Product Design Outsourcing in Competitive Markets

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Abstract

Original design manufacturers (ODM) is a new form of global outsourcing. Traditional outsourcing only transfers the production of a product from brands to manufacturers. An ODM, in contrast, not only manufactures the product for a brand, but also designs the product. Using an analytical model, we investigate strategic design outsourcing decisions of firms. Two firms competing in a horizontally differentiated market decide whether to design the products by themselves or to outsource product design to an ODM. We consider two different channel structures – one in which each firm partners with an exclusive ODM and the other in which both firms partner with a common ODM. We find that both symmetric and asymmetric outsourcing outcomes can arise in the equilibrium, even though competing firms are assumed to be completely symmetric. Surprisingly, firms' outsourcing incentive can be inversely related to the cost of designing a product, i.e., neither firm outsources product design when the cost is high, one firm outsources product design and the other insources when the cost is in an intermediate range, and both firms outsource product design when the cost is low. We also find that firms are less likely to outsource product design when there is a common ODM in the channel than when there are exclusive ODMs.

Keywords: Original Design Manufacturer, Game Theory, Firm Competition, Outsourcing, Supply Chain Management

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1 Introduction

Outsourcing the production process to external manufacturers has been a longstanding supply chain management strategy for firms. Firms usually develop their products in house and then contract the production to an external manufacturer[1]. Over the past two decades, however, some manufacturers have become more involved in the product development process as they gained more expertise through contract manufacturing. As a result, a new form of global outsourcing emerged in the manufacturing sector: original design manufacturers (hereafter ODMs). Unlike contract manufacturers, an ODM not only manufactures the product for a brand, but also designs the product. The brand is responsible only for marketing the product under its own brand name and selling through its channels[2].

Consider the example of Sengled, a Chinese LED light bulb and equipment company that has successfully transformed from a contract manufacturer into an ODM. Sengled originally manufactured light bulbs for well-known brands such as Philips, GE, and Osram. To develop its own products, Sengled has been investing over 40% of its annual profit in R&D activities since 2010. Currently, over 80% of Sengled's profit comes from products designed and manufactured by the company but sold under the name of lighting brands.[3]

At the same time, big-name brands are also transforming their role in the supply chain. Philips, for instance, states on their website that "in recent years, Philips has transformed its activities from purchasing to supply management." In particular, they "focus on the suppliers that can work closely with us through early involvement in the innovation process", and the goal is to "build long-term relationships with key strategic suppliers who share in the risk and rewards of innovation."[4] This is reflected in their outsourcing strategy, which is to

[1] These manufacturers are usually referred to as offshore manufacturers, but location alone does not dictate role.

[2] We use firm and brand interchangeably in the paper to refer to the outsourcing company that owns the product brand, and manufacturer to mean the supplier that brands outsource to

[3] See http://www.csrc.gov.cn/pub/zjhpublic/G00306202/201406/P020140627503369683075.pdf for the Sengled prospectus, accessed on Nov 28, 2014.

[4] See http://www.philips.com/about/company/businesses/suppliers/aboutsupplymanagement.page for the statement on the Philips supply management strategy, accessed on Nov 28, 2014.

increase cooperation with ODMs instead of using contract manufacturers. Many firms with similar strategies are now found in different industries, including Dell, HP, T-Mobile, Sony and Google (Feng and Lu, 2011). A recent report shows that in 2011, 94% of the notebooks sold in the world were assembled by Taiwanese vendors, the majority of which were through ODM contracts rather than traditional manufacturing contracts.[5]

A product's manufacturing process can usually be standardized and easily contracted. Design is quite the opposite, yet it is of paramount importance to a product's success in today's competitive market. A well-known example is Blackberry, which is famous for the full physical keyboard on its smartphones. Once a producer of the most popular consumer smartphone, the company has been through a difficult time in the past few years. Its global share slumped from 20.1% in 2009 to only 0.4% in the first quarter of 2015[6]. An important reason for Blackberry's failure was its outdated product design, including its insistence on keeping the keyboard that many consumers find inconvenient for webpage navigation and video viewing[7]. The decision to adopt its own RIM operating system might have been another mistake, as it ignored the strong network externality of operating systems. The company has recently introduced several smartphones with the Android operating system in an attempt to keep up with market trends and revitalize its business. For Apple, on the other hand, the success of its iPhone in the smartphone market could be accredited to its successful product design. In an interview with the online news website Cult of Mac, the former Apple CEO John Sculley attributed the success of Apple to the design philosophy of Steve Jobs. "Apple is not really a technology company. Apple is really a design company," he said[8].

Firms face many challenges when designing their products, including the challenge to

[5] See http://www.prnewswire.com/news-releases/global-and-china-laptop-and-tablet-pc-industry-report-2011-2012-152524185.html for the report, accessed on Nov 28, 2014.

[6] Source: http://www.statista.com/statistics/263439/global-market-share-held-by-rim-smartphones/, accessed on July 16, 2014.

[7] "The Fatal Mistake That Doomed BlackBerry," available at http://business.time.com/2013/09/24/the-fatal-mistake-that-doomed-blackberry/, accessed on Nov 28, 2014.

[8] For the full transcript of the interview, see http://www.cultofmac.com/63295/john-sculley-on-steve-jobs-the-full-interview-transcript/, accessed on Nov 28, 2014.

cater to heterogeneous consumer tastes. What is preferred by one consumer may not be liked by another. The physical keyboard of Blackberry smartphones, for instance, although unappealing to most consumers, may still be an attractive design to others, including President Barack Obama [9]. The TrackPoint design of laptops that was popularized by ThinkPad is another example of a feature that received mixed reactions from consumers. While some consumers love it and purchase a ThinkPad computer just for the TrackPoint, others find it dispensable or even repulsive [10]. The brand, Lenovo, remarks in its official blog that "it's hard to make everyone happy," and notes that "any time we make the slightest change, we get reams of comments some 'thank you' and 'I love this,' and some, 'What are you doing?' and 'Don't mess with it.'"[11] Since it is hard to appeal to all consumers, the challenge faced by firms is to target the consumers that bring the largest profit with the right product design.

When outsourcing to a contract manufacturer, firms are able to maintain full control over the designing process of a product. When they outsource to an ODM, however, the ODM determines the specific design of the product (Feng and Lu, 2011). Whether to outsource product design along with manufacturing is a crucial strategic decision for firms, because it may lead to a change in their product design and affect their position against competition. Despite the strategic importance of design outsourcing and the increasing popularity of ODMs in the manufacturing sector, there has been very limited academic research on this issue. We conduct the current study to investigate firms' outsourcing choice between a contract manufacturer and an ODM in the presence of competition. We adopt a competitive framework because competition is common in industries where ODMs are most often found, such as lighting, computers, digital audio players, cameras, cellphones, refrigerator, and TVs (Feng and Lu, 2011). In both outsourcing strategies, firms will outsource production to an

[9] "You Can't Run the Worlds Most Powerful Nation Without Your BlackBerry, President Obama Discovers." Blackberry official blog, available at http://blogs.blackberry.com/2014/11/you-cant-run-the-worlds-most-powerful-nation-without-your-blackberry-president-obama-discovers/, accessed on Nov 28, 2014

[10] See the discussion of consumers at http://ask.metafilter.com/187175/Talk-to-me-about-the-trackpoint, and the blog at http://blog.codinghorror.com/touchpad-vs-trackpoint/, accessed on Nov 28, 2014.

[11] "New T431s Illustrates How ThinkPad Loyalists, Techies and the People Will Define Future Design." Lenovo official blog, available at http://blog.lenovo.com/en/blog/thinkpad-t431s-laptop-new-design, accessed on Nov 28, 2014.

external manufacturer. By examining a firm's outsourcing choice between contract manufacturers and ODMs, we are essentially studying whether a firm should outsource the design of its products. We address the following questions: why do some firms outsource their product design together with manufacturing, while others only outsource manufacturing? Under what conditions should firms outsource their product design? How does the structure of the channel affect the outsourcing decision? We investigate these issues through an analytical model of outsourcing under competition.

In the model, consumers are assumed to be distributed uniformly on a straight line that represents heterogeneous consumer preferences, and they incur a dis-utility from purchasing a product that is different from their ideal. Two competing firms, each offering one product to the market, decide whether to outsource the design of the product to an ODM. If a firm does not outsource product design, it will choose the location of the product by itself. If it outsources, the ODM will determine the location of the product. A product development cost will be incurred by the designer of the product, and that cost is determined by how much the product differs from the zero point. A company (firm or manufacturer) that desires a greater differentiation between its product and that of the competitor needs to invest more money to modify its product features. Regarding cost of product design, neither the firm nor the ODM has an advantage. We consider two different channel structures, both of which are widely observed in the manufacturing industry. In the first situation, each firm partners with an exclusive ODM. If both firms decide to outsource product design, the two products are designed by different ODMs. In the second situation, there is only one ODM. Therefore, if both firms decide to outsource product design, both products will be designed by the same ODM. In both situations, the wholesale price of a product is determined through a bargaining process between the manufacturer and the firm. We examine how the outsourcing equilibrium differs across the two channel structures.

Assuming that competing firms are otherwise completely symmetric, in both the exclusive–ODM channel and the common–ODM channel, we find the existence of asymmetric equilibrium in outsourcing, i.e., one firm optimally outsources design to an ODM and the other insources product design. Asymmetric equilibria exist when the bargaining power of manufacturers and the product design cost are both small enough. Under this condition, manufacturers are less inclined to invest in product design than firms. While the first firm to outsource product design is able to save the design cost and expect only a slight decrease in product differentiation thanks to the efforts of the other firm to invest in product design, the second firm that outsources product design will suffer a huge drop in product differentiation because neither company is willing to invest in product design. When the bargaining power of manufacturers is large enough to justify more investment in product design from ODMs than from firms, both firms outsourcing design is the unique equilibrium. When manufacturers' bargaining power is relatively small, but the design cost is relatively large, both firms will insource product design in the equilibrium.

We also find that, contrary to conventional wisdom, the incentive for firms to outsource does not necessarily increase when design cost increases. When firms are more powerful than manufacturers in either the exclusive–ODM channel or the common–ODM channel, it is possible to observe both brands outsourcing product design when the design cost is low, one of the brands outsourcing product design when the design cost is in an intermediate range, and neither brand outsourcing product design when the design cost is high. This happens for two reasons. First, when a firm incourses its product design, it will respond to increased design cost by reducing its design effort. Thus the potential cost saving from outsourcing design is largely capped. The second reason is that, when firms have relatively large power in the channel, they will develop better differentiated products than the ODMs. This in turn leads to higher profits. The second effect is especially prominent when the design cost is high, thus dampening brands' incentive to outsource.

Comparing results between the exclusive–ODM channel and the common–ODM channel, we find that product differentiation may be either larger or smaller when the two products are designed by a common ODM than by competing ODMs. This is driven by two incentives. One one hand, increasing the investment in product design on either product leads to higher product differentiation and benefits both products. While competing ODMs take into account only the benefit for their own products when deciding how much investment to make, the common ODM has a stronger motive to invest in product design because it incorporates the benefits for both products into its decision. On the other hand, however, a smaller differentiation between products gives the manufacturer a greater advantage when negotiating wholesale prices because the manufacturer can use the bargaining with one brand as a threat to the other brand. So the manufacturer also has an incentive to design products with a smaller differentiation. These two incentives combined lead to less differentiated products when the manufacturer's bargaining power in the channel is relatively small, but greater differentiation when the manufacturer's bargaining power is relatively large.

With regard to the optimal outsourcing strategy, we find that outsourcing is less likely to be observed in the equilibrium when there is a common ODM in the channel. The area in which both firms insource design in the equilibrium is the same in both situations. However, some of the area in which both firms outsources design in the exclusive–ODM channel sees only one firm outsourcing in the common–ODM channel. This is mainly due to the ODM's incentive to reduce the differentiation between products in order to gain the upper hand in negotiations. Foreseeing the decrease in product differentiation and expected profit when both brands outsource to the same ODM, brands will optimally choose to diverse their outsourcing choice to minimize competition.

The reminder of the paper is organized as follows. The following section discusses the literature related to production outsourcing and channel management. In Section 3, we formally define the model and discuss the model assumptions. Section 4 and 5 present detailed analyses of the model under different channel structures. Section 6 concludes the paper.

2 Related Literature

This paper is related to several streams of literature. First, our paper is related to a few studies on product design outsourcing. Parker and Anderson (2002) used case study data to document how a large computer company that had outsourced both production and product design to external suppliers successfully fulfilled its role as a suppler chain coordinator by creating highly-skilled supply chain “integrators”. Also using a case study approach, Caputo and Zirpoli (2002) looked at the transformation of a major European auto maker who outsources both design and production to external suppliers. They concluded that the increasing involvement of suppliers in the design process does not jeopardize the leader role of car makers, because the ability to coordinate and integrate the product development process has become a new core competence for car makers. Iyer et al. (2005) examined the optimal contract design problem faced by outsourcing firms through a principal-agent model in which an auto maker commissions a supplier to complete the product design and manufacturing process. Feng and Lu (2011) provided an excellent overview of the background, current situation, and important strategic considerations of design outsourcing in Asia. While stressing the importance of product design and the increasing popularity of design outsourcing, they also called for more academic research on this issue. Overall, research on product design outsourcing is scarce. Most existing studies focus on the managerial and logistic issues associated with design outsourcing, but do not examine the outsourcing decision itself. In contrast, the objective of our paper is to explicitly investigate the strategic trade-offs of design outsourcing in a competitive environment.

Our research is also related to the literature on production outsourcing, a major focus of which is to investigate the rationale for outsourcing production. The most commonly-given reason for outsourcing production is potential cost savings (Haksöz et al., 2011). If an external manufacturer is able to produce a product more efficiently than a firm, the firm can reduce its cost of production by transferring this process to the manufacturer. In addition to cost savings, various other reasons have also been proposed in the literature. For example, Cachon and Harker (2002) demonstrated that in the presence of economies of scale, competing firms may decide to outsource production to external suppliers even though the suppliers are no more efficient than firms. Liu and Tyagi (2011) showed that, if firms are allowed to change their positioning, they may strategically outsource production to upstream suppliers even when the suppliers do not have any cost advantage over firms. Chalos and Sung (1998) investigated firms' trade-off between coordination costs of outsourcing and improvement in managerial incentives when deciding whether to outsource production. Gilbert et al. (2006) studied the outsourcing decisions of competing firms facing cost-reduction opportunities. They showed that firms tend to over-invest in cost reduction when producing the product in-house but are able to invest optimally when outsourcing production to external suppliers. Feng and Lu (2012) found that, contrary to conventional wisdom, firms may not always benefit from outsourcing production to a more efficient supplier in a competitive setting, because the cost disadvantage will put the firm into a less favourable position in the negotiation with the supplier. While these papers examine the trade-offs between outsourcing and insourcing production, our paper focuses on the trade-offs in a different type of outsourcing – design outsourcing.

Another stream of relevant research is the large body of literature on product line design. Previous studies have exmined the optimal product line design of firms with vertical differentiation (Moorthy, 1984; Guo and Zhang, 2012; Desai et al., 2001; Orhun, 2009; Villas-Boas, 1998), horizontal differentiation (Kuksov and Villas-Boas, 2010; Liu and Cui, 2010; Villas-Boas, 2009), and a combination of both (Desai, 2001; Villas-Boas, 2004). Of particular relevance to our research is the literature that examines how channel issues affect the quality and position choices of firms. For example, Villas-Boas (1998) investigated how selling through a distribution channel affects the quality choices of a manufacturer in a vertical product line. Our paper differs from his in two aspects. First, he studies product line design in a vertical differentiation setting, while we adopt a horizontal differentiation framework. Second, in his model, product design decisions are always made by the manufacturer. In our paper, however, we focus on whether these decisions should be fulfilled by the manufacturer or the brand. Liu and Cui (2010) also studied how the product line design of a firm is affected by channel structure, albeit in a horizontal differentiation setting. Our paper also adopts a horizontal differentiation framework, but differs from theirs in three important ways. First, although we explicitly model product design in our study, we are not looking at product line decisions. Each firm in our model is assumed to introduce only one product to the market, and is not considering expanding it into a product line. Second, they examine a monopoly firm's product line design decision in a centralized versus decentralized channel, while we take a different perspective by investigating whether the design process should be completed in-house or outsourced to an ODM. Third, while they focus more on the optimal product line length than the specific design of products, we are doing the opposite by looking at the specific design and how it affects firms' sourcing decision.

Broadly speaking, our paper also speaks to the research that examines the benefits of channel decentralization and the conditions under which a decentralized channel will arise (McGuire and Staelin, 1983; Moorthy, 1988; Desai et al., 2004; Liu and Tyagi, 2011), as well as the research on channel power (Messinger and Narasimhan, 1995; Kadiyali et al., 2000; Tian and Jiang, 2018). We study decentralized channels in the paper, but we do not consider the option of establishing a centralized channel because firms are not able to build their own production facilities in the short run. Instead, given a decentralized channel, we investigate the conditions under which firms will prefer to outsource only production versus to outsource both production and product design.

3 Model

We model two competing firms each offering a branded product in a horizontally differentiated market. Consumers are located uniformly on a line. The location of a consumer represents her ideal product type, for which her valuation is V. For a product that is different from her ideal, she suffers a disutility due to the mismatch. Specifically, we denote the location of product i ($i = 1, 2$) by x_i. If the consumer is located at x, her valuation for product i is equal to $V - t|x - x_i|$, where t captures the degree of consumer disutility from product mismatch. We assume that the size of the market (length of the line) is large enough that the market will not be fully covered in the equilibrium. This means if both brands lower their prices by the same amount, demands for both products will go up and the market will be expanded. Such an assumption is widely used in the literature to model product demand (e.g., Raju et al., 1995; Jain and Srivastava, 2000). Without loss of generality, we normalize the density of consumers on the line to 1, which means the market size between any two points a and b ($a \geq b$) is simply equal to $a - b$.

The aforementioned market structure captures the notion that consumers have heterogeneous preferences. By changing the design of its product, a firm also changes its location on the line, because different designs appeal to different consumer preferences. However, product design is costly, especially if the firm wants to differentiate its product from the competitor. To explicitly model the tension faced by firms in strategic product design, we assume that there is a product that costs the least amount of effort to design, and normalize its location to 0. Any other product location incurs additional design cost and the cost depends on how much the product differs from the zero point. The zero point could a be product with standardized features that all companies know how to design. Adding unique features to the product requires additional investment. For example, in the design of laptops, the zero point could be a regular 13" or 14" laptop with an integrated keyboard, a built-in camera and other features that laptops usually come standard with. Companies should find it easy to design such a product because the technologies of these features have been fairly mature and widely-adopted. Laptops with more uncommon features, such as a detachable keyboard, a 3D camera or touchscreen, will require more design effort and upfront R&D investment. The zero point could also be a product that has already existed in the market, i.e., an older-generation product that was designed in the past and may serve as the starting

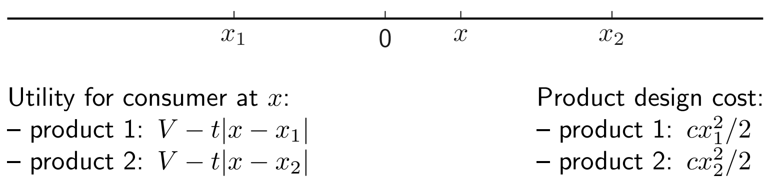

Figure 1: Consumer Utility and Product Design Cost

point in the design of new products. In such industries as cellphones and tablets, where new products are frequently introduced in the form of upgrades, the design cost is largely determined by how much the new product differs from the old one. To capture this idea, we assume that designing a product located at x_i incurs a cost of $cx_i^2/2$, and the cost does not vary with the number of units sold. We illustrate the structure of the market as well as the assumptions on consumer utility and product design cost in Figure 1.

Because neither of the two competing firms has their own manufacturing facility, they need to outsource the production process to an external manufacturer. Each firm has two outsourcing options: outsourcing to a contract manufacturer or outsourcing to an ODM. A contract manufacturer only produces the product according to the specifications of the firm. An ODM, on the other hand, designs and produces the product for the firm. In both options, the production of the product will be fulfilled by the external manufacturer (contract manufacturer or ODM). We normalize the marginal production cost of both types of manufacturers to 0. By assuming away any cost discrepancy between contract manufacturers and ODMs, we are able to tease out the strategic effect of product design on the firm's sourcing decisions. Therefore, the only difference between the two outsourcing options is whether the firm outsources the design of its product along with production. If the firm decides not to outsource product design, it will choose the location of the product by itself and incur the design cost. If the firm decides to outsource design to an ODM, the ODM will determine the location of the product and bear the design cost.

The timeline of the model is shown in Figure 2. At the first stage, both brands simultaneously decide whether to outsource product design. The decisions will be observed by all parties at the beginning of the second stage. At the second stage, a location x_i will be chosen for each product. If a firm decided to insource product design in the previous stage, it will choose the location by itself. Otherwise the ODM chooses the location of the product. At the third stage, brands and manufacturers negotiate about the wholesale prices of the two products. We assume the bargaining power of manufacturers and brands to be w and $1-w$ respectively. At the fourth stage of the model, both brands simultaneously set the retail prices of their products. Brands and manufacturers then engage in ex-post bargaining about wholesale prices. Consumers decide whether and which product to buy at the last stage of the model. In the next section, we will present the analysis of the situation in which each firm partners with an exclusive ODM. In Section 5, we will analyze the situation in which a common ODM serves both firms.

Instead of assuming that the manufacturer makes a take-it-or-leave-it offer to the firm, we assume that the wholesale price of a product is determined through a bargaining process between the brand and the manufacturer. We make this assumptions for several reasons. First, in the business world, wholