{4t(1 - k_A - k_B)}$$

<sup>8</sup>Please refer to the Proof of Lemma 11 for the derivation of the sensitivities.

<sup>9</sup>Please refer to the Proof of Lemma 12 for an analytic derivation of the sensitivities.

The resulting demand functions are defined as  $D_A = \theta'$  and  $D_B = 1 - \theta'$ . Hence, consumers located at  $\theta \in [0, \theta']$  purchase from firm  $A$  while those located at  $\theta \in [\theta', 1]$  buy firm  $B$ 's product.

In the third stage of the interaction, firms set prices in order to optimize profits given by Equation 4.3.

**Lemma 13** *When both firms offer mass customized products, then in equilibrium the price of firm  $i$  is given by*

$$p_i^* = t + \frac{r(k_i - k_j) - t(k_i + 2k_j) + b(2k_i^2 + k_j^2)}{3} - \frac{t(k_i - k_j)(k_i + k_j)}{12}$$

Firm  $i$ 's optimal price is increasing in consumers' sensitivity to product differences  $t$  since an increase in  $t$  increases differentiation between firms' products, leading to less intense price competition. Given consumers' reservation price  $r$  is sufficiently high, firm  $i$ 's optimal price is increasing in its degree of mass customization  $k_i$  and decreasing in its competitor's degree of mass customization  $k_j$ . An increase in  $k_i$  makes firm  $i$ 's product more attractive to consumers, because misfit costs' are reduced and the perceived uniqueness of the product increases consumers' reservation price. Since consumers derive a greater gross utility from buying firm  $i$ 's product, the firm can charge a higher price. Accordingly, an increase in  $k_j$  makes the competitor's product more attractive to consumers so that firm  $i$  has to lower its price in order to attract consumers. Firm  $i$ 's optimal price is increasing in consumers' reservation price  $r$  if the own degree of mass customization  $k_i$  is greater than the competitor's degree of mass customization  $k_j$ . This is because consumers' valuation for uniqueness is increasing in  $k_i$  and, thus, makes buying from firm  $i$  more attractive. Accordingly, for  $k_i < k_j$ , the optimal price of firm  $i$  is decreasing in  $r$ . For  $k_i = k_j$ , the optimal price is unaffected by  $r$ , because firms cannot exploit consumers' reservation price for competitive reasons.<sup>10</sup>

Firms choose the degree of mass customization to maximize their profits in the second stage of the game.

**Lemma 14** *When  $b$  is sufficiently large, the equilibrium degree of mass customization chosen by firm  $i$  is given by*

$$k_i^* = \frac{4r - t}{8b + 2t} \in (0, 1)$$

<sup>10</sup>Please refer to the Proof of Lemma 13 for an analytic derivation of the sensitivities.

When  $b$  is small enough, the optimal degree of mass customization becomes

$$k_i^* = 1$$

Similar to Subgame 2, firms fully mass customize, i.e. set  $k_i^* = 1$ , when the variable cost of producing mass customized products  $b$  is sufficiently small. When this variable cost is large enough, firms partially mass customize, i.e. set  $k_i^* \in (0, 1)$ . The degree of mass customization offered in equilibrium  $k_i^*$  is, thus, decreasing in  $b$ . Firms always choose to mass customize, i.e. choose  $k_i^* > 0$ , for strategic reasons. Further, the optimal degree of mass customization is increasing in consumers' reservation price  $r$ , because an increase in  $r$  leads to a higher reservation price due to the perceived uniqueness of the product. The optimal degree of mass customization is decreasing in consumers' sensitivity for product differences  $t$ . As  $t$  increases, price competition becomes less intense. Increasing the degree of mass customization would lead to less differentiated products and, thus, intensify price competition.<sup>11</sup>

Finally, payoffs are realized.

**Lemma 15** *In equilibrium, firm  $i$ 's profit  $\pi_i^*$  and consumer surplus  $CS$  when both firms mass customize are given by*

$$\begin{aligned}\pi_i^*(k_i^*) &= \frac{t}{2}(1 - k_i^*) \\ \pi_i^* &= \frac{t(8b - 4r + 3t)}{4(4b + t)} \\ CS(k_i^*) &= r - \frac{13}{12}t - bk_i^{*2} - \frac{1}{4}tk_i^{*2} + \frac{1}{12}tk_i^{*3} + k_i^*r + \frac{5}{4}tk_i^*\end{aligned}$$

Firm  $i$ 's profit is decreasing in  $k_i^*$ . However, due to strategic effects, firms always choose to mass customize ( $k_i^* > 0$ ). When firms fully mass customize, i.e.  $k_i^* = 1$ , product differentiation between the firms' products vanishes and firms price at marginal costs, leading to zero profits. When  $b$  is large enough, firms choose to partially mass customize and price above marginal costs, leading to positive profits. This profit is increasing in the variable cost of producing a mass customized product  $b$  and consumers' sensitivity to product differences  $t$  as an increase in  $b$  and  $t$  lowers the optimal degree of mass customization. The profit is decreasing in consumers' reservation price  $r$  as an increase in  $r$  leads to an increase in the optimal degree of mass customization. Consumer surplus is increasing in the degree of mass customization for  $k_i \in [0, k_i^*]$ . Since an increase in the variable cost of producing a mass customized product  $b$  decreases the optimal degree of mass customization and, hence, lowers price competition, consumer surplus is decreasing in  $b$ . Accordingly, an increase in consumers' reservation price  $r$  increases consumer surplus, because

<sup>11</sup>Please refer to the Proof of Lemma 14 for an analytic derivation of the sensitivities.

a higher degree of mass customization leads to lower prices.<sup>12</sup>

#### Subgame 4: Cooperative mass customization

This subgame analyzes the optimal degree of mass customization offered by both firms given they can cooperate in the second stage, i.e. cooperatively choose the degree of mass customization. Prices of this subgame are derived as in the previous subgame when both firms decide to offer mass customized products in the first stage of the game (Subgame 3). Before choosing the degree of mass customization in the second stage, symmetry is invoked by setting  $k_i = k_j$ . When symmetry is invoked, firm  $i$ 's optimal price and profit from Subgame 3 become

$$\begin{aligned} p_i^* &= t - tk_i + bk_i^2 \\ \pi_i^* &= \frac{t}{2} (1 - k_i) \end{aligned}$$

**Lemma 16** *Since firms' profits are decreasing in  $k_i$ , the degree of mass customization offered by both firms in equilibrium is given by*

$$k_i^* = 0$$

When firms can cooperatively choose the degree of mass customization, they only sell a standard product, i.e. set  $k_i^* = 0$ . In a competitive setting, mass customization reduces product differentiation. Subsequently, price competition intensifies leading to lower profits. Hence, firms are better off selling only a standard product.

Finally, payoffs are realized.

**Lemma 17** *When the degree of mass customization is a cooperative decision, optimal profits and consumer surplus are given by*

$$\begin{aligned} \pi_i^* &= \frac{t}{2} \\ CS &= r - \frac{13}{12}t \end{aligned}$$

Please note that the equilibrium profits and consumer surplus are identical to the subgame when no firm mass customizes (Subgame 1).

<sup>12</sup>Please refer to the Proof of Lemma 15 for an analytic derivation of the sensitivities.

### 4.3.2 Model with consumer effort

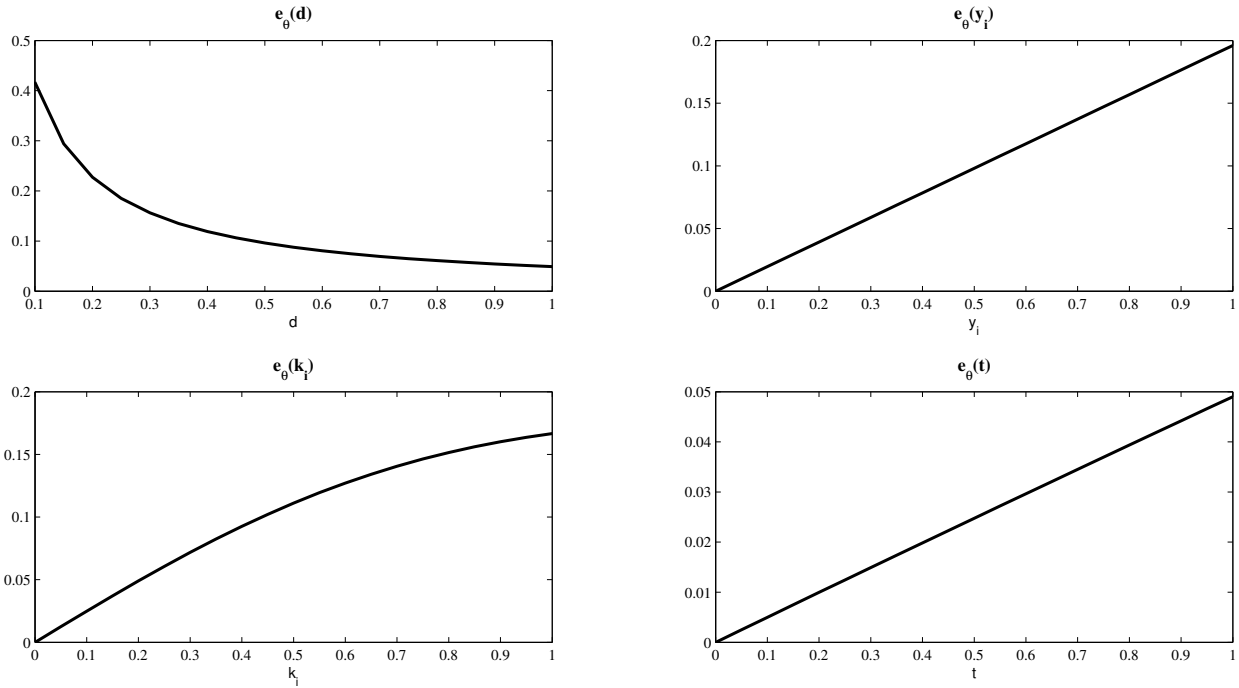
This subsection analyzes four subgames conditional on firms' first-stage decisions: both firms offer only a standard product (Subgame 1); one firm offers a mass customized product and its competitor offers a standard product (Subgame 2); both firms offer a mass customized product (Subgame 3); and, finally, firms cooperatively choose the degree of mass customization (Subgame 4).

Given firm  $i$  decides to offer a mass customized product in the first stage of the game, consumer utility from purchasing firm  $i$ 's mass customized product is given by Equation 4.4. Consumers maximize their utility by choosing the effort level  $e_\theta$  to put into the configuration process of the mass customized product.

**Lemma 18** *In equilibrium, a type- $\theta$  customer chooses an effort level of  $e_\theta^* = \frac{2tk_i y_i}{2d + tk_i^2} \in [0, 1]$  when  $d$  is sufficiently high and  $e_\theta^* = 1$  when  $d$  is low enough.*

When choosing the effort level to put into the product configuration, consumers trade-off the reduction of misfit costs with interaction costs. If the complexity of the interaction, measured by  $d$ , is low enough, interaction costs are so small that consumers will exert as much effort as possible, i.e.  $e_\theta^* = 1$ . To include each consumer's trade-off of tailoring a product to her needs and interaction costs, it is assumed that the complexity of the interaction process  $d$  is high enough so that  $e_\theta^*$  is such that  $e_\theta^* \in [0, 1]$ . Hence, when the complexity of the interaction  $d$  is sufficiently high, consumers may choose not to provide full effort. The individual effort level depends on the product's initial fit, measured by a consumer's distance to the firm  $y_i$ , the complexity of the interaction process  $d$ , the degree of mass customization  $k_i$ , and consumers' sensitivity to product differences  $t$ . Specifically, a consumer's effort level is decreasing in  $d$ . The more complex the interaction with the firm, the higher the interaction costs, and, therefore, the lower the effort level a consumer puts into the mass customization of firm  $i$ 's product. This finding is consistent with literature suggesting that consumers might not customize all options when the complexity of the configuration process is too high. Further, the closer a consumer's ideal product configuration to the offered product, i.e. the better the initial aesthetic and functional fit measured by  $y_i$ , the lower the effort level as less effort is needed to approach the ideal product configuration. The consumer, whose preferences are already perfectly met by the initial product offering, chooses an effort level of  $e_\theta^* = 0$ . Consequently, a consumer's effort level is increasing in the distance between her ideal product configuration and the initial product offered by the firm. Additionally, the effort level is increasing in the degree of customization  $k_i$  as the provided effort becomes more efficient in reducing the misfit costs given the assumption of a sufficiently complex interaction process. When the firm sets  $k_i = 0$ , consumers optimal response is to provide zero effort, i.e.  $e_\theta^* = 0$ . The results further show that the effort level is increasing in consumers' sensitivity to product differences  $t$ . For a given change in  $e_\theta$ , misfit costs are reduced to a greater absolute amount as

$t$  increases.<sup>13</sup> Figure 4.4 provides a graphical summary of the described sensitivities of the effort level with respect to the model parameters.



**Figure 4.4** Effort level: The effort level with respect to the model parameters is shown for  $y_i = 0.25$ ,  $k_i = 0.2$ ,  $t = 1$ , and  $d = 1$ .

Inserting the optimal choice of effort  $e_\theta^*$ , consumer utility becomes<sup>14</sup>

$$U_i = r(1 + k_i) - t_i y_i^2 - p_i, \quad (4.8)$$

where

$$t_i = \frac{2dt}{tk_i^2 + 2d}$$

Compared to consumer utility with quadratic transportation costs when firm  $i$  offers a standard product, given by Equation 4.1, offering a mass customized product leads to an increase of consumers' reservation price and a reduction of misfit costs.

### Subgame 1: No firm mass customizes

In case both firms decide to offer a standard product in the first stage of the game, Equation 4.8 reduces to Equation 4.1 since consumers choose to provide an effort level of zero, i.e.  $e_\theta^* = 0$ . It follows that this subgame is identical to the subgame when both firms offer a standard product (Subgame 1) in the benchmark model. Therefore, only the following facts are mentioned

<sup>13</sup>Please refer to the Proof of Lemma 18 for an analytical derivation of the sensitivities.

<sup>14</sup>It can be shown that for any given  $\theta$ ,  $(y_i - e_\theta \frac{k_i}{2})$  maximizes the distance between firm  $i$  and a type- $\theta$  consumer. Please refer to the Proof of Lemma 18 for the proof.



- The two firms share the market evenly, i.e.  $D_i = \frac{1}{2}$
- Firm  $i$  charges a price of  $p_i = t$
- Each firm makes a profit of  $\pi_i = \frac{t}{2}$
- Consumer surplus is  $CS = r - \frac{13}{12}t$

### Subgame 2: One firm mass customizes

Given one firm, say firm  $A$ , decides to offer a mass customized product and its competitor (firm  $B$ ) decides to offer a standard product in the first stage of the game. Then, consumer utility from buying from firm  $A$  is defined in Equation 4.8 and from firm  $B$  in Equation 4.1. A type- $\theta$  consumer purchases firm  $A$ 's mass customized product iff

$$U_A \geq U_B$$

$$r(1 + k_A) - t_A\theta^2 - p_A \geq r - t(1 - \theta)^2 - p_B$$

The left-hand side of the above inequality denotes the net utility from purchasing firm  $A$ 's mass customized product and the right-hand side that from choosing to buy from firm  $B$ . Solving the inequality with respect to  $\theta$ , yields the consumer who is indifferent between buying from firm  $A$  or  $B$ , which is denoted by  $\theta'^{15}$

$$\theta' = \frac{1}{2} + \frac{t + t_A - 2\sqrt{(p_A - p_B - rk_A)(t - t_A) + tt_A}}{2(t - t_A)} \quad (4.9)$$

The resulting demand functions are defined as  $D_A = \theta'$  and  $D_B = 1 - \theta'$ . Hence, consumers located at  $\theta \in [0, \theta']$  purchase from firm  $A$  while those located at  $\theta \in [\theta', 1]$  buy firm  $B$ 's product.

In the third stage of the interaction, firms set prices in order to optimize profits given by Equation 4.3.

**Lemma 19** *When only one firm (firm  $A$ ) offers a mass customized product while its competitor (firm  $B$ ) offers a standard product, optimal prices are given by*

<sup>15</sup>Please note that this solution is the only solution satisfying  $D_i \in [0, 1]$ .

$$p_A^* = \frac{1}{25t_A - 25t} (8tt_A + 4t_A^2 - 6t^2 - 5k_A(t - t_A)(2r + 3bk_A) + (4t_A - 6t) \sqrt{t^2 + 7tt_A + t_A^2 + 5k_A(t - t_A)(bk_A - r)})$$

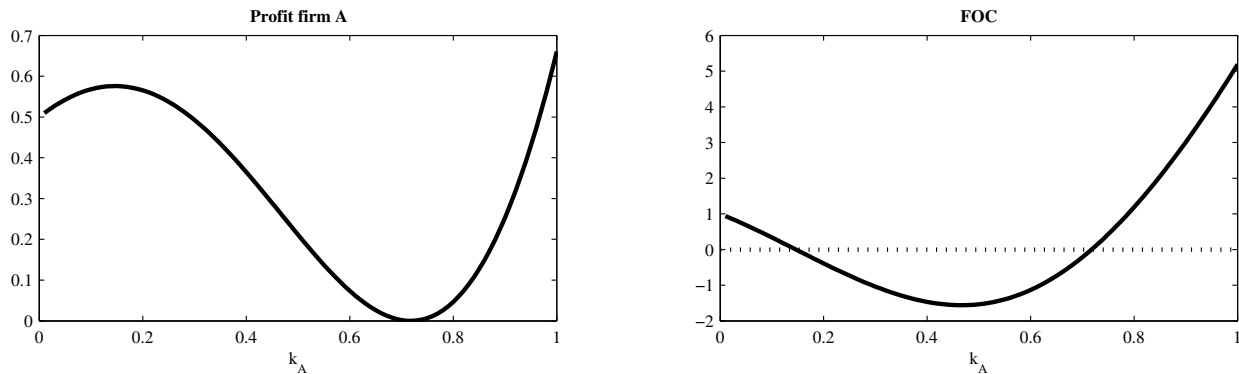
$$p_B^* = \frac{1}{25t - 25t_A} (8tt_A - 6t_A^2 + 4t^2 + 10k_A(t - t_A)(bk_A - r) + (4t - 6t_A) \sqrt{t^2 + 7tt_A + t_A^2 + 5k_A(t - t_A)(bk_A - r)})$$

Buying a mass customized product increases consumer utility, because it increases consumers' reservation price due to the perceived uniqueness of the mass customized product and lowers misfit costs. Hence, selling a mass customized product enables firm  $A$  to charge a higher price than firm  $B$ , given consumers' reservation price  $r$  is sufficiently high.

Firm  $A$  chooses the degree of mass customization in the second stage in order to maximize its profit.

**Lemma 20** *In equilibrium, the optimal degree of mass customization  $k_A^*$  of firm  $A$  is such that  $k_A^* \in [0, 1]$ .*

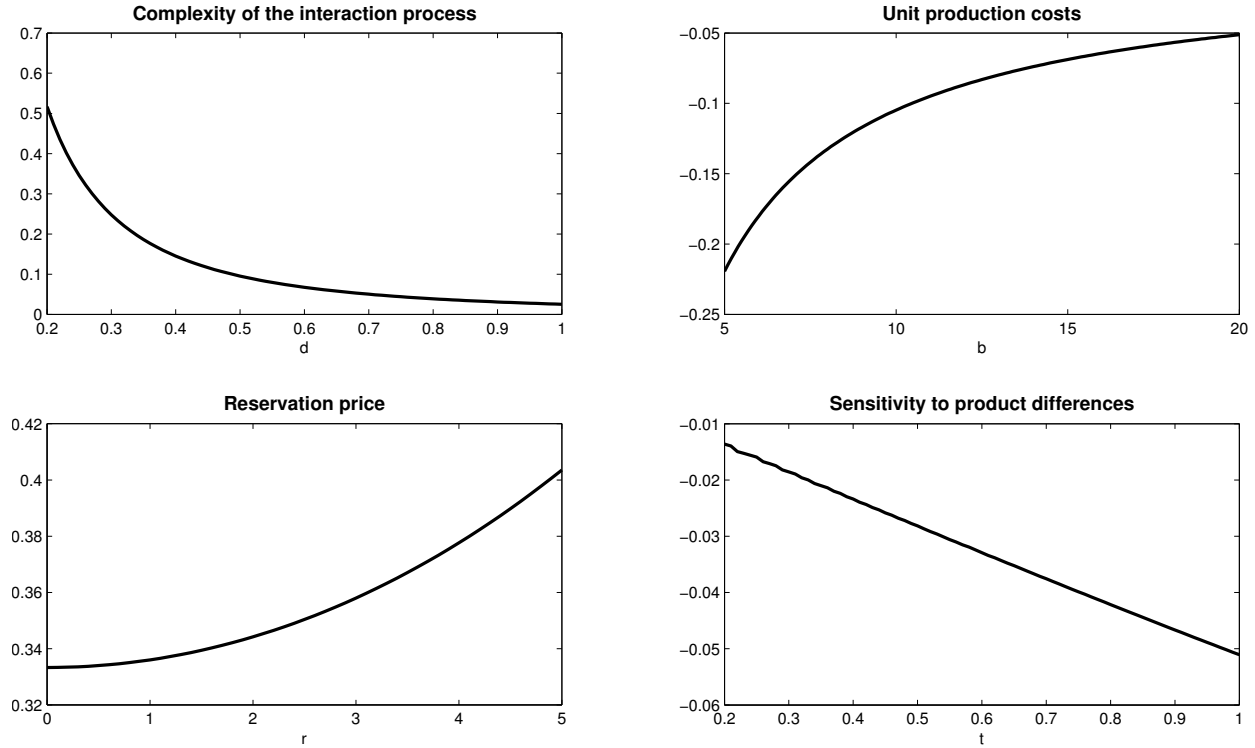
Since the analytical solution of the first derivative of firm  $A$ 's profit with respect to  $k_A$  is very lengthy, a formal description is omitted. Figure 4.5 illustrates firm  $A$ 's profit and the necessary first-order condition. Note that the border solution can be neglected since it does not satisfy  $D_A \in [0, 1]$ .



**Figure 4.5** Firm  $A$ 's profit and the necessary first-order condition (FOC) are shown for  $b = 10$ ,  $r = 3$ ,  $t = 1$ , and  $d = 1$ .

Using the envelope theorem, the sensitivities of the optimal degree of mass customization with respect to the model parameters can be derived. The analytical sensitivities are very lengthy and therefore omitted. Figure 4.6 illustrates the sensitivities of the optimal degree of mass customization<sup>16</sup> with respect to the model parameters.

<sup>16</sup>The optimal degree of mass customization is derived by numerically solving the necessary first-order condition with respect to  $k_A$ .



**Figure 4.6** The sensitivities of the necessary-first order condition with respect to the model parameters are shown for  $b = 10$ ,  $r = 3$ ,  $t = 1$ , and  $d = 1$ .

The degree of mass customization realized in equilibrium is decreasing in the variable production cost for mass customized products  $b$ . The greater the dis-economies of scale from mass customized production, the lower the degree of mass customization offered by firm  $A$ . Further, the degree of mass customization is increasing in consumers' reservation price  $r$  since an increase in  $r$  increases the value of the perceived uniqueness of the mass customized product. Similar to the benchmark model, the degree of mass customization is decreasing in consumers' sensitivity for product differences  $t$ . As  $t$  increases, price competition becomes less intense. Increasing the degree of mass customization would lead to less differentiated products and, thus, intensify price competition. Further, the higher  $t$ , the higher the effort level  $e_\theta$  chosen by consumers, and, therefore, a lower degree of mass customization is needed to reduce consumers' misfit costs in the same amount. These two effects lead to a negative relation between the degree of mass customization and consumers' sensitivity to product differences  $t$ . The degree of mass customization is increasing in the complexity of the interaction process  $d$ . As consumers effort level  $e_\theta$  is decreasing in  $d$  but increasing in  $k_A$ , firm  $A$  needs to offer a higher degree of mass customization to absorb consumers' lower effort level in order to reduce misfit costs' in the same amount.

Finally, payoffs are realized.

**Lemma 21** *In equilibrium, firm  $A$ 's profit  $\pi_A^*$ , firm  $B$ 's profit  $\pi_B^*$ , and consumer surplus  $CS$  are given by*

$$\begin{aligned}\pi_A^*(k_A^*, p_A^*, p_B^*) &= \frac{t - \sqrt{(p_A^* - p_B^* - rk_A^*)(t - t_A) + tt_A}}{t - t_A} (p_A^* - bk_A^*) \\ \pi_B^*(k_A^*, p_A^*, p_B^*) &= \frac{t_A - \sqrt{(p_A^* - p_B^* - rk_A^*)(t - t_A) + tt_A}}{t_A - t} p_B^* \\ CS(k_A^*, p_A^*, p_B^*) &= -\frac{1}{3(t - t_A)^2} \left( -3(t - t_A)(-tp_A^* - rt_A + p_B^*t_A + rt + rtk_A^*) + tt_A^2 + t^2t_A \right. \\ &\quad \left. + (2(t - t_A)(p_B^* - p_A^* + rk_A^*) - 2tt_A) \sqrt{(p_A^* - p_B^* - rk_A^*)(t - t_A) + tt_A} \right)\end{aligned}$$

### Subgame 3: Both firms mass customize

When both firms decide to offer mass customized products in the first stage of the game, consumer utility is described by Equation 4.8. A type- $\theta$  consumer purchases firm  $A$ 's product iff

$$\begin{aligned}U_A &\geq U_B \\ r(1 + k_A) - t_A\theta^2 - p_A &\geq r(1 + k_B) - t_B(1 - \theta)^2 - p_B\end{aligned}$$

The left-hand side of the above inequality denotes the net utility from purchasing firm  $A$ 's product and the right-hand side that from choosing to buy from firm  $B$ . Solving the inequality with respect to  $\theta$ , yields the consumer who is indifferent between buying from firm  $A$  or  $B$ , which is denoted by  $\theta'$ <sup>17</sup>

$$\theta' = \frac{1}{2} + \frac{t_A + t_B - 2\sqrt{(t_A - t_B)(-p_A + p_B + rk_A - rk_B) + t_A t_B}}{2(t_B - t_A)} \quad (4.10)$$

The resulting demand functions are defined as  $D_A = \theta'$  and  $D_B = 1 - \theta'$ . Hence, consumers located at  $\theta \in [0, \theta']$  purchase from firm  $A$  while those located at  $\theta \in [\theta', 1]$  buy firm  $B$ 's product.

In the third stage of the interaction, firms set prices in order to optimize profits given by Equation 4.3.

**Lemma 22** *In equilibrium, the optimal price  $p_i^*$  of firm  $i$  is given by*

$$\begin{aligned}p_i^* &= \frac{1}{25(t_i - t_j)} \left[ (t_i - t_j) \left( 6t_j - 2t_i + 10r(k_i - k_j) + b(15k_i^2 + 10k_j^2) \right) + 6t_i^2 \right. \\ &\quad \left. + (4t_i - 6t_j) \sqrt{5(t_i - t_j)(k_i - k_j)(r - bk_i - bk_j) + t_i^2 + 7t_i t_j + t_j^2} \right]\end{aligned}$$

<sup>17</sup>Please note that this solution is the only solution satisfying  $D_i \in [0, 1]$ .

Firms choose the degree of mass customization that maximizes their profits in the second stage. The equilibrium solution is derived by solving Equation 4.11, invoking symmetry by setting  $k_i = k_j$ , and applying L'Hôspital's Rule.

$$\frac{\partial}{\partial k_i} \pi_i : \left( \frac{d}{dk_i} p_i(k_i, t_i(k_i)) - 2bk_i \right) \theta'(k_i, t_i(k_i)) + \frac{d}{dk_i} \theta'(k_i, t_i(k_i)) (p_i(k_i, t_i(k_i)) - bk_i^2) = 0, \quad (4.11)$$

where

$$\begin{aligned} \frac{d}{dk_i} p_i(k_i, t_i(k_i)) &= \frac{\partial}{\partial k_i} p_i + \frac{\partial}{\partial t_i} p_i \frac{\partial}{\partial k_i} t_i, \\ \frac{d}{dk_i} \theta'(k_i, t_i(k_i)) &= \frac{\partial}{\partial k_i} \theta' + \frac{\partial}{\partial t_i} \theta' \frac{\partial}{\partial k_i} t_i \end{aligned}$$

**Lemma 23** *When  $b$  is sufficiently large, the equilibrium degree of mass customization chosen by firm  $i$  is such that  $k_i^* \in (0, 1)$  and is defined as*

$$\frac{\partial}{\partial k_i} \pi_i : -\frac{1}{3(tk_i^2 + 2d)^2} \left[ (2d + tk_i^2)^2 (2bk_i - r) + 2dt^2k_i \right] = 0$$

When  $b$  is small enough, then, in equilibrium, firm  $i$  chooses a degree of mass customization of

$$k_i^* = 1$$

Integrating the consumer into the production process decreases consumers' misfit costs and increases consumers' reservation price, and, thereby, increases the utility consumers derive from a purchase. This allows firms to charge a higher price and extract greater surplus from their consumers. If this integration is not too costly for firms, then they will integrate consumers as much as possible into the production process. If this integration is, however, sufficiently costly, firms trade off the price premium with higher manufacturing costs in order to find the optimal degree of mass customization. Results show that symmetric firms always adopt mass customization, i.e.  $k_i^* > 0$ , and choose a symmetric degree of mass customization. The degree of mass customization realized in equilibrium is decreasing in the variable cost of producing a mass customized product  $b$ . The greater the dis-economies of scale from mass customized production, the lower the degree of mass customization offered by the firms. Further, the degree of mass customization is increasing in consumers' reservation price  $r$ , because the perceived uniqueness of the mass customized product increases. Similar to the benchmark model, the degree of mass customization is decreasing in consumers' sensitivity for product differences  $t$  in the competitive setting. As  $t$  increases, price competition becomes less intense. Increasing the degree of mass customization would lead to less differentiated products and, thus, intensify price competition. Further, the higher  $t$ , the higher the effort level  $e_\theta$  chosen by consumers, and, therefore, a lower degree of mass customization is needed to reduce consumers' misfit costs in the same amount. These two effects lead to a negative relation between the degree of mass customization and con-

sumers' sensitivity to product differences  $t$ . The degree of mass customization is increasing in the complexity of the interaction process  $d$  given the assumption of a sufficiently complex interaction process. As consumers effort level  $e_\theta$  is decreasing in  $d$  but increasing in  $k_i$ , firms need to offer a higher degree of mass customization to absorb consumers' lower effort in order to reduce misfit costs in the same amount.

Finally, payoffs are realized.

**Lemma 24** *In equilibrium, firm  $i$ 's profit  $\pi_i^*$  and consumer surplus  $CS$  are given by*

$$\pi_i^*(k_i^*) = \frac{dt}{tk_i^{*2} + 2d}$$

$$CS(k_i^*) = r(1 + k_i^*) + \frac{13}{12} \left( \frac{2dt}{tk_i^{*2} + 2d} \right) - bk_i^{*2}$$

Firms' profits are decreasing in the optimal degree of customization  $k_i^*$ , because firms products become less differentiated as  $k_i^*$  increases. This, in turn, leads to increased price competition and lower profits. Firms' equilibrium profits are increasing in  $t$  since greater transportation costs decrease the optimal degree of mass customization and, therefore, increase profits. Profits are increasing in the complexity of the interaction process  $d$  since an increase in  $d$  lowers the exerted effort level  $e_\theta^*$  and, thereby, increases differentiation between the firms' products. Consumer surplus is increasing in  $k_i^*$  if  $b$  is not too large. This result can be explained by increased price competition as  $k_i$  increases as well as firms' inability to price differentiate in this model. If  $b$  is sufficiently large, the price increase of the mass customized product is so high that consumer surplus decreases in  $k_i$ . Given  $k_i^*$ , consumer surplus is decreasing in the complexity of the interaction process  $d$  and consumers' sensitivity to product differences  $t$  since an increase in these parameters lowers consumer utility. Consumer surplus is further decreasing in the variable cost of producing a mass customized product  $b$ , given  $k_i^*$ , because firms are able to transfer parts of their production costs to the customer via the price. Consumer surplus is increasing in consumers' reservation price  $r$ , given  $k_i^*$ , since firms are not able to fully exploit consumers' reservation price in a competitive setting.

### Cooperative mass customization

This subgame analyzes the optimal degree of mass customization offered by both firms given they can cooperate in the second stage, i.e. cooperatively choose the degree of mass customization. Prices of this subgame are derived as in the previous subgame when both firms decide to offer mass customized products in the first stage of the game (Subgame 3). Before choosing the degree of mass customization in the second stage, symmetry is invoked by setting  $k_i = k_j$ . When symmetry is invoked, firm  $i$ 's optimal price and profit from Subgame 3 become

$$p_i^* = bk_i^2 + \frac{2dt}{tk_i^2 + 2d}$$

$$\pi_i = \frac{dt}{tk_i^2 + 2d}$$

**Lemma 25** *Since firms' profits are decreasing in  $k_i$ , the degree of mass customization offered by both firms in equilibrium is given by*

$$k_i^* = 0$$

When firms can cooperatively choose the degree of mass customization, they only sell a standard product, i.e. set  $k_i^* = 0$ . In a competitive setting, mass customization reduces product differentiation. Subsequently, price competition intensifies leading to lower profits. Hence, firms are better off selling only a standard product.

Finally, payoffs are realized.

**Lemma 26** *When the degree of mass customization is a cooperative decision, the optimal profits and consumer surplus are given by*

$$\pi_i^* = \frac{t}{2}$$

$$CS = r - \frac{13}{12}t$$

Please note that the equilibrium profits and consumer surplus are identical to the subgame when no firms mass customizes (Subgame 1).

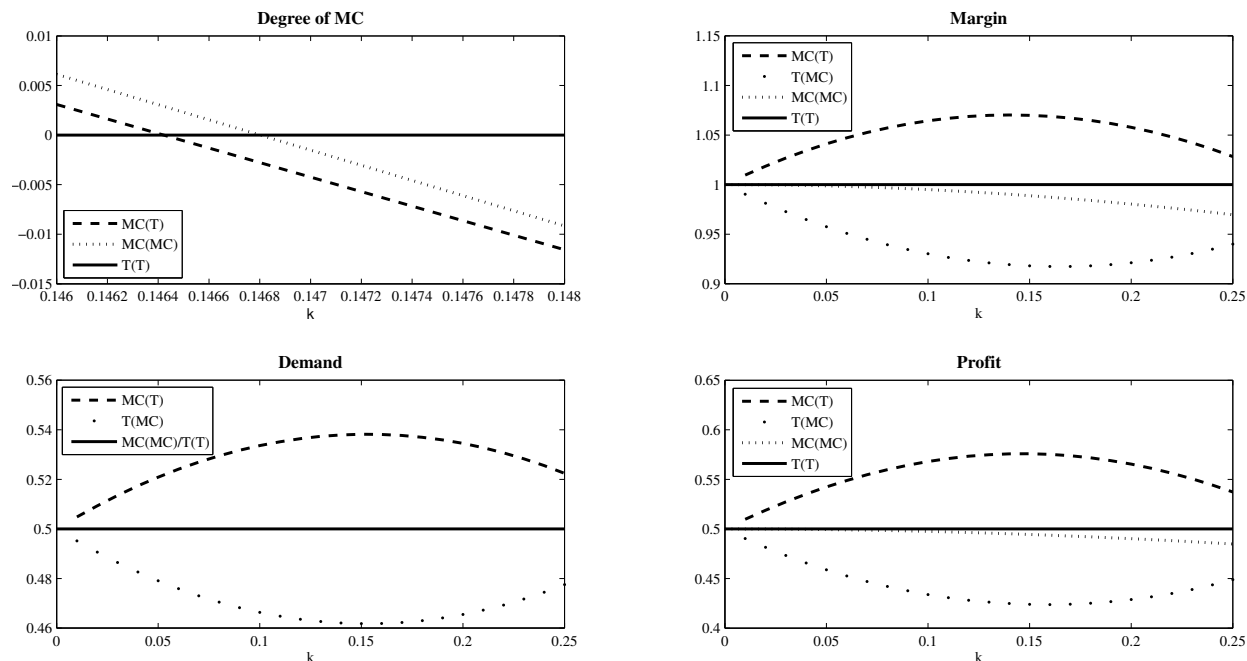
### 4.3.3 Comparative analysis

This subsection compares the optimal degree of mass customization and pricing decisions as well as resulting profits of all subgames in order to characterize the equilibrium outcome of the first-stage. Additionally, the value of integrating consumer effort into a model of mass customization is assessed.

#### Equilibrium outcome

In order to determine the equilibrium outcome of the first-stage of the game, firms' profits of each subgame are compared<sup>18</sup>.

<sup>18</sup>The analytical comparison for both the model with and without consumer effort can be found in the Proof of Proposition 9.



**Figure 4.7** Comparative analysis of subgames with consumer effort for  $t = 1, d = 1, r = 3, b = 10$ . The results of the subgame MC (MC) are shown with invoked symmetry. The first-stage decision of firm  $i$  is denoted by  $T$  (standard product) or  $MC$  (mass customized product) given the decision of its competitor  $j$ .

**Proposition 9** *Customizing products under competition with simultaneous choices is a prisoner's dilemma if consumers' reservation price  $r$  is sufficiently high.*

As shown in Figure 4.7, firms' profits are higher when both firms sell standard products than when they mass customize,  $\pi_i(T(T)) \geq \pi_i(MC(MC))$ . This is because in a competitive setting, firms over-customize<sup>19</sup> their products, i.e. set  $k_i^* > 0$ . Mass customization leads to less differentiation between firms' products resulting in intensified price competition between the two firms. Thus, prices are lower when both firms adopt mass customization compared to the case when they sell standard products. Additionally, customizing products evokes dis-economies of scale and, therefore, higher per unit production costs. Consequently, firms' margins reduce when they both adopt mass customization,  $m_i(T(T)) \geq m_i(MC(MC))$ , leading to lower profits. However, firms have an incentive to deviate from selling standard products. Compared to the profit from offering a standard product, the profit of the firm that is the only one mass customizing is higher,  $\pi_i(MC(T)) \geq \pi_i(MC(MC))$ , if  $r$  is sufficiently high. The product of the firm that adopts mass customization becomes more attractive to consumers, because it reduces consumers' misfit costs and increases the perceived uniqueness of the product so that the firm is able to sell its product at a higher price,  $p_i(MC(T)) \geq p_i(T(T))$ , and gains market share at the same time,  $D_i(MC(T)) \geq D_i(T(T))$ , given the assumption of  $r$ . Since the price increases at a faster rate than per unit production costs, the firm that adopts mass customization sees an increase in its

<sup>19</sup>The choice of  $k_i^* = 0$  in a cooperative duopoly is used as a benchmark to define over-customization from the firms' perspective.



margin,  $m_i(MC(T)) \geq m_i(T(T))$ . The increase in the firm's margin and demand subsequently lead to an increase in its profit. The firm that is not mass customizing its product, however, is forced to lower its price in order to attract consumers, because it is not able to reduce misfit costs and increase the perceived uniqueness of the product. The profit maximizing price leads to a loss in demand. The firm has an incentive to deviate from selling a standard product, because the profit from selling a standard product is lower than the profit when both firms mass customize,  $\pi_i(MC(MC)) \geq \pi_i(T(MC))$ , if  $r$  is sufficiently high. Subsequently, in equilibrium, both firms choose to offer mass customized products in the first-stage of the game given the assumption of  $r$ .<sup>20</sup> This situation is commonly known as the prisoner's dilemma. Please refer to Figure 4.8 for the matrix depiction of the prisoner's dilemma. The total degree of mass customization in equilibrium is greater than the degree of mass customization when only one firm offers mass customized products if the variable cost of producing a mass customized product  $b$  is sufficiently high.<sup>21</sup> When only one firm offers a mass customized product, its competitor is confronted with a superior product since consumers face lower misfit costs for the mass customized product and the perceived uniqueness of the mass customized product increases consumers' reservation price. Therefore, the firm is forced to lower its price in order to attract consumers. However, this puts downward pressure on the prices of both firms. In order to relax price competition, the mass customizing firm keeps the degree of mass customization at a low level. When both firms mass customize, competitive pressure forces firms to offer higher levels of mass customization.

|                            |      | <b>Firm <math>j</math></b>   |                                |
|----------------------------|------|------------------------------|--------------------------------|
|                            |      | $T$                          | $MC$                           |
| <b>Firm <math>i</math></b> | $T$  | $\pi_i(T(T)), \pi_j(T(T))$   | $\pi_i(T(MC)), \pi_j(MC(T))$   |
|                            | $MC$ | $\pi_i(MC(T)), \pi_j(T(MC))$ | $\pi_i(MC(MC)), \pi_j(MC(MC))$ |

**Figure 4.8** The highlighted payoff represents a firm's best response.

### The value of company-customer interaction in mass customization

The value of integrating consumers' choice of effort and interaction costs into a model of mass customization is assessed in terms of the optimal mass customization and pricing strategy as

<sup>20</sup>The higher  $r$ , the higher the increase in consumer utility due to the perceived uniqueness of the mass customized product for a given change in  $k_i$ . When  $r$  decreases, consumers find it less attractive to buy the mass customized product relative to the standard product and the mass customizing firm has to lower its price while production costs remain unchanged. However, the assumption of directly competing firms requires a sufficiently high  $r$ .

<sup>21</sup>Please refer to the Proof of Proposition 9 for the analytic proof of the case without consumers' choice of effort. The case with consumers' choice of effort is numerically depicted in Figure 4.7.

well as the resulting profits and consumer surplus.<sup>22</sup>

**Proposition 10** *Integrating consumers' choice of effort increases the optimal degree of mass customization when the interaction process is sufficiently complex.*

From Lemma 18 it follows that consumers may choose not to exert full effort given the complexity of the interaction process  $d$  is high enough. Hence, the degree of mass customization is not fully exploited. Consequently, mass customization is more effective in reducing consumers' misfit costs when consumers benefit directly from mass customization compared to the case when consumers have to exert effort and face interaction costs. Therefore, firms have to increase the degree of mass customization in order to offset the loss in potential misfit costs' reduction caused by consumers' choice of effort. The necessary first-order condition with consumer effort  $\frac{\partial}{\partial k_i^E} \pi_i^E$  is given by

$$\frac{\partial}{\partial k_i^E} \pi_i^E : \tilde{\pi}_i^E = -\frac{1}{3(tk_i^{E2} + 2d)} \left[ (2d + tk_i^{E2})^2 (2bk_i^E - r) + 2dt^2k_i^E \right] = 0$$

while the necessary first-order condition  $\frac{\partial}{\partial k_i} \pi_i$  and optimal degree of mass customization  $k_i^*$  without consumers' choice of effort is given by

$$\begin{aligned} \frac{\partial}{\partial k_i} \pi_i : \tilde{\pi}_i &= \frac{1}{12} (4r - t - 8bk_i - 2tk_i) = 0 \\ k_i^* &= \frac{4r - t}{8b + 2t} \end{aligned}$$

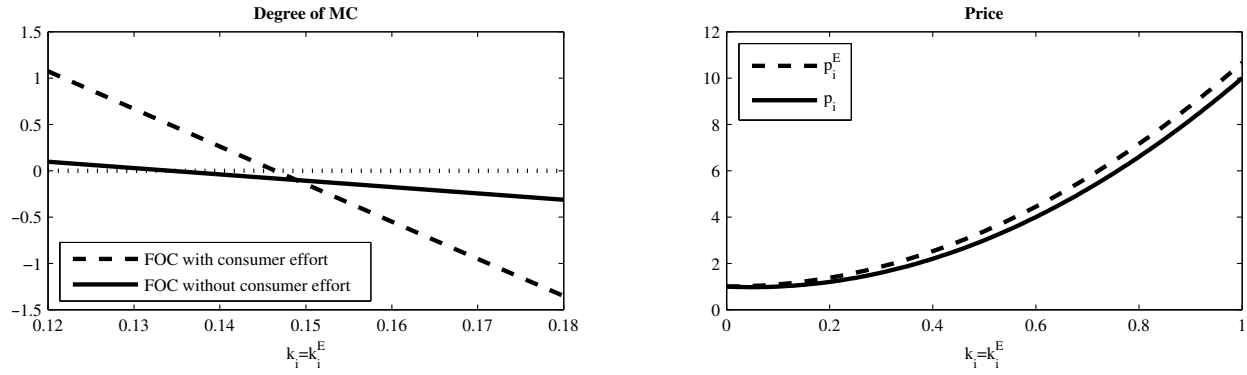
For the boundary values of the domain of definition of the degree of mass customization  $k_i = k_i^E \in [0, 1]$ ,  $\tilde{\pi}_i^E$  is greater than  $\tilde{\pi}_i$ . Further,  $\tilde{\pi}_i^E$  and  $\tilde{\pi}_i$  are strictly decreasing in  $k_i^E$  and  $k_i$ , respectively.<sup>23</sup> Inserting the optimal degree of mass customization  $k_i^*$  into  $\tilde{\pi}_i^E$  yields a positive value given the interaction process is sufficiently complex. It follows that the optimal degree of mass customization when consumers exert effort is higher than the degree of mass customization when consumers benefit from mass customization directly, i.e.  $k_i^{*E} > k_i^*$ .<sup>24</sup> Figure 4.9 illustrates the reasoning. Hence, integrating consumers' choice of effort and resulting costs of interaction into a model of mass customization leads to a higher degree of mass customization chosen by firms in equilibrium.

**Proposition 11** *Consumers' choice of effort and resulting interaction costs relax price competition, because firms' mass customized products become more differentiated.*

<sup>22</sup>For greater clarity, the superscript  $E$  is added to all decision variables in the model with consumer effort.

<sup>23</sup>For  $\tilde{\pi}_i^E$ , this assumption is satisfied if  $b$  is sufficiently high.

<sup>24</sup>Please refer to the Proof of Proposition 10 for the analytic proof.



**Figure 4.9** This figure shows the necessary first-order conditions of the profit and the price for  $b = 10$ ,  $r = 3$ ,  $t = 1$ , and  $d = 1$ .

When offering mass customized products, firms move closer towards each other. Since consumers may choose not to exert full effort when faced with the choice, this movement is reduced. This means that the loss of differentiation between the two firms that results from mass customizing products is diminished leading to a less intensified price competition from mass customization.<sup>25</sup>

When consumers face the choice of effort, the optimal price is given by

$$p^{E*} = bk_i^{E2} + \frac{2dt}{tk_i^{E2} + 2d}$$

while the optimal price without consumers' choice of effort is given by

$$p^* = t - tk_i + bk_i^2$$

For the boundary values of the domain of definition of the degree of mass customization  $k_i = k_i^E \in [0, 1]$ , the optimal price with consumer effort is greater or equal than without. For  $k_i = k_i^E = 0$ , optimal prices are identical. While firms price at marginal costs for  $k_i = 1$  when consumers face no effort choice, firms can charge a price premium for  $k_i^E = 1$  when consumer effort is integrated. This implies that although firms' differentiation vanishes under full mass customization ( $k_i = 1$ ), consumers' choice of effort creates differentiation between the two firms. Further, the first derivatives of the prices with respect to  $k_i$  and  $k_i^E$ , respectively, are strictly increasing in  $k_i$  and  $k_i^E$ , respectively, if the variable cost of producing a mass customized product  $b$  is sufficiently high. Additionally, the second derivatives of the prices with respect to  $k_i$  and  $k_i^E$ , respectively, show that this increase in  $k_i$  and  $k_i^E$ , respectively, is convex. Hence,  $p_i^{*E} \geq p_i^*$  for a given  $k_i = k_i^E$ . It follows that  $p_i^{E*}(k_i^*)$  must be greater or equal than  $p_i^*(k_i^*)$ . Since the optimal degree of mass

<sup>25</sup>Please refer to the Proof of Proposition 11 for the analytic proof.

customization with consumers' choice of effort  $k_i^{E*}$  is higher than that without consumers' choice of effort  $k_i^*$  and the price function is convexly increasing in  $k_i$ ,  $p_i^{*E}(k_i^{E*})$  must be greater than  $p_i^*(k_i^*)$ .<sup>26</sup> Figure 4.9 illustrates the reasoning.

Given the Hotelling setting of this model, the demand when symmetric firms are directly competing is neither affected by the adoption of mass customization nor consumers' choice of effort as firms evenly share the market with a total mass of 1. Consequently, an analysis of firm  $i$ 's margin is sufficient to determine the effect of mass customization and consumers' choice of effort on firm  $i$ 's profit.<sup>27</sup>

**Proposition 12** *The adoption of mass customization is detrimental to firms' profits but this effect is mitigated by including consumers' choice of effort.*

When firms sell standard products, the margin  $m_i$  of firm  $i$  is given by

$$m_i = t$$

The margin  $m_i^C$  of firm  $i$  when both firms mass customize is given by

$$m_i^C = t - tk_i$$

When consumers farther can choose the effort they want to put into the configuration process and incur interaction costs, firm  $i$ 's margin  $m_i^{CE}$  is given by

$$m_i^{CE} = \frac{2dt}{tk_i^{E2} + 2d}$$

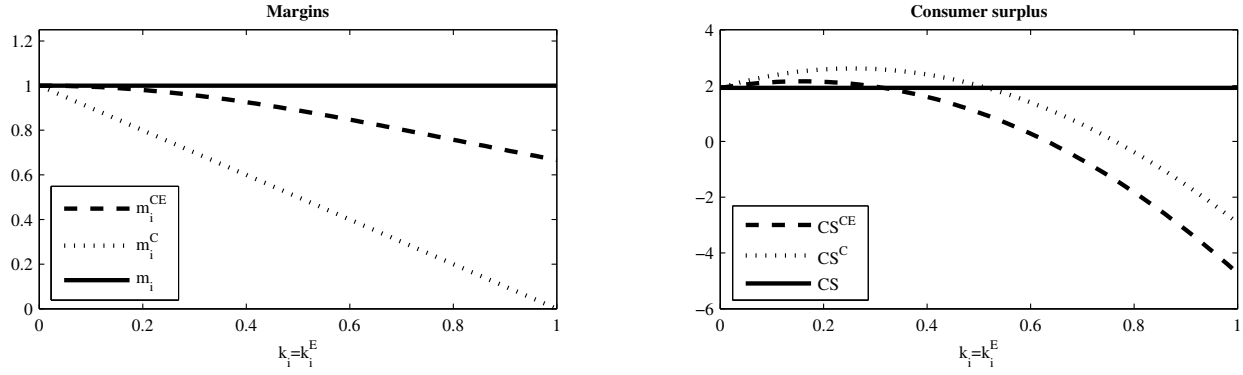
It follows that firm  $i$ 's margin is greatest when both firms sell a standard product since  $k_i^* = k_i^{E*} > 0$ . When firm  $i$  offers a mass customized product, its margin is higher with consumers' choice of effort than without if the variable costs of producing mass customized products  $b$  is not too high. Hence, the adoption of mass customization is detrimental to firms profits, but this effect is mitigated by including consumers' choice of effort.<sup>28</sup> Figure 4.10 illustrates firm  $i$ 's margin for the three cases.

**Proposition 13** *Consumer surplus is greater with mass customization, but this effect is mitigated when consumer effort and resulting interaction costs are integrated.*

<sup>26</sup>Under the assumption that  $b$  is sufficiently high.

<sup>27</sup>For greater clarity, the superscript C is added to the margin when firms sell mass customized products.

<sup>28</sup>Please refer to the Proof of Proposition 12 for the analytic proof.



**Figure 4.10** This figure shows firm  $i$ 's margin and consumer surplus for  $t = 1, d = 1, r = 3, b = 10$ .

When both firms sell a standard product, consumer surplus  $CS$  is given by

$$CS = r - \frac{13}{12}t$$

Consumer surplus<sup>29</sup>  $CS^C$  when both firms sell mass customized products is given by

$$CS^C(k_i^*) = r - \frac{13}{12}t - bk_i^{*2} - \frac{1}{4}k_i^{*2}t + \frac{1}{12}k_i^{*3}t + k_i^*r + \frac{5}{4}tk_i^*$$

When consumers farther can choose the effort they want to put into the configuration process and incur interaction costs, consumer surplus  $CS^{CE}$  is given by

$$CS^{CE}(k_i^{E*}) = r(1 + k_i^{E*}) - \frac{13}{12} \left( \frac{2dt}{tk_i^{E*2} + 2d} \right) - bk_i^{E*2}$$

Analysis shows that consumer surplus with mass customization but without consumers' choice of effort  $CS^C$  is greater or equal than consumer surplus without mass customization  $CS$ . When firms adopt mass customization, they move closer towards each other and become less differentiated, leading to intensified price competition and, thus, to lower prices for consumers. As firms are charging lower prices, they extract less surplus from the infra-marginal consumer. Integrating consumers' choice of effort and resulting interaction costs into the model makes the above statement less clear. Analysis shows that consumer surplus with mass customization  $CS^{CE}$  may not always be greater than without mass customization  $CS$ . Only when firm  $i$ 's variable cost of producing a mass customized product  $b$  is sufficiently low, consumer surplus is enhanced. As previously explained, consumers' choice of effort mitigates the loss of product differentiation from mass customization and, therefore, mitigates price competition. Since consumer effort leads to differentiation between firms, firm  $i$  transfers parts of its increase in the variable cost of

<sup>29</sup>For greater clarity, the superscript C is added to consumer surplus when firms sell mass customized products.

producing a mass customized product  $b$  via the price to the consumer and extracts more surplus from the infra-marginal consumer. As consumer effort leads to interaction costs, consumer surplus further declines. Numerically solving  $\frac{\partial}{\partial k_i^E} \pi_i^E$  for any given  $b \in [0, 1000]$  shows that firm  $i$  chooses  $k_i^{E*}$  such that  $CS^{CE} \geq CS$ .<sup>30</sup>

## 4.4 Extensions

This section extends the duopoly model when both firms mass customize in four ways: first, it introduces asymmetric firms (Subsection 4.4.1); second, it analyzes consumers' valuation for perceived uniqueness of mass customized products (Subsection 4.4.2); third, it examines firm's incentive to offer both a lower-priced standard product and a mass customized product (Subsection 4.4.3); and, finally, it studies firms' location choice (Subsection 4.4.4).

### 4.4.1 Asymmetric firms

This subsection analyzes the equilibrium solutions for the case when firm  $A$  and firm  $B$  are asymmetric using numerical analysis. In particular, firms are studied that are asymmetric in their variable production costs for mass customized product parts,  $b_A \neq b_B$ , and the complexity of their interaction processes,  $d_A \neq d_B$ . Firm  $i$ 's optimal degree of mass customization and the resulting optimal prices and profits are computed by iteratively maximizing firm  $i$ 's profit function given the best response of its competitor.

#### Asymmetric production costs

First, the effect of asymmetric production costs,  $b_A \neq b_B$ , on the optimal degree of mass customization is analyzed. Specifically, it is assumed that firm  $B$  has a cost disadvantage compared to firm  $A$ ,  $b_A \leq b_B$ . This means that firm  $B$  incurs greater dis-economies of scale when integrating consumers into the production process, represented by  $\lambda$ .

Firm  $A$  incurs unit production costs of

$$c_A = a + (b - a) k_A^2 \quad (4.12)$$

while variable manufacturing costs of firm  $B$  are given by

$$c_B = a + (b + \lambda - a) k_B^2, \quad (4.13)$$

with

<sup>30</sup>Please refer to the Proof of Proposition 13 for the analytic proof.

$$\lambda \geq 0$$

Hence,  $b_B = b_A + \lambda$ . Note that  $a$  is normalized to zero. Equation 4.13 implies the following. For any  $\lambda > 0$ , firm  $B$  has a cost disadvantage while for  $\lambda = 0$ , firms are symmetric.

Table 4.1 presents all the parameter values used in the numerical analysis. The primary goal in setting the parameters is to be able to derive an intuition about a firm's strategic decision in case of a production cost disadvantage.

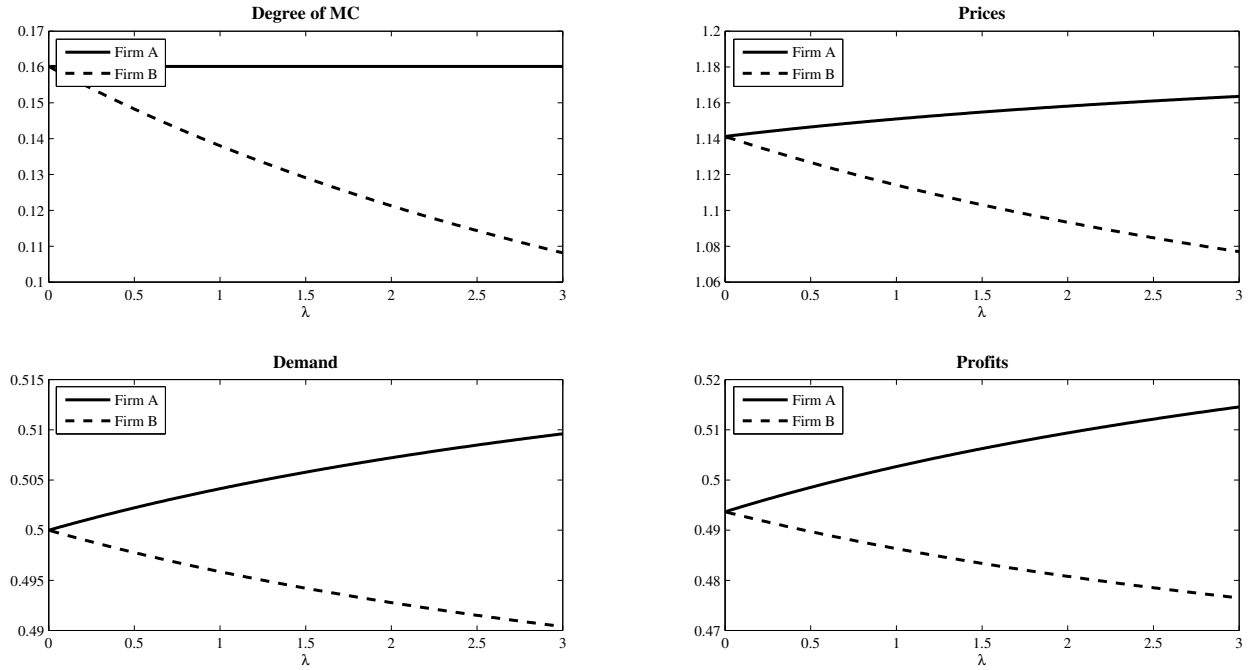
**Table 4.1** Asymmetries in the production process

| Parameter | Definition                                    | Number of values | Value       |
|-----------|---|------------------|-------------|
| $r$       | Reservation price                             | 1                | 2           |
| $t$       | Sensitivity to product differences            | 1                | 1           |
| $d$       | Complexity of the interaction process         | 1                | 1           |
| $b$       | Variable costs for mass customized production | 1                | 6           |
| $\lambda$ | Degree of production cost asymmetry           | 3000             | [0:0.001:3] |

The numerical analysis is run for 3000 values of  $\lambda$ , from 0 to 3 in steps of 0.001.

**Conjecture 1** *When firm  $B$  has a production cost disadvantage ( $\lambda > 0$ ), then the firm decreases its price and chooses a lower degree of mass customization. This leads to a loss in demand and decreases its profit.*

These effects can be explained as follows. When dis-economies of scale for mass customized production increase, firm  $B$  needs to lower its degree of mass customization in order to stay profitable. Firm  $A$ 's best response to the significant decrease of  $k_B$ , on the contrary, is to only slightly lower its degree of mass customization. As the two firms directly compete, firm  $B$  has to decrease its price in order to stay competitive. Offering a lower degree of mass customization than its competitor, makes firm  $B$  less attractive to its consumers, because misfit costs are reduced less and the reservation price decreases. Therefore, it has to lower its price in order to still attract consumers. However, due to increased production costs, firm  $B$ 's price reduction cannot be large enough to hinder the loss in demand. Firm  $B$ 's price reduction, hence, does not capture consumers' loss in the reduction of misfit costs and a reduced reservation price due to a lower degree of mass customization compared to its competitor. Therefore, more consumers find it utility maximizing to buy from firm  $A$  than from firm  $B$ . As demand and price decrease while production costs increase for a given  $k_B$ , firm  $B$  exhibits a loss in profit while firm  $A$ 's profit increases. Figure 4.11 illustrates the results from the iterative computation.



**Figure 4.11** The optimal choices of the degree of mass customization as well as the resulting prices, profits, and demand are shown for firm *A* (solid line) and firm *B* (dashed line).  $\lambda > 0$  represents a cost disadvantage. The higher  $\lambda$ , the more disadvantageous firm *B* becomes.

### Asymmetric interaction costs

Second, the effect of asymmetric interaction costs,  $d_A \neq d_B$ , on the optimal degree of mass customization is analyzed. This asymmetry emerges from interaction processes with different complexities. If an interaction process is more complex, consumers incur higher interaction costs. Specifically, it is assumed that firm *B* has a cost disadvantage compared to firm *A*,  $d_A \leq d_B$ . This means that consumers may incur greater interaction costs when purchasing firm *B*'s product compared to purchasing from firm *A*, represented by  $\mu$ .

Consumers purchasing firm *A*'s product incur interaction costs of

$$\frac{1}{2} d e_{\theta}^2 \quad (4.14)$$

while consumers purchasing firm *B*'s product incur interaction costs of

$$\frac{1}{2} (d + \mu) e_{\theta}^2, \quad (4.15)$$

with

$$\mu \geq 0$$



Hence,  $d_B = d_A + \mu$ . Equation 4.15 implies the following. For any  $\mu > 0$ , firm  $B$ 's interaction process is more complex and, thus, costlier for consumers than that of firm  $A$  while for  $\mu = 0$ , firms are symmetric.

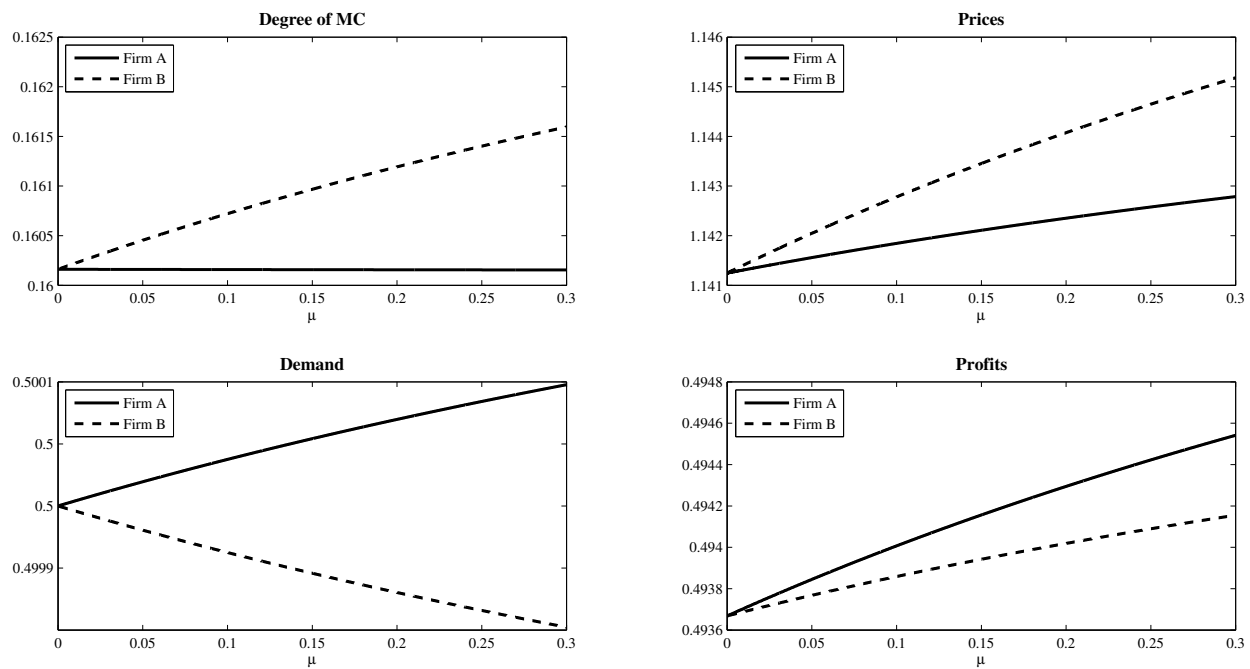
Table 4.2 presents all the parameter values used in the numerical analysis. The primary goal in setting the parameters is to be able to derive an intuition about a firm's strategic decision in case of an interaction cost disadvantage.

**Table 4.2** Asymmetries in the interaction process

| Parameter | Definition                                    | Number of values | Value          |
|-----------|---|------------------|----------------|
| $r$       | Reservation price                             | 1                | 2              |
| $t$       | Sensitivity to product differences            | 1                | 1              |
| $d$       | Complexity of the interaction process         | 1                | 1              |
| $b$       | Variable costs for mass customized production | 1                | 6              |
| $\mu$     | Degree of interaction cost asymmetry          | 3000             | [0:0.0001:0.3] |

The numerical analysis is run for 3000 values of  $\mu$ , from 0 to 0.3 in steps of 0.0001.

**Conjecture 2** *When firm B has an interaction cost disadvantage ( $\mu > 0$ ), then the firm chooses a higher degree of mass customization and increases its price. This leads to a loss in demand, but increases its profit.*



**Figure 4.12** The optimal choices of the degree of mass customization as well as the resulting prices, profits, and demand are shown for firm A (solid line) and firm B (dashed line).  $\mu > 0$  represents a cost disadvantage. The higher  $\mu$ , the more disadvantageous firm  $B$  becomes.

These effects can be explained as follows. When the firm has an interaction cost disadvantage, consumers find it less attractive to buy from that firm due to higher marginal costs of effort, leading to a loss in demand. In order to fight this effect and make purchasing attractive again, the firm increases its degree of mass customization since an increase in the degree of mass customization makes consumer effort more effective and, hence, less costly. The increase in the degree of mass customization leads to higher production costs and, therefore, requires an increase in the firm's price in order to stay profitable. However, the increase in the degree of mass customization, which results in lower misfit costs and an increased reservation price, does not outweigh the increased interaction costs and price raise so that less consumers find it attractive to buy from firm *B* compared to firm *A*. This loss in demand, however, is not significant as the best response of the competitor is to slightly lower its degree of mass customization and increase its price at the same time so that consumers find it less attractive to buy from the competitor as well. The increase in price captures the loss in demand and higher production costs due to an increased degree of mass customization of firm *B*. Subsequently, firm *B*'s profit increases. It follows that an increase in consumers' interaction costs is profitable for both firms. Figure 4.12 illustrates the results from the iterative computation.

#### 4.4.2 Consumers' valuation for uniqueness

As observed by a variety of experimental studies<sup>31</sup>, mass customization leads to an increase in consumers' reservation price, because consumers attach additional value to mass customized products due to perceived uniqueness.<sup>32</sup> In this subsection, the effect of consumers' valuation for perceived uniqueness of mass customized products on the optimal degree of mass customization in a competitive setting is analyzed. It is assumed that firms are symmetric and that consumers' reservation price is high enough so that firms directly compete. The reservation price for a customized product  $r$  is given by

$$r(1 + \alpha k_i) \quad (4.16)$$

where  $\alpha \in [0, 1]$  measures consumers' valuation for perceived uniqueness. Thus, when  $\alpha = 0$ , consumers do not value uniqueness and do not exhibit an increase in their reservation price. When  $\alpha > 0$ , consumers appreciate uniqueness, resulting in an increase in their reservation price. The higher  $\alpha$ , the greater consumers' valuation for uniqueness.

Including  $\alpha$  into the model leads to the following main results<sup>33</sup>

<sup>31</sup>For example Schreier (2006), Franke and Schreier (2008), and Franke et al. (2010).

<sup>32</sup>This assumption is similar to Loginova and Wang (2009) and Wong and Lesmono (2013).

<sup>33</sup>Please note that an analytical derivation of these results is omitted as the derivation is done as in previous sections.

$$\begin{aligned}\theta' &= \frac{1}{2} + \frac{t_i + t_j - 2\sqrt{(t_i - t_j)(-p_i + p_j + rak_i - rak_j) + t_it_j}}{2(t_j - t_i)} \\ p_i^* &= \frac{1}{25(t_i - t_j)} \left[ (t_i - t_j) \left( 6t_j - 2t_i + 10\alpha r(k_i - k_j) + b(15k_i^2 + 10k_j^2) \right) + 6t_i^2 \right. \\ &\quad \left. + (4t_i - 6t_j) \sqrt{5(t_i - t_j)(k_i - k_j)(\alpha r - bk_i - bk_j) + t_i^2 + 7t_it_j + t_j^2} \right] \\ \frac{\partial}{\partial k_i} \pi_i &: -\frac{1}{3(tk_i^2 + 2d)^2} \left[ (2d + tk_i^2)^2 (2bk_i - \alpha r) + 2dt^2k_i \right] = 0,\end{aligned}$$

where

$$\begin{aligned}t_i &= \frac{2dt}{tk_i^2 + 2d} \\ t_j &= \frac{2dt}{tk_j^2 + 2d}\end{aligned}$$

**Proposition 14** *The optimal degree of mass customization  $k_i^*$  is increasing in consumers' valuation for perceived uniqueness  $\alpha$ . When consumers do not value uniqueness, firms find it most profitable to set  $k_i^* = 0$  and only offer standard products.*

From the first derivative of  $k_i^*$  with respect to  $\alpha$  it follows that the optimal degree of mass customization  $k_i^*$  is increasing in consumers' valuation for uniqueness  $\alpha$

$$\frac{\partial}{\partial \alpha} \frac{\partial}{\partial k_i} \pi_i : \frac{1}{3}r \geq 0$$

While variable production costs are unaffected by consumers' valuation for perceived uniqueness  $\alpha$ , firms need to lower their prices as  $\alpha$  decreases since consumers' reservation price declines. Consequently, when consumers do not value the uniqueness of mass customized products, firms cannot charge a price that is high enough to capture unit manufacturing costs for mass customized products. Therefore, firms do not offer mass customized products when consumers do not value uniqueness, i.e. when  $\alpha = 0$ .  $k_i^* = 0$  is the only solution that solves the first-order necessary condition when  $\alpha = 0$  given the domain of definition of the model parameters

$$\begin{aligned}\frac{\partial}{\partial k_i} \pi_i (\alpha = 0) &: -\frac{1}{3(tk_i^2 + 2d)^2} \left[ (2d + tk_i^2)^2 (2bk_i) + 2dt^2k_i \right] = 0 \\ k_i^* (\alpha = 0) &= 0\end{aligned}$$

### 4.4.3 Incentive to offer a standard and a mass customized product

This subsection analyzes firm  $i$ 's incentive to offer (i) a lower-priced standard product in addition to its mass customized product and (ii) a mass customized product in addition to its standard product. The standard products  $x_i^S$  of firm  $A$  and firm  $B$  are located at  $x_A^S = 0$  and  $x_B^S = 1$ , respectively. It is assumed that firms are symmetric and that consumers' reservation price is large enough so that firms directly compete with their mass customized products.<sup>34</sup>

When firm  $i$  offers both a standard product  $x_i^S$  and a mass customized product  $x_i^C$ , the mass customized product is priced at  $p_i$  and the standard product is sold with a price discount of  $z_i$ . In this case, a type- $\theta$  consumer purchases the standard product  $x_i^S$  iff

$$\begin{aligned} U_{x_i^S} &\geq U_{x_i^C} \\ r - ty_i^2 - (p_i - z_i) &\geq r(1 + k_i) - ty_i^2 - p_i, \end{aligned}$$

where

$$t_i = \frac{2dt}{tk_i^2 + 2d}$$

The consumer  $\theta^A$ , who is indifferent between purchasing firm  $A$ 's standard product and its mass customized product, is located at

$$\theta^A = \sqrt{\frac{z_A - rk_A}{t - t_A}} \quad (4.17)$$

The consumer  $\theta^B$ , who is indifferent between buying firm  $B$ 's standard product and its mass customized product, is located at

$$\theta^B = 1 - \sqrt{\frac{z_B - rk_B}{t - t_B}} \quad (4.18)$$

Recall from Subsection 4.3.2 that the consumer  $\theta^{AB}$  who is indifferent between purchasing the mass customized product of firm  $A$  and that of firm  $B$  is given by

$$\theta^{AB} = \frac{1}{2} + \frac{t_A + t_B - 2\sqrt{(t_A - t_B)(-p_A + p_B + rk_A - rk_B) + t_A t_B}}{2(t_B - t_A)} \quad (4.19)$$

<sup>34</sup>Please refer to Appendix B.4 Incentive to offer a standard and a mass customized product for the proof that consumers distant to firm  $i$  buy the mass customized product while those close by buy the standard product.

The demand for the standard product  $D_i^S$  of firm  $A$  and firm  $B$  is as follows

$$\begin{aligned} D_A^S &= \theta^A \\ D_B^S &= 1 - \theta^B \end{aligned} \quad (4.20)$$

The demand for the mass customized product  $D_i^C$  of firm  $A$  and firm  $B$  is given by

$$\begin{aligned} D_A^C &= \theta^{AB} - \theta^A \\ D_B^C &= 1 - \theta^{AB} - (1 - \theta^B) \end{aligned} \quad (4.21)$$

Firm  $i$  bears variable costs of  $c_i^S = a$  for the standard product and  $c_i^C = a + (b - a)k_i^2$  for the mass customized product, where  $a$  is normalized to zero. Since consumers close to firm  $i$  buy the standard product and consumers distant to firm  $i$  buy the mass customized product, the profit of firm  $i$  is as follows. The profit of firm  $A$  is given by

$$\begin{aligned} \pi_A &= D_A^S (p_A - z_A) + D_A^C (p_A - c_A) \\ &= \theta^A (p_A - z_A) + (\theta^{AB} - \theta^A) (p_A - c_A) \\ &= \theta^A (c_A - z_A) + \theta^{AB} (p_A - c_A) \\ &= \pi_A^S + \pi_A^C \end{aligned} \quad (4.22)$$

The profit of firm  $B$  is given by

$$\begin{aligned} \pi_B &= D_B^S (p_B - z_B) + D_B^C (p_B - c_B) \\ &= (1 - \theta^B) (p_B - z_B) + (1 - \theta^{AB} - (1 - \theta^B)) (p_B - c_B) \\ &= (1 - \theta^B) (c_B - z_B) + (1 - \theta^{AB}) (p_B - c_B) \\ &= \pi_B^S + \pi_B^C \end{aligned} \quad (4.23)$$

To set the price for the mass customized product  $p_i$  and the discount  $z_i$ , firms simultaneously maximize their profit functions with respect to  $p_i$  and  $z_i$ .<sup>35</sup> The profit maximizing price  $p_i^*$  and discount  $z_i^*$  are given by

<sup>35</sup>The derivation of  $p_i^*$  and  $z_i^*$  can be found in Appendix B.4 Incentive to offer a standard and a mass customized product.

$$p_i^* = \frac{1}{25(t_i - t_j)} \left[ (t_i - t_j) \left( 6t_j - 2t_i + 10r(k_i - k_j) + b(15k_i^2 + 10k_j^2) \right) + 6t_i^2 \right. \\ \left. + (4t_i - 6t_j) \sqrt{5(t_i - t_j)(k_i - k_j)(r - bk_i - bk_j) + t_i^2 + 7t_it_j + t_j^2} \right] \\ z_i^* = \frac{2}{3}rk_i + \frac{1}{3}bk_i^2$$

**Proposition 15** *Firm  $i$  has an incentive to additionally offer a lower-priced standard product.*

As can be noticed from Equations 4.22 and 4.23, the profit of firm  $i$  when it offers both products is the additive product of offering a mass customized product  $\pi_i^C$  (identical to the profit of Subgame 3 in Subsection 4.3.2) and the additional profit of selling a standard product  $\pi_i^S$ . The additional profit from offering a standard product  $\pi_i^S$  is greater or equal zero iff

$$\begin{aligned} \pi_i^S &\geq 0 \\ D_i^S(c_i - z_i) &\geq 0 \\ bk_i^2 &\geq \frac{2}{3}rk_i + \frac{1}{3}bk_i^2 \\ bk_i &\geq r \end{aligned}$$

When the production cost savings from offering a standard product  $bk_i^2$  are greater or equal than the price discount for the standard product  $z$ , firm  $i$  has an incentive to offer a standard product in addition to its mass customized product. This is true if the marginal increase in production costs of the mass customized product  $bk_i$  is greater or equal than the marginal increase in consumers' reservation price due to the perceived uniqueness of the mass customized product  $r$ . Inserting  $z_i^*$  into the demand for the standard product  $D_i^S$  reveals that this is given as long as  $D_i^S$  is positively defined.

**Proposition 16** *Firm  $i$  finds it unprofitable to offer a mass customized product next to its standard product when the variable production cost of mass customization is not too high. However, in equilibrium firm  $i$  offers both a mass customized and a standard product.*

Offering a mass customized product cannibalizes demand in the region distant to the firm. Hence, firms compete with the mass customized product. Firm  $i$  finds it profitable to offer a mass customized product in addition to its standard product if the margin in the cannibalized region and the margin of the standard product is greater or equal than the margin when only the standard product is offered.<sup>36</sup> Recall from Subsection 4.3.2 that this margin equals  $t$ . The margin of the mass customized product is greater or equal iff

<sup>36</sup>Note that margins are compared with invoked symmetry, i.e.  $k_i = k_j$ .

$$\frac{2dt}{tk_i^2 + 2d} \geq t$$

$$k_i \leq 0$$

This is never satisfied given  $k_i^* > 0$ . The margin of the standard product is greater or equal iff

$$\frac{2dt}{tk_i^2 + 2d} - \frac{2}{3}k_i(r - bk_i) \geq t$$

$$\frac{1}{4dk_i + 2tk_i^3} (3t^2k_i + 4dr + 2rtk_i^2) \leq b$$

When  $b$  is sufficiently high, firm  $i$  can increase the price for the standard product in case it additionally sells a mass customized product. Offering an additional mass customized product increases firm  $i$ 's profit if the joint profit is greater or equal than the profit of selling a standard product only. Recall from Subsection 4.3.2 that the profit of only selling a standard product is  $\frac{t}{2}$ .

$$\pi_i^C + \pi_i^S \geq \frac{t}{2}$$

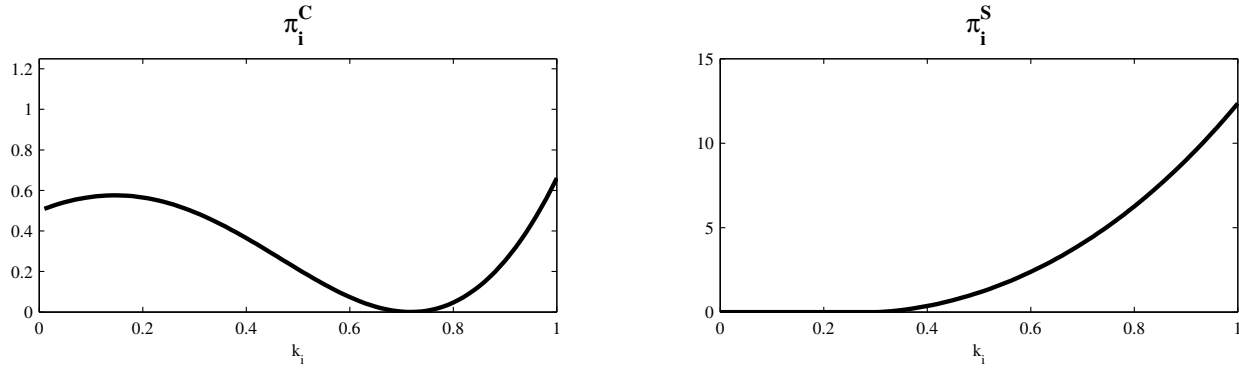
$$\frac{1}{3(tk_i^2 + 2d)} \left( 3dt + \left( \frac{2}{3}\sqrt{3} \right) k_i (2d + tk_i^2) \sqrt{\frac{k_i}{t-t_i} (bk_i - r)^3} \right) \geq \frac{t}{2}$$

$$\frac{r}{k_i} + \sqrt[3]{\frac{27t^4(t-t_i)}{16k_i^2(2d+tk_i^2)^2}} \leq b$$

When  $b$  is sufficiently large, firms find it profitable to offer a mass customized product in addition to their standard products. As the variable cost of producing a mass customized product  $b$  increases, the optimal degree of mass customization decreases. Hence, differentiation between firms increases. This allows firms to charge a higher price for their standard product and relaxes price competition between the firms' mass customized product. When  $b$  is low enough, firms' profits are higher when they only sell a standard product. However, due to strategic effects in a competitive market as shown in Subsection 4.3.2, both firms have an incentive offer an additional mass customized product in equilibrium.

**Proposition 17** *When firm  $i$  has an incentive to offer both a standard and a mass customized product, the optimal degree of mass customization is greater or equal than the optimal degree of mass customization when only the mass customized product is offered. This increase in  $k_i^*$  is convex.*

As can be noticed from Equations 4.22 and 4.23, the profit of firm  $i$  is the additive profit of offering a mass customized product  $\pi_i^C$  (identical to the profit of Subgame 3 in Subsection 4.3.2) and selling a standard product  $\pi_i^S$ . Figure 4.13 illustrates firm  $i$ 's profit from offering a mass customized product  $\pi_i^C$  and its additional profit from offering a standard product  $\pi_i^S$ .



**Figure 4.13** Profits are depicted for  $r = 3$ ,  $t = 1$ ,  $d = 1$ ,  $b = 10$ , and  $k_j = 0$ . Note that the border solution can be neglected since it does not satisfy  $D_i \in [0, 1]$ .

The optimal degree of mass customization when both firms only sell a mass customized product is analyzed in Subsection 4.3.2. The profit from offering a standard product  $\pi_i^S$  is increasing in  $k_i$  iff

$$\begin{aligned} \frac{\partial}{\partial k_i} \pi_i^S &\geq 0 \\ \frac{\partial}{\partial k_i} \left( \sqrt{\frac{4}{27} \frac{k_i}{t^2} (tk_i^2 + 2d) (bk_i - r)^3} \right) &\geq 0 \\ \sqrt{\frac{bk_i - r}{27k_i t^2 (tk_i^2 + 2d)}} (6bt k_i^3 - 3rt k_i^2 + 8bd k_i - 2dr) &\geq 0 \\ b &\geq \frac{2dr + 3k_i^2 rt}{6tk_i^3 + 8dk_i} \end{aligned}$$

Given there is demand for the standard product, this condition is always satisfied since  $\frac{r}{k_i} \geq \frac{2dr + 3k_i^2 rt}{6tk_i^3 + 8dk_i}$ . Consequently, the optimal degree of mass customization offered in equilibrium when both firms offer a standard and a mass customized product is greater or equal than the degree of mass customization when firms only sell a mass customized product. From the second derivative of  $\pi_i^S$  with respect to  $k_i$  it follows that this increase is convex, i.e.  $\frac{\partial^2}{\partial k_i^2} \pi_i^S \geq 0$ , given there is demand for the standard product.<sup>37</sup>

#### 4.4.4 Location choice

In prior sections, maximum differentiation with firm  $A$  and firm  $B$  located at zero and one, respectively, was assumed. This subsection examines whether firms have an incentive to deviate from maximum differentiation. It is assumed that firms are symmetric and that consumers' reservation price is high enough so that firms directly compete.

<sup>37</sup>Please refer to the Proof of Proposition 17 for the analytic proof.



Suppose firm  $B$  is located at one while firm  $A$  is located  $\phi$  units away from zero. A type- $\theta$  consumer purchases firm  $A$ 's product iff

$$U_A \geq U_B$$

$$r(1+k_A) - t_A(\theta - \phi)^2 - p_A \geq r(1+k_B) - t_B(1 - \theta)^2 - p_B$$

The left-hand side of the above inequality denotes the net utility from purchasing firm  $A$ 's mass customized product and the right-hand side that from choosing to buy from firm  $B$ . Solving the inequality with respect to  $\theta$ , yields the consumer who is indifferent between buying from firm  $A$  or  $B$ , which is denoted by  $\theta'$ <sup>38</sup>

$$\theta' = \frac{1}{t_A - t_B} \left( \phi t_A - t_B + \sqrt{t_A t_B (\phi - 1)^2 + (t_A - t_B) (-p_A + p_B + r k_A - r k_B)} \right) \quad (4.24)$$

The resulting demand functions are defined as  $D_A = \theta'$  and  $D_B = 1 - \theta'$ . Hence, consumers located at  $\theta \in [0, \theta']$  purchase from firm  $A$  while those located at  $\theta \in [\theta', 1]$  buy firm  $B$ 's product.

The optimal prices  $p_A^*$  and  $p_B^*$  are given by<sup>39</sup>

$$p_A^* = \frac{1}{25(t_B - t_A)} \left( 2\phi t_A (3t_A + 3t_B + 2\phi t_A - 5\phi t_B) - 2(2t_A^2 - 3t_B^2 + 4t_A t_B) \right. \\ \left. - 5(t_A - t_B) (2rk_A - 2rk_B + 3bk_A^2 + 2bk_B^2) + (6t_B - 4t_A - 2\phi t_A) \sqrt{\chi} \right)$$

$$p_B^* = \frac{1}{25(t_A - t_B)} \left( 2\phi t_A (13t_B - 7t_A + 2\phi t_A - 5\phi t_B) + 2(3t_A^2 - 2t_B^2 - 4t_A t_B) \right. \\ \left. + 5(t_A - t_B) (2rk_B - 2rk_A + 2bk_A^2 + 3bk_B^2) + (6t_A - 4t_B - 2\phi t_A) \sqrt{\chi} \right),$$

where

$$t_i = \frac{2dt}{tk_i^2 + 2d}$$

$$\chi = t_A^2 + t_B^2 + 7t_A t_B - 5(k_A - k_B)(t_A - t_B)(-r + bk_A + bk_B) - \phi t_A (4t_A + 14t_B - 4\phi t_A - 5\phi t_B)$$

In order to analyze whether firm  $A$  has an incentive to move towards firm  $B$ , i.e. to choose  $\phi > 0$ , a numerical analysis is run. Firm  $i$ 's optimal choice of the degree of mass customization  $k_i$  and the resulting optimal prices  $p_i$ , profits  $\pi_i$ , and demand  $D_i$  are computed by iteratively maximizing a firm's profit function given the best response of its competitor. Table 4.3 presents all the

<sup>38</sup>Please note that this solution is the only solution satisfying  $D_i \in [0, 1]$ .

<sup>39</sup>Please note that an analytic derivation of the prices is omitted as it is done as in previous sections.

parameter values used in the numerical analysis. The primary goal in setting the parameters is to be able to derive an intuition about a firm's location choice.

**Table 4.3** Location choice

| Parameter | Definition                                    | Number of values | Value       |
|-----------|---|------------------|-------------|
| $r$       | Reservation price                             | 1                | 2           |
| $t$       | Sensitivity to product differences            | 1                | 1           |
| $d$       | Complexity of the interaction process         | 1                | 1           |
| $b$       | Variable costs for mass customized production | 1                | 10          |
| $\phi$    | Firm $A$ 's distance to zero                  | 1000             | [0:0.001:1] |

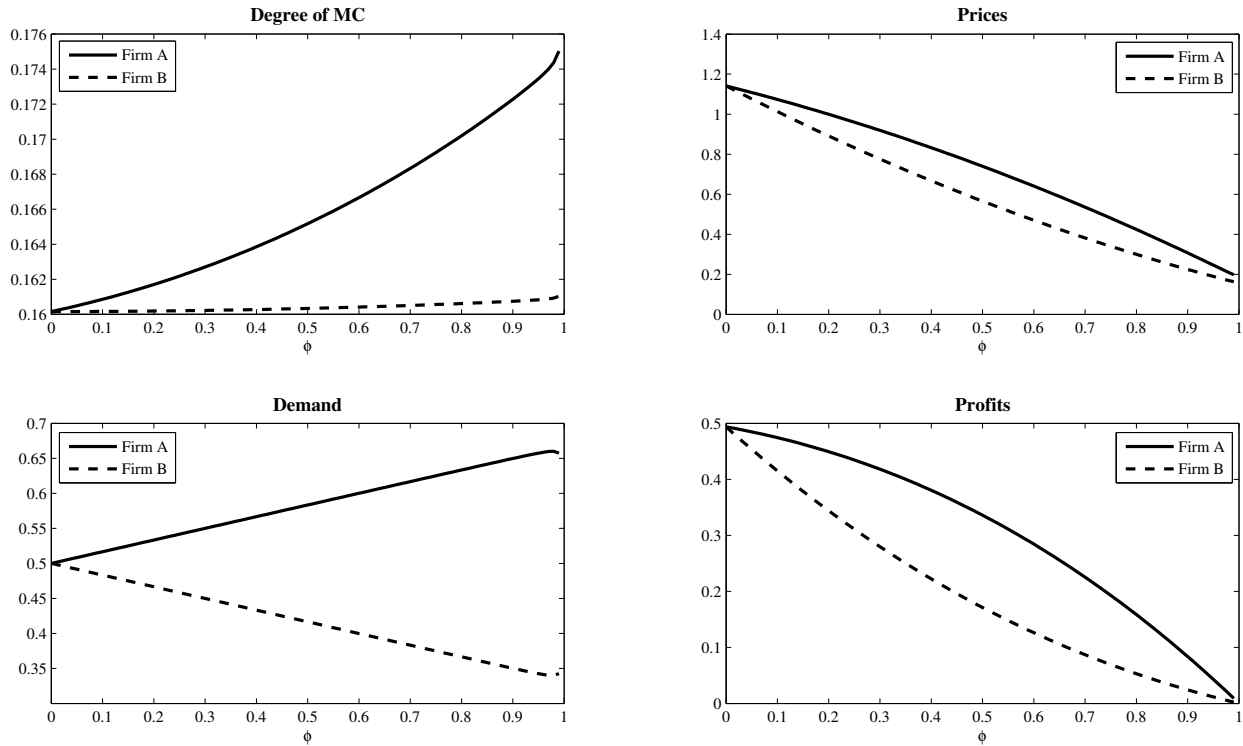
The numerical analysis is run for 1000 values of  $\phi$ , from 0 to 1 in steps of 0.001.

**Conjecture 3** *In equilibrium, firms choose to locate at zero and one and no firm has an incentive to deviate.*

Figure 4.14 illustrates the effects of  $\phi$  on the degree of mass customization, price, demand, and profit. Firm  $A$  increases its degree of mass customization as mass customization becomes more profitable when moving away from zero. This is because firms lose half of their mass customization efforts when located at the ends of the unit line. Firm  $B$ 's best response is to slightly increase its degree of mass customization in order to attract consumers. As the distance between firms becomes smaller, products become less differentiated, leading to a more intense price competition. Hence, firms have to lower prices when firm  $A$  moves towards firm  $B$ . However, as firm  $A$  offers a higher degree of mass customization than its competitor, it can charge a higher price than firm  $B$ . What can be noticed from Figure 4.14 is that the demand of firm  $A$  is increasing in  $\phi$ . The deviating firm, firm  $A$ , can increase its market share as it serves consumers in its 'backyard' and is competing for the marginal consumer while firm  $B$  loses market share. Overall, it follows that the price reduction outweighs the demand increase of firm  $A$ , resulting in a decrease in profits of both firms. Therefore, firm  $A$  chooses the smallest possible  $\phi$ , which is  $\phi = 0$ . Since firms are symmetric, results can be generalized. Hence, firms do not have an incentive to deviate from their locations at zero and one.

## 4.5 Summary of the results

A mass customized product enhances consumer utility in two ways: first, it reduces consumers' misfit costs; and second, it increases consumers' reservation price due to perceived uniqueness. When one firm adopts mass customization while its competitor sells a standard product, the mass customizing firm is able to charge a higher price and gains market share at the expense of its competitor. The optimal degree of mass customization in a competitive setting is increasing



**Figure 4.14** The optimal choices of the degree of mass customization as well as the resulting prices, profits, and demand are shown for  $t = 1, d = 1, r = 2, b = 6$  dependent on  $\phi$ . The greater  $\phi$ , the greater firm A's distance to zero.

in consumers' reservation price and the complexity of the interaction process while it is decreasing in consumers' sensitivity to product differences and the variable cost of producing a mass customized product. When a firm adopts mass customization, it partially mass customizes if the variable cost of producing the mass customized product is sufficiently high and fully mass customizes if this cost is low enough. When both firms adopt mass customization, the total scope of mass customization increases due to strategic effects.

In equilibrium, both firms choose to offer mass customized products in the first-stage of the game. This situation can be referred to as a prisoner's dilemma since firms have an incentive to deviate from offering a standard product, which is detrimental to their profits. Specifically, a firm has the incentive to switch to mass customization when its competitor offers a standard product and when its competitor offers a mass customized product, both in the benchmark model and the model with consumers' choice of effort. Mass customization reduces differentiation between firms resulting in intensified price competition and, thus, lower profits. Although, profits decrease in the degree of mass customization, strategic effects lead to the adoption of mass customization. The case of cooperative mass customization, i.e. when firms cooperatively choose the optimal degree of mass customization, shows that firms prefer to only sell a standard product. The introduction of consumers' choice of effort and resulting interaction costs leads to the following results. When the interaction process is sufficiently complex, consumers provide only

partial effort. The effort level is increasing in a consumer's distance to the firm. Hence, the better the initial aesthetic and functional fit, the lower the effort level and vice versa. Further, consumers decrease their effort the more complex the interaction process. The higher the degree of mass customization, the higher the effort level of a consumer since the provided effort becomes more effective. As consumers' sensitivity to product differences increases, so does the effort level. Since it is assumed that the interaction process is sufficiently complex so that consumers provide partial effort, the loss in differentiation between firms' products is alleviated, relaxing price competition. Hence, including consumer effort and interaction costs into a model of mass customization shows that the adoption of mass customization is less detrimental to firms' profits than presumed. Further, the optimal degree of mass customization is higher when consumers' strategic role in mass customization is included in the modeling approach. This is due to the fact that a higher degree of mass customization is needed in order to offset the lower reduction of misfit costs due to the provision of partial effort. Because mass customization lowers the differentiation between firms' products and intensifies price competition, consumer surplus is enhanced. Since the integration of consumer effort lowers the loss in differentiation between firms' products, consumer surplus is lower with consumer effort relative to the benchmark model.

When firms face asymmetric variable costs for integrating consumers into the production process, the firm with a cost disadvantage has to lower its degree of mass customization in order to stay profitable. Subsequently, it charges a lower price for the product to still attract consumers. However, the price reduction cannot outweigh consumers' disutility from a lower reduction of misfit costs. Hence, more consumers find it utility maximizing to buy from the competitor. This leads to a lower profit for the disadvantageous firms and a profit increase for the advantageous firm. Contrary to the findings when production costs are asymmetric, the introduction of asymmetries in the complexity of the interaction process leads to an increase in the degree of mass customization of the disadvantageous firm. This results from the fact that consumers find it less attractive to buy from the firm with a more complex interaction process and exert less effort. In order to counterbalance this effect, the disadvantageous firm increases its degree of mass customization. Consequently, it can raise its price. Although, more consumers buy from the firm with the less complex interaction process, both firms can increase their profits.

The analysis of the effect of consumers' preferences for uniqueness on the optimal degree of mass customization reveals the following. The optimal degree of mass customization is increasing in consumers' valuation for uniqueness. When consumers do not value the uniqueness of a mass customized product, firms' find it most profitable to sell a standard product.

When firms offer both a lower-priced standard product and a mass customized product, the optimal degree of mass customization increases. While offering a lower-priced standard product in addition to a mass customized product is margin enhancing (given there is demand for the standard product), offering a mass customized product in addition to a standard product is only profitable when the variable cost of producing a mass customized product is high enough. High variable costs for producing a mass customized product decrease the optimal degree of mass cus-

tomization and relax price competition for the mass customized product as well as allow firms to charge a higher price for their standard products. However, strategic effects in a competitive setting lead to the adoption of a mass customized product in addition to a standard product.

The model developed in this chapter assumes that firms are located at opposite ends of the unit line. Analyzing whether firms have an incentive to move towards each other shows that firms do not deviate from maximum differentiation.



# Chapter 5

## Discussion

In this section, novel insights for a firm's optimal mass customization strategy in a monopoly and duopoly market based on the previously derived findings are presented. The contribution of these insights to the current state of research is highlighted and the implications of these insights for managerial decision making are investigated. Finally, limitations of the models are discussed to reveal possible directions for future research.

### 5.1 Contribution to research

Mass customization is customer-driven: consumers' need for uniqueness pre-dominantly drives the evolution of mass customization; consumers actively participate in the value creation of the firm; consumers are co-producers in the mass customization process. The production of a mass customized product is impossible without the interaction of firms and customers. Consumers have to define their preferences and select the product configuration that best fits these preferences, the firm then individualizes the product based on this customer-specific information. Since consumers choose how much effort to exert in the configuration process, they inherit a strategic role in the mass customization process. Extant studies on mass customization focus on the firm and neglect the consumer's strategic role in the mass customization process. The central contribution of this dissertation is to incorporate the strategic role of the consumer and the interaction between firms and customers into the game-theoretical analysis of mass customization. Advances in production technologies have made it possible for firms to offer mass customized products. This dissertation adopts the view that the degree of mass customization is determined by the extent of customer involvement in the firm's production process. The stages of the production process that the customer is not involved in can be run commonly for all products and compose the product platform. The stages of the production process that the customer is involved in have to be run distinctively for each product after customer-specific information has been received. Since distinct operations are complex and costly, they lead to dis-economies of scale.

Based on this model of strategic company-customer interaction, the dissertation provides novel insights into the optimal mass customization strategy of firms in a number of different settings. By deriving best responses of firms and customers, insight into the decision problems and trade-offs faced by each player in the game is gained.

Several novel insights of strategic company-customer interaction for the optimal mass customization strategy of a monopolist can be derived. *First*, the firm adopts partial mass customization. Conceptual literature suggests that a firm's optimal mass customization strategy lies on a continuum of strategies between pure standardization and pure customization. Analysis indeed reveals that a firm chooses partial mass customization given the dis-economies of scale from running through distinct production stages are sufficiently high. The optimal degree of mass customization is dependent on the dis-economies of scale associated with mass customized production, the complexity of the interaction process, consumers' reservation price, and consumers' sensitivity to product differences. Pure customization is the optimal strategy of the monopolist when the dis-economies of scale from mass customized production are relatively small. *Second*, neglecting the strategic role of the consumer leads to an overestimation of the profitability of the mass customization strategy. Integrating consumer effort and resulting interaction costs reduces consumer gross utility, everything else equal. Consequently, the monopolist has to lower its price, leading to a decreased profit. *Third*, neglecting the strategic role of the consumer leads to over-customization. While marginal benefits of mass customization decrease, marginal costs remain unchanged. As a consequence, the monopolist decreases its degree of mass customization. *Fourth*, neglecting the strategic role of the consumer leads to an underestimation of consumer surplus. Selling mass customized products enables the monopolist to exploit consumers' willingness to pay. In the extreme case of full mass customization, consumer surplus is zero. Integrating consumer effort leads to a higher consumer surplus since the firm's ability to exploit consumers' willingness to pay is mitigated. *Fifth*, the monopolist might only sell a standard product when consumers have no valuation for uniqueness. This dissertation shows that consumers' valuation for the perceived uniqueness of mass customized products is a key determinant for the profitability of mass customization. Since consumers' marginal benefits from mass customization decrease as their perceived uniqueness of mass customized products decreases, a firm's ability to charge a higher price is alleviated. Hence, the firm finds it most profitable to offer a lower degree of mass customization. *Sixth*, the firm might find it profitable to offer both a lower-priced standard product and a mass customized product. Offering both products leads to an increase in the optimal degree of mass customization.

Investigating the strategic interaction between firms and consumers in a competitive setting, provides several novel insights for the optimal mass customization strategy of competing firms.<sup>1</sup>

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<sup>1</sup>Note that only insights from the competitive model that differ from these derived in the monopoly model are presented.



*First*, mass customization can lead to a prisoner's dilemma. Several theoretical studies examine whether mass customization is a profitable strategy. This dissertation contributes to the ongoing debate about the profitability of mass customization compared to mass production. Analysis shows that competing firms in a duopoly have an incentive to adopt mass customization to the detriment of their profits. Mass customization lowers product differentiation, leading to intensified price competition. *Second*, consumer effort is a differentiating factor. This dissertation is the first to theoretically analyze a consumer's strategic role in the mass customization process as discussed in conceptual, experimental, and qualitative literature. Consumers choose to exert partial effort given the interaction process is sufficiently complex. The exerted effort depends on the product's initial and aesthetic fit, the complexity of the interaction process, consumers' sensitivity to product differences, and the degree of mass customization. The provision of partial effort alleviates the loss in differentiation between firms' products from mass customization, relaxing price competition. Hence, consumer effort acts as differentiating factor. Including consumer effort and resulting interaction costs into the model reveals that the adoption of mass customization is less detrimental to firms' profits than presumed. *Third*, neglecting consumer effort leads to under-customization. Incorporating consumers' strategic role in mass customization reveals that the optimal degree of mass customization needs to be higher in order to offset consumers' lower reduction of misfit costs due to the partial provision of effort. *Fourth*, neglecting the strategic role of the consumer leads to an overestimation of consumer surplus. Because mass customization intensifies price competition, consumer surplus is enhanced when firms adopt mass customization. Since consumer effort acts as a differentiating factor, this price war is mitigated, leading to lower consumer surplus. *Fifth*, a more complex interaction process of one firm makes both firms better off. A more complex interaction process leads to a lower effort level. Since a lower effort level increases the differentiation between the firms' products, price competition is mitigated, leading to higher profits for both firms. *Sixth*, firms choose maximum differentiation. The analysis of firms' optimal location on the unit line shows that firms have no incentive to move towards each other.

Finally, the contribution of this dissertation to existing literature is threefold: first, the thesis adds to product differentiation literature by analyzing a firm's optimal product and positioning strategy; second, the modeling approach captures the idea of platform sharing and postponed differentiation that enable cost-efficient mass customization, thereby adding to the literature in operations management; third, the monopoly and duopoly models are an important extension to the existing models of mass customization by incorporating the strategic role of the consumer and strategic interaction between firms and consumers in mass customization. The theoretical framework of this dissertation validates some observations made by academics and practitioners alike. Several new and interesting insights are derived regarding mass customization as a product strategy in a monopoly and duopoly market. The next section investigates the implications of these insights in different market settings.

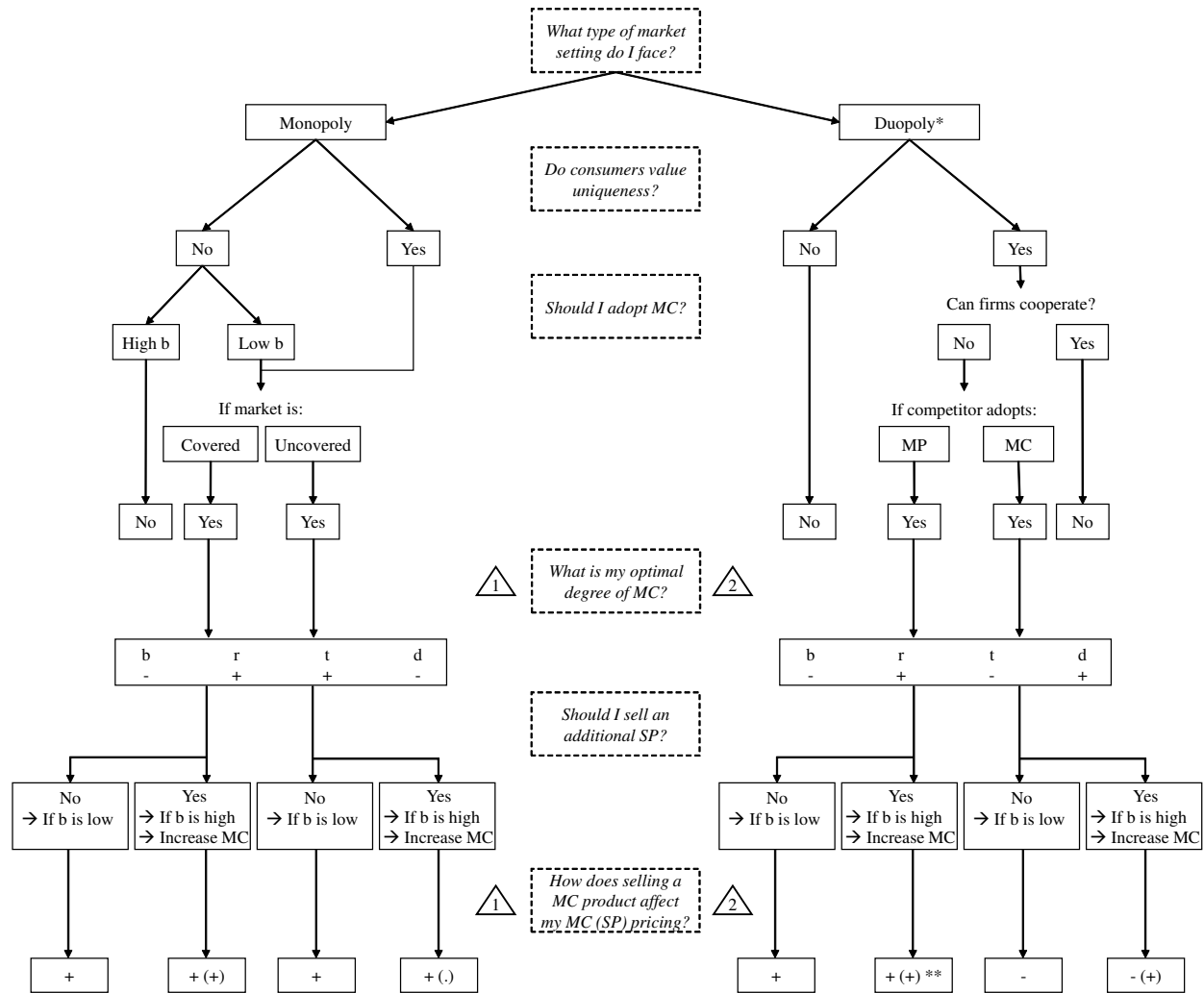
## 5.2 Managerial implications

Determining the optimal mass customization strategy, i.e. finding the optimal degree of mass customization, is a critical managerial decision in many industries. In deciding on the optimal mass customization strategy, firms need to take into account the market setting, the strategic role of the consumer, and prevailing industry conditions. Based on a model of strategic company-customer interaction, this dissertation provides novel insights into the optimal mass customization strategy of firms in different settings by considering decision problems and trade-offs faced by each player involved in the interaction. This section derives implications from these insights for managerial decision-making. Particularly, Figure 5.1 summarizes the main findings and provides a simplified framework that implies what actions a firm should take given the current market and competitive conditions.

In the following, the primary implications are highlighted. The first question management should address is the competitive setting of their firm. As can be noticed in the following, the competitive situation of a firm can have quite contrary managerial implications for the optimal mass customization strategy.

Second, management should pay attention to the consumers they serve. Finding out whether their customers value the uniqueness of mass customized products or not critically affects the profitability of mass customization. Whether consumers value uniqueness or not primarily depends upon the industry the firm operates in. For example, consumers attempt to express their individuality via the clothes they wear. Hence, consumers' valuation for uniqueness may be relatively high in the apparel industry.

Third, management should make the decision whether to adopt mass customization or not. The management of a monopolist that faces consumers that have no valuation for uniqueness should first of all determine the variable production costs of producing a mass customized product. When these costs are sufficiently high, management is well-advised to sell a standard product. When the variable costs of mass customized production are low enough or consumers value uniqueness, management is able to profitably adopt mass customization independent of the fraction of consumers in the industry that is served. The management of a firm facing competition and serving consumers that do not value uniqueness at all is well-advised to sell a standard product. When consumers value uniqueness, the decision whether or not to adopt mass customization depends on a firm's competitor. Given managers of competing firms can bindingly cooperate in their mass customization decision, they are better off not to adopt mass customization. In case managers of competing firms cannot bindingly cooperate in their mass customization decision, management always adopts mass customization independent of the managerial decision of the competing firm. Although, management's best response is to sell a mass customized product in case its competitor adopts mass customization, this scenario is a prisoner's dilemma, because both firms are worse off.



**Figure 5.1** Warning signs: 1 overestimation, 2 underestimation in case of neglecting the strategic consumer role; MC: mass customization, MP: mass production, SP: standard product,  $b$ : unit costs for mass customized production,  $t$ : sensitivity to product differences,  $r$ : reservation price,  $d$ : complexity of the interaction process; + positive, - negative, . unaffected; \* symmetric competitive positioning, \*\* not analytically derived

As a fourth step, management should carefully address the question of the optimal degree of mass customization. The optimal degree of mass customization depends on industry conditions. Specifically, independent of the competitive situation, for high variable costs of producing a mass customized product, it is optimal to integrate consumers only in the final production stages, i.e. choose a small degree of mass customization, and vice versa. Independent of the competitive situation, management is well-advised to integrate consumers early in the production of the product, i.e. choose a high degree of mass customization, when consumers' reservation price for the product is high (and vice versa). Management should pay attention to consumers' sensitivity to product differences and the complexity of the interaction process since these two determinants of the optimal degree of mass customization have contrary implications depending on the competitive situation. For the management of a monopolist firm, the optimal degree of mass

customization is higher the more sensitive consumers are to product differences while management's best response is to implement a lower degree of mass customization the more complex the interaction process is. For the management of a competing firm, it is advisable to integrate consumers only in the final stages of the production process when consumers are sensitive to product differences. Otherwise, management finds itself in a situation of price war. Contrary to one's expectations, management should integrate its consumer early in the production process when interacting with consumers is complex. Since consumers bear higher costs for configuring the product, this creates differentiation, i.e. mitigates price war, between competing firms. Management should note that neglecting the strategic role of the consumer at this point leads to over-customization in a monopoly setting and under-customization in a competitive setting.

Fifth, management should decide whether to offer only a mass customized product or to additionally offer a lower-priced standard product. Generally, it is only profitable to offer both products in case variable costs for mass customized production are sufficiently high. Otherwise, management is better off to only sell a mass customized product. In case management decides to offer both products, this implies that the optimal degree of mass customization is higher than when only the mass customized product is sold.

Finally, management should address the question of how to price its products. When the firm is a monopolist, selling a mass customized product, in general, enables management to charge a higher price. In case an additional standard product is sold, the price of the standard product can be increased in case every consumer in the industry purchases a product and should be unchanged in case only parts of the industry are served. Management of a competing firm should be aware that selling a mass customized product has a contradicting effect on pricing dependent on the competitor's product strategy. In case the competitor operates as a mass producer, management is able to charge a higher price for its mass customized product and can also increase the price of the standard product. In case the competitor also operates as a mass customizer, however, management is advised to lower its price - this situation is a prisoner's dilemma. Otherwise, the firm loses consumers to the competing firm. Given management decided to offer an additional standard product, it can increase the price for the standard product. Management should be aware that neglecting the strategic role of the consumer at this point leads to an overestimation of pricing power in a monopoly and underestimation of pricing power in a competitive situation.

Going beyond this framework, several implications for the optimal mass customization strategy of the management of competing firms with asymmetric competitive positions can be derived. The management of a firm with a production cost (dis)advantage should note that the optimal degree of mass customization (decreases) increases and that this implies the firm should (lower) increase its price. The management of a firm with a (dis)advantage in interacting with its consumers should note that the optimal degree of mass customization (increases) decreases, leading to a greater pricing power for both firms.

To briefly reconcile the introductory examples with the implications derived in this dissertation, the following is noted. Levi's first attempt to mass customization involved consumers early in the production process although, the production costs for a mass customized jeans were tremendous. This mass customization strategy proved to be unprofitable. From the framework it follows that high variable production costs imply a low degree of mass customization, i.e. the integration of consumers in the final stages of the production process. Since Adidas operates as a mass customizer in the footwear industry with mass producing competitors, the company can charge approximately 30 percent more for a mass customized pair of sneakers. This shows that Adidas is well aware of the strategic role of its consumers. Neglecting this role would lead to an underestimation of the company's pricing power. The managerial implications derived in this section emphasize where mass customization offers the most value, that mass customization is not the right product strategy for every firm, and that the decision of the optimal mass customization strategy always includes the integration of a consumer's decision problem.

### 5.3 Limitations and future research directions

The purpose of game-theoretical models is to analyze real-life decisions by making specific assumptions that simplify reality. While this enables the analytical study of strategic effects, the assumptions made constrain the solution space. Hence, only particular aspects of real-life problems can be examined while others are left unconsidered. The monopoly and duopoly model introduced in Chapters 3 and 4 are based on specific assumptions that simplify the situation. This section discusses possible limitations that arise from these assumptions and ways to reduce them. Particularly, it is examined how future research could address these limitations, which concern the cost structure of the firm, consumers' utility function, product line design, pricing, and the timing of the game.

#### 5.3.1 Cost structure of the firm

The monopoly and duopoly model assume that variable costs for integrating consumers into the production process  $b_i$  are increasing in the degree of mass customization  $k_i$ , representing dis-economies of scale from mass customized production, while variable costs for a standard product  $a$  are normalized to zero. Recall that unit production costs are given by

$$c = a + (b_i - a) k_i^2$$

Fixed costs are neglected. While this set-up allows to focus on the strategic effect of dis-economies of scale on the optimal degree of mass customization, several limitations arise.

### Fixed costs for mass customization

The literature review, for example Agrawal et al. (2001) and Zipkin (2001), suggests that firms face fixed costs due to increased set-up costs and investment costs in flexible machinery as well as production technology. Another fixed cost driver is the process of eliciting customer preferences as it requires the set-up of an elaborated system (Piller and Moeslein 2002, Zipkin 2001). This dissertation assumes fixed costs associated with mass customization to be zero since an upfront investment will pay itself off in the long-run. Additionally, a fixed upfront investment that does not depend on the degree of mass customization leads to identical results.

Syam and Kumar (2006) include fixed costs of a mass customizing firm that do not depend on the degree of mass customization into their model and find that normalizing these costs to zero does not change the main findings. The authors suggest that the inclusion of fixed costs reflects the commitment by a firm to offer mass customized products. A number of studies includes fixed costs that depend on the degree of mass customization. Mendelson and Parlaktürk (2008a), for example, include fixed costs  $S(k)$  that are convex and non-decreasing in the degree of mass customization  $k$ .<sup>2</sup> Also Dewan et al. (2000) and Dewan et al. (2003) adopt fixed costs for acquiring manufacturing flexibility and information technology, which depend on the firm's degree of mass customization  $x$ . The authors suggest fixed costs of  $ax^2 + bx$ , where  $ax^2$  is called the flexibility cost and  $bx$  denotes the information cost.

When fixed costs depend on the degree of mass customization, these costs have a strategic effect on the equilibrium solution. Future research could address the fixed costs of mass customization in a differentiated way, similar to Dewan et al. (2000) and Dewan et al. (2003), to examine which investment necessary for the adoption of mass customization has the greatest strategic effect. A conceivable fixed cost function that depends on the degree of mass customization  $F(k_i)$  could be

$$F(k_i) = \omega + mk_i^2 + ik_i^2$$

with  $F(k_i) > 0$ ,  $F'(k_i) \geq 0$ , and  $F''(k_i) \geq 0$ .  $\omega$  represents the commitment of a mass customizing firm,  $m$  stands for the investment in flexible machinery, and  $i$  for the investment in technology that enables the gathering and transferring of consumers-specific information. This fixed cost function  $F(k_i)$  reflects an up-front commitment and is convexly increasing in the degree of mass customization.

### Inventory costs vs. lead time

The literature review suggests that firms compete with delivery times next to production costs (Da Cunha et al. 2007). While the manufacturing of mass customized product parts is postponed

<sup>2</sup>Specifically, the authors assume that  $S(k) > 0$ ,  $S'(k) \geq 0$ ,  $S''(k) \geq 0$  for all  $k \in [0, 1]$ .

until the customer order is received, standard products are immediately available. Hence, consumers have to wait and incur waiting costs for customized products. At the same time, this implies that the mass customizing firm incurs lower inventory holding costs than the mass producing firm. As the monopoly and duopoly paper of this dissertation focus on production costs only, this trade-off is not covered.

There exists literature covering this trade-off. Mendelson and Parlaktürk (2008b), for example, model the competition between a mass customizing and a mass producing firm by including inventory holding costs and replenishment time for the mass producing firm and customization time for the mass customizing firm with consumers sensitive to waiting time.

What has not been studied so far is the sourcing decision of a mass customizing firm that chooses the optimal degree of mass customization. It is indeed observable that products with a lower degree of customer integration exhibit shorter lead times than products with a high level of customer involvement. Consumers have to wait four to six weeks for a customer-specific mi adidas sneaker and only four work days for fast personalization, i.e. name or logo, of the product. Future research could address this issue by integrating the bi-sourcing decision of a mass customizing firm. In mass customization, the duality between the product platform and the customized components allows for dual approaches to supplier selection (bi-sourcing). The product platform can be pre-produced and is sensitive to sourcing costs while quick delivery of mass customized product parts is important. Similar to the sole-sourcing problem in Wu and Zhang (2014), the trade-off could be modeled by integrating a firm's choice of suppliers. There are two types of suppliers, one incurs low production costs but high lead time while the other one has a short lead time but high production costs. In addition to the utility function used in this dissertation, consumers incur a disutility from waiting. The mass customizing firm could then determine which share of the production process to source to which supplier.

### 5.3.2 Consumers' utility function

The utility function developed in this dissertation assumes that consumer utility is increasing in consumers' reservation price while it is decreasing in a consumer's distance to the firm, which can be reduced by joint consumer effort and mass customization, the price, and interactions costs. Recall that the utility function in the duopoly setting is given by

$$U_i = r(1 + k_i) - t \left( \max \left\{ 0, y_i - e_\theta \frac{k_i}{2} \right\} \right)^2 - \frac{1}{2} d_i e_\theta^2 - p_i$$

#### Consumer characteristics

This dissertation assumes that, apart from heterogeneous preferences for product attributes that are modeled on the unit line, all consumers have identical characteristics. This assumption may

not hold true in reality. However, it is assumed that the differences between consumers cancel out so that the main findings of the models still hold true when the assumption of identical consumer characteristics is modified. However, it might be interesting to unveil strategic effects of different consumer segments. Existing literature, for example Syam and Kumar (2006) and Wong and Lesmono (2013), introduce two consumer segments that differ in their characteristics. Consumers in the model by Syam and Kumar (2006) differ in their intensity of preference for products, i.e. the first consumer segment incurs a higher disutility when the offered product does not match their ideal product than the second segment. Wong and Lesmono (2013) include two consumer segments that differ in their valuation for product customization and importance for lead time.

The monopoly and duopoly model of this dissertation provide several options to include differences in consumer characteristics. Next to the differences in consumer characteristics already covered in existing literature, future research could, for example, address differences in perceived effort costs. Similar to Syam and Kumar (2006) and Wong and Lesmono (2013), two consumer segments could be introduced. One consumer segment perceives exerting effort to customize a product as negative while the other segment perceives the customization process as positive.

### Relation of interaction costs and initial aesthetic and functional fit

In the monopoly and duopoly model discussed in this dissertation, consumers face interaction costs for exerting effort of

$$\frac{1}{2}de_{\theta}^{*2},$$

with

$$e_{\theta}^{*} = \frac{2tk_i y_i}{2d + tk_i^2}$$

It follows that interaction costs are only implicitly dependent on a consumer's distance to firm  $i$ , given by  $y_i$ , through the choice of the optimal effort level  $e_{\theta}^{*}$ . Hence, interaction costs are only implicitly dependent on a consumer's initial preference fit and independent on the preference fit achieved through the customization process. This assumption limits the monopoly and duopoly model since Franke and Schreier (2010) find that the interaction of preference fit and perceived process effort impacts the value of a customized product. In an experimental study, the authors show that the provided effort is only perceived as negative when the outcome of the process displays a low preference fit.

Future research could alter interaction costs to cover for the interaction of preference fit and perceived process effort and compare a consumer's optimal effort level when the costs for the



exerted effort are decreasing in either the initial preference fit or the preference fit achieved through the customization process.

### **Return policy**

Since mass customized products are tailored to meet an individual customer's preferences, the vast majority of firms that offer mass customized products have a no return policy. This can be illustrated with the example of Adidas. For standard sneakers, Adidas guarantees a 100 day refund period while custom and personalized mi adidas sneakers are not returnable. Because the outcome of the mass customized product is not that certain and is first revealed when the package arrives, consumers may derive a negative utility from the fact that they cannot return the customized product.

To all conscience, the effect of a no return policy on the profitability of mass customization and the optimal degree of mass customization has not yet been studied in game-theoretical research. Future research could alter consumers' utility function to cover the disutility from having to purchase a mass customized product that falls short of expectations.

### **5.3.3 Product line design**

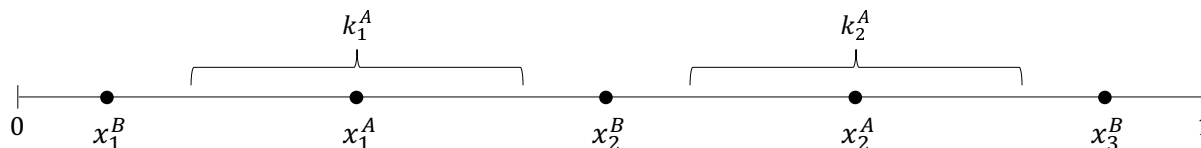
The model of this dissertation assumes that a mass customizing firm can offer an interval long scope of mass customization around its location on the unit line while a mass producing firm offers one standard product. For an illustration please refer to the respective model framework. While this simplified display of reality allows for an analytical derivation of results, it contains several limitations.

#### **Mass customization scope**

As can be noticed, most mass customizing firms offer several standard products that can be mass customized. Future research could alter the mass customization decision of a firm. Instead of determining the general degree of mass customization, firms could choose several uncontinuous mass customization scopes as in Alexandrov (2008), who models product flexibility via interval-long products.

#### **Product variety**

To compare the profitability of mass customization and mass production, the mass producing firm is assumed to produce one standard product. However, single-product firms are rare in the current market environment. Future research could alter the decision scope of a mass producing firm to allow for the production of various standard products as in Alptekinoglu and Corbett (2008) and Mendelson and Parlaktürk (2008b), just to name a few.



**Figure 5.2** Firms' standard products and mass customization scopes are represented on a unit line.

Figure 5.2 illustrates a potential model set-up. Firm  $A$ , the mass customizing firm, decides how many products ( $x_1^A$  and  $x_2^A$ ) to offer and determines the degree of mass customization of each product ( $k_1^A$  and  $k_2^A$ ). Firm  $B$ , the mass producing firm, decides how many products to produce ( $x_1^B$ ,  $x_2^B$ , and  $x_3^B$ ).

### 5.3.4 Pricing

Mass customization allows a firm to differentiate its price on a customer level since it is able to charge each consumer an individual price based on her customized configuration. Mymuesli, for example, charges an individual price for each muesli configuration as different ingredients have different prices. Thereby, companies are able to capture individual differences in the willingness-to-pay between different consumers and extract more consumer surplus. This dissertation project, however, models the situation where a firm charges the same price for all customized products even if customers choose different effort levels. This is analog to many company examples that adopt mass customization in a horizontally differentiated market.

Literature has already discussed the differences evolving from game-theoretical models with and without price differentiation in the context of mass customization and has not yet come to a consensus. Syam and Kumar (2006), for example, show that their main results are not sensitive to the assumption of uniform prices. Mendelson and Parlaktürk (2008a) find that price differentiation leads to a broader adoption of mass customization while the degree of mass customization may be lower when prices are on a customer-specific level. The authors further show that price and product customization are substitutes.

Although, the issue of price differentiation has been widely discussed in the literature and also studied jointly with the topic of mass customization, there is still room for future research. Integrating price differentiation into the model of this dissertation could result in an additional trade-off for consumers. Exerting effort could lead to interaction costs on the one hand and a higher price on the other. Hence, consumers would balance the improved preference fit not only with effort costs but also with a higher price.

### 5.3.5 Multi-period model

This dissertation considers a one-period model where the interaction between the firm and consumers takes place only once. In reality, firms and consumers have long-term relations. To all conscience, so far no game-theoretical model in the context of mass customization exists that

covers a firm's benefits and problems arising from long-term relations with its customers and long-term competition. Future research could study mass customization in a multi-period model to examine, for example, the competition between an incumbent and an entrant, consumer loyalty, and the resale market for mass customized goods.

### **Incumbent and entrant**

During the evolution of mass customization, a couple of firms in each industry can be seen as the leaders in adopting mass customization. Levi's, for example, was the first to offer mass customized jeans. Gradually, more firms started to offer mass customized jeans. A few studies, for example Dewan et al. (2003), exist that examine the effect of a first mover, i.e. leader and follower, in mass customization. In reality, however, a large number of firms offering mass customized products can be referred to as start-ups. To the best of one's knowledge, no theoretical work on mass customization yet exists that examines the competition between an incumbent firm that adopts mass customization after having been an established mass producer and entrants that "start-up" with a mass customized product after having observed the incumbent's decision.

### **Consumer loyalty**

Mass customization allows firms to build up a stable relationship with its customers due to the creation of switching costs, which in turn increase loyalty (Piller et al. 2004, Piller and Möslin 2002).

Future research could cover this issue in a competitive setting as follows. Each period presents a new product life cycle so that consumers buy in each period. It is assumed that consumers incur effort costs only once for a firm, i.e. if consumers buy firm *A*'s product in period 1, they will incur effort costs in period 2 when they buy from firm *B* but not when they buy from firm *A* (and vice versa). Further, the fit of the product is noisy at the beginning of the customization process and uncertainty disappears when the product is delivered to the consumer. Hence, consumers have no incentive to switch the firm in the second period if they were satisfied with the outcome of the customization process in the first period since switching results into renewed effort costs. Consumers, who were not satisfied with the outcome of the customization process in the first period, balance renewed effort costs with misfit costs.

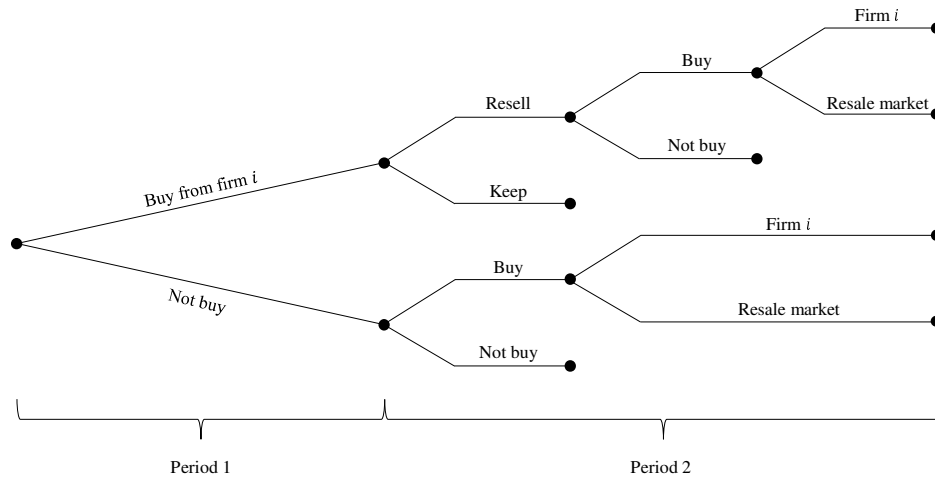
### **Resale market**

So far, the model assumes that the mass customized product is sold in one market only and that all consumers buy<sup>3</sup>. This assumption could be removed by introducing a second market - the resale market. Hence, consumers who have bought a mass customized product can resell it in a consumer resale market. This implies that the utility function of a consumer is extended to cover for a potential resale value and a second-period value. As the potential resale value depends

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<sup>3</sup>The monopoly model is not constraint to the assumption of a covered market.

on how good the product fits other consumers' preferences, consumers may tend to lower their effort in order to personalize the product only slightly. Consequently, firms will lower their degree of mass customization. Figure 5.3 illustrates a conceivable decision tree that includes each consumer's possible actions in period 1 and period 2 when a resale market is introduced in period 2.



**Figure 5.3** The decision tree depicts each consumer's choices in period 1 and period 2 when a resale market is introduced in period 2.

## Chapter 6

# Conclusion

Advanced manufacturing and information technologies, changing consumer markets as well as consumers' growing need for individualism have increased the interest of practitioners and academics alike in mass customization in the recent past. Mass customizing products to fit consumers' needs is prevalent in almost all industries today. However, the introductory examples show that a firm's optimal mass customization strategy is still not that clear. The profitable implementation of mass customization has been more difficult to achieve than presumed. The initial attempt to mass customization of a number of firms failed, because it proved to be unprofitable, while others have successfully established mass customization as a product strategy. This dissertation adopts the view that the extent of customer integration into the production process determines the degree of mass customization. Firms that adopt mass customization face a trade-off between tailoring products to customers' needs and cost-efficient production. To determine the optimal degree of mass customization, a firm needs to balance the benefits and costs associated with mass customization. While most companies regarded their customers as passive in the past, the most distinctive feature of mass customization is the strategic role of the consumer in the mass customization process. To configure a mass customized product, consumers interact with the firm, for example via an online configurator, in order to transmit customer-specific information. This interaction requires the definition of preferences and cognitive effort. Hence, each consumer faces the trade-off between tailoring a product to her needs and interaction costs. The overarching question that this dissertation tries to answer is *what is a firm's optimal mass customization strategy?* In order to answer this question, the dissertation studies a firm's mass customization decision in a game-theoretical model that combines the decision problems faced by each player in the interaction.

The analysis of the literature in Section 2 discusses the empirical, experimental, conceptual, and game-theoretical contributions of past research on the topic of mass customization. As far as the profitability of mass customization relative to mass production is concerned, theoretical literature has made a substantial progress. However, only a few studies exist that integrate a firm's optimal degree of mass customization as critical decision variable in their modeling approaches in order

to assess a firm's optimal mass customization strategy. The evaluation of the literature in Subsection 2.4 helps to identify the current state of research on product customization. To stress a point, while conceptual, experimental, and qualitative research has highlighted the strategic role of the consumer and the strategic interaction between firms and consumers in mass customization, theoretical research has not yet taken these issues into account. The monopoly and duopoly model developed in this dissertation are the first to address the strategic role of the consumer and the strategic interaction between firms and consumers in mass customization.

The monopoly model extends the theoretical research on mass customization by integrating a consumer's choice of effort as decision variable. The monopolist is located in the center of the Hotelling (1929) line and determines its optimal degree of mass customization and pricing. All production stages that do not involve the consumer are run commonly in advance. Having observed the firm's decision, consumers choose an individual effort level and make a purchasing decision. To benefit from mass customization, consumers have to exert effort. Exerting effort, however, leads to interaction costs. After having received customer-specific information, the firm distinctively runs through all production stages that involve a consumer's preferences. Running through production stages distinctively involves dis-economies of scale. Several interesting and novel insights on a firm's optimal mass customization strategy are derived. Given the complexity of the interaction process is sufficiently high, not every consumer chooses full effort. Particularly, the effort level is increasing in a consumer's distance to the firm. Given the dis-economies of scale arising from distinct operations are sufficiently high, the firm chooses partial mass customization. Neglecting consumers' decision problem leads to over-customization. Only when consumers have no valuation for uniqueness and dis-economies of scale are high, the monopolist finds it most profitable to produce a standard product. The monopolist can charge a higher price for its mass customized product and, in case the market is uncovered, increases its market share. Neglecting consumers' decision problem leads to an overestimation of the monopolist's pricing power. Since the firm is able to exploit consumers' willingness to pay, consumers are, in general, worse off with mass customization. Examining the optimal composition of a firm's product line, i.e. whether the firm finds it most profitable to offer a mass customized and a standard product, reveals that the monopolist may find it profitable to offer both products dependent on its variable production costs for mass customized production. Interestingly, when the monopolist offers both products, the optimal degree of mass customization is higher.

In the competitive setting, it is assumed that firms locate at the opposite ends of the unit line and make their decisions simultaneously. Mass customization in a duopoly leads to a prisoner's dilemma since both firms have an incentive to adopt mass customization to the detriment of their profits. Mass customization decreases the differentiation between firms' products and, therewith, intensifies price competition. Neglecting consumers' decision problem leads to an underestimation of a firm's pricing power in a competitive setting. If firms can cooperate on their mass customization decision, they will not customize at all. Symmetric firms choose symmetric levels of mass customization. Neglecting the decision problem faced by consumers leads to under-

customization. The analysis of firm asymmetries in the production costs and interaction process leads to contrary implications. While a firm with a disadvantage in variable production costs finds it optimal to lower the degree of mass customization and sees a decline in its profit, a firm with a disadvantage in interacting with its customers finds it optimal to increase the degree of mass customization, leading to a profit increase for both firms. Consumer surplus is higher under mass customization than under mass production. Similar to the monopoly case, firms choose to sell a standard product when consumers do not value uniqueness and firms may find it profitable to offer a standard and a mass customized product, leading to an increase in the optimal degree of mass customization. The analysis of a firm's location choice reveals that firms choose maximum differentiation.

The contribution of these insights into the current state of research in Subsection 5.1 reveals that this thesis contributes to the product differentiation literature, the literature on operations management that focuses on cost-efficient ways to manufacture high variety, and the literature on product customization. Subsection 5.2 investigates the implications of the insights and highlights the actions a firm should take given the current market and competitive conditions. The monopoly and duopoly model of this dissertation exhibit several limitations that can be addressed by future research, concerning the cost structure of the firm, consumers' utility function, pricing, and the periodicity of the game (Subsection 5.3). To conclude, the thesis attempts to provide novel insights on a firm's optimal mass customization strategy that can be transferred to managerial decision making by taking into account the strategic role of the consumer and the strategic interaction between firms and consumers.





# Appendices



## Appendix A

# Monopoly model

When the firm only sells a standard product, consumer utility is given by Equation 3.1. A type- $\theta$  consumer purchases the standard product iff

$$\begin{aligned} U &\geq 0 \\ r - t \left( \theta - \frac{1}{2} \right)^2 - p &\geq 0 \end{aligned} \tag{A.1}$$

Solving A.1 with respect to  $\theta$ , yields the consumer (to the left and to the right of the firm), who is indifferent between buying or not, denoted by  $\underline{\theta}$  and  $\bar{\theta}$ , respectively

$$\begin{aligned} \underline{\theta} &= \frac{1}{2} - \frac{1}{t} \sqrt{t(r-p)} \\ \bar{\theta} &= \frac{1}{2} + \frac{1}{t} \sqrt{t(r-p)} \end{aligned} \tag{A.2}$$

The resulting demand  $D$  is given by

$$D = \bar{\theta} - \underline{\theta} = 2\sqrt{\frac{1}{t}(r-p)} \tag{A.3}$$

Inserting A.3 into firm's profit function given by Equation 3.3, the firm's profit function becomes

$$\pi = 2\sqrt{\frac{1}{t}(r-p)}p \tag{A.4}$$

To find the optimal price, the firm maximizes A.4 with respect to  $p$  subject to  $D \leq 1$

$$\begin{aligned} \frac{\partial}{\partial p} \pi \left( 2\sqrt{\frac{1}{t}(r-p)}p \right) \\ \text{s.t. } 2\sqrt{\frac{1}{t}(r-p)} \leq 1 \end{aligned} \quad (\text{A.5})$$

The Lagrangian  $\mathcal{L}(p, \lambda)$  describes the firm's price optimization problem

$$\mathcal{L}(p, \lambda) = 2\sqrt{\frac{1}{t}(r-p)}p + \lambda \left( 2\sqrt{\frac{1}{t}(r-p)} - 1 \right) \quad (\text{A.6})$$

Solving the Lagrangian, the first-order condition becomes

$$\frac{\partial}{\partial p} \mathcal{L} : -\frac{1}{\sqrt{rt-pt}}(3p - 2r + \lambda) = 0 \quad (\text{A.7})$$

The  $p$  that solves A.7 is given by<sup>1</sup>

$$p = \frac{2}{3}r - \frac{1}{3}\lambda \quad (\text{A.8})$$

The complementary slackness condition is given by

$$\lambda \left( 2\sqrt{\frac{1}{t}(r-p)} - 1 \right) = 0 \quad (\text{A.9})$$

A.9 is either solved with  $\lambda = 0$ , in which case the constraint is not binding, or with  $\lambda > 0$ , in which case the constraint holds.

When the constraint is not binding, i.e.  $\lambda = 0$ , A.8 reduces to

$$p^* = \frac{2}{3}r \quad (\text{A.10})$$

When the constraint is binding, i.e.  $\lambda > 0$ , the optimal price  $p^*$  that solves A.9 is given by

$$p^* = r - \frac{1}{4}t \quad (\text{A.11})$$

---

<sup>1</sup>A.8 defines a maximum since  $\frac{\partial^2}{\partial p^2} \mathcal{L} : -\frac{1}{2}t \frac{(4r-3p+\lambda)}{(rt-pt)^{\frac{3}{2}}} \leq 0$ .

The  $\lambda$  that solves A.7 for this  $p^*$  is given by

$$\begin{aligned} r - \frac{1}{4}t &= \frac{2}{3}r - \frac{1}{3}\lambda \\ \lambda &= \frac{3}{4}t - r \end{aligned} \quad (\text{A.12})$$

Thus, there are two possible solutions. Either

$$\begin{aligned} p^* &= \frac{2}{3}r, \quad \lambda = 0; \quad \text{or} \\ p^* &= r - \frac{1}{4}t, \quad \lambda = \frac{3}{4}t - r \end{aligned} \quad (\text{A.13})$$

Which of these two solutions solves the maximization problem, depends on the values of the parameters. The first solution solves the maximization problem iff

$$\begin{aligned} 2\sqrt{\frac{1}{t}\left(r - \frac{2}{3}r\right)} &\leq 1 \\ r &\leq \frac{3}{4}t \end{aligned}$$

Otherwise, i.e. if consumers' reservation price  $r$  is high enough so that all consumers buy, the second solution solves the maximization problem. When  $r \leq \frac{3}{4}t$  (the market is uncovered), the profit of the monopolist is given by

$$\pi = 2\sqrt{\frac{1}{t}\left(r - \frac{2}{3}r\right)}\frac{2}{3}r = \sqrt{\frac{16r^3}{27t}} \quad (\text{A.14})$$

This leads to a consumer surplus of

$$\begin{aligned} CS &= \int_{\underline{\theta}}^{\bar{\theta}} U d\theta = \int_{\underline{\theta}}^{\bar{\theta}} \left( r - t\left(\theta - \frac{1}{2}\right)^2 - \frac{2}{3}r \right) d\theta \\ &= 2 \left[ r\theta - \frac{1}{3}t\left(\theta - \frac{1}{2}\right)^3 - \frac{2}{3}r\theta \right]_{\underline{\theta}}^{\bar{\theta}} = \sqrt{\frac{16r^3}{243t}} \end{aligned} \quad (\text{A.15})$$

When  $r > \frac{3}{4}t$  (the market is covered), the profit of the monopolist is given by

$$\pi = r - \frac{1}{4}t \quad (\text{A.16})$$

In this case, consumer surplus is given by

$$\begin{aligned} CS &= 2 \int_0^{\frac{1}{2}} U \, d\theta = 2 \int_0^{\frac{1}{2}} \left( r - t \left( \theta - \frac{1}{2} \right)^2 - \left( r - \frac{1}{4}t \right) \right) \, d\theta \\ &= 2 \left[ r\theta - \frac{1}{3}t \left( \theta - \frac{1}{2} \right)^3 - \left( r - \frac{1}{4}t \right) \theta \right]_0^{\frac{1}{2}} = \frac{1}{6}t \end{aligned} \quad (\text{A.17})$$

### A.1 Model without consumer effort

The term  $\left( \left| \theta - \frac{1}{2} \right| - \frac{k}{2} \right)$  maximizes the distance between the firm and the marginal consumer,  $\underline{\theta}$  and  $\bar{\theta}$ , respectively, since

$$\begin{aligned} \frac{1-k}{2} - \underline{\theta} &= \frac{1-k}{2} - \left( \frac{1-k}{2} - \sqrt{\frac{1}{t}(-p+r+kr)} \right) = \sqrt{\frac{1}{t}(-p+r+kr)} \geq 0 \\ \bar{\theta} - \frac{1+k}{2} &= \frac{1+k}{2} + \sqrt{\frac{1}{t}(-p+r+kr)} - \frac{1+k}{2} = \sqrt{\frac{1}{t}(-p+r+kr)} \geq 0 \end{aligned}$$

Given  $p \leq r(1+k)$ , i.e. demand is defined, the above inequalities hold.

**Proof of Lemma 1.** Inserting the demand function given by Equation 3.7 into the firm's profit function given by Equation 3.3, yields

$$\pi = \left( 2\sqrt{\frac{1}{t}(r(1+k)-p)} + k \right) (p - bk^2) \quad (\text{A.18})$$

To find the optimal price, the firm maximizes A.18 with respect to  $p$  subject to  $D \leq 1$

$$\begin{aligned} \frac{\partial}{\partial p} \pi &\left( \left( 2\sqrt{\frac{1}{t}(r(1+k)-p)} + k \right) (p - bk^2) \right) \\ &\text{s.t. } 2\sqrt{\frac{1}{t}(r(1+k)-p)} + k \leq 1 \end{aligned} \quad (\text{A.19})$$

The Lagrangian  $\mathcal{L}(p, \lambda)$  describes the firm's price optimization problem

$$\mathcal{L}(p, \lambda) = \left( 2\sqrt{\frac{1}{t}(r(1+k)-p)} + k \right) (p - bk^2) + \lambda \left( 2\sqrt{\frac{1}{t}(r(1+k)-p)} + k - 1 \right) \quad (\text{A.20})$$

Solving the Lagrangian, the first-order condition becomes

$$\frac{\partial}{\partial p} \mathcal{L} : \frac{1}{\sqrt{t(r(1+k)-p)}} \left( 2r(1+k) + bk^2 - 3p - \lambda + k\sqrt{t(r(1+k)-p)} \right) = 0 \quad (\text{A.21})$$

The  $p$  that solves A.21 is given by<sup>2</sup>

$$p = \frac{1}{18} \left( 12r(1+k) + 6bk^2 - 6\lambda - k^2t + k\sqrt{t(12\lambda + k^2t + 12r(1+k) - 12bk^2)} \right) \quad (\text{A.22})$$

The complementary slackness condition is given by

$$\lambda \left( 2\sqrt{\frac{1}{t}(r(1+k)-p)} + k - 1 \right) = 0 \quad (\text{A.23})$$

The complementary slackness condition is either solved with  $\lambda = 0$ , in which case the constraint is not binding, or with  $\lambda > 0$ , in which case the constraint holds.

When the constraint is not binding, i.e.  $\lambda = 0$ , A.22 reduces to

$$p^* = \frac{1}{18} \left( 12r(1+k) + 6bk^2 - tk^2 + k\sqrt{t(tk^2 + 12r(1+k) - 12bk^2)} \right) \quad (\text{A.24})$$

When the constraint is binding, i.e.  $\lambda > 0$ , the optimal price  $p^*$  that solves A.23 is given by

$$p^* = r(1+k) - \frac{1}{4}t(k-1)^2 \quad (\text{A.25})$$

The  $\lambda$  that solves A.21 for this  $p^*$  is given by

$$r(1+k) - \frac{t(k-1)^2}{4} = \frac{12r(1+k) + 6bk^2 - 6\lambda - k^2t + k\sqrt{t(12\lambda + k^2t + 12r(1+k) - 12bk^2)}}{18}$$

$$\lambda = bk^2 - r(1+k) + \frac{1}{4}t(5k-3)(k-1) \quad (\text{A.26})$$

Thus, there are two possible solutions. Either

---

<sup>2</sup>Note that this is the only solution satisfying  $\frac{\partial}{\partial r} p \geq 0$ . A.22 defines a maximum since  $\frac{\partial^2}{\partial p^2} \mathcal{L} : -\frac{1}{2} \frac{t(4r(1+k) - bk^2 - 3p + \lambda)}{(rt - pt + krt)^{\frac{3}{2}}} \leq 0$  given  $p \leq \frac{1}{3}\lambda + \frac{4}{3}r(k+1) - \frac{1}{3}bk^2$ . Note that this holds true for A.22.

$$\begin{aligned}
p^* &= \frac{1}{18} \left( 12r(1+k) + 6bk^2 - tk^2 + k\sqrt{t(tk^2 + 12r(1+k) - 12bk^2)} \right), \quad \lambda = 0; \quad \text{or} \\
p^* &= r(1+k) - \frac{1}{4}t(k-1)^2, \quad \lambda = bk^2 - r(1+k) + \frac{1}{4}t(5k-3)(k-1) \quad (\text{A.27})
\end{aligned}$$

Which of these two solutions solves the maximization problem, depends on the values of the parameters. The first solution solves the maximization problem iff

$$\begin{aligned}
\frac{2}{t} \sqrt{rt - \left( \frac{1}{18} \left( 12r(1+k) + 6bk^2 - tk^2 + k\sqrt{t(tk^2 + 12r(1+k) - 12bk^2)} \right) \right) t + krt + k} \leq 1 \\
\frac{3t - 8tk + 4bk^2 + 5tk^2}{4(1+k)} \geq r
\end{aligned}$$

Otherwise, the second solution solves the maximization problem, i.e. if  $r$  is sufficiently high so that all consumers buy. For the following analysis, both solutions are analyzed.

For  $\lambda = 0$ , the sensitivities of the price with respect to the model parameters are<sup>3</sup>

$$\begin{aligned}
\frac{\partial}{\partial k} p &: \frac{t(12bk^2 - tk^2 - 6r - 9kr) + (tk - 6r - 6bk)\sqrt{t(k^2t + 12r(1+k) - 12bk^2)}}{t(12bk^2 - 12r(1+k) - tk^2)} \\
&\begin{cases} \geq 0 & \text{if } b \leq \frac{1}{12k^2}(6r + k^2t + 9kr) \\ < 0 & \text{if } b > \frac{1}{12k^2}(6r + k^2t + 9kr) \end{cases} \\
\frac{\partial}{\partial b} p &: \sqrt{k^2t^2 - 12bk^2t + 12rkt + 12rt} - kt \begin{cases} \geq 0 & \text{if } b \leq \frac{1}{k^2t}(r + krt) \\ < 0 & \text{if } b > \frac{1}{k^2t}(r + krt) \end{cases} \\
\frac{\partial}{\partial r} p &: \frac{2}{3} \frac{\left( \sqrt{t(k^2t + 12r(1+k) - 12bk^2)} + 9kt \right) (1+k)}{\sqrt{t(k^2t + 12r(1+k) - 12bk^2)}} \geq 0 \\
\frac{\partial}{\partial t} p &: \frac{k \left( 6r(1+k) - 6bk^2 + tk^2 - k\sqrt{t(k^2t + 12r(1+k) - 12bk^2)} \right)}{18\sqrt{t(tk^2 + 12r(1+k) - 12bk^2)}} \geq 0
\end{aligned}$$

For  $\lambda > 0$ , the sensitivities of the price with respect to the model parameters are

<sup>3</sup>Note that the threshold values of  $b$  do not violate the assumption of an uncovered market.



$$\begin{aligned}\frac{\partial}{\partial k}p &: r + \frac{1}{2}t(1-k) > 0 \\ \frac{\partial}{\partial r}p &: 1+k > 0 \\ \frac{\partial}{\partial t}p &: -\frac{1}{4}(k-1)^2 \leq 0\end{aligned}$$

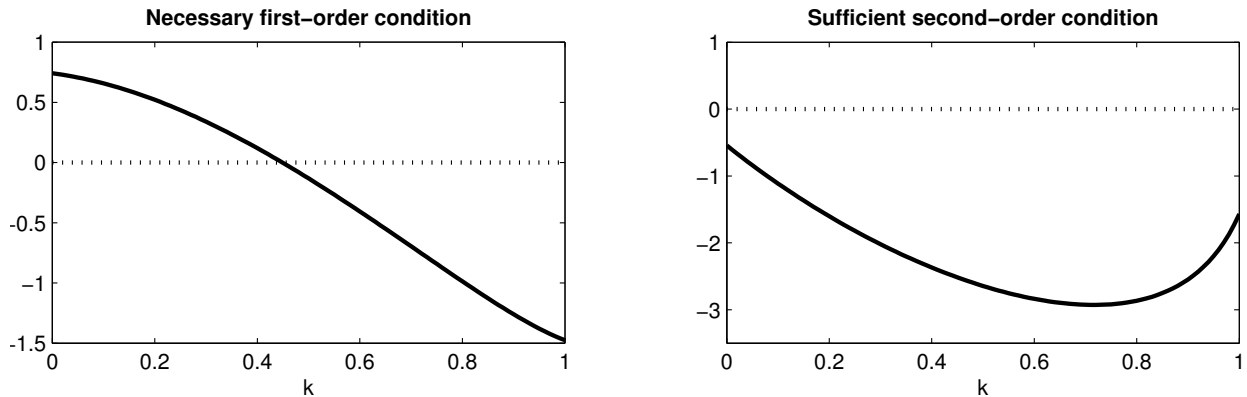
QED

**Proof of Lemma 2.** Inserting A.24 and A.25, respectively, into the profit function, the monopolist's profit function becomes

$$\begin{aligned}\pi &= \left( 2\sqrt{3}\sqrt{t(r-18bk^2+3k^2t+kr)} - 3kt\sqrt{t(12r(k+1)-12bk^2+k^2t)} + 3kt \right) \\ &\quad \frac{2r+15bk^2-3k^2t+2kr+3k\sqrt{t(12r(k+1)-12bk^2+k^2t)}}{9t} \quad \text{when } \lambda = 0 \\ \pi &= r(1+k) - \frac{1}{4}t(k-1)^2 - bk^2 \quad \text{when } \lambda > 0\end{aligned}\tag{A.28}$$

Differentiating the firm's profit with respect to  $k$ , yields the necessary first-order condition. Due to lengthiness, the first-order condition for  $\lambda = 0$  is depicted in Figure A.1. The first-order condition for  $\lambda > 0$  is given by

$$\frac{\partial}{\partial k}\pi : r + \frac{1}{2}t - 2bk - \frac{1}{2}kt = 0\tag{A.29}$$



**Figure A.1** The necessary first-order condition and sufficient second-order condition for  $\lambda = 0$  are shown for  $t = 1$ ,  $b = 2$ , and  $r = 0.5$ .

Solving A.29 for  $k$ , yields the optimal degree of mass customization  $k^*$ . The necessary first-order condition for  $\lambda = 0$  is solved numerically. Figure A.2 depicts  $k^*$  for  $\lambda = 0$  dependent on  $b$ ,  $r$ , and

$t$ . The optimal degree of mass customization  $k^*$  for  $\lambda > 0$  is given by

$$k^* = \begin{cases} \frac{2r+t}{4b+t} & \text{if } b > \frac{1}{2}r \\ 1 & \text{if } b \leq \frac{1}{2}r \end{cases} \quad (\text{A.30})$$



**Figure A.2** The optimal degree of mass customization  $k^*$  for  $\lambda = 0$  is shown for  $t = 1$ ,  $b = 2$ , and  $r = 0.5$ .

The monopolist sets  $k^* > 0$  since  $r$  needs to be sufficiently high to serve all consumers in a covered market. Taking the second derivative of the firm's profit with respect to  $k$ , yields the sufficient second-order condition. Note that Figure A.1 displays the sufficient second-order condition for  $\lambda = 0$ . The sufficient second-order condition for  $\lambda > 0$  is given by

$$\frac{\partial^2}{\partial k^2} \pi : -2b - \frac{1}{2}t \leq 0 \quad (\text{A.31})$$

Since A.31 is smaller or equal zero,  $k^*$  defines a maximum. The sensitivities of  $k^*$  with respect to the model parameters for  $\lambda > 0$  are given by

$$\begin{aligned} \frac{\partial}{\partial b} &: -\frac{4}{(4b+t)^2} (2r+t) < 0 \\ \frac{\partial}{\partial r} &: \frac{2}{4b+t} > 0 \\ \frac{\partial}{\partial t} &: \frac{4b-2r}{(4b+t)^2} \geq 0 \end{aligned}$$

Please refer to Figure A.2 for the sensitivities when  $\lambda = 0$ .

QED

**Proof of Lemma 3.** The monopolist's profit function is given by

$$\pi^*(k^*) = \left( \frac{2\sqrt{3}\sqrt{t(r - 18bk^{*2} + 3k^{*2}t + k^*r) - 3k^*t\sqrt{t(12r(k^* + 1) - 12bk^{*2} + k^{*2}t) + 3k^*t}}}{2r + 15bk^{*2} - 3k^{*2}t + 2kr + 3k^*\sqrt{t(12r(k^* + 1) - 12bk^{*2} + k^{*2}t)}} \right) \text{ when } \lambda = 0$$

$$\pi^*(k^*) = r(1 + k^*) - \frac{1}{4}t(k^* - 1)^2 - bk^{*2} \text{ when } \lambda > 0 \quad (\text{A.32})$$

Inserting  $k^* \in (0, 1)$  into A.32 when  $\lambda > 0$ , the monopolist's profit becomes

$$\pi^* = \begin{cases} \frac{4br - bt + 2rt + r^2}{4b + t} & \text{when } k^* \in (0, 1) \\ 2r - b & \text{when } k^* = 1 \end{cases} \quad (\text{A.33})$$

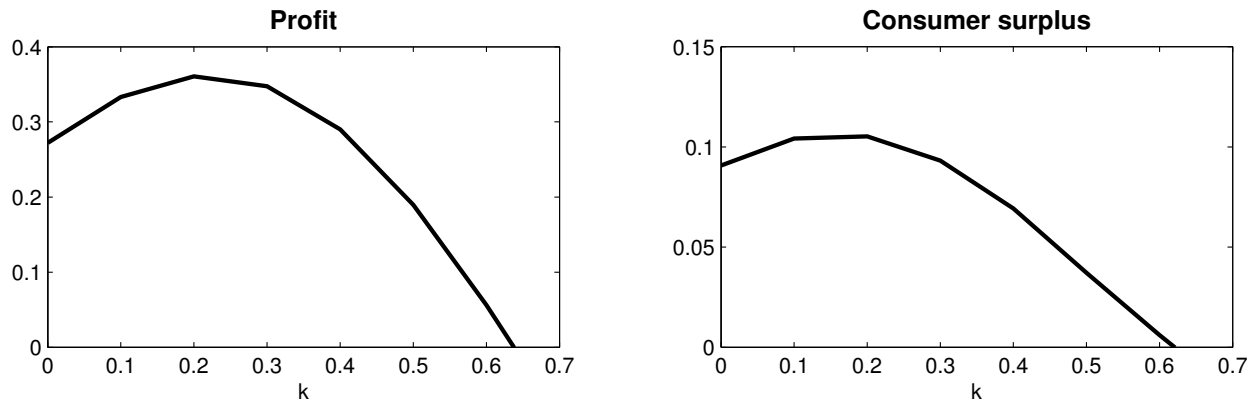
For  $\lambda > 0$ , the sensitivities of the profit function when  $k^* \in (0, 1)$  are given by

$$\frac{\partial}{\partial b} \pi^* : -\frac{1}{(4b + t)^2} (2r + t)^2 < 0$$

$$\frac{\partial}{\partial r} \pi^* : \frac{1}{4b + t} (4b + 2r + 2t) > 0$$

$$\frac{\partial}{\partial t} \pi^* : -\frac{(r - 2b)^2}{(4b + t)^2} \leq 0$$

For  $\lambda = 0$ , the firm's profit with respect to  $k$  is displayed in Figure A.3.



**Figure A.3** Profit and consumer surplus are shown for  $b = 2$ ,  $r = 0.5$ , and  $t = 1$  when  $\lambda = 0$ .

Consumer surplus is given by

$$\begin{aligned}
CS(k^*) &= \frac{\left(3k^* + \frac{4}{3}\sqrt{3}\sqrt{\frac{1}{t}\left(r(1+k^*) - 18bk^{*2} + 3k^{*2}t - 3k^*\sqrt{t(12r(k^*+1) - 12bk^{*2} + k^{*2}t)}\right)}\right)}{9} \\
&\quad \left(r(1+k^*) - 18bk^{*2} + 3k^{*2}t - 3k^*\sqrt{t(12r(k^*+1) - 12bk^{*2} + k^{*2}t)}\right) \quad \text{when } \lambda = 0 \\
CS(k^*) &= \frac{1}{12}t(k^*-1)^2(k^*+2) \quad \text{when } \lambda > 0
\end{aligned} \tag{A.34}$$

Inserting  $k^*$  into A.34 when  $\lambda > 0$ , consumer surplus becomes

$$CS = \begin{cases} t(2b-r)^2 \frac{8b+2r+3t}{3(4b+t)^3} & \text{if } k^* \in (0,1) \\ 0 & \text{if } k^* = 1 \end{cases} \tag{A.35}$$

For  $\lambda > 0$ , consumer surplus is decreasing in  $k$  since

$$\frac{\partial}{\partial k} CS : \frac{1}{4}t(k^2 - 1) \leq 0$$

The sensitivities of consumer surplus if  $k^* \in (0,1)$  for  $\lambda > 0$  are given by

$$\begin{aligned}
\frac{\partial}{\partial b} CS &: -4t \frac{r-2b}{(4b+t)^4} (2r+t)(2b+r+t) > 0 \\
\frac{\partial}{\partial r} CS &: 2t \frac{r-2b}{(4b+t)^3} (2b+r+t) < 0 \\
\frac{\partial}{\partial t} CS &: \frac{1}{3} \frac{(r-2b)^2}{(4b+t)^4} (32b^2 + 8bt + 8rb - 3t^2 - 4rt) > 0
\end{aligned}$$

For  $\lambda = 0$ , consumer surplus with respect  $k$  is displayed in Figure A.3.

*QED*

## A.2 Model with consumer effort

**Proof of Lemma 4.** Consumer utility is given by

$$U = r(1+k) - t \left( \max \left\{ 0, \left| \theta - \frac{1}{2} \right| - e_\theta \frac{k}{2} \right\} \right)^2 - \frac{1}{2} de_\theta^2 - p \tag{A.36}$$

Optimizing A.36 with respect to  $e_\theta$ , yields the necessary first-order condition

$$\frac{\partial}{\partial e_\theta} U : tk \left| \theta - \frac{1}{2} \right| - \frac{1}{2} t e_\theta k^2 - d e_\theta = 0 \quad (\text{A.37})$$

Solving A.37 for  $e_\theta$ , yields the optimal level of effort  $e_\theta^*$

$$e_\theta^* = \frac{2tk \left| \theta - \frac{1}{2} \right|}{tk^2 + 2d} \quad (\text{A.38})$$

Taking the second derivative of A.36 with respect to  $e_\theta$ , yields the sufficient second-order condition

$$\frac{\partial^2}{\partial e_\theta^2} U : -\frac{1}{2} tk^2 - d \leq 0 \quad (\text{A.39})$$

Since the sufficient second-order condition is smaller or equal zero,  $e_\theta^*$  is a maximum.

In equilibrium, the optimal effort level  $e_\theta^*$  is given by

$$e_\theta^* = \begin{cases} 0 & \text{if } k = 0 \vee t = 0 \vee \left| \theta - \frac{1}{2} \right| = 0 \\ \frac{2tk \left| \theta - \frac{1}{2} \right|}{2d + tk^2} \in [0, 1] & \text{if } d \geq tk \left| \theta - \frac{1}{2} \right| - \frac{1}{2} tk^2 \\ 1 & \text{if } d < tk \left| \theta - \frac{1}{2} \right| - \frac{1}{2} tk^2 \end{cases} \quad (\text{A.40})$$

It is assumed that  $d \geq tk \left| \theta - \frac{1}{2} \right| - \frac{1}{2} tk^2$  for all  $\theta \in [0, 1]$ , i.e.  $d \geq \bar{d} = \frac{1}{2} tk (1 - k)$ .

The sensitivities of  $e_\theta^*$  with respect to the model parameters are given by

$$\begin{aligned} \frac{\partial}{\partial k} e_\theta^* : -2t \left| \theta - \frac{1}{2} \right| \frac{tk^2 - 2d}{(tk^2 + 2d)^2} & \begin{cases} \geq 0 & \text{if } k \leq \sqrt{\frac{2d}{t}} \\ < 0 & \text{if } k > \sqrt{\frac{2d}{t}} \end{cases} \\ \frac{\partial}{\partial \left| \theta - \frac{1}{2} \right|} e_\theta^* : \frac{2tk}{tk^2 + 2d} & \geq 0 \\ \frac{\partial}{\partial d} e_\theta^* : -\frac{4tk \left| \theta - \frac{1}{2} \right|}{(tk^2 + 2d)^2} & \leq 0 \\ \frac{\partial}{\partial t} e_\theta^* : \frac{4dk \left| \theta - \frac{1}{2} \right|}{(tk^2 + 2d)^2} & \geq 0 \end{aligned}$$

The term  $\left( \left| \theta - \frac{1}{2} \right| - e_\theta \frac{k}{2} \right)$  maximizes the distance between a type- $\theta$  consumer and the monopolist

for any  $\theta \in [0, 1]$ , since

$$\left| \theta - \frac{1}{2} \right| - e^\theta \frac{k}{2} = \left| \theta - \frac{1}{2} \right| - \frac{2tk|\theta - \frac{1}{2}|k}{2d + tk^2} \frac{k}{2} = \left| \theta - \frac{1}{2} \right| \left( \frac{2d}{tk^2 + 2d} \right) \geq 0$$

QED

**Proof of Lemma 5.** Inserting the demand function into the firm's profit function given by Equation 3.3 yields

$$\pi = \sqrt{\frac{2}{dt} (tk^2 + 2d) (r + kr - p) (p - bk^2)} \quad (\text{A.41})$$

To find the optimal price, the firm maximizes A.41 with respect to  $p$  subject to  $D \leq 1$

$$\begin{aligned} \frac{\partial}{\partial p} \pi \left( \sqrt{\frac{2}{dt} (tk^2 + 2d) (r + kr - p) (p - bk^2)} \right) \\ \text{s.t. } \sqrt{\frac{2}{dt} (tk^2 + 2d) (r + kr - p)} \leq 1 \end{aligned} \quad (\text{A.42})$$

The Lagrangian  $\mathcal{L}(p, \lambda)$  describes the firm's price optimization problem

$$\mathcal{L}(p, \lambda) = \sqrt{\frac{2}{dt} (tk^2 + 2d) (r + kr - p) (p - bk^2)} + \lambda \left( \sqrt{\frac{2}{dt} (tk^2 + 2d) (r + kr - p)} - 1 \right) \quad (\text{A.43})$$

Solving A.43, the first-order condition becomes

$$\frac{\partial}{\partial p} \mathcal{L} : \frac{1}{r + rk - p} (bk^2 + 2r + 2rk - 3p + \lambda) = 0 \quad (\text{A.44})$$

The  $p$  that solves A.44 is given by<sup>4</sup>

$$p = \frac{2}{3}r(1 + k) + \frac{1}{3}bk^2 - \frac{1}{3}\lambda \quad (\text{A.45})$$

The complementary slackness condition is given by

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<sup>4</sup>A.45 defines a maximum since  $\frac{\partial^2}{\partial p^2} \mathcal{L} : -\frac{1}{4} \frac{\sqrt{2}}{(r-p+kr)^2} \sqrt{\frac{1}{dt} (tk^2 + 2d) (r - p + kr) (-bk^2 + 4rk - 3p + 4r + \lambda)} \leq 0$  given  $p \leq -\frac{1}{3}(-4r - \lambda + bk^2 - 4kr)$ . Note that this holds true for A.45.

$$\lambda \left( \sqrt{\frac{2}{dt} (tk^2 + 2d) (r + kr - p) - 1} \right) = 0 \quad (\text{A.46})$$

The complementary slackness condition is either solved with  $\lambda = 0$ , in which case the constraint is not binding, or with  $\lambda > 0$ , in which case the constraint holds.

When the constraint is not binding, i.e.  $\lambda = 0$ , the optimal price  $p^*$  reduces to

$$p^* = \frac{2}{3}r(1+k) + \frac{1}{3}bk^2 \quad (\text{A.47})$$

When the constraint is binding, i.e.  $\lambda > 0$ , the optimal price  $p^*$  is given by

$$p^* = r + rk - \frac{dt}{2tk^2 + 4d} \quad (\text{A.48})$$

The  $\lambda$  that solves A.44 for this  $p^*$  is given by

$$\begin{aligned} r + rk - \frac{dt}{2tk^2 + 4d} &= \frac{2}{3}r(1+k) + \frac{1}{3}bk^2 - \frac{1}{3}\lambda \\ \lambda &= bk^2 - r(1+k) + \frac{3dt}{2tk^2 + 4d} \end{aligned} \quad (\text{A.49})$$

Thus, there are two possible solutions. Either

$$\begin{aligned} p^* &= \frac{2}{3}r(1+k) + \frac{1}{3}bk^2, \quad \lambda = 0; \quad \text{or} \\ p^* &= r + rk - \frac{dt}{2tk^2 + 4d}, \quad \lambda = bk^2 - r(1+k) + \frac{3dt}{2tk^2 + 4d} \end{aligned} \quad (\text{A.50})$$

Which of these two solutions solves the maximization problem, depends on the values of the parameters. The first solution solves the maximization problem iff

$$\begin{aligned} \sqrt{\frac{2}{dt} (tk^2 + 2d) \left( r + kr - \left( \frac{2}{3}r(1+k) + \frac{1}{3}bk^2 \right) \right)} &\leq 1 \\ \frac{4(r + rk - bk^2) - 3t}{3t} + \frac{2k^2(r + rk - bk^2)}{3d} &\leq 0 \\ r &\leq \frac{1}{2} \frac{3dt + 4bdk^2 + 2bk^4t}{(k+1)(2d + tk^2)} \end{aligned}$$

Otherwise, i.e. if  $r$  is large enough so that all consumers buy, the second solution solves the maximization problem. For the following analysis, both solutions are analyzed.

When  $\lambda = 0$ , the sensitivities of the price are as follows

$$\begin{aligned}\frac{\partial}{\partial r}p &: \frac{2}{3}k + \frac{2}{3} > 0 \\ \frac{\partial}{\partial b}p &: \frac{1}{3}k^2 \geq 0 \\ \frac{\partial}{\partial k}p &: \frac{2}{3}r + \frac{2}{3}bk > 0\end{aligned}$$

When  $\lambda > 0$ , the sensitivities of the price are given by

$$\begin{aligned}\frac{\partial}{\partial k}p &: \frac{1}{(tk^2 + 2d)^2} (4rd^2 + 4rdk^2t + dkt^2 + rk^4t^2) > 0 \\ \frac{\partial}{\partial r}p &: 1 + k > 0 \\ \frac{\partial}{\partial t}p &: -\frac{d^2}{(tk^2 + 2d)^2} < 0 \\ \frac{\partial}{\partial d}p &: -\frac{1}{2} \frac{k^2t^2}{(tk^2 + 2d)^2} \leq 0\end{aligned}$$

*QED*

**Proof of Lemma 6.** For solution  $\lambda = 0$ , inserting the optimal price into the profit function, yields

$$\pi = \sqrt{\frac{8}{27dt} (2d + tk^2) (r + rk - bk^2)^3} \quad (\text{A.51})$$

Optimizing A.51 with respect to  $k$ , yields the necessary first-order condition

$$\frac{\partial}{\partial k}\pi : \frac{8}{27dt} (r + rk - bk^2)^2 (6dr - 8btk^3 + 5k^2rt - 12bdk + 2krt) = 0 \quad (\text{A.52})$$

Solving A.52 for  $k$ , yields the optimal degree of mass customization  $k^*$

$$k^* = \frac{5r}{24b} + \frac{x}{\sqrt[3]{\sqrt{y^2 - x^3} + y}} + \sqrt[3]{\sqrt{y^2 - x^3} + y}, \quad (\text{A.53})$$



where

$$x = \frac{1}{12b}r - \frac{1}{2} \frac{d}{t} + \frac{25}{576b^2}r^2$$

$$y = \frac{5}{192b^2}r^2 + \frac{125}{13824b^3}r^3 + \frac{7}{32b}d \frac{r}{t}$$

In equilibrium, the optimal degree of mass customization  $k^*$  is given by

$$k^* = \begin{cases} \frac{5r}{24b} + \frac{x}{\sqrt[3]{\sqrt{y^2 - x^3} + y}} + \sqrt[3]{\sqrt{y^2 - x^3} + y} \in (0, 1) & \text{if } b > \frac{r(6d+7t)}{12d+8t} \\ 1 & \text{if } b \leq \frac{r(6d+7t)}{12d+8t} \end{cases} \quad (\text{A.54})$$

Given the domains of definition of the parameters, the firm always offers mass customization, i.e.  $k^* > 0$ .

Using the envelope theorem, the sensitivities of  $k^*$  with respect to the model parameters are as follows

$$\frac{\partial}{\partial b} \frac{\partial}{\partial k} \pi : -8tk^3 - 12dk \leq 0$$

$$\frac{\partial}{\partial r} \frac{\partial}{\partial k} \pi : 5tk^2 + 2tk + 6d \geq 0$$

$$\frac{\partial}{\partial t} \frac{\partial}{\partial k} \pi : k(-8bk^2 + 5rk + 2r) \geq 0 \quad \text{if } k \leq \frac{1}{16} \frac{5r + \sqrt{r(64b+25r)}}{b}$$

$$\frac{\partial}{\partial d} \frac{\partial}{\partial k} \pi : 6r - 12bk \leq 0 \quad \text{if } k \geq \frac{r}{2b}$$

Inserting  $k = \frac{1}{16} \frac{5r + \sqrt{r(64b+25r)}}{b}$  and  $k = \frac{r}{2b}$ , respectively into the first derivative of the profit function with respect to  $k$  shows that  $\frac{r}{2b} \leq k \leq \frac{1}{16} \frac{5r + \sqrt{r(64b+25r)}}{b}$  to satisfy  $\frac{\partial}{\partial k} \pi = 0$ .

Taking the second derivative of A.51 with respect to  $k$ , yields

$$\frac{\partial^2}{\partial k^2} \pi : -2(6bd - rt + 12bk^2t - 5krt) \quad (\text{A.55})$$

The sufficient second-order derivative is smaller or equal zero iff

$$-2(6bd - rt + 12bk^2t - 5krt) \leq 0$$

$$\frac{rt(1+5k)}{6d+12k^2t} \leq b$$

If  $b$  is sufficiently large<sup>5</sup>,  $k^*$  is a maximum.

For  $\lambda > 0$ , inserting the optimal price into the profit function, yields

$$\pi = r + rk - \frac{dt}{2tk^2 + 4d} - bk^2 \quad (\text{A.56})$$

Optimizing A.56 with respect to  $k$ , yields the necessary first-order condition

$$\begin{aligned} \frac{\partial}{\partial k} \pi : \frac{1}{(tk^2 + 2d)^2} & \left( -8bd^2k + 4rd^2 - 8bdk^3t + 4rdk^2t + dkt^2 - 2bk^5t^2 + rk^4t^2 \right) \\ & = (2d + k^2t)^2 (r - 2bk) + dkt^2 = 0 \end{aligned} \quad (\text{A.57})$$

Taking the second derivative of A.56 with respect to  $k$ , yields the sufficient second-order condition

$$\frac{\partial^2}{\partial k^2} \pi : -\frac{1}{(tk^2 + 2d)^3} \left( 16bd^3 + 24bd^2k^2t - 2d^2t^2 + 12bdk^4t^2 + 3dk^2t^3 + 2bk^6t^3 \right) \leq 0 \quad (\text{A.58})$$

Since the sufficient second-order condition is smaller or equal zero,  $k^*$  defines a maximum.

In equilibrium, the optimal degree of mass customization  $k^*$  when  $b > \frac{r}{2} + \frac{dt^2}{2(2d+t)^2}$  is given by

$$(2d + k^2t)^2 (r - 2bk) + dkt^2 = 0 \quad (\text{A.59})$$

and when  $b \leq \frac{r}{2} + \frac{dt^2}{2(2d+t)^2}$  by

$$k^* = 1 \quad (\text{A.60})$$

Given the domains of definition of the parameters, the firm always offers mass customization, i.e.  $k^* > 0$ .

Using the envelope theorem, the sensitivities of  $k^*$  with respect to the model parameters are as follows

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<sup>5</sup>Note that this condition does not violate the assumption of an uncovered market.

$$\begin{aligned}
\frac{\partial}{\partial b} \frac{\partial}{\partial k} \pi &: -2k \leq 0 \\
\frac{\partial}{\partial r} \frac{\partial}{\partial k} \pi &: 1 \geq 0 \\
\frac{\partial}{\partial t} \frac{\partial}{\partial k} \pi &: \frac{4d^2 tk}{(tk^2 + 2d)^3} \geq 0 \\
\frac{\partial}{\partial d} \frac{\partial}{\partial k} \pi &: kt^2 \frac{(tk^2 - 2d)}{(tk^2 + 2d)^3} \begin{cases} \leq 0 & \text{if } \frac{\partial}{\partial k} e_\theta \geq 0 \\ > 0 & \text{if } \frac{\partial}{\partial k} e_\theta < 0 \end{cases}
\end{aligned}$$

QED

**Proof of Lemma 7.** The profit functions given  $k^*$  are as follows

$$\pi^*(k^*) = \begin{cases} \sqrt{\frac{8}{27dt} (r(1+k^*) - bk^{*2})^3 (tk^{*2} + 2d)} & \text{when } \lambda = 0 \\ r(1+k^*) - \frac{dt}{2tk^{*2} + 4d} - bk^{*2} & \text{when } \lambda = bk^{*2} - r(1+k^*) + \frac{3dt}{2tk^{*2} + 4d} \end{cases} \quad (\text{A.61})$$

The sensitivities of the firm's profit with respect to the model parameters for  $\lambda = 0$  are as follows

$$\begin{aligned}
\frac{\partial}{\partial b} \pi^*(k^*) &: -k^{*2} \sqrt{\frac{2}{3dt} (tk^{*2} + 2d) (-bk^{*2} + r(1+k^*))} \leq 0 \\
\frac{\partial}{\partial r} \pi^*(k^*) &: (1+k^*) \sqrt{\frac{2}{3dt} (tk^{*2} + 2d) (-bk^{*2} + r(1+k^*))} \geq 0 \\
\frac{\partial}{\partial t} \pi^*(k^*) &: -\frac{2}{9t^2} \sqrt{\frac{6dt (-bk^{*2} + r(1+k^*))^3}{tk^{*2} + 2d}} \leq 0 \\
\frac{\partial}{\partial d} \pi^*(k^*) &: -\frac{k^{*2}}{9d^2} \sqrt{\frac{6dt (-bk^{*2} + r(1+k^*))^3}{tk^{*2} + 2d}} \leq 0
\end{aligned}$$

For  $\lambda > 0$ , the sensitivities of the firm's profit for with respect to the model parameters are given by

$$\begin{aligned}\frac{\partial}{\partial b} \pi^*(k^*) &: -k^{*2} < 0 \\ \frac{\partial}{\partial r} \pi^*(k^*) &: 1 + k^* > 0 \\ \frac{\partial}{\partial t} \pi^*(k^*) &: -\frac{d^2}{(tk^{*2} + 2d)^2} < 0 \\ \frac{\partial}{\partial d} \pi^*(k^*) &: -\frac{t^2 k^{*2}}{2(tk^{*2} + 2d)^2} \leq 0\end{aligned}$$

Consumer surplus for  $\lambda = 0$  is given by

$$\begin{aligned}CS(k^*) &= \int_{\underline{\theta}}^{\bar{\theta}} U(1+k^*) \, d\theta \\ &= \int_{\underline{\theta}}^{\bar{\theta}} \left( r(1+k^*) - \left( \frac{2d}{tk^{*2} + 2d} \right) \left( \theta - \frac{1}{2} \right)^2 - \left( \frac{2}{3}r(1+k^*) - \frac{1}{3}bk^{*2} \right) \right) \, d\theta \\ &= \left[ r(1+k^*)\theta - \frac{1}{3} \left( \frac{2d}{tk^{*2} + 2d} \right) \left( \theta - \frac{1}{2} \right)^3 - \left( \frac{2}{3}r(1+k^*) - \frac{1}{3}bk^{*2} \right) \theta \right]_{\underline{\theta}}^{\bar{\theta}} \\ &= \sqrt{\frac{8}{243dt} (tk^{*2} + 2d) (r(1+k^*) - bk^{*2})^3}\end{aligned}\tag{A.62}$$

The sensitivities of A.62 with respect to the model parameters are given by

$$\begin{aligned}\frac{\partial}{\partial t} CS(k^*) &: -\sqrt{\frac{8d}{243t^3} \frac{(r(1+k^*) - bk^{*2})^3}{(2d + k^{*2}t)}} \leq 0 \\ \frac{\partial}{\partial d} CS(k^*) &: -\sqrt{\frac{2tk^{*4}}{243d^3} \frac{(r(1+k^*) - bk^{*2})^3}{(2d + k^{*2}t)}} \leq 0 \\ \frac{\partial}{\partial r} CS(k^*) &: \sqrt{2(2d + k^{*2}t)(1+k^*)^2 \frac{(r(1+k^*) - bk^{*2})}{27dt}} \geq 0 \\ \frac{\partial}{\partial b} CS(k^*) &: -\sqrt{2k^{*4}(2d + k^{*2}t) \frac{(r(1+k^*) - bk^{*2})}{27dt}} \leq 0 \\ \frac{\partial}{\partial k} CS(k^*) &: \sqrt{\frac{2}{243} \frac{(r(1+k^*) - bk^{*2})}{dt(2d + k^{*2}t)}} (6dr - 8bk^{*3}t + 5k^{*2}rt - 12bdk^* + 2k^*rt) = 0\end{aligned}$$

Consumer surplus for  $\lambda > 0$  is given by

$$\begin{aligned}
CS(k^*) &= 2 \int_0^{\frac{1}{2}} U(1+k^*) \, d\theta \\
&= 2 \int_0^{\frac{1}{2}} \left( r(1+k^*) - \left( \frac{2d}{tk^{*2} + 2d} \right) \left( \theta - \frac{1}{2} \right)^2 - \left( r(1+k^*) - \frac{dt}{2tk^{*2} + 4d} \right) \right) d\theta \\
&= 2 \left[ r(1+k^*)\theta - \frac{1}{3} \left( \frac{2d}{tk^{*2} + 2d} \right) \left( \theta - \frac{1}{2} \right)^3 - \left( r(1+k^*) - \frac{dt}{2tk^{*2} + 4d} \right) \theta \right]_0^{\frac{1}{2}} \\
&= \frac{2dt}{6tk^{*2} + 12d} \tag{A.63}
\end{aligned}$$

The sensitivities of A.63 with respect to the model parameters are given by

$$\begin{aligned}
\frac{\partial}{\partial t} CS(k^*) &: \frac{2d^2}{3(tk^{*2} + 2d)^2} > 0 \\
\frac{\partial}{\partial d} CS(k^*) &: \frac{t^2 k^{*2}}{3(tk^{*2} + 2d)^2} \geq 0 \\
\frac{\partial}{\partial k} CS(k^*) &: -\frac{2}{3} dk^* \frac{t^2}{(tk^{*2} + 2d)^2} \leq 0
\end{aligned}$$

*QED*

### A.3 Comparative analysis

**Proof of Proposition 1.** For  $k^E = k = 0$ ,  $\tilde{\pi} \geq \tilde{\pi}^E$  since

$$\begin{aligned}
\tilde{\pi}(k=0) &\geq \tilde{\pi}^E(k^E=0) \\
r + \frac{1}{2}t &\geq r
\end{aligned}$$

For  $k^E = k = 1$ , the necessary first-order condition with consumer effort  $\tilde{\pi}^E \geq \tilde{\pi}$  since

$$\begin{aligned}
\tilde{\pi}^E(k^E=1) &\geq \tilde{\pi}(k=1) \\
\frac{1}{(2d+t)^2} (4d^2r - 2bt^2 - 8bd^2 + dt^2 + rt^2 - 8bdt + 4drt) &\geq r - 2b \\
\frac{dt^2}{(2d+t)^2} &\geq 0
\end{aligned}$$

It follows that the necessary first-order conditions intersect in  $k = k^E \in [0, 1]$ .

The necessary first-order conditions are strictly decreasing in  $k^E$  and  $k$ , respectively, if the second derivatives of the profits with respect to  $k^E$  and  $k$ , respectively, are smaller or equal zero.  $\frac{\partial}{\partial k^E} \tilde{\pi}^E$  and  $\frac{\partial}{\partial k} \tilde{\pi}$  are smaller or equal zero since

$$\begin{aligned} \frac{\partial}{\partial k^E} \tilde{\pi}^E &: -\frac{1}{(tk^{E2} + 2d)^3} \left( 16bd^3 + 24bd^2k^{E2}t - 2d^2t^2 + 12bdk^{E4}t^2 + 3dk^{E2}t^3 + 2bk^{E6}t^3 \right) \leq 0 \\ \frac{\partial}{\partial k} \tilde{\pi} &: -2b - \frac{1}{2}t \leq 0 \end{aligned} \quad (\text{A.64})$$

$\tilde{\pi}$  is linearly decreasing in  $k$  while  $\tilde{\pi}^E$  is concavely decreasing in  $k^E$  for small values of  $k^E$  and convexly decreasing in  $k^E$  for large values of  $k^E$  since

$$\begin{aligned} \frac{\partial^2}{\partial k^{E2}} \tilde{\pi}^E &: 12dk^E t^3 \frac{k^{E2}t - 2d}{(tk^{E2} + 2d)^4} \begin{cases} \leq 0 & \text{if } k^E \leq \sqrt{\frac{2d}{t}} \\ > 0 & \text{if } k^E > \sqrt{\frac{2d}{t}} \end{cases} \\ \frac{\partial^2}{\partial k^2} \tilde{\pi} &: 0 \end{aligned} \quad (\text{A.65})$$

Inserting the optimal degree of mass customization without consumer effort  $k^*$  into  $\tilde{\pi}^E$ , yields

$$\begin{aligned} \tilde{\pi}^E(k^*) &= t \left( 16b^2d - 2bt^2 + dt^2 + rt^2 + 2r^2t + 8bdt - 4brt \right) \\ &\quad \frac{(-128b^3d + 6rt^3 + 8r^3t + 12r^2t^2 + t^4 + 64b^2dr - 8bdt^2 - 64b^2dt + 4drt^2 + 32bdrt)}{(4b + t)(32b^2d + 2dt^2 + 4rt^2 + 4r^2t + t^3 + 16bdt)^2} \end{aligned}$$

$\tilde{\pi}^E(k^*)$  is smaller or equal zero iff

$$\begin{aligned} \tilde{\pi}^E(k^*) &\leq 0 \\ \frac{t(2r + t)(2b - r)}{(4b + t)^2} &\leq d \end{aligned}$$

This threshold value of  $d$  equals the the assumption of  $d \geq \frac{1}{2}tk^*(1 - k^*)$  from Lemma 4 for  $k^*$ . Hence,  $\tilde{\pi}^E(k^*) \leq 0$ . Consequently,  $k^{E*} \leq k^*$ .

*QED*

**Proof of Proposition 2.** For the boundary values of the domain of definition of the degree of mass customization  $k^E = k \in [0, 1]$ ,  $p \geq p^E$  since

$$p(k=0) = p^E(k^E=0) \Leftrightarrow r - \frac{1}{4}t = r - \frac{1}{4}t$$

$$p(k=1) \geq p^E(k^E=1) \Leftrightarrow 2r \geq 2r - \frac{dt}{2t+4d}$$

Taking the first derivatives of the prices with respect to  $k$  and  $k^E$ , respectively, shows that the prices are strictly increasing in  $k$  and  $k^E$ , respectively, for  $k = k^E \in [0, 1]$

$$\frac{\partial}{\partial k} p : r + \frac{1}{2}t(1 - k^E) > 0$$

$$\frac{\partial}{\partial k^E} p^E : \frac{4rd^2 + 4rdk^2t + dkt^2 + rk^4t^2}{(tk^2 + 2d)^2} > 0 \quad (\text{A.66})$$

$p$  is concavely increasing in  $k$  since

$$\frac{\partial^2}{\partial k^2} p : -\frac{1}{2}t \leq 0 \quad (\text{A.67})$$

$p^E$  is convexly increasing in  $k^E$  for small  $k^E$  and concavely increasing in  $k^E$  for large values of  $k^E$  since

$$\frac{\partial^2}{\partial k^{E2}} p^E : \frac{dt^2(2d - 3k^{E2}t)}{(tk^{E2} + 2d)^3} \begin{cases} \geq 0 & \text{if } k^E \leq \sqrt{\frac{2d}{3t}} \\ < 0 & \text{if } k^E > \sqrt{\frac{2d}{3t}} \end{cases} \quad (\text{A.68})$$

Since  $p \geq p^E$  for  $k = k^E = 1$  and  $p = p^E$  for  $k = k^E = 0$ , the price difference  $\Delta p = p - p^E$  is zero for  $k = k^E = 0$  and positive for  $k = k^E = 1$ . To show that  $p > p^E$  for any  $k$ , the superscript  $E$  is dropped in the following analysis. The price difference is increasing in  $k$  iff

$$\frac{\partial}{\partial k} \Delta p : -\frac{1}{2}t(-2d + k^3t + 2dk) \frac{2d + k^2t - kt}{(2d + k^2t)^2} \geq 0$$

$$k \leq \sqrt[3]{\sqrt{\frac{d^2}{t^2} + \frac{8d^3}{27t^3}} + \frac{d}{t}} - \frac{2}{3} \frac{d}{t \sqrt[3]{\sqrt{\frac{d^2}{t^2} + \frac{8d^3}{27t^3}} + \frac{d}{t}}} \quad (\text{A.69})$$

and decreases in  $k$  iff

$$\begin{aligned} \frac{\partial}{\partial k} \Delta p &: -\frac{1}{2}t(-2d + k^3t + 2dk) \frac{2d + k^2t - kt}{(2d + k^2t)^2} < 0 \\ k &> \sqrt[3]{\sqrt{\frac{d^2}{t^2} + \frac{8d^3}{27t^3}} + \frac{d}{t}} - \frac{2}{3} \frac{d}{t \sqrt[3]{\sqrt{\frac{d^2}{t^2} + \frac{8d^3}{27t^3}} + \frac{d}{t}}} \end{aligned} \quad (\text{A.70})$$

Since  $\Delta p$  is zero for  $k = 0$ , positive for  $k = 1$ , first increasing in  $k$  and then decreasing in  $k$ , the price functions only intersect at  $k = 0$  in the interval  $k \in [0, 1]$ . It follows that  $p(k^*)$  is greater or equal than  $p^E(k^*)$ . Since  $k^* \geq k^{E*}$ ,  $p(k^*)$  is greater than  $p^E(k^{E*})$ .

In an uncovered market, the monopolist's price without consumer effort is given by

$$p = \frac{1}{18} \left( 12r(1+k) + 6bk^2 - tk^2 + k\sqrt{t(tk^2 + 12r(1+k) - 12bk^2)} \right) \quad (\text{A.71})$$

Integrating consumer effort, the price becomes

$$p^E = \frac{2}{3}r(1+k^E) + \frac{1}{3}bk^{E2} \quad (\text{A.72})$$

Please note that for  $k = k^E = 0$ , both prices are identical to the monopolist's price for a standard product in an uncovered market ( $p = \frac{2}{3}$ ). To show that  $p \geq p^E$  for a given  $k$ , the superscript  $E$  is dropped for the following analysis.  $p \geq p^E$  for a given  $k$  if the price difference  $\Delta p = p - p^E$  is positive.  $\Delta p$  is positive iff

$$\begin{aligned} \frac{1}{18} \left( 12r(1+k) + 6bk^2 - k^2t + k\sqrt{t(k^2t + 12r(1+k) - 12bk^2)} \right) - \left( \frac{2}{3}r + \frac{1}{3}bk^2 + \frac{2}{3}kr \right) &\geq 0 \\ \frac{r(1+k)}{k^2} &\geq b \end{aligned} \quad \Delta p \geq 0$$

Since  $b \leq \frac{r(1+k)}{k^2}$  is satisfied as long as demand is positively defined,  $p \geq p^E$  for a given  $k$ .

*QED*

**Proof of Proposition 3.** For the boundary values of the domain of definition of the degree of mass customization  $k^E = k \in [0, 1]$ ,  $m \geq m^E$  since



$$m(k=0) = m^E(k^E=0) \Leftrightarrow r - \frac{1}{4}t = r - \frac{1}{4}t$$

$$m(k=1) \geq m^E(k^E=1) \Leftrightarrow 2r - b \geq 2r - b - \frac{dt}{2t+4d}$$

Taking the first derivatives of  $m$  and  $m^E$  with respect to  $k$  and  $k^E$ , respectively, shows that the margins are strictly increasing in  $k$  and  $k^E$ , respectively, for  $k \in [0, k^*]$  and  $k^E \in [0, k^{E*}]$ , respectively

$$\frac{\partial}{\partial k} m : r + \frac{1}{2}t(1-k) - 2bk \geq 0 \quad \text{if } k \leq \frac{2r+t}{4b+t}$$

$$\frac{\partial}{\partial k^E} m^E : \frac{4rd^2 + 4rdk^{E2}t + dk^{E2}t^2 + rk^{E4}t^2}{(tk^{E2} + 2d)^2} \geq 0 \quad \text{if } (2d + k^{E2}t)^2 (r - 2bk^E) + dk^{E2}t^2 \leq 0 \quad (\text{A.73})$$

$m$  is concavely increasing in  $k$  for  $k \in [0, k^*]$  since

$$\frac{\partial^2}{\partial k^2} m : -2b - \frac{1}{2}t \leq 0 \quad (\text{A.74})$$

$m^E$  is concavely increasing in  $k^E$  for  $k^E \in [0, k^{E*}]$  since

$$\frac{\partial^2}{\partial k^{E2}} m^E : -\frac{16bd^3 - 2d^2t^2 + 2bk^{E6}t^3 + 3dk^{E2}t^3 + 24bd^2k^{E2}t + 12bdk^{E4}t^2}{(2d + k^{E2}t)^3} \leq 0 \quad (\text{A.75})$$

Since  $m \geq m^E$  for  $k = k^E = 1$  and  $m = m^E$  for  $k = k^E = 0$ , the margin difference  $\Delta m = m - m^E$  is zero for  $k = k^E = 0$  and positive for  $k = k^E = 1$ . To show that  $m > m^E$  for any  $k$ , the superscript  $E$  is dropped in the following analysis. The margin difference is increasing in  $k$  iff

$$\frac{\partial}{\partial k} \Delta m : -\frac{1}{2}t(-2d + k^3t + 2dk) \frac{2d + k^2t - kt}{(2d + k^2t)^2} \geq 0$$

$$k \leq \sqrt[3]{\sqrt{\frac{d^2}{t^2} + \frac{8d^3}{27t^3}} + \frac{d}{t}} - \frac{2}{3} \frac{d}{t \sqrt[3]{\sqrt{\frac{d^2}{t^2} + \frac{8d^3}{27t^3}} + \frac{d}{t}}} \quad (\text{A.76})$$

and decreases in  $k$  iff

$$\begin{aligned} \frac{\partial}{\partial k} \Delta m : -\frac{1}{2}t(-2d + k^3t + 2dk) \frac{2d + k^2t - kt}{(2d + k^2t)^2} < 0 \\ k > \sqrt[3]{\sqrt{\frac{d^2}{t^2} + \frac{8}{27} \frac{d^3}{t^3}} + \frac{d}{t}} - \frac{2}{3} \frac{d}{t \sqrt[3]{\sqrt{\frac{d^2}{t^2} + \frac{8}{27} \frac{d^3}{t^3}} + \frac{d}{t}}} \end{aligned} \quad (\text{A.77})$$

Since  $\Delta m$  is zero for  $k = 0$ , positive for  $k = 1$ , first increasing in  $k$  and then decreasing in  $k$ , the margin functions only intersect at  $k = 0$  in the interval  $k \in [0, 1]$ . It follows that  $m(k^*)$  is greater or equal than  $m^E(k^*)$ . Since  $k^* \geq k^{E*}$ ,  $m(k^*)$  is greater than  $m^E(k^{E*})$ . In a covered market,  $D = 1$ . Consequently,  $\pi(k^*) > \pi^E(k^{E*})$ .

In an uncovered market, the monopolist's demand without consumer effort is given by

$$D = 2\sqrt{\frac{1}{t}(r(1+k) - p) + k} \quad (\text{A.78})$$

Integrating consumer effort, the demand becomes

$$D^E = \sqrt{\frac{2}{dt}(tk^{E2} + 2d)(r(1+k^E) - p)} \quad (\text{A.79})$$

To show that  $D \geq D^E$  for a given  $k$ , the superscript  $E$  is dropped for the following analysis. The demand difference  $\Delta D = D - D^E$  for a given  $k$  is positive iff

$$\begin{aligned} \Delta D &\geq 0 \\ 2\sqrt{\frac{1}{t}(r(1+k) - p) + k} - \sqrt{\frac{2}{dt}(tk^2 + 2d)(r(1+k) - p)} &\geq 0 \\ 2\sqrt{\frac{6r(1+k) - 6bk^2 + tk^2 - k\sqrt{t(12r(k+1) - 12bk^2 + k^2t)}}{18t}} + k - \sqrt{\frac{2(tk^2 + 2d)(r + rk - bk^2)}{3dt}} &\geq 0 \\ \frac{k}{9dt} \left( tk(6bk^2 - 6r(1+k) + 11d) - 2d\sqrt{t(tk^2 + 12r(1+k) - 12bk^2)} + \right. \\ \left. 36dt\sqrt{\frac{6r(1+k) - 6bk^2 + tk^2 - k\sqrt{t(tk^2 + 12r(1+k) - 12bk^2)}}{18t}} \right) &\geq 0 \\ \frac{4d\sqrt{(2d+k^2t)(8d+k^2t)} - 16d^2 - k^2t(5d - 6r(1+k))}{6k^4t} &\geq b \end{aligned}$$

Hence, for  $b \leq \frac{4d\sqrt{(2d+k^2t)(8d+k^2t)} - 16d^2 - k^2t(5d - 6r(1+k))}{6k^4t}$ ,  $D \geq D^E$ .<sup>6</sup> Since  $b$  is unaffected by consumer effort,  $c = c^E$  for a given  $k$ . The monopolist chooses  $k^*$  to maximize its profit function. Because

<sup>6</sup>Note that this condition does not violate the assumption of an uncovered market.

$D \geq D^E$ ,  $p \geq p^E$ , and  $c = c^E$  for a given  $k$ ,  $\pi(k^*) \geq \pi^E(k^{*E})$ .

QED

**Proof of Proposition 4.** For  $k = k^E = 0$ , consumer surplus with mass customization equals consumer surplus when only a standard product is sold

$$CS^E(k^E = 0) = CS(k = 0) = \frac{1}{6}t$$

For  $k = k^E = 1$ , consumer surplus with consumer effort  $CS^E$  is greater or equal than consumer surplus without consumer effort  $CS$  since

$$CS^E(k^E = 1) \geq CS(k = 1)$$

$$\frac{dt}{6d + 3t} \geq 0$$

Consumer surplus is strictly decreasing in  $k$  and  $k^E$ , respectively, since the first derivatives of  $CS$  and  $CS^E$  with respect to  $k$  and  $k^E$ , respectively, are smaller or equal zero

$$\frac{\partial}{\partial k} CS : \frac{1}{4}t(k^2 - 1) \leq 0$$

$$\frac{\partial}{\partial k^E} CS^E : -\frac{2}{3}dk^E \frac{t^2}{(tk^{E2} + 2d)^2} \leq 0 \quad (\text{A.80})$$

To proof that  $CS^E > CS$ , the superscript  $E$  is dropped for the following analysis. The difference in consumer surplus  $\Delta CS = CS^E - CS$  for a given  $k$  is

$$\Delta CS = \frac{2dt}{6tk^2 + 12d} - \frac{1}{12}t(k-1)^2(k+2) \quad (\text{A.81})$$

$\Delta CS$  is increasing in  $d$  since

$$\frac{\partial}{\partial d} \Delta CS : \frac{k^2 t^2}{3(tk^2 + 2d)^2} \geq 0 \quad (\text{A.82})$$

Given the assumption of  $d$  from Lemma 4,  $d \geq \bar{d}$ ,  $\Delta CS$  is greater or equal zero for a given  $k$  since

$$\Delta CS(d = \bar{d}) = \frac{1}{12}tk(1 - k^2) \geq 0$$

Hence,  $CS^E(k^*)$  is greater or equal than  $CS(k^*)$ . Since  $CS^E$  and  $CS$  are strictly decreasing in  $k$  and  $k^* \geq k^{E*}$ ,  $CS^E(k^{E*})$  must be greater than  $CS(k^*)$ .

QED

## A.4 Extensions

### A.4.1 Consumers' valuation for uniqueness

**Proof of Proposition 5.** Consumer utility is given by

$$U = r(1 + \alpha k) - \frac{2dt}{tk^2 + 2d} \left( \theta - \frac{1}{2} \right)^2 - p \quad (\text{A.83})$$

A type- $\theta$  consumer purchases the mass customized product iff

$$\begin{aligned} U &\geq 0 \\ r(1 + \alpha k) - \frac{2dt}{tk^2 + 2d} \left( \theta - \frac{1}{2} \right)^2 - p &\geq 0 \end{aligned} \quad (\text{A.84})$$

Solving A.84 with respect to  $\theta$ , yields the consumer (to the left and to the right of the firm), who is indifferent between buying or not, denoted by  $\underline{\theta}$  and  $\bar{\theta}$ , respectively

$$\begin{aligned} \underline{\theta} &= \frac{1}{2} - \sqrt{\frac{1}{2dt} (2d + k^2 t) (r(1 + \alpha k) - p)} \\ \bar{\theta} &= \frac{1}{2} + \sqrt{\frac{1}{2dt} (2d + k^2 t) (r(1 + \alpha k) - p)} \end{aligned} \quad (\text{A.85})$$

This leads to a demand of

$$D = \bar{\theta} - \underline{\theta} = \sqrt{\frac{2}{dt} (tk^2 + 2d) (r(1 + \alpha k) - p)} \quad (\text{A.86})$$

The monopolist's price optimization problem under the demand constraint  $D \leq 1$  becomes

$$\mathcal{L}(p, \lambda) = \sqrt{\frac{2}{dt} (tk^2 + 2d) (r(1 + \alpha k) - p)} (p - bk^2) + \lambda \left( \sqrt{\frac{2}{dt} (tk^2 + 2d) (r(1 + \alpha k) - p)} - 1 \right) \quad (\text{A.87})$$

Solving the Lagrangian, the first-order condition becomes

$$\frac{\partial}{\partial p} \mathcal{L} : \frac{1}{2} \frac{\sqrt{2}}{r(1+\alpha k) - p} \sqrt{\frac{1}{dt} (tk^2 + 2d) (r(1+\alpha k) - p) (bk^2 - 3p + 2r(1+\alpha k) - \lambda)} = 0 \quad (\text{A.88})$$

The  $p$  that solves A.88 is given by<sup>7</sup>

$$p = \frac{2}{3}r(1+\alpha k) + \frac{1}{3}bk^2 - \frac{1}{3}\lambda \quad (\text{A.89})$$

The complementary slackness condition is given by

$$\lambda \left( \sqrt{\frac{2}{dt} (tk^2 + 2d) (r(1+\alpha k) - p) - 1} \right) = 0 \quad (\text{A.90})$$

A.90 is either solved with  $\lambda = 0$ , in which case the constraint is not binding, or with  $\lambda > 0$ , in which case the constraint holds.

When the constraint is not binding, i.e.  $\lambda = 0$ , A.89 reduces to

$$p^* = \frac{2}{3}r(1+\alpha k) + \frac{1}{3}bk^2 \quad (\text{A.91})$$

When the constraint is binding, i.e.  $\lambda > 0$ , the optimal price  $p^*$  that solves A.90 is given by

$$p^* = r(1+\alpha k) - \frac{dt}{2tk^2 + 4d} \quad (\text{A.92})$$

The  $\lambda$  that solves A.88 for this  $p^*$  is given by

$$\begin{aligned} r(1+\alpha k) - \frac{dt}{2tk^2 + 4d} &= \frac{2}{3}r(1+\alpha k) + \frac{1}{3}bk^2 - \frac{1}{3}\lambda \\ \lambda &= bk^2 - r(1+\alpha k) + \frac{3dt}{2tk^2 + 4d} \end{aligned} \quad (\text{A.93})$$

Thus, there are two possible solutions. Either

---

<sup>7</sup>A.89 defines a maximum since  $\frac{\partial^2}{\partial p^2} \mathcal{L} : \frac{1}{4} \frac{\sqrt{2}}{(r-p+k\alpha)^2} \sqrt{\frac{1}{dt} (tk^2 + 2d) (r-p+k\alpha) (bk^2 - 4rak + 3p - 4r)} \leq 0$  given  $p \leq -\frac{1}{3}(-4r + bk^2 - 4k\alpha r)$ . Note that this holds true for A.89.

$$\begin{aligned}
p^* &= \frac{2}{3}r(1 + \alpha k) + \frac{1}{3}bk^2, \quad \lambda = 0; \quad \text{or} \\
p^* &= r(1 + \alpha k) - \frac{dt}{2tk^2 + 4d}, \quad \lambda = bk^2 - r(1 + \alpha k) + \frac{3dt}{2tk^2 + 4d}
\end{aligned} \tag{A.94}$$

Which of these two solutions solves the maximization problem, depends on the values of the parameters. The first solution solves the maximization problem iff

$$\begin{aligned}
\sqrt{\frac{2}{3dt}(tk^2 + 2d)(r(1 + \alpha k) - bk^2)} &\leq 1 \\
r &\leq \frac{1}{2} \frac{3dt + 4bdk^2 + 2bk^4t}{(k\alpha + 1)(2d + k^2t)}
\end{aligned}$$

Otherwise, i.e. if consumers' reservation price  $r$  is high enough so that all consumers buy, the second solution solves the maximization problem.

Inserting A.92 into the profit function, yields

$$\pi = r(1 + \alpha k) - \frac{dt}{2tk^2 + 4d} - bk^2 \tag{A.95}$$

Taking the first derivative of A.95 with respect to  $k$  and setting the derivative equal zero, yields the necessary first-order condition

$$\frac{\partial}{\partial k} \pi : \frac{1}{(tk^2 + 2d)^2} \left( -8bd^2k + 4r\alpha d^2 - 8bdk^3t + 4r\alpha dk^2t + dkt^2 - 2bk^5t^2 + rak^4t^2 \right) = 0 \tag{A.96}$$

Simplifying A.96, yields

$$\frac{\partial}{\partial k} \pi : (2d + k^2t)^2 (r\alpha - 2bk) + dkt^2 = 0 \tag{A.97}$$

Using the envelope theorem, it follows that the optimal degree of mass customization is increasing in  $\alpha$

$$\frac{\partial}{\partial \alpha} \frac{\partial}{\partial k} \pi : r(tk^2 + 2d)^2 \geq 0$$

When  $\alpha = 0$ , A.97 reduces to

$$\frac{\partial}{\partial k} \pi (\alpha = 0) : (2d + k^2 t)^2 (-2bk) + dkt^2 = 0 \quad (\text{A.98})$$

Solving A.98 for  $k$ , the optimal degree of mass customization  $k^*$  is given by<sup>8</sup>

$$\begin{aligned} k^* = 0 & \quad \text{if} \quad b \geq \frac{dt^2}{2(2d + k^2 t)^2} \\ (2d + k^2 t)^2 (-2bk) + dkt^2 = 0 & \quad \text{if} \quad \frac{dt^2}{2(2d + k^2 t)^2} < b < \frac{dt^2}{2(2d + t)^2} \\ k^* = 1 & \quad \text{if} \quad b \leq \frac{dt^2}{2(2d + t)^2} \end{aligned} \quad (\text{A.99})$$

Inserting A.91 into the profit function, yields

$$\pi = \sqrt{\frac{8}{27dt} (2d + k^2 t) (r(1 + \alpha k) - bk^2)^3} \quad (\text{A.100})$$

Taking the first derivative of A.100 with respect to  $k$  and setting the derivative equal zero, yields the necessary first-order condition

$$\frac{\partial}{\partial k} \pi : \frac{1}{9} \sqrt{2} \frac{\sqrt{3}}{dt} \frac{(-bk^2 + r\alpha k + r)^2}{\sqrt{\frac{1}{dt} (tk^2 + 2d) (-bk^2 + r\alpha k + r)^3}} (6dra - 8bk^3 t - 12bdk + 2krt + 5k^2 r t \alpha) = 0 \quad (\text{A.101})$$

Solving A.101 for  $k$ , yields the optimal degree of mass customization  $k^*$

$$k^* = \sqrt[3]{\sqrt{y^2 - x^3} + y} + \frac{5}{24b} r + \frac{x}{\sqrt[3]{\sqrt{y^2 - x^3} + y}}, \quad (\text{A.102})$$

where

$$\begin{aligned} x &= \frac{1}{12b} r - \frac{1}{2} \frac{d}{t} + \frac{25}{576b^2} r^2 \alpha^2 \\ y &= \frac{5}{192b^2} r^2 \alpha + \frac{125}{13824b^3} r^3 \alpha^3 + \frac{7}{32b} d \frac{r}{t} \alpha \end{aligned}$$

Using the envelope theorem, it follows that the optimal degree of mass customization is increasing in  $\alpha$

<sup>8</sup>Note that these conditions of  $b$  do not violate the assumption of a covered market.

$$\frac{\partial}{\partial \alpha} \frac{\partial}{\partial k} \pi : 5rtk^2 + 6dr \geq 0$$

When  $\alpha = 0$ , A.101 reduces to

$$\frac{\partial}{\partial k} \pi (\alpha = 0) : \frac{1}{9} \sqrt{2} \frac{\sqrt{3}}{dt} \frac{(-bk^2 + r)^2}{\sqrt{\frac{1}{dt} (tk^2 + 2d) (-bk^2 + r)^3}} (-8bk^3t - 12bdk + 2krt) = 0 \quad (\text{A.103})$$

Solving A.103 for  $k$ , the optimal degree of mass customization  $k^*$  is given by<sup>9</sup>

$$k^* = \begin{cases} 0 & \text{if } b \geq \frac{rt}{6d+4k^2t} \\ \sqrt{\frac{1}{2bt} (rt - 6bd)} \in (0, 1) & \text{if } \frac{rt}{6d+4t} < b < \frac{rt}{6d+4k^2t} \\ 1 & \text{if } b \leq \frac{rt}{6d+4t} \end{cases} \quad (\text{A.104})$$

*QED*

#### A.4.2 Incentive to offer a standard and a mass customized product

Consumers close to the firm purchase the standard product while distant consumers buy the mass customized product since  $U^S (\theta = \frac{1}{2})$  is greater or equal  $U^C (\theta = \frac{1}{2})$ . In a covered market,  $U^S$  and  $U^C$  for the consumer located at  $\theta = \frac{1}{2}$  are given by

$$U^S \left( \theta = \frac{1}{2} \right) = \frac{1}{3} (bk^2 - rk) + \frac{dt}{2tk^2 + 4d}$$

$$U^C \left( \theta = \frac{1}{2} \right) = \frac{dt}{2tk^2 + 4d}$$

For consumer  $\theta = \frac{1}{2}$ ,  $U^S \geq U^C$  iff

$$\frac{1}{3} (bk^2 - rk) + \frac{dt}{2tk^2 + 4d} \geq \frac{dt}{2tk^2 + 4d}$$

$$bk \geq r$$

Given  $bk \geq r$ ,  $p$  is such that the consumer located at  $\theta = \frac{1}{2}$  purchases the standard product. The consumer who is indifferent between buying the standard product and buying the mass customized product is given by

<sup>9</sup>Note that these conditions of  $b$  do not violate the assumption of an uncovered market.



$$\bar{\theta}^S = \frac{1}{2} + \frac{1}{tk} \sqrt{\frac{1}{3}k(2d + k^2t)(-r + bk)} \quad (\text{A.105})$$

If  $\frac{r}{k} < b < \frac{1}{4k(2d+k^2t)}(3kt^2 + 8dr + 4k^2rt)$ ,  $\bar{\theta}^S$  is such that  $\bar{\theta}^S \in (\frac{1}{2}, 1)$ .<sup>10</sup> Hence, there exists demand for the mass customized product.

In an uncovered market,  $U^S$  and  $U^C$  for the consumer located at  $\theta = \frac{1}{2}$  are given by

$$\begin{aligned} U^S\left(\theta = \frac{1}{2}\right) &= \frac{1}{3}r \\ U^C\left(\theta = \frac{1}{2}\right) &= \frac{1}{3}r(1+k) - \frac{1}{3}bk^2 \end{aligned}$$

For consumer  $\theta = \frac{1}{2}$ ,  $U^S \geq U^C$  iff

$$\begin{aligned} \frac{1}{3}r &\geq \frac{1}{3}r(1+k) - \frac{1}{3}bk^2 \\ bk &\geq r \end{aligned}$$

Given  $bk \geq r$ ,  $p$  is such that the consumer  $\theta = \frac{1}{2}$  purchases the standard product. The consumer who is indifferent between buying the standard product and buying the mass customized product is given by

$$\bar{\theta}^S = \frac{1}{2} + \frac{1}{tk} \sqrt{\frac{1}{3}k(2d + k^2t)(-r + bk)} \quad (\text{A.106})$$

If  $\frac{r}{k} < b < \frac{1}{4k(2d+k^2t)}(3kt^2 + 8dr + 4k^2rt)$ ,  $\bar{\theta}^S$  is such that  $\bar{\theta}^S \in (\frac{1}{2}, 1)$ .<sup>11</sup> Hence, there exists demand for the mass customized product.

**Proof of Proposition 7.** Recall from Chapter 3.3 that when the monopolist firm only sells a standard product, the optimal price in a covered market is given by

$$p^* = r - \frac{1}{4}t \quad (\text{A.107})$$

When the market is uncovered, the demand and optimal price of the monopolist are given by

<sup>10</sup>This condition does not violate the assumption of a covered market.

<sup>11</sup>This condition does not violate the assumption of an uncovered market.

$$D = 2\sqrt{\frac{1}{t}(r-p)} \quad (\text{A.108})$$

$$p^* = \frac{2}{3}r \quad (\text{A.109})$$

In a covered market, the firm additionally sells the mass customized product if  $\pi^{\text{CS}} \geq \pi^{\text{S}}$ .  $\pi^{\text{CS}} \geq \pi^{\text{S}}$  iff

$$\begin{aligned} & \pi^{\text{CS}} \geq \pi^{\text{S}} \\ & \left(1 - \frac{2}{kt} \sqrt{\frac{1}{3}k(tk^2 + 2d)(bk - r)}\right) \left(r + rk - \frac{dt}{2tk^2 + 4d} - bk^2\right) + \\ & \left(\frac{2}{kt} \sqrt{\frac{1}{3}k(tk^2 + 2d)(bk - r)}\right) \left(r + \frac{1}{3}rk - \frac{dt}{2tk^2 + 4d} - \frac{1}{3}bk^2\right) \geq r - \frac{1}{4}t \\ & \frac{1}{4k(2d + k^2t)} (3kt^2 + 8dr + 4k^2rt) = b''' \geq b \end{aligned}$$

If  $b$  is smaller or equal  $b'''$ , the firm finds it most profitable to sell both products. Note that this condition is satisfied if  $D^{\text{C}} \geq 0$ . This is because for  $b \leq b'''$ ,  $m^{\text{S}}$  increases when both products are sold

$$\begin{aligned} r + \frac{1}{3}rk - \frac{dt}{2tk^2 + 4d} - \frac{1}{3}bk^2 & \geq r - \frac{1}{4}t \\ b & \leq \frac{1}{4k(2d + k^2t)} (3kt^2 + 8dr + 4k^2rt) \end{aligned}$$

The firm has an incentive to only sell the mass customized product if  $m^{\text{C}}$  is greater than the margin for the standard product when both products are offered. This is true iff

$$\begin{aligned} r + rk - \frac{dt}{2tk^2 + 4d} - bk^2 & > r + \frac{1}{3}rk - \frac{dt}{2tk^2 + 4d} - \frac{1}{3}bk^2 \\ b & < \frac{r}{k} = b' \end{aligned}$$

When  $b < b'$ , the firm finds it most profitable to only offer the mass customized product. Note that for  $b < b'$ , the  $D^{\text{S}}$  is undefined, i.e. there is no demand for the standard product.

When the market is uncovered,  $m^{\text{S}}$  when an additional mass customized product is offered remains unchanged.  $m^{\text{C}} > m^{\text{S}}$  iff

$$\begin{aligned} \frac{2}{3}r + \frac{1}{3}bk^2 + \frac{2}{3}kr - bk^2 &> \frac{2}{3}r \\ b &< \frac{r}{k} = b' \end{aligned}$$

If this condition is satisfied, the firm finds it profitable to only sell the mass customized product since there is no demand for the standard product. In case  $b \geq b'$ ,  $D^S$  is positive defined but  $m^C < m^S$ . However, additionally selling a mass customized product increases the firm's demand iff

$$\begin{aligned} \sqrt{2} \sqrt{\frac{1}{3dt} (tk^2 + 2d) (r(1+k) - bk^2)} &\geq 2 \sqrt{\frac{1}{t} \left(\frac{1}{3}r\right)} \\ b &\leq \frac{1}{k^3t + 2dk} (2dr + k^2rt + krt) = b'' \end{aligned}$$

This condition does not contradict the condition of an uncovered market since

$$\begin{aligned} \frac{1}{k^3t + 2dk} (2dr + k^2rt + krt) &\geq \frac{1}{4dk^2 + 2k^4t} (4dr - 3dt + 2k^2rt + 2k^3rt + 4dkr) \\ r &\leq \frac{3}{4}t \end{aligned}$$

If  $b \leq b''$ , the firm is able to increase its demand when it sells both products. Note that when  $b > b''$ , the firm sells only the standard product since selling a mass customized product does not increase demand. The firm has an incentive offer both products if the profit increase from the increase in demand from selling a mass customized product outweighs the margin loss in the cannibalized region. The increase in demand leads to an additional profit of

$$\tilde{D} = \left( \sqrt{2} \sqrt{\frac{1}{dt} (tk^2 + 2d) \left( -\frac{1}{3}bk^2 + \frac{1}{3}rk + \frac{1}{3}r \right)} - 2 \sqrt{\frac{1}{t} \left(\frac{1}{3}r\right)} \right) \left( \frac{2}{3} (r(1+k) - bk^2) \right) \quad (\text{A.110})$$

The margin loss in the cannibalized region is given by

$$\tilde{m} = \left( 2 \sqrt{\frac{1}{t} \left(\frac{1}{3}r\right)} - \frac{2}{kt} \sqrt{\frac{1}{3}k (tk^2 + 2d) (bk - r)} \right) \left( \frac{2}{3}r - \frac{2}{3} (r(1+k) - bk^2) \right) \quad (\text{A.111})$$

The demand increase is greater or equal the margin loss in the cannibalized region iff

$$\frac{\partial}{\partial b} (\bar{D} - \bar{m}) : \frac{k}{t} \left( 2\sqrt{\frac{1}{3}k(2d+k^2t)(-r+bk)} + 4r\sqrt{\frac{1}{3}rt} + 2t\sqrt{2}(-r+bk^2-kr)\sqrt{\frac{1}{3dt}(r-bk^2+kr)(2d+k^2t)} \right) \geq 0 \quad (\text{A.112})$$

Taking the first derivative of A.112 with respect to  $b$  and setting the derivative equal zero, yields the necessary first-order condition

$$\frac{\partial}{\partial b} (\bar{D} - \bar{m}) : \frac{k}{t} \left( 2\sqrt{\frac{1}{3}k(2d+k^2t)(-r+bk)} - \sqrt{2}kt\sqrt{\frac{1}{3dt}(r-bk^2+kr)(2d+k^2t)} \right) = 0 \quad (\text{A.113})$$

Solving A.113 with respect to  $b$ , yields the minimum of the profit difference

$$b = b'' = \frac{1}{k^3t + 2dk} (2dr + k^2rt + krt) \quad (\text{A.114})$$

$b = b''$  defines a minimum if the second derivative of A.112 with respect to  $b$  is greater or equal zero. The second derivative is given by

$$\frac{\partial^2}{\partial b^2} (\bar{D} - \bar{m}) : \frac{1}{6}\sqrt{3}k^3 \frac{2d\sqrt{\frac{1}{dt}(tk^2+2d)(-bk^2+rk+r)} + \sqrt{2}k\sqrt{-k(tk^2+2d)(r-bk)}}{(-bk^2+rk+r)\sqrt{-k(tk^2+2d)(r-bk)}} \geq 0 \quad (\text{A.115})$$

Given the firm also sells a standard product, this derivative is greater or equal zero.

Inserting  $b = b''$  into A.112, A.112 becomes

$$\frac{4}{9}r \frac{-2\sqrt{3}\sqrt{d^2rt} + \sqrt{3k^4rt^3} + 2\sqrt{3}\sqrt{d^2rt} - \sqrt{3k^4rt^3}}{t(2d+k^2t)} = 0 \quad (\text{A.116})$$

Hence, when selling an additional mass customized product increases demand ( $b \leq b''$ ), A.112 is positive. Consequently, in equilibrium, the firm sells both products if  $b'$  is such that  $b' \leq b \leq b''$ , only the mass customized product if  $b < b'$ , and only the standard product if  $b > b''$ .

*QED*

**Proof of Proposition 8.** The profit for the standard product  $\pi^S$  is increasing in  $k$  iff

$$b \geq \frac{1}{6k^3t + 8dk} (2dr + 3k^2rt)$$

In order to have a positive demand for the standard product,  $bk^2$  has to be greater or equal than  $rk$ . When this condition is satisfied, the profit for the standard product  $\pi^S$  is increasing in  $k$  since

$$\begin{aligned} \frac{r}{k} &\geq \frac{1}{6k^3t + 8dk} (2dr + 3k^2rt) \\ \frac{1}{6tk^3 + 8dk} (3rtk^2 + 6dr) &\geq 0 \end{aligned}$$

From the second derivative of the standard product's profit with respect to  $k$ , it follows that this increase is convex since

$$\begin{aligned} \frac{\partial^2}{\partial k^2} \pi^S &\geq 0 \\ -\frac{32}{9t^2} (r - bk) (5tb^2k^3 + 4db^2k - 5tbk^2r - 2dbr + tkr^2) &\geq 0 \\ \frac{r}{10k^3t + 8dk} \left( 2d + 5k^2t + \sqrt{5k^4t^2 + 4d^2 + 4dk^2t} \right) &\leq b \end{aligned}$$

In order to have a positive demand for the standard product,  $bk^2$  has to be greater or equal than  $rk$ . When this condition is satisfied, the increase in  $k^*$  is convex since

$$\begin{aligned} \frac{r}{k} &\geq \frac{r}{10k^3t + 8dk} \left( 2d + 5k^2t + \sqrt{5k^4t^2 + 4d^2 + 4dk^2t} \right) \\ 32d^2 + 56dk^2t + 20k^4t^2 &\geq 0 \end{aligned}$$

*QED*



# Appendix B

## Duopoly model

### B.1 Model without consumer effort

The term  $\left(y_i - \frac{k_i}{2}\right)$  maximizes distance between a type- $\theta$  consumer and firm  $i$  for any  $k_i \in [0, 1]$  iff

$$\begin{aligned}y_i - \frac{k_i}{2} &\geq 0 \\y_i &\geq \frac{1}{2}\end{aligned}$$

It can be shown that  $\theta' \geq \frac{1}{2}$  in each subgame. Please refer to the respective subgame for the proof.

**Proof of Lemma 8.** Inserting the demand functions into firms' profit functions defined in Equations 4.3 and differentiating these with respect to  $p_i$ , yields the necessary first-order condition

$$\frac{\partial}{\partial p_i} \pi_i : \frac{1}{2t} (t - 2p_i + p_j) = 0 \tag{B.1}$$

Solving B.1 with respect to  $p_i$ , yields firm  $i$ 's best response function

$$p_i^* (p_j) = \frac{1}{2} (t + p_j) \tag{B.2}$$

Inserting B.2 of the respective other firm into  $p_i^* (p_j)$  and solving it for  $p_i$ , the equilibrium price  $p_i^*$  becomes

$$p_i^* = t \tag{B.3}$$

B.3 is increasing in  $t$  since

$$\frac{\partial}{\partial t} p_i^* : 1 > 0$$

Taking the second derivative of firm  $i$ 's profit with respect to  $p_i$ , yields the sufficient second-order condition

$$\frac{\partial^2}{\partial p_i^2} \pi_i : -\frac{1}{t} \leq 0 \quad (\text{B.4})$$

Since B.4 is smaller or equal zero, the equilibrium price  $p_i^*$  defines a maximum.

Inserting B.3 into  $\theta'$  shows that the marginal consumer in this subgame is given by  $\theta' = \frac{1}{2}$ .

*QED*

**Proof of Lemma 9.** Inserting B.3 into firm  $i$ 's profit function, yields the equilibrium profit  $\pi_i^*$

$$\pi_i^* = \frac{1}{2}t \quad (\text{B.5})$$

B.5 is increasing in  $t$  since

$$\frac{\partial}{\partial t} \pi_i^* : \frac{1}{2} > 0$$

To calculate consumer surplus in this subgame, consumer surplus for consumers buying from firm  $A$  is calculated and multiplied by 2 since firms are symmetric.

$$CS = 2 \int_0^{\frac{1}{2}} U_A d\theta = 2 \int_0^{\frac{1}{2}} (r - t(\theta)^2 - t) d\theta = 2 \left[ r\theta - \frac{1}{3}t(\theta)^3 - t\theta \right]_0^{\frac{1}{2}} = r - \frac{13}{12}t \quad (\text{B.6})$$

B.6 is decreasing in  $t$  since

$$\frac{\partial}{\partial t} CS : -\frac{13}{12} < 0$$

B.6 is increasing in  $r$  since

$$\frac{\partial}{\partial r} CS : 1 > 0$$



QED

**Proof of Lemma 10.** Inserting the demand functions into firms' profit functions defined in Equation 4.3 and differentiating these with respect to  $p_A$  and  $p_B$ , respectively, yields the necessary first-order conditions

$$\begin{aligned}\frac{\partial}{\partial p_A} \pi_A &: \frac{1}{4t(2-k_A)} (4t - 8p_A + 4p_B + 4k_A(r + bk_A) - tk_A^2) = 0 \\ \frac{\partial}{\partial p_B} \pi_B &: \frac{1}{4t(2-k_A)} (4t + 4p_A - 8p_B - 4k_A(r + t) + tk_A^2) = 0\end{aligned}\quad (\text{B.7})$$

Solving B.7 with respect to  $p_A$  and  $p_B$ , respectively, yields the firms' best response functions

$$\begin{aligned}p_A^*(p_B) &= \frac{1}{8} (4t + 4p_B + 4k_A(r + bk_A) - tk_A^2) \\ p_B^*(p_A) &= \frac{1}{8} (4t + 4p_A - 4k_A(r + t) + tk_A^2)\end{aligned}\quad (\text{B.8})$$

Inserting the best response function of the respective other firm into Equation B.8 and solving it for  $p_A$  and  $p_B$ , respectively, equilibrium prices  $p_A^*$  and  $p_B^*$  are

$$\begin{aligned}p_A^* &= \frac{1}{12} (12t + k_A^2(8b - t) + 4k_A(r - t)) \\ p_B^* &= \frac{1}{12} (12t + k_A^2(4b + t) - 4k_A(r + 2t))\end{aligned}\quad (\text{B.9})$$

Taking the second derivative of firms' profits with respect to  $p_A$  and  $p_B$ , respectively, yields the sufficient second-order conditions

$$\begin{aligned}\frac{\partial^2}{\partial p_A^2} \pi_A &: \frac{2}{t(k_A - 2)} \leq 0 \\ \frac{\partial^2}{\partial p_B^2} \pi_B &: \frac{2}{t(k_A - 2)} \leq 0\end{aligned}\quad (\text{B.10})$$

Since  $k_A \in [0, 1]$ , the sufficient second-order conditions given by B.10 are smaller or equal zero. Hence, the equilibrium prices define maxima.

The sensitivities of  $p_A^*$  are as follows

$$\begin{aligned}\frac{\partial}{\partial r} p_A^* &: \frac{1}{3} k_A \geq 0 \\ \frac{\partial}{\partial t} p_A^* &: 1 - \frac{1}{12} k_A^2 - \frac{1}{3} k_A > 0 \\ \frac{\partial}{\partial b} p_A^* &: \frac{2}{3} k_A^2 \geq 0\end{aligned}$$

The sensitivities of  $p_B^*$  are given by

$$\begin{aligned}\frac{\partial}{\partial r} p_B^* &: -\frac{1}{3} k_A \leq 0 \\ \frac{\partial}{\partial t} p_B^* &: 1 + \frac{1}{12} k_A^2 - \frac{2}{3} k_A > 0 \\ \frac{\partial}{\partial b} p_B^* &: \frac{1}{3} k_A^2 \geq 0\end{aligned}$$

Firm  $A$  can charge a price for its mass customized product that is greater or equal than the price of firm  $B$ 's standard product since

$$\begin{aligned}p_A^* &\geq p_B^* \\ \frac{1}{12} (12t + k_A^2 (8b - t) + 4k_A (r - t)) &\geq \frac{1}{12} (12t + k_A^2 (4b + t) - 4k_A (r + 2t)) \\ \frac{1}{6} k_A (4r + t (2 - k_A) + 2bk_A) &\geq 0\end{aligned}\tag{B.11}$$

B.11 is increasing in  $k_A$  since the first derivative of the price difference with respect to  $k_A$  is greater zero

$$\frac{\partial}{\partial k_A} (p_A^* - p_B^*) : \frac{1}{3} (2r + t(1 - k_A) + 2bk_A) > 0$$

*QED*

**Proof of Lemma 11.** Inserting B.9 into the respective profit functions of the firms, firm  $A$ 's and firm  $B$ 's profits become

$$\begin{aligned}\pi_A &= \frac{1}{144t(2 - k_A)} (4k_A (bk_A - r + t) - 12t + tk_A^2)^2 \\ \pi_B &= \frac{1}{144t(2 - k_A)} (4k_A (bk_A - r - 2t) + 12t + tk_A^2)^2\end{aligned}\tag{B.12}$$

Differentiating firm  $A$ 's profit with respect to  $k_A$ , yields the necessary first-order condition

$$\frac{\partial}{\partial k_A} \pi_A : - \frac{(-12t + 4bk_A^2 + tk_A^2 - 4k_A r + 4tk_A)(16r - 4t - 4k_A r - 4tk_A + 3tk_A^2 - 32bk_A + 12bk_A^2)}{144t(k_A - 2)^2} = 0 \quad (\text{B.13})$$

Solving the necessary first-order condition for  $k_A$ , yields the optimal degree of customization  $k_A^*$ <sup>1</sup>

$$k_A^* = \begin{cases} \frac{2(8b+r+t - \sqrt{4b(16b-8r+7t) - 10rt+r^2+4t^2})}{3(4b+t)} & \text{if } b > \frac{3}{5}r - \frac{1}{4}t \\ 1 & \text{if } b \leq \frac{3}{5}r - \frac{1}{4}t \end{cases} \quad (\text{B.14})$$

Firm  $A$  sets  $k_A^* > 0$ .  $k_A^* = 0$  solves the necessary first-order condition in case  $r \leq \frac{1}{4}t$ . This violates the assumption of  $r$  in a covered market since in case  $k_A^* = 0$ ,  $\theta'$  makes a purchase iff

$$\begin{aligned} U_A(\theta', k_A^* = 0) &\geq 0 \\ r - t \left(\frac{1}{2}\right)^2 - t &\geq 0 \\ r - \frac{5}{4}t &\geq 0 \\ r &\geq \frac{5}{4}t \end{aligned}$$

Taking the second derivative of firm  $A$ 's profit with respect to  $k_A$ , yields the sufficient second-order condition

$$\frac{\partial^2}{\partial k_A^2} \pi_A : \frac{\sigma_1 \sigma_2}{36t(k_A - 2)^2} - \frac{\sigma_1^2}{72t(k_A - 2)^3} - \frac{\sigma_1(8b + 2t) - \sigma_2^2}{72t(k_A - 2)}, \quad (\text{B.15})$$

where

$$\begin{aligned} \sigma_1 &= 4tk_A - 4k_A r - 12t + 4bk_A^2 + tk_A^2 \\ \sigma_2 &= 4t - 4r + 8bk_A + 2tk_A \end{aligned}$$

Inserting  $k_A^* \in (0, 1)$ , the sufficient second-order conditions is negative and defines a maximum iff

$$b \geq \frac{1}{4}r - \frac{7}{32}t + \frac{1}{32}\sqrt{3(4r - t)(4r + 5t)}$$

<sup>1</sup>Please note that this is the only solution satisfying  $k_A^* \in [0, 1]$ ,  $D_i \in [0, 1]$ , and the assumption of a covered market.

This condition is satisfied for  $k_A^* \in (0, 1)$  since the threshold of  $b$  defined above is smaller or equal  $\frac{3}{5}r - \frac{1}{4}t$

$$\begin{aligned} \frac{3}{5}r - \frac{1}{4}t &\geq \frac{1}{4}r - \frac{7}{32}t + \frac{1}{32}\sqrt{3(4r-t)(4r+5t)} \\ (5t - 11r)^2 &\geq 0 \end{aligned}$$

Given the parametric assumptions are satisfied, the sensitivities of  $k_A^*$  with respect to the model parameters are

$$\begin{aligned} \frac{\partial}{\partial r} k_A^* &: \frac{2(\sqrt{\omega} + 16b - r + 5t)}{3(4b+t)\sqrt{\omega}} \geq 0 \\ \frac{\partial}{\partial b} k_A^* &: -\frac{4(2(r-t)\sqrt{\omega} + 4(8br + bt + 3rt) - 2r^2 - t^2)}{3(4b+t)^2\sqrt{\omega}} \leq 0 \quad \text{if } r \geq \frac{1}{4}t \\ \frac{\partial}{\partial t} k_A^* &: -\frac{2((4b+r)\sqrt{\omega} + 12br + 2bt + 5rt - 8b^2 - r^2)}{3(4b+t)^2\sqrt{\omega}} \leq 0, \end{aligned}$$

where

$$\omega = 64b^2 - 32br + 28bt + r^2 - 10rt + 4t^2$$

QED

**Proof of Lemma 12.** The profit functions given  $k_A^*$  are as follows

$$\begin{aligned} \pi_A^*(k_A^*) &= \frac{1}{144t(2-k_A^*)} (4k_A^*(bk_A^* - r + t) - 12t + tk_A^{*2})^2 \\ \pi_B^*(k_A^*) &= \frac{1}{144t(2-k_A^*)} (4k_A^*(bk_A^* - r - 2t) + 12t + tk_A^{*2})^2 \end{aligned} \quad (\text{B.16})$$

The margin of firm  $A$ ,  $m_A$ , is greater or equal than the margin of firm  $B$ ,  $m_B$ , iff

$$\begin{aligned} m_A &\geq m_B \\ p_A - bk_A^{*2} &\geq p_B \\ \frac{1}{12} (12t - 4bk_A^{*2} - k_A^{*2}t + 4k_A^*r - 4k_A^*t) &\geq \frac{1}{12} (12t + 4bk_A^{*2} + tk_A^{*2} - 4kr - 8k_A^*t) \\ 4r + 2t - 4bk_A^* - k_A^*t &\geq 0 \end{aligned}$$

Inserting the optimal degree of mass customization  $k_A^*$ , the inequality becomes

$$\frac{10}{3}r - \frac{16}{3}b + \frac{4}{3}t + \frac{2}{3}\sqrt{64b^2 - 32br + 28bt + r^2 - 10rt + 4t^2} \geq 0$$

$$r \geq -\frac{5}{4}t$$

Given the model's parametric assumptions, the inequality always holds.

Firm  $A$  has a higher or equal market share than firm  $B$  iff

$$D_A \geq D_B$$

$$\frac{1}{2} + \frac{k_A^*}{12} + \frac{k_A^*(r - bk_A^*)}{3t(2 - k_A^*)} \geq \frac{1}{2} - \frac{k_A^*}{12} - \frac{k_A^*(r - bk_A^*)}{3t(2 - k_A^*)}$$

$$4r + 2t - 4bk_A^* - k_A^*t \geq 0$$

Inserting the optimal degree of mass customization  $k_A^*$ , the inequality becomes

$$-\frac{2}{3} \left( 8b - 5r - 2t - \sqrt{-32br + 28bt - 10rt + 64b^2 + r^2 + 4t^2} \right) \geq 0$$

$$r \geq -\frac{5}{4}t$$

Given the model's parametric assumptions, the inequality always holds. Since  $\theta' \geq \frac{1}{2}$ , the subgame satisfies the condition that the term  $\left(y_i - \frac{k_i}{2}\right)$  maximizes the distance between the marginal consumer and firm  $i$ .

First, consumer surplus for those consumers buying from firm  $A$  is characterized

$$\begin{aligned} CS_A(k_A^*, p_A^*) &= \int_0^{\theta'} U_A(k_A^*, p_A^*) d\theta \\ &= \int_0^{\frac{k_A^*}{2}} (r(1 + k_A^*) - p_A^*) d\theta + \int_{\frac{k_A^*}{2}}^{\theta'} \left( r(1 + k_A^*) - t \left( \theta - \frac{k_A^*}{2} \right)^2 - p_A^* \right) d\theta \\ &= [r(1 + k_A^*)\theta - p_A^*\theta]_0^{\frac{k_A^*}{2}} + \left[ r(1 + k_A^*)\theta - \frac{1}{3}t \left( \theta - \frac{k_A^*}{2} \right)^3 - p_A^*\theta \right]_{\frac{k_A^*}{2}}^{\theta'} \end{aligned} \quad (\text{B.17})$$

Consumer surplus from buying firm  $B$ 's product is given by

$$\begin{aligned} CS_B(k_A^*, p_B^*) &= \int_{\theta'}^1 U_B(k_A^*, p_B^*) d\theta = \int_{\theta'}^1 (r - t(1 - \theta)^2 - p_B^*) d\theta \\ &= \left[ r\theta + \frac{1}{3}t(1 - \theta)^3 - p_B^*\theta \right]_{\theta'}^1 \end{aligned} \quad (\text{B.18})$$

Therefore, consumer surplus in case only one firm customizes is given by

$$\begin{aligned} CS(k_A^*) &= \int_0^{\theta'} U_A(k_A^*) d\theta + \int_{\theta'}^1 U_B(k_A^*) d\theta \\ &= r - \frac{13}{12}t + \frac{k_A^*(r - bk_A^*)}{2} + \frac{5tk_A^*}{8} + \frac{k_A^{*2}(r - bk_A^*)}{36} + \frac{k_A^{*2}t(11k_A^* - 34)}{288} - \frac{k_A^{*2}(r - bk_A^*)^2}{18t(k_A^* - 2)} \end{aligned} \quad (\text{B.19})$$

*QED*

**Proof of Lemma 13.** Inserting the demand functions into firms' profit functions defined in Equation 4.3 and differentiating these with respect to  $p_i$ , yields the necessary first-order condition

$$\frac{\partial}{\partial p_i} \pi_i : -\frac{1}{4t(k_i + k_j - 2)} (4t - 8p_i + 4p_j + 4rk_i - 4rk_j - 4tk_j + 4bk_i^2 - tk_i^2 + tk_j^2) = 0 \quad (\text{B.20})$$

Solving B.20 with respect to  $p_i$ , yields the best-response function

$$p_i^*(p_j) = \frac{1}{2} \left( t + p_j + rk_i - rk_j - tk_j + bk_i^2 - \frac{1}{4}tk_i^2 + \frac{1}{4}tk_j^2 \right) \quad (\text{B.21})$$

Inserting the competitor's best response function into Equation B.21 and solving it for  $p_i$ , the equilibrium price  $p_i^*$  becomes

$$p_i^* = t + \frac{r(k_i - k_j) - t(k_i + 2k_j) + b(2k_i^2 + k_j^2)}{3} - \frac{t(k_i - k_j)(k_i + k_j)}{12} \quad (\text{B.22})$$

Taking the second derivative of firm  $i$ 's profit with respect to  $p_i$ , yields the sufficient second-order condition

$$\frac{\partial^2}{\partial p_i^2} \pi_i : \frac{2}{t(k_i + k_j - 2)} \leq 0 \quad (\text{B.23})$$

Since B.23 is smaller or equal zero, the equilibrium price  $p_i$  is a maximum.

The sensitivities of the optimal price  $p_i^*$  with respect to  $t$ ,  $k_i$ ,  $k_j$ , and  $r$  are given by

$$\begin{aligned}
\frac{\partial}{\partial t} p_i^* &: \frac{1}{12} (k_i - k_j + 6) (2 - k_i - k_j) \geq 0 \\
\frac{\partial}{\partial k_i} p_i^* &: \frac{1}{3} r - \frac{1}{3} t + \frac{4}{3} b k_i - \frac{1}{6} t k_i \geq 0 \quad \text{if } r \geq t - 4b k_i + \frac{1}{2} t k_i \\
\frac{\partial}{\partial k_j} p_i^* &: \frac{2}{3} b k_j - \frac{2}{3} t - \frac{1}{3} r + \frac{1}{6} t k_j \leq 0 \quad \text{if } r \geq 2b k_j - 2t + \frac{1}{2} t k_j \\
\frac{\partial}{\partial r} p_i^* &: \frac{1}{3} (k_i - k_j) \begin{cases} > 0 & \text{if } k_i > k_j \\ < 0 & \text{if } k_i < k_j \\ = 0 & \text{if } k_i = k_j \end{cases}
\end{aligned}$$

QED

**Proof of Lemma 14.** Inserting B.22 into firm  $i$ 's profit function given by Equation 4.3 and differentiating the resulting profit function with respect to  $k_i$ , the necessary first-order condition becomes

$$\begin{aligned}
\frac{\partial}{\partial k_i} \pi_i &: \frac{1}{144t (k_i + k_j - 2)^2} \left( 12t + 4rk_i - 4rk_j - 4tk_i - 8tk_j - 4bk_i^2 + 4bk_j^2 - tk_i^2 + tk_j^2 \right) \\
&\left( 16r - 4t - 32bk_i - 4rk_i - 12rk_j - 4tk_i + 12bk_i^2 + 4bk_j^2 + 3tk_i^2 + tk_j^2 + 16bk_i k_j + 4tk_i k_j \right) = 0 \quad (\text{B.24})
\end{aligned}$$

Since firms are symmetric, symmetry is invoked by setting  $k_i = k_j$ . B.24 becomes

$$\frac{\partial}{\partial k_i} \pi_i (k_i = k_j) : \frac{1}{3} r - \frac{1}{12} t - \frac{2}{3} b k_i - \frac{1}{6} t k_i = 0 \quad (\text{B.25})$$

Solving B.25 for  $k_i$ , yields the optimal degree of mass customization  $k_i^*$

$$k_i^* = \begin{cases} \frac{4r-t}{8b+2t} & \text{if } b > \frac{1}{2} r - \frac{3}{8} t \\ 1 & \text{if } b \leq \frac{1}{2} r - \frac{3}{8} t \end{cases} \quad (\text{B.26})$$

Firm  $i$  sets  $k_i^* > 0$ .  $k_i^* = 0$  solves the necessary first-order condition in case  $r \leq \frac{1}{4} t$ . This violates the assumption of  $r$  in a covered market since in case  $k_i^* = 0$ ,  $\theta'$  makes a purchase iff

$$\begin{aligned}
U_i(\theta') &\geq 0 \\
r - t \left(\frac{1}{2}\right)^2 - t &\geq 0 \\
r - \frac{5}{4}t &\geq 0 \\
r &\geq \frac{5}{4}t
\end{aligned}$$

Taking the second derivative of firm  $i$ 's profit with respect to  $k_i$ , yields the sufficient second-order condition

$$\frac{\partial^2}{\partial k_i^2} \pi_i(k_i = k_j) : -\frac{2}{3}b - \frac{1}{6}t \leq 0 \quad (\text{B.27})$$

Since B.27 is smaller or equal zero,  $k_i^*$  is a maximum.

The sensitivities of  $k_i^*$  with respect to the model parameters are given by

$$\begin{aligned}
\frac{\partial}{\partial r} k_i^* &: \frac{2}{4b+t} > 0 \\
\frac{\partial}{\partial b} k_i^* &: \frac{2(t-4r)}{(4b+t)^2} < 0 \\
\frac{\partial}{\partial t} k_i^* &: -\frac{2(b+r)}{(4b+t)^2} < 0
\end{aligned}$$

*QED*

**Proof of Lemma 15.** Given  $k_i^*$ , firm  $i$ 's price in equilibrium is given by

$$p_i^*(k_i^* = k_j^*) = t - tk_i^* + bk_i^* \quad (\text{B.28})$$

Inserting the optimal price into  $\theta'$ , yields the location of the marginal consumer

$$\theta' = \frac{1}{2} \quad (\text{B.29})$$

Hence, Subgame 3 satisfies the condition that  $\theta' \geq \frac{1}{2}$ .

This leads to equilibrium profits of



$$\pi_i^* (k_i^* = k_j^*) = \frac{t}{2} (1 - k_i^*) \quad (\text{B.30})$$

The profit is decreasing in  $k_i^*$  since

$$\frac{\partial}{\partial k_i^*} \pi_i^* (k_i^* = k_j^*) : -\frac{1}{2}t \leq 0$$

Inserting  $k_i^* = 1$  into B.30, firms make zero profits. Inserting  $k_i^* \in (0, 1)$  into B.30, the optimal profit becomes

$$\pi_i^* (k_i^* \in (0, 1)) = \frac{t(8b - 4r + 3t)}{4(4b + t)} \quad (\text{B.31})$$

The sensitivities of B.31 with respect to the model parameters are given by

$$\begin{aligned} \frac{\partial}{\partial b} \pi_i^* (k_i^* \in (0, 1)) &: \frac{t(4r - t)}{(4b + t)^2} \geq 0 \\ \frac{\partial}{\partial r} \pi_i^* (k_i^* \in (0, 1)) &: \frac{32b^2 + 24bt - 16rb + 3t^2}{4(4b + t)^2} \geq 0 \\ \frac{\partial}{\partial t} \pi_i^* (k_i^* \in (0, 1)) &: -\frac{t}{4b + t} \leq 0 \end{aligned}$$

To calculate consumer surplus, consumer surplus for consumers buying from firm  $A$  is multiplied by 2 since firms are symmetric.

$$\begin{aligned} CS(k_A^*) &= 2 \int_0^{\frac{k_A^*}{2}} U_A(k_A^*) d\theta + 2 \int_{\frac{k_A^*}{2}}^{\frac{1}{2}} U_A(k_A^*) d\theta \\ &= 2 \int_0^{\frac{k_A^*}{2}} (r(1 + k_A^*) - (t - tk_A^* + bk_A^{*2})) d\theta \\ &\quad + 2 \int_{\frac{k_A^*}{2}}^{\frac{1}{2}} \left( r(1 + k_A^*) - t \left( \theta - \frac{k_A^*}{2} \right)^2 - (t - tk_A^* + bk_A^{*2}) \right) d\theta \\ &= 2 \left[ r(1 + k_A^*) \theta - (t - tk_A^* + bk_A^{*2}) \theta \right]_0^{\frac{k_A^*}{2}} \\ &\quad + 2 \left[ r(1 + k_A^*) \theta - \frac{1}{3} t \left( \theta - \frac{k_A^*}{2} \right)^3 - (t - tk_A^* + bk_A^{*2}) \theta \right]_{\frac{k_A^*}{2}}^{\frac{1}{2}} \\ &= r - \frac{13}{12}t - bk_A^{*2} - \frac{1}{4}tk_A^{*2} + \frac{1}{12}tk_A^{*3} + k_A^*r + \frac{5}{4}tk_A^* \end{aligned} \quad (\text{B.32})$$

Inserting  $k_i^* = 1$  into B.32, consumer surplus becomes

$$CS(k_i^* = 1) = 2r - b \quad (\text{B.33})$$

The sensitivities of B.33 with respect to the model parameters are given by

$$\begin{aligned} \frac{\partial}{\partial b} CS(k_i^* = 1) &: -1 < 0 \\ \frac{\partial}{\partial r} CS(k_i^* = 1) &: 2 > 0 \end{aligned}$$

Inserting  $k_i^* \in (0, 1)$  into B.32, consumer surplus becomes

$$CS(k_i^* \in (0, 1)) = r - \frac{13}{12}t + \frac{1}{96}(4r - t) \frac{384b^2r + 528bt^2 + 1056b^2t + 16rt^2 + 16r^2t + 67t^3 + 192brt}{(4b + t)^3} \quad (\text{B.34})$$

The sensitivities of B.34 with respect to the model parameters are given by

$$\begin{aligned} \frac{\partial}{\partial b} CS(k_i^* \in (0, 1)) &: -\frac{1}{8}(4r - t) \frac{128b^2r + 176bt^2 + 352b^2t + 16r^2t + 23t^3 + 64brt}{(4b + t)^4} < 0 \\ \frac{\partial}{\partial r} CS(k_i^* \in (0, 1)) &: \frac{1}{8} \frac{256b^2r + 256bt^2 + 704b^2t + 8rt^2 + 16r^2t + 512b^3 + 29t^3 + 128brt}{(4b + t)^3} > 0 \end{aligned}$$

*QED*

**Proof of Lemma 16.** The derivation of the marginal consumer and prices is done as in Subgame 2. Then, symmetry is invoked by setting  $k_i = k_j$ . The optimal price becomes

$$p_i^* = t + bk_i^2 - tk_i \quad (\text{B.35})$$

Inserting B.35 into the profit function of firm  $i$ , yields

$$\pi_i = \frac{1}{2}t(1 - k_i) \quad (\text{B.36})$$

Taking the derivative of B.36 with respect to  $k_i$ , yields the necessary first-order condition

$$\frac{\partial}{\partial k_i} \pi_i : -\frac{1}{2}t \leq 0 \quad (\text{B.37})$$

Since B.37 is smaller or equal zero for  $k_i \in [0, 1]$ , firm  $i$ 's profit is strictly decreasing in  $k_i$ . In

equilibrium, firm  $i$  chooses the smallest possible  $k_i$ . The optimal degree of mass customization is given by

$$k_i^* = 0 \quad (\text{B.38})$$

*QED*

**Proof of Lemma 17.** Inserting  $k_i^*$  into  $\theta'$ , the marginal consumer is located at

$$\theta' = \frac{1}{2} \quad (\text{B.39})$$

Hence, Subgame 4 satisfies the condition that  $\theta' \geq \frac{1}{2}$ .

Inserting B.38 into B.36, the equilibrium profit becomes

$$\pi_i^* = \frac{t}{2} \quad (\text{B.40})$$

To calculate consumer surplus, consumer surplus for consumers buying from firm  $A$  is calculated and multiplied by 2 since firms are symmetric.

$$CS = 2 \int_0^{\frac{1}{2}} U_A d\theta = 2 \int_0^{\frac{1}{2}} (r - t(\theta)^2 - t) d\theta = 2 \left[ r\theta - \frac{1}{3}t(\theta)^3 - t\theta \right]_0^{\frac{1}{2}} = r - \frac{13}{12}t \quad (\text{B.41})$$

*QED*

## B.2 Model with consumer effort

**Proof of Lemma 18.** Consumer utility is given by

$$U_i = r(1 + k_i) - t \left( \max \left\{ 0, y_i - e_\theta \frac{k_i}{2} \right\} \right)^2 - \frac{1}{2} d_i e_\theta^2 - p_i \quad (\text{B.42})$$

Optimizing B.42 with respect to  $e_\theta$ , yields the necessary first-order condition

$$\frac{\partial}{\partial e_\theta} U_i : tk_i y_i - de_\theta - \frac{1}{2} t e_\theta k_i^2 = 0 \quad (\text{B.43})$$

Solving B.43 for  $e_\theta$ , yields the optimal level of effort  $e_\theta^*$

$$e_\theta^* = \frac{2tk_i y_i}{2d + tk_i^2} \quad (\text{B.44})$$

Taking the second derivative of B.42 with respect to  $e_\theta$ , yields the sufficient second-order condition

$$\frac{\partial^2}{\partial e_\theta^2} U_i : -\frac{1}{2}tk_i^2 - d \leq 0 \quad (\text{B.45})$$

Since B.45 is smaller or equal zero,  $e_\theta^*$  is a maximum.

In equilibrium, the optimal effort level  $e_\theta^*$  is given by

$$e_\theta^* = \begin{cases} 0 & \text{if } k_i = 0 \vee t = 0 \vee y_i = 0 \\ \frac{2tk_i y_i}{2d + tk_i^2} & \text{if } d \geq tk_i (y_i - \frac{1}{2}k_i) \\ 1 & \text{if } d < tk_i (y_i - \frac{1}{2}k_i) \end{cases} \quad (\text{B.46})$$

It is assumed that  $d \geq tk_i (y_i - \frac{1}{2}k_i)$  for  $y_i \in [0, 1]$ , i.e.  $d \geq \bar{d} = \frac{1}{2}tk_i (2 - k_i)$ .

The sensitivities of  $e_\theta^*$  with respect to the model parameters are given by

$$\begin{aligned} \frac{\partial}{\partial k_i} e_\theta^* &: -2ty_i \frac{tk_i^2 - 2d}{(tk_i^2 + 2d)^2} \geq 0 \quad \text{for } d \geq \bar{d} \\ \frac{\partial}{\partial y_i} e_\theta^* &: \frac{2tk_i}{tk_i^2 + 2d} \geq 0 \\ \frac{\partial}{\partial d} e_\theta^* &: -\frac{4tk_i y_i}{(tk_i^2 + 2d)^2} \leq 0 \\ \frac{\partial}{\partial t} e_\theta^* &: \frac{4dk_i y_i}{(tk_i^2 + 2d)^2} \geq 0 \end{aligned}$$

The term  $(y_i - \frac{e_\theta^* k_i}{2})$  maximizes the distance between the firm and a type- $\theta$  consumer for any  $\theta \in [0, 1]$  since

$$y_i - \frac{e_\theta^* k_i}{2} = y_i - \frac{2tk_i y_i}{2d + tk_i^2} \frac{k_i}{2} = \frac{2dy_i}{2d + tk_i^2} \geq 0$$

QED

**Proof of Lemma 19.** Inserting the demand functions into firms' profit functions defined in Equations 4.3 and differentiating these with respect to  $p_A$  and  $p_B$ , respectively, yields the necessary first-order conditions

$$\begin{aligned}\frac{\partial}{\partial p_A} \pi_A &: \frac{2t\sqrt{(p_A - p_B - rk_A)(t - t_A) + tt_A} + (-3p_A + 2p_B + 2rk_A + bk_A^2)(t - t_A) - 2tt_A}{2(t - t_A)\sqrt{(p_A - p_B - rk_A)(t - t_A) + tt_A}} = 0 \\ \frac{\partial}{\partial p_B} \pi_B &: \frac{2t_A\sqrt{(p_A - p_B - rk_A)(t - t_A) + tt_A} - (2p_A - 3p_B - 2rk_A)(t - t_A) - 2tt_A}{2(t_A - t)\sqrt{(p_A - p_B - rk_A)(t - t_A) + tt_A}} = 0\end{aligned}\quad (\text{B.47})$$

Solving B.47 with respect to  $p_A$  and  $p_B$ , respectively, yields the firms' best response functions<sup>2</sup>

$$\begin{aligned}p_A^*(p_B) &= -\frac{1}{-9t + 9t_A} \left( 3(2p_B + 2rk_A + bk_A^2)(t - t_A) + 2t^2 - 6tt_A + \right. \\ &\quad \left. 2t\sqrt{3(-p_B - rk_A + bk_A^2)(t - t_A) + t^2 + 3tt_A} \right) \\ p_B^*(p_A) &= \frac{1}{-9t + 9t_A} \left( 6(-p_A + rk_A)(t - t_A) - 6tt_A + 2t_A^2 + \right. \\ &\quad \left. 2t_A\sqrt{-3(-p_A + rk_A)(t - t_A) + 3tt_A + t_A^2} \right)\end{aligned}\quad (\text{B.48})$$

Inserting the best response function of the respective other firm into B.48 and solving it for  $p_i$ , the equilibrium prices  $p_A^*$  and  $p_B^*$  become<sup>3</sup>

$$\begin{aligned}p_A^* &= \frac{1}{25t_A - 25t} \left( 8tt_A + 4t_A^2 - 6t^2 - 5k_A(t - t_A)(2r + 3bk_A) + (4t_A - 6t) \right. \\ &\quad \left. \sqrt{t^2 + 7tt_A + t_A^2 + 5k_A(t - t_A)(bk_A - r)} \right) \\ p_B^* &= \frac{1}{25t - 25t_A} \left( 8tt_A - 6t_A^2 + 4t^2 + 10k_A(t - t_A)(bk_A - r) + (4t - 6t_A) \right. \\ &\quad \left. \sqrt{t^2 + 7tt_A + t_A^2 + 5k_A(t - t_A)(bk_A - r)} \right)\end{aligned}\quad (\text{B.49})$$

Taking the second derivative of firms' profits with respect to  $p_A$  and  $p_B$ , respectively, yields the sufficient second-order conditions

<sup>2</sup>Note that these necessary first-order conditions are the only solutions that satisfy  $p_i^*(p_j) \geq 0$ .

<sup>3</sup>Note that these optimal prices are the only solutions that satisfy  $p_i^* \geq 0$  and  $D_i \in [0, 1]$ .

$$\begin{aligned}\frac{\partial^2}{\partial p_A^2} \pi_A &: -\frac{(3p_A - 4p_B - 4rk_A + bk_A^2)(t - t_A) + 4tt_A}{4((p_A - p_B - rk_A)(t - t_A) + tt_A)^{\frac{3}{2}}} \leq 0 \\ \frac{\partial^2}{\partial p_B^2} \pi_A &: -\frac{(4p_A - 3p_B - 4rk_A)(t - t_A) + 4tt_A}{4((p_A - p_B - rk_A)(t - t_A) + tt_A)^{\frac{3}{2}}} \leq 0\end{aligned}\quad (\text{B.50})$$

Given demand is positively defined, B.50 is smaller or equal zero and the equilibrium prices  $p_A^*$  and  $p_B^*$  are maxima.

Firm  $A$  can charge a price that is greater or equal than the price of its competitor iff

$$\begin{aligned}2t_A^2 - 16tt_A + 2t^2 + 5k_A(t - t_A)(4r + bk_A) + 2(t + t_A)\sqrt{t^2 + 7tt_A + t_A^2 + 5k_A(t - t_A)(-r + bk_A)} &\geq 0 \\ -\frac{1}{8k_A(t - t_A)}\left(-6tt_A + t_A^2 + t^2 + 2bk_A^2(t - t_A) + (t + t_A)\sqrt{2tt_A + t_A^2 + t^2 + 4bk_A^2(t - t_A)}\right) &\leq r\end{aligned}$$

*QED*

**Proof of Lemma 21.** Inserting  $p_A^*$  and  $p_B^*$  into firms' profit functions, yields the equilibrium profits  $\pi_A^*$  and  $\pi_B^*$

$$\begin{aligned}\pi_A^*(k_A^*, p_A^*, p_B^*) &= \frac{t - \sqrt{(p_A^* - p_B^* - rk_A^*)(t - t_A) + tt_A}}{t - t_A} (p_A^* - bk_A^{*2}) \\ \pi_B^*(k_A^*, p_A^*, p_B^*) &= \frac{t_A - \sqrt{(p_A^* - p_B^* - rk_A^*)(t - t_A) + tt_A}}{t_A - t} p_B^*\end{aligned}\quad (\text{B.51})$$

Consumer surplus for consumers buying from firm  $A$  is given by

$$\begin{aligned}CS_A(p_A^*, p_B^*, k_A^*) &= \int_0^{\theta'} U_A(p_A^*, p_B^*, k_A^*) d\theta = \int_0^{\theta'} (r(1 + k_A^*) - t_A\theta^2 - p_A^*) d\theta \\ &= \left[ r(1 + k_A^*)\theta - \frac{1}{3}t_A\theta^3 - p_A^*\theta \right]_0^{\theta'}\end{aligned}\quad (\text{B.52})$$

while consumers derive the following surplus from purchasing firm  $B$ 's product

$$\begin{aligned}CS_B(p_A^*, p_B^*, k_A^*) &= \int_{\theta'}^1 U_B(p_A^*, p_B^*, k_A^*) d\theta = \int_{\theta'}^1 (r - t(1 - \theta)^2 - p_B^*) d\theta \\ &= \left[ r\theta + \frac{1}{3}t(1 - \theta)^3 - p_B^*\theta \right]_{\theta'}^1\end{aligned}\quad (\text{B.53})$$

In total, consumer surplus is given by

$$\begin{aligned}
CS(k_A^*, p_A^*, p_B^*) &= CS_A(p_A^*, p_B^*, k_A^*) + CS_B(p_A^*, p_B^*, k_A^*) \\
&= -\frac{1}{3(t-t_A)^2} \left( -3(t-t_A)(-tp_A^* - rt_A + p_B^*t_A + rt + rtk_A^*) + tt_A^2 + t^2t_A \right. \\
&\quad \left. + (2(t-t_A)(p_B^* - p_A^* + rk_A^*) - 2tt_A) \sqrt{(p_A^* - p_B^* - rk_A^*)(t-t_A) + tt_A} \right) \quad (B.54)
\end{aligned}$$

QED

**Proof of Lemma 22.** Inserting the demand functions into firms' profits function given by Equation 4.3 and simultaneously optimizing the profit functions with respect to  $p_i$ , yields the necessary first-order condition

$$\frac{\partial}{\partial p_i} \pi_i : \frac{(t_i - t_j) (2rk_i - 2rk_j - 3p_i + 2p_j + bk_i^2) + 2t_it_j - 2t_j \sqrt{t_it_j + (t_i - t_j) (rk_i - rk_j - p_i + p_j)}}{2(t_i - t_j) \sqrt{t_it_j + (t_i - t_j) (rk_i - rk_j - p_i + p_j)}} = 0 \quad (B.55)$$

Solving B.55 with respect to  $p_i$ , yields firm  $i$ 's best response function<sup>4</sup>

$$\begin{aligned}
p_i^*(p_j) &= -\frac{1}{9(t_i - t_j)} \left( 2t_j^2 - 6t_it_j - 3(t_i - t_j) (bk_i^2 + 2r(k_i - k_j) + 2p_j) + \right. \\
&\quad \left. 2t_j \sqrt{t_j^2 + 3t_it_j + 3(t_i - t_j) (r(k_i - k_j) - bk_i^2 + p_j)} \right) \quad (B.56)
\end{aligned}$$

Inserting firm  $j$ 's best response function into Equation B.56 and solving the equation for  $p_i$ , yields the equilibrium price<sup>5</sup>

$$\begin{aligned}
p_i^* &= \frac{1}{25(t_i - t_j)} \left[ (t_i - t_j) (6t_j - 2t_i + 10r(k_i - k_j) + b(15k_i^2 + 10k_j^2)) + 6t_i^2 + (4t_i - 6t_j) \right. \\
&\quad \left. \sqrt{5(t_i - t_j) (k_i - k_j) (r - bk_i - bk_j) + t_i^2 + 7t_it_j + t_j^2} \right] \quad (B.57)
\end{aligned}$$

Taking the second derivative of the profit with respect to  $p_i$ , yields the sufficient second-order condition

$$\frac{\partial^2}{\partial p_i^2} \pi_i : -\frac{4t_it_j - (t_i - t_j) (3p_i - 4p_j - 4rk_i + 4rk_j + bk_i^2)}{4(t_it_j + (t_i - t_j) (p_j - p_i + rk_i - rk_j))^{\frac{3}{2}}} \quad (B.58)$$

B.58 is smaller or equal zero in case both firms make symmetric pricing and customization decisions since

<sup>4</sup>Please note that this best response function is the only solution satisfying  $p_i^*(p_j) \geq 0$ .

<sup>5</sup>Please note that this equilibrium price is the only solution satisfying  $p_i \geq 0$  and  $D_i \in [0, 1]$ .

$$\frac{\partial^2}{\partial p_i^2} \pi_i (k_i = k_j) : -\frac{1}{t_i} \leq 0$$

In this case,  $p_i^*$  is a maximum.

QED

**Proof of Lemma 23.** The first derivative of the profit with respect to  $k_i$  can be written as

$$\frac{\partial}{\partial k_i} \pi_i = \left( \frac{d}{dk_i} p_i (k_i, t_i (k_i)) - 2bk_i \right) \theta' (k_i, t_i (k_i)) + \frac{d}{dk_i} \theta' (k_i, t_i (k_i)) (p_i (k_i, t_i (k_i)) - bk_i^2) = 0, \quad (\text{B.59})$$

where

$$\begin{aligned} \frac{d}{dk_i} p_i (k_i, t_i (k_i)) &= \frac{\partial}{\partial k_i} p_i + \frac{\partial}{\partial t_i} p_i \frac{\partial}{\partial k_i} t_i \\ \frac{d}{dk_i} \theta' (k_i, t_i (k_i)) &= \frac{\partial}{\partial k_i} \theta' + \frac{\partial}{\partial t_i} \theta' \frac{\partial}{\partial k_i} t_i \end{aligned}$$

Taking the partial derivatives of the price  $p_i$  and demand  $D_i$  with respect to  $k_i$  and  $t_i$  as well the derivative of  $t_i$  with respect to  $k_i$  and invoking symmetry by setting  $k_i = k_j$ , the partial derivatives are given by

$$\begin{aligned} \frac{\partial}{\partial k_i} p_i &: \frac{1}{3}r + \frac{4}{3}bk_i \\ \frac{\partial}{\partial t_i} p_i &: \frac{5}{12} \\ \frac{\partial}{\partial k_i} D_i &: \frac{1}{6t_i} (r - 2bk_i) \\ \frac{\partial}{\partial t_i} D_i &: -\frac{1}{24t_i} \\ \frac{\partial}{\partial k_i} t_i &: -4dt^2 \frac{k_i}{(tk_i^2 + 2d)^2} \end{aligned}$$

Invoking symmetry by setting  $k_i = k_j$ , the optimal price  $p_i^*$  and demand  $D_i^*$  become

$$\begin{aligned} p_i^* &= bk_i^2 + t_i \\ D_i^* &= \frac{1}{2} \end{aligned}$$



The necessary first-order condition of firm  $i$ 's profit with respect to  $k_i$  is given by

$$\frac{\partial}{\partial k_i} \pi_i = \tilde{\pi}_i : -\frac{1}{3(tk_i^2 + 2d)^2} \left[ (2d + tk_i^2)^2 (2bk_i - r) + 2dt^2k_i \right] = 0 \quad (\text{B.60})$$

Taking the second derivative of firm  $i$ 's profit with respect to  $k_i$ , yields the sufficient second-order condition

$$\frac{\partial}{\partial k_i} \tilde{\pi}_i : -\frac{2(8bd^3 + 12bd^2k_i^2t + 6bdk_i^4t^2 + 2d^2t^2 - 3dk_i^2t^3 + bk_i^6t^3)}{3(tk_i^2 + 2d)^2} \leq 0 \quad (\text{B.61})$$

Since B.61 is smaller or equal zero, B.60 defines a maximum.

In order to determine under which conditions firms find it profitable to fully mass customize,  $k_i$  is set to 1 and B.60 is solved for  $b$

$$0 = -\frac{1}{3(t + 2d)^2} \left[ (2d + t^2)^2 (2b - r) + 2dt^2 \right]$$

$$b = \frac{1}{2} \left( r - \frac{2dt^2}{(2d + t)^2} \right)$$

Thus, when  $b$  is small enough,  $b \leq \frac{1}{2} \left( r - \frac{2dt^2}{(2d+t)^2} \right)$ , then, in equilibrium, firms choose a degree of mass customization of

$$k_i^* = 1$$

Setting  $k_i = 0$ , reveals the conditions under which firms find it unprofitable to adopt mass customization

$$0 = -\frac{1}{3(2d)^2} \left[ (2d)^2 (-r) \right]$$

$$0 = \frac{1}{3}r$$

The assumption of a covered market requires  $r$  to be sufficiently high. Hence, firms will always adopt mass customization, i.e. set  $k_i^* > 0$ .

Using the implicit function theorem to determine how the model parameters affect the optimal

degree of customization  $k_i^*$  offered in equilibrium, yields

$$\begin{aligned}\frac{\partial}{\partial b} \tilde{\pi}_i &: -\frac{2}{3}k_i \leq 0 \\ \frac{\partial}{\partial r} \tilde{\pi}_i &: \frac{1}{3} > 0 \\ \frac{\partial}{\partial t} \tilde{\pi}_i &: -\frac{8}{3} \frac{d^2 t k_i}{(t k_i^2 + 2d)^3} \leq 0 \\ \frac{\partial}{\partial d} \tilde{\pi}_i &: -\frac{2}{3} k_i t^2 \frac{t k_i^2 - 2d}{(t k_i^2 + 2d)^3} \geq 0 \quad \text{for } d \geq \bar{d}\end{aligned}$$

QED

**Proof of Lemma 24.** Firm  $i$ 's optimal profit is given by

$$\pi_i^*(k_i^*) = \frac{1}{2} (b k_i^{*2} + t_i - b k_i^{*2}) = \frac{dt}{t k_i^{*2} + 2d} \quad (\text{B.62})$$

The sensitivities of the profit with respect to the model parameters are as follows

$$\begin{aligned}\frac{\partial}{\partial k_i^*} \pi_i^*(k_i^*) &: -\frac{2d k_i^{*2} t^2}{(t k_i^{*2} + 2d)^2} \leq 0 \\ \frac{\partial}{\partial t} \pi_i^*(k_i^*) &: \frac{2d^2}{(t k_i^{*2} + 2d)^2} > 0 \\ \frac{\partial}{\partial d} \pi_i^*(k_i^*) &: \frac{t^2 k_i^{*2}}{(t k_i^{*2} + 2d)^2} \geq 0\end{aligned}$$

Consumer surplus is calculated by multiplying consumer surplus from consumers buying firm  $A$ 's product by 2 since firms are symmetric.

$$\begin{aligned}CS(k_A^*) &= 2 \int_0^{\frac{1}{2}} U(k_A^*, p_A^*) d\theta = 2 \int_0^{\frac{1}{2}} (r(1 + k_A^*) - t_A \theta^2 - p_A^*) d\theta \\ &= 2 \left[ r(1 + k_A^*) \theta - \frac{1}{3} t_A \theta^3 - p_A^* \theta \right]_0^{\frac{1}{2}} \\ &= r(1 + k_A^*) + \frac{13}{12} t_A - b k_A^{*2} = r(1 + k_A^*) + \frac{13}{12} \left( \frac{2dt}{t k_A^{*2} + 2d} \right) - b k_A^{*2} \quad (\text{B.63})\end{aligned}$$

Consumer surplus is increasing in  $k_i^*$  iff

$$\frac{\partial}{\partial k_i^*} CS(k_i^*) : -\frac{24bd^2k_i^* - 12d^2r - 13dk_i^*t^2 + 6bk_i^{*5}t^2 - 3k_i^{*4}rt^2 + 24bdk_i^{*3}t - 12dk_i^{*2}rt}{3(2d + k_i^{*2}t)^2} \geq 0$$

$$b \leq \frac{12d^2r + 13dk_i^*t^2 + 3k_i^{*4}rt^2 + 12dk_i^{*2}rt}{6k_i^*(2d + k_i^{*2}t)^2}$$

The sensitivities of consumer surplus with respect to the other model parameters are as follows

$$\frac{\partial}{\partial t} CS(k_i^*) : -\frac{13}{3} \frac{d^2}{(tk_i^{*2} + 2d)^2} < 0$$

$$\frac{\partial}{\partial d} CS(k_i^*) : -\frac{13}{6} k_i^{*2} \frac{t^2}{(tk_i^{*2} + 2d)^2} \leq 0$$

$$\frac{\partial}{\partial r} CS(k_i^*) : 1 + k_i^* > 0$$

$$\frac{\partial}{\partial b} CS(k_i^*) : -k_i^{*2} < 0$$

*QED*

**Proof of Lemma 25.** The derivation of the marginal consumer and prices is done as in Subgame 3. Then, symmetry is invoked by setting  $k_i = k_j$ . The optimal price becomes

$$p_i^* = bk_i^2 + \frac{2dt}{tk_i^2 + 2d} \quad (\text{B.64})$$

Inserting B.64 into the profit function of firm  $i$ , yields

$$\pi_i = \frac{dt}{tk_i^2 + 2d} \quad (\text{B.65})$$

Taking the derivative of B.65 with respect to  $k_i$ , yields the necessary first-order condition

$$\frac{\partial}{\partial k_i} \pi_i : -2dt^2 \frac{k_i}{(tk_i^2 + 2d)^2} \leq 0 \quad (\text{B.66})$$

Since B.67 is smaller or equal zero for  $k_i \in [0, 1]$ , firm  $i$ 's profit is strictly decreasing in  $k_i$ . Firm  $i$  chooses the smallest possible  $k_i$  in equilibrium. The optimal degree of mass customization is given by

$$k_i^* = 0 \quad (\text{B.67})$$

*QED*

**Proof of Lemma 26.**

Inserting B.67 into B.65, yields the equilibrium profit

$$\pi_i^* = \frac{t}{2} \quad (\text{B.68})$$

To calculate consumer surplus, consumer surplus for consumers buying from firm  $A$  is calculated and multiplied by 2 since firms are symmetric.

$$\begin{aligned} CS &= 2 \int_0^{\frac{1}{2}} U(p_A^*) \, d\theta = 2 \int_0^{\frac{1}{2}} \left( r - t(\theta)^2 - p_A^* \right) \, d\theta = 2 \left[ r\theta - \frac{1}{3}t(\theta)^3 - p_A^*\theta \right]_0^{\frac{1}{2}} \\ &= r - \frac{13}{12}t \end{aligned} \quad (\text{B.69})$$

*QED*

### B.3 Comparative analysis

**Proof of Proposition 9.** In order to proof that mass customization under competition with simultaneous choices is a prisoner's dilemma if  $r$  is sufficiently high, it is shown that firms have an incentive to adopt mass customization to the detriment of their profits.

*Model with consumer effort*

$\pi_i(T(T)) \geq \pi_i(MC(MC))$  iff

$$\begin{aligned} \frac{t}{2} &\geq \frac{1}{2} \left( \frac{2dt}{tk_i^2 + 2d} \right) \\ k_i &\geq 0 \end{aligned}$$

Since firms choose  $k_i^* > 0$  in case both firms decide to offer mass customized products in the first stage of the game,  $\pi_i(T(T)) \geq \pi_i(MC(MC))$ .

Firm  $i$  has an incentive to deviate from offering a standard product if  $\pi_i(MC(T)) \geq \pi_i(T(T))$ . The margin from deviating is higher iff

$$m_i (MC (T)) \geq m_i (T (T))$$

$$\begin{aligned} & \frac{1}{25t_i - 25t} \left( 8tt_i + 4t_i^2 - 6t^2 - 5k_i (t - t_i) (2r + 3bk_i) \right. \\ & \left. + (4t_i - 6t) \sqrt{t^2 + 7tt_i + t_i^2 + 5k_i (t - t_i) (-r + bk_i)} \right) - bk_i^2 \geq t \\ & \frac{1}{2k_i (t_i - t)} \left( (3t - 2t_i) \sqrt{t(2t_i - t)} + t(-2t + t_i) - 2bk_i^2 (t - t_i) \right) \leq r \end{aligned}$$

The demand from deviating is higher iff

$$\begin{aligned} & D_i (MC (T)) \geq D_i (T (T)) \\ & \frac{1}{t - t_i} \left( t - \frac{1}{5} \sqrt{9tt_i + 2t_i^2 + 2t^2 + 5k_i (t - t_i) (-r + bk_i)} \right. \\ & \left. + 2(t + t_i) \sqrt{t^2 + 7tt_i + t_i^2 + 5k_i (t - t_i) (-r + bk_i)} \right) \geq \frac{1}{2} \\ & \frac{1}{4k_i} (4bk_i^2 - t + t_i) \leq r \end{aligned}$$

When  $r$  is sufficiently high,  $\pi_i (MC (T)) \geq \pi_i (T (T))$ . Consequently, firm  $i$  has an incentive to deviate from offering a standard product.

The firm that does not offer a mass customized product while its competitors does has an incentive to adopt mass customization if  $\pi_i (MC (MC)) \geq \pi_i (T (MC))$ . The margin from deviating is higher iff

$$\begin{aligned} & m_i (T (MC)) \leq m_i (MC (MC)) \\ & \frac{1}{25(t - t_j)} \left( 8tt_j - 6t_j^2 + 4t^2 + 10k_j (t - t_j) (-r + bk_j) \right. \\ & \left. + (4t - 6t_j) \sqrt{t^2 + 7tt_j + t_j^2 + 5k_j (t - t_j) (-r + bk_j)} \right) \leq t_i \\ & \frac{1}{2k_j (t_j - t)} \left( -4tt_j + 5tt_i + 3t_j^2 - 5t_it_j - 2bk_j^2 (t - t_j) + (3t_j - 2t) \sqrt{2tt_i + t_j^2 - 2t_it_j} \right) \leq r \end{aligned}$$

The demand from deviating is higher iff

$$\begin{aligned} & D_i (T (MC)) \leq D_i (MC (MC)) \\ & 1 - \frac{1}{t - t_j} \left( t - \frac{1}{5} \sqrt{9tt_j + 2t_j^2 + 2t^2 + 5k_j (t - t_j) (-r + bk_j)} \right. \\ & \left. + 2(t + t_j) \sqrt{t^2 + 7tt_j + t_j^2 + 5k_j (t - t_j) (-r + bk_j)} \right) \leq \frac{1}{2} \\ & \frac{1}{4k_j} (4bk_j^2 - t + t_j) \leq r \end{aligned}$$

When  $r$  is sufficiently high,  $\pi_i(MC(MC)) \geq \pi_i(T(MC))$ . Consequently, firm  $i$  has an incentive to deviate from offering a standard product.

*Model without consumer effort*

$\pi_i(T(T)) \geq \pi_i(MC(MC))$  iff

$$\begin{aligned} \frac{t}{2} &\geq \frac{t}{2} (1 - k_i) \\ k_i &\geq 0 \end{aligned}$$

Since firms choose  $k_i^* > 0$  in case both firms decide to offer mass customized products in the first stage of the game,  $\pi_i(T(T)) \geq \pi_i(MC(MC))$ .

Firm  $i$  has an incentive to deviate from offering a standard product if  $\pi_i(MC(T)) \geq \pi_i(T(T))$ . The margin from deviating is higher iff

$$\begin{aligned} m_i(MC(T)) &\geq m_i(T(T)) \\ t + \frac{2}{3}bk_i^2 - \frac{1}{12}tk_i^2 + \frac{1}{3}k_i r - \frac{1}{3}tk_i - bk_i^2 &\geq t \\ t + bk_i + \frac{1}{4}tk_i &\leq r \end{aligned}$$

The demand from deviating is higher iff

$$\begin{aligned} D_i(MC(T)) &\geq D_i(T(T)) \\ \frac{1}{2} + \frac{1}{12}k_i - \frac{k_i(r - bk_i)}{3t(k_i - 2)} &\geq \frac{1}{2} \\ bk_i - \frac{1}{2}t + \frac{1}{4}tk_i &\leq r \end{aligned}$$

When  $r$  is sufficiently high,  $\pi_i(MC(T)) \geq \pi_i(T(T))$ . Consequently, firm  $i$  has an incentive to deviate from offering a standard product.

The firm that does not offer a mass customized product while its competitors does has an incentive to adopt mass customization if  $\pi_i(MC(MC)) \geq \pi_i(T(MC))$ . The margin from deviating is higher iff

$$\begin{aligned}
m_i(\text{MC}(\text{MC})) &\geq m_i(\text{T}(\text{MC})) \\
t - tk_i &\geq t + \frac{1}{3}bk_j^2 + \frac{1}{12}tk_j^2 - \frac{1}{3}k_jr - \frac{2}{3}tk_j \\
bk_j - 2t + \frac{1}{4}k_jt + \frac{3tk_i}{k_j} &\leq r
\end{aligned}$$

The demand from deviating is higher iff

$$\begin{aligned}
D_i(\text{MC}(\text{MC})) &\geq D_i(\text{T}(\text{MC})) \\
\frac{1}{2} &\geq 1 - \left( \frac{1}{2} + \frac{1}{12}k_j - \frac{k_j(r - bk_j)}{3t(k_j - 2)} \right) \\
bk_j - \frac{1}{2}t + \frac{1}{4}tk_j &\leq r
\end{aligned}$$

When  $r$  is sufficiently high,  $\pi_i(\text{MC}(\text{MC})) \geq \pi_i(\text{T}(\text{MC}))$ . Consequently, firm  $i$  has an incentive to deviate from offering a standard product.

The degree of mass customization when only one firm offers mass customization is given by

$$k_i^* = \frac{1}{12b + 3t} \left( 16b + 2r + 2t - 2\sqrt{-32br + 28bt - 10rt + 64b^2 + r^2 + 4t^2} \right) \quad (\text{B.70})$$

The total scope of mass customization when both firms adopt mass customization is given by

$$2k_i^* = \frac{4r - t}{4b + t} \quad (\text{B.71})$$

The total scope of mass customization is greater when both firms offer mass customized products than when only one firm adopts mass customization iff

$$\begin{aligned}
\frac{4r - t}{4b + t} &> \frac{1}{12b + 3t} \left( 16b + 2r + 2t - 2\sqrt{-32br + 28bt - 10rt + 64b^2 + r^2 + 4t^2} \right) \\
b &> \frac{1}{2}r - \frac{3}{16}t
\end{aligned}$$

*QED*

**Proof of Proposition 10.** For the boundary values of the domain of definition of the degree of mass customization  $k_i = k_i^E \in [0, 1]$ ,  $\tilde{\pi}_i^E \geq \tilde{\pi}_i$

$$\begin{aligned}\tilde{\pi}_i^E(k_i^E = 0) &\geq \tilde{\pi}_i(k_i = 0) \Leftrightarrow \frac{1}{3}r \geq \frac{1}{3}r - \frac{1}{12}t \\ \tilde{\pi}_i^E(k_i^E = 1) &\geq \tilde{\pi}_i(k_i = 1) \Leftrightarrow -\frac{1}{3(2d+t)^2} \left[ (2d+t)^2(2b-r) + 2dt^2 \right] \geq \frac{1}{3}r - \frac{2}{3}b - \frac{1}{4}t\end{aligned}$$

It can easily be noticed that  $\tilde{\pi}_i^E(k_i^E = 0) \geq \tilde{\pi}_i(k_i = 0)$ .  $\tilde{\pi}_i^E(k_i^E = 1) \geq \tilde{\pi}_i(k_i = 1)$

$$\begin{aligned}-\frac{1}{3(2d+t)^2} \left[ (2d+t)^2(2b-r) + 2dt^2 \right] &\geq \frac{1}{3}r - \frac{2}{3}b - \frac{1}{4}t \\ \frac{1}{12} \frac{t(12d^2 + 4dt + 3t^2)}{(2d+t)^2} &\geq 0\end{aligned}$$

It follows that  $\tilde{\pi}_i^E(k_i^E = 1) \geq \tilde{\pi}_i(k_i = 1)$ .

$\tilde{\pi}_i^E$  is strictly decreasing in  $k_i^E$  if  $\frac{\partial}{\partial k_i^E} \tilde{\pi}_i^E$  is smaller or equal zero.  $\frac{\partial}{\partial k_i^E} \tilde{\pi}_i^E$  is given by

$$\frac{\partial}{\partial k_i^E} \tilde{\pi}_i^E : -\frac{2(8bd^3 + 12bd^2k_i^{E2}t + 2d^2t^2 + 6bdk_i^{E4}t^2 - 3dk_i^{E2}t^3 + bk_i^{E6}t^3)}{3(tk_i^{E2} + 2d)^3} \quad (\text{B.72})$$

B.72 is smaller or equal zero iff

$$\begin{aligned}-\frac{2(8bd^3 + 12bd^2k_i^{E2}t + 2d^2t^2 + 6bdk_i^{E4}t^2 - 3dk_i^{E2}t^3 + bk_i^{E6}t^3)}{3(tk_i^{E2} + 2d)^3} &\leq 0 \\ -\frac{2d^2t^2 - 3dk_i^{E2}t^3}{(2d + tk_i^{E2})^3} &\leq b\end{aligned}$$

When  $b$  is sufficiently high, B.72 is smaller or equal zero. It follows that  $\tilde{\pi}_i^E$  is strictly decreasing in  $k_i^E$  given the assumption of  $b$ .

$\tilde{\pi}_i$  is strictly decreasing in  $k_i$  if  $\frac{\partial}{\partial k_i} \tilde{\pi}_i$  is smaller or equal zero.  $\frac{\partial}{\partial k_i} \tilde{\pi}_i$  is given by

$$\frac{\partial}{\partial k_i} \tilde{\pi}_i : -\frac{2}{3}b - \frac{1}{6}t \leq 0 \quad (\text{B.73})$$

Since B.73 is smaller or equal zero,  $\tilde{\pi}_i$  is strictly decreasing in  $k_i$ .

Inserting  $k_i^*$  into  $\tilde{\pi}_i^E$  yields



$$\tilde{\pi}_i^E(k_i^*) = -\frac{1}{3\left(t\left(\frac{4r-t}{8b+2t}\right)^2 + 2d\right)^2} \left( \left(2d + t\left(\frac{4r-t}{8b+2t}\right)^2\right)^2 \left(2b\left(\frac{4r-t}{8b+2t}\right) - r\right) + 2dt^2\left(\frac{4r-t}{8b+2t}\right) \right) \quad (\text{B.74})$$

B.74 is greater zero iff

$$-\frac{1}{3\left(t\left(\frac{4r-t}{8b+2t}\right)^2 + 2d\right)^2} \left( \left(2d + t\left(\frac{4r-t}{8b+2t}\right)^2\right)^2 \left(2b\left(\frac{4r-t}{8b+2t}\right) - r\right) + 2dt^2\left(\frac{4r-t}{8b+2t}\right) \right) > 0$$

$$\frac{t(4r-t)\left((4b+t)\sqrt{(2b-2r+t)(8b+4r+t)} - 4br + 9bt + rt + 16b^2 - 4r^2 + t^2\right)}{8(4b+t)^2(b+r)} < d$$

Since  $\tilde{\pi}_i^E$  is higher for the boundary values of the domain of definition than  $\tilde{\pi}_i$ , both functions are strictly decreasing in  $k_i^E$  (given the assumption of  $b$ ) and  $k_i$ , respectively, and  $\tilde{\pi}_i^E(k_i^*) > 0$  if  $d$  is sufficiently high,  $k_i^{E*}$  is greater than  $k_i^*$ .

QED

**Proof of Proposition 11.** For the boundary values of the domain of definition of the degree of mass customization  $k_i = k_i^E \in [0, 1]$ ,  $p_i^{E*}$  and  $p_i^*$  become

$$p_i^{*E}(k_i^E = 0) = p_i^*(k_i = 0) \Leftrightarrow t = t$$

$$p_i^{*E}(k_i^E = 1) \geq p_i^*(k_i = 1) \Leftrightarrow b + \frac{2dt}{t+2d} \geq b$$

For  $k_i = k_i^E = 0$ , optimal prices are identical. While firms price at marginal costs for  $k_i = 1$  when consumers face no effort choice, firms can charge a price premium for  $k_i^E = 1$  when consumers' choice of effort is integrated.

$p_i^{E*}$  is strictly increasing in  $k_i^E$  if its derivative with respect to  $k_i^E$  is greater or equal zero. The first derivative of  $p_i^{E*}$  with respect to  $k_i^E$  is given by

$$\frac{\partial}{\partial k_i^E} p_i^{E*} : \frac{2k_i^E}{(tk_i^{E2} + 2d)^2} \left( 4bd^2 - 2dt^2 + 4bdtk_i^{E2} + bt^2k_i^{E4} \right) \quad (\text{B.75})$$

B.75 is greater or equal zero iff

$$\begin{aligned} \frac{\partial}{\partial k_i^E} p_i^{E*} &\geq 0 \\ \frac{2k_i^E}{(tk_i^{E2} + 2d)^2} (4bd^2 - 2dt^2 + 4bdtk_i^{E2} + bt^2k_i^{E4}) &\geq 0 \\ \frac{2dt^2}{(2d + tk_i^{E2})^2} &\leq b \end{aligned}$$

When  $b$  is sufficiently high, B.75 is greater or equal zero.

$p_i^{E*}$  is convexly increasing in  $k_i^E$  if the second derivative of  $p_i^{E*}$  with respect to  $k_i^E$  is greater or equal zero. The second derivative of  $p_i^{E*}$  with respect to  $k_i^E$  is given by

$$\frac{\partial^2}{\partial k_i^{E2}} p_i^{E*} : \frac{2}{(tk_i^{E2} + 2d)^3} (8bd^3 - 4d^2t^2 + 12bd^2tk_i^{E2} + 6dt^3k_i^{E2} + 6bdt^2k_i^{E4} + bt^3k_i^{E6}) \quad (\text{B.76})$$

B.76 is greater or equal zero iff

$$\begin{aligned} \frac{\partial^2}{\partial k_i^{E2}} p_i^{E*} &\geq 0 \\ \frac{2}{(tk_i^{E2} + 2d)^3} (8bd^3 - 4d^2t^2 + 12bd^2tk_i^{E2} + 6dt^3k_i^{E2} + 6bdt^2k_i^{E4} + bt^3k_i^{E6}) &\geq 0 \\ 2dt^2 \frac{2d - 3tk_i^{E2}}{(2d + tk_i^{E2})^3} &\leq b \end{aligned}$$

Please note that the threshold value of  $b$  is always satisfied when  $p_i^{E*}$  is strictly increasing in  $k_i^E$  since  $\frac{2dt^2}{(2d + tk_i^{E2})^2} \geq 2dt^2 \frac{2d - 3tk_i^{E2}}{(2d + tk_i^{E2})^3}$ .

$p_i^*$  is strictly increasing in  $k_i$  if its derivative with respect to  $k_i$  is greater or equal zero. The first derivative of  $p_i^*$  with respect to  $k_i$  is given by

$$\frac{\partial}{\partial k_i} p_i^* : 2bk_i - t \quad (\text{B.77})$$

B.77 is greater or equal zero iff

$$\begin{aligned}\frac{\partial}{\partial k_i} p_i^* &\geq 0 \\ 2bk_i - t &\geq 0 \\ \frac{t}{2k_i} &\leq b\end{aligned}$$

When  $b$  is sufficiently high, B.77 is greater or equal zero.

$p_i^*$  is convexly increasing in  $k_i$  if the second derivative of the price with respect to  $k_i$  is greater or equal zero. The second derivative of  $p_i^*$  with respect to  $k_i$  is given by

$$\frac{\partial^2}{\partial k_i^2} p_i^* : 2b \geq 0 \quad (\text{B.78})$$

It follows that  $p_i^*$  is convexly increasing in  $k_i$ .

*QED*

**Proof of Proposition 12.** Since firms always choose to adopt mass customization, i.e.  $k_i^* > 0$ , it can easily be seen that  $m_i$  is greater  $m_i^C$ . Also,  $m_i^{CE}$  is lower than  $m_i$  since

$$\begin{aligned}m_i &\geq m_i^{CE} \\ t &\geq \frac{2dt}{tk_i^{E2} + 2d} \\ k_i^E &\geq 0\end{aligned}$$

Integrating consumers' choice of effort increases firm  $i$ 's margin, i.e.  $m_i^{CE} \geq m_i^C$ , iff

$$\begin{aligned}m_i^{CE} &\geq m_i^C \\ \frac{2dt}{tk_i^{E2} + 2d} &\geq t - t \left( \frac{4r - t}{8b + 2t} \right) \\ \frac{1}{8tk_i^{E2}} \left( -3t^2k_i^{E2} + 8dr - 2dt + 4rtk_i^{E2} \right) &\geq b\end{aligned}$$

Given the variable cost of producing a mass customized product  $b$  is not too high,  $m_i^{CE} \geq m_i^C$ .

*QED*

**Proof of Proposition 13.** Consumer surplus is greater when firms adopt mass customization, i.e.  $CS^C(k_i^*) \geq CS$ , iff

$$\begin{aligned} CS^C(k_i^*) &\geq CS \\ r - \frac{13}{12}t - bk_i^{*2} - \frac{1}{4}k_i^{*2}t + \frac{1}{12}k_i^{*3}t + k_i^*r + \frac{5}{4}tk_i^* &\geq r - \frac{13}{12}t \\ -bk_i^{*2} - \frac{1}{4}k_i^{*2}t + \frac{1}{12}k_i^{*3}t + k_i^*r + \frac{5}{4}tk_i^* &> 0 \end{aligned}$$

Inserting the optimal degree of mass customization  $k_i^*$ , the above inequality becomes

$$\frac{1}{96}(4r - t) \frac{384b^2r + 528bt^2 + 1056b^2t + 16rt^2 + 16r^2t + 67t^3 + 192brt}{(4b + t)^3} \geq 0$$

Given  $k_i^* \in (0, 1)$ , the above inequality is always true. It follows that  $CS^C > CS$ .

Consumer surplus is greater when firms adopt mass customization and consumers exert effort, i.e.  $CS^{CE}(k_i^*) > CS$ , iff

$$\begin{aligned} CS^{CE}(k_i^*) &> CS \\ r(1 + k_i^{E*}) - \frac{13}{12} \left( \frac{2dt}{tk_i^{E*2} + 2d} \right) - bk_i^{E*2} &\geq r - \frac{13}{12}t \\ -12bk_i^{E*3}t + 12rk_i^{E*2}t + 13k_i^{E*}t^2 - 24bdk_i^{E*} + 24dr &\geq 0 \\ \frac{1}{12k_i^{E*3}t + 24dk_i^{E*}} (13k_i^{E*}t^2 + 24dr + 12k_i^{E*2}rt) &\geq b \end{aligned}$$

It follows that  $CS^{CE}(k_i^{E*}) \geq CS$  if the variable cost of producing a mass customized product  $b$  is sufficiently low. Numerically solving  $\frac{\partial}{\partial k_i^E} \pi_i^E$  for any given  $b \in [0, 1000]$  shows that firm  $i$  chooses  $k_i^{E*}$  such that  $CS^{CE} \geq CS$ .

*QED*

## B.4 Extensions

### B.4.1 Incentive to offer a standard and a mass customized product

When firms offers both a standard and a mass customized product, profit functions are given by

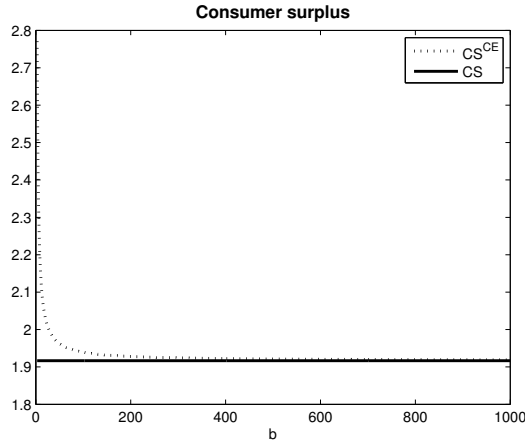


Figure B.1 Consumer surplus is shown for  $t = 1, r = 3, d = 1$ .

$$\begin{aligned}\pi_A &= \theta^A (c_A - z_A) + \theta^{AB} (p_A - c_A) \\ \pi_B &= (1 - \theta^B) (c_B - z_B) + (1 - \theta^{AB}) (p_B - c_B)\end{aligned}\quad (\text{B.79})$$

Differentiating B.79 with respect to  $z_i$  yields the optimal discount  $z_i^*$

$$\begin{aligned}\frac{\partial}{\partial z_i} \pi_i &: \frac{1}{2\sqrt{(z_i - rk_i)(t - t_i)}} (bk_i^2 + 2rk_i - 3z_i) = 0 \\ z_i^* &= \frac{2}{3}rk_i + \frac{1}{3}bk_i^2\end{aligned}\quad (\text{B.80})$$

Simultaneously optimizing B.79 with respect to  $p_i$ , yields the necessary first-order condition

$$\frac{\partial}{\partial p_i} \pi_i : \frac{(t_i - t_j) (-3p_i + 2p_j + 2rk_i - 2rk_j + bk_i^2) + 2t_i t_j - 2t_j \sqrt{(t_i - t_j) (-p_i + p_j + rk_i - rk_j)} + t_i t_j}{2(t_i - t_j) \sqrt{(t_i - t_j) (-p_i + p_j + rk_i - rk_j)} + t_i t_j} = 0 \quad (\text{B.81})$$

Solving B.81 with respect to  $p_i$ , yields firm  $i$ 's best response function<sup>6</sup>

$$\begin{aligned}p_i^*(p_j) &= -\frac{1}{9t_i - 9t_j} (2t_j^2 - 6t_i t_j - 3(t_i - t_j) (2p_j + 2rk_i - 2rk_j + bk_i^2) + \\ &\quad 2t_j \sqrt{t_j^2 + 3t_i t_j - 3(t_i - t_j) (-p_j - rk_i + rk_j + bk_j^2)})\end{aligned}\quad (\text{B.82})$$

Inserting firm  $j$ 's best response function into Equation B.82 and solving the equation for  $p_i$ , yields

<sup>6</sup>Please note that this best response function is the only solution satisfying  $p_i^*(p_j) \geq 0$ .

the equilibrium price<sup>7</sup>

$$p_i^* = \frac{1}{25(t_i - t_j)} \left[ (t_i - t_j) \left( 6t_j - 2t_i + 10r(k_i - k_j) + b(15k_i^2 + 10k_j^2) \right) + 6t_i^2 + (4t_i - 6t_j) \sqrt{5(t_i - t_j)(k_i - k_j)(r - bk_i - bk_j) + t_i^2 + 7t_it_j + t_j^2} \right] \quad (\text{B.83})$$

Taking the second derivative of the profit with respect to  $p_i$ , yields the sufficient second-order condition

$$\frac{\partial^2}{\partial p_i^2} \pi_i : - \frac{4t_it_j - (t_i - t_j)(3p_i - 4p_j - 4rk_i + 4rk_j + bk_i^2)}{4(t_it_j + (t_i - t_j)(p_j - p_i + rk_i - rk_j))^{\frac{3}{2}}} \quad (\text{B.84})$$

B.84 is smaller or equal zero in case both firms make symmetric pricing and mass customization decisions since  $\frac{\partial^2}{\partial p_i^2} \pi_i (k_i = k_j) : - \frac{t_it_j}{(t_it_j)^{\frac{3}{2}}} \leq 0$ . In this case,  $p_i^*$  is a maximum.

Consumers close to firm  $i$  purchase the standard product while distant consumers buy the mass customized product since  $U_A^S(\theta = 0)$  is greater or equal  $U_A^C(\theta = 0)$ .<sup>8</sup> The utility from buying firm  $A$ 's standard product  $U_A^S$  and that from buying firm  $A$ 's mass customized product  $U_A^C$  of the consumer who is located at  $\theta = 0$  are given by

$$U_A^S(\theta = 0) = r - p_A + z_A = r + \frac{2}{3}rk_A + \frac{1}{3}bk_A^2 - p_A$$

$$U_A^C(\theta = 0) = r + rk_A - p_A$$

The type- $\theta$  consumer located at  $\theta = 0$  derives a utility from purchasing the standard product that is greater or equal than the utility buying the mass customized product iff

$$r + \frac{2}{3}rk_A + \frac{1}{3}bk_A^2 - p_A \geq r + rk_A - p_A$$

$$bk_A \geq r$$

Given  $bk_A \geq r$ , the consumer located at  $\theta = 0$  purchases firm  $A$ 's standard product. The consumer who is indifferent between buying the standard product and buying the mass customized product from firm  $A$  is given by

$$\theta^A = \sqrt{\frac{z_A - rk_A}{t - t_A}} = \sqrt{\frac{k_A(bk_A - r)}{3(t - t_A)}} \quad (\text{B.85})$$

<sup>7</sup>Please note that this equilibrium price is the only solution satisfying  $p_i^* \geq 0$  and  $D_i \in [0, 1]$ .

<sup>8</sup>The same holds true for consumers of firm  $B$ . Due to symmetry only firm  $A$  is considered in detail.

If  $\theta^A$  is such that  $D_A^C \in (0,1)$ , there exists demand for the standard and the mass customized product. This is true if  $\frac{r}{k_A} < b < \frac{3(t-t_A)+rk_A}{k_A^2}$ . Due to symmetry,  $\theta^B$  is such that  $D_B^C \in (0,1)$  if  $\frac{r}{k_B} < b < \frac{3(t-t_B)+rk_B}{k_B^2}$ .

QED

**Proof of Proposition 17.** The second derivative of the profit with respect to  $k_i$  is given by

$$\frac{\partial^2}{\partial k_i^2} \pi_i^S = \frac{1}{\sqrt{108t^2k_i^3(tk_i^2+2d)^3(bk_i-r)}} \left( 32b^2d^2k_i^2 + 72b^2dk_i^4t + 24b^2k_i^6t^2 - 16bd^2k_i r - 72bdk_i^3rt \right. \\ \left. - 24bk_i^5rt^2 + 12dk_i^2r^2t + 3k_i^4r^2t^2 - 4d^2r^2 \right) \quad (\text{B.86})$$

The increase in the optimal degree of mass customization is convex if B.86 is greater or equal zero. This is true iff

$$b \geq \frac{r \left( 2(3k_i^4t^2 + 2d^2 + 9dk_i^2t) - (k_i^2t + 2d) \sqrt{6(3k_i^4t^2 + 2d^2 + 3dk_i^2t)} \right)}{4k_i(3k_i^4t^2 + 4d^2 + 9dk_i^2t)}$$

Since  $\frac{r}{k_i} \geq \frac{r(2(3k_i^4t^2+2d^2+9dk_i^2t)-(k_i^2t+2d)\sqrt{6(3k_i^4t^2+2d^2+3dk_i^2t)})}{4k_i(3k_i^4t^2+4d^2+9dk_i^2t)}$  the above inequality is always true. It follows that the profit function is convexly increasing in  $k_i$ .

QED





# Appendix C

## Supplement to the appendices

### C.1 Remark 1

Consumer utility is given by

$$U = r(1+k) - t \left( \max \left\{ 0, \left| \theta - \frac{1}{2} \right| - e_\theta \frac{k}{2} \right\} \right)^2 - \frac{1}{2} d e_\theta^2 - p \quad (\text{C.1})$$

Optimizing C.1 with respect to  $e_\theta$  for the case  $\left| \theta - \frac{1}{2} \right| - e_\theta \frac{k}{2} < 0$ , yields the necessary first-order condition

$$\frac{\partial}{\partial e_\theta} U : -d e_\theta = 0 \quad (\text{C.2})$$

Since  $d$  is assumed to be sufficiently high, the only  $e_\theta^*$  that solves C.2 is given by

$$e_\theta^* = 0 \quad (\text{C.3})$$

The utility function reduces to

$$U = r(1+k) - p \quad (\text{C.4})$$

Consumers buy iff

$$U \geq 0 \quad (\text{C.5})$$

$$r(1+k) - p \geq 0 \quad (\text{C.6})$$

It follows that the optimal price  $p^*$  of the monopolist is given by

$$p^* = r(1+k) \quad (\text{C.7})$$

The profit function of the monopolist is given by

$$\pi = p^* - bk^2 = r(1+k) - bk^2 \quad (\text{C.8})$$

Differentiating C.8 with respect to  $k$  and solving the necessary first-order condition for  $k$  yields the optimal degree of mass customization  $k^*$

$$k^* = \frac{r}{2b} \quad (\text{C.9})$$

Since  $\frac{\partial}{\partial r}k^* > 0$  and  $\frac{\partial}{\partial b}k^* < 0$ , the optimal degree of mass customization is increasing in  $r$  and decreasing in  $b$ .

Inserting C.9 into the firm's profit function, leads to an optimal profit  $\pi^*$  of

$$\pi^* = \frac{r(4b+r)}{4b} \quad (\text{C.10})$$

## C.2 Remark 2

Recall from A.52 that the necessary first-order condition is given by

$$\frac{\partial}{\partial k}\pi : \frac{8}{27dt} (r + rk - bk^2)^2 (6dr - 8btk^3 + 5k^2rt - 12bdk + 2krt) = 0 \quad (\text{C.11})$$

For  $k^* = 1$  the necessary first-order condition becomes

$$\frac{8}{27dt} (r + r - b)^2 (6dr - 8bt + 5rt - 12bd + 2rt) = 0 \quad (\text{C.12})$$

$$6dr - 8bt + 5rt - 12bd + 2rt = 0 \quad (\text{C.13})$$

The above equation holds true iff

$$b = \frac{r(6d + 7t)}{12d + 8t} \quad (\text{C.14})$$

Since  $k^*$  is decreasing in  $b$  as shown in the Proof of Lemma 6, it follows that  $k^* < 1$  for  $b > \frac{r(6d+7t)}{12d+8t}$ .

Given the assumption that  $r$  is large enough so that consumers buy, the term  $\frac{5r}{24b}$  is always positive. As  $k^*$  is an additive function, it follows that  $k^* > 0$ .

Hence,  $k^*$  is such that  $k^* \in (0, 1)$ .

### C.3 Remark 4

To verify that  $p \leq -\frac{1}{3}(-4r - \lambda + bk^2 - 4kr)$  holds true for  $p$  given by A.45, it is shown that  $p$  given by A.45 is smaller or equal the threshold value  $-\frac{1}{3}(-4r - \lambda + bk^2 - 4kr)$

$$\begin{aligned} p &\leq -\frac{1}{3}(-4r - \lambda - bk^2 - 4rk) \\ \frac{2}{3}r(1+k) + \frac{1}{3}bk^2 - \frac{1}{3}\lambda &\leq -\frac{1}{3}(-4r - \lambda - bk^2 - 4rk) \\ \frac{1}{3}bk^2 + \frac{2}{3}r(1+k) - \frac{1}{3}\lambda - \left[ \frac{1}{3}bk^2 + \frac{4}{3}r(1+k) + \frac{1}{3}\lambda \right] &\leq 0 \\ -\frac{2}{3}(r(1+k) + \lambda) &\leq 0 \end{aligned}$$

Given the domains of definition of  $r$ ,  $k$ , and  $\lambda$ , this inequation always holds true.



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# Declaration

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## **Affirmation – Statutory Declaration**

**According to § 10 part 1 no. 6 of the Doctoral Studies' Guide Lines  
(dated 5th March 2008 as amended on the 8th September 2009)**

I hereby declare, that the

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was produced independently and without the aid of sources other than those which have been indicated. All ideas and thoughts coming both directly and indirectly from outside sources have been noted as such.

This work has previously not been presented in any similar form to any other board of examiners.

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*Verl, March 2017*

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**Continuation of Affirmation – Statutory Declaration**

The following persons helped me gratuitous / non-gratuitous in the indicated way in selecting and evaluating the used materials:

| Last name | First name | Kind of support | Gratuitous / non-gratuitous |
|-----------|------------|-----------------|-----------------------------|
| Jost      | Peter-J.   | Advisor         | Gratuitous                  |
| Spinler   | Stefan     | Co-advisor      | Gratuitous                  |

Further persons have not been involved in the preparation of the presented dissertation as regards contents or in substance. In particular, I have not drawn on the non-gratuitous help of placement or advisory services (doctoral counsels / PhD advisors or other persons). Nobody has received direct or indirect monetary benefits for services that are in connection with the contents of the presented dissertation.

The dissertation does not contain texts or (parts of) chapters that are subject of current or completed dissertation projects.

*Verl, March 2017*

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Theresa Süsser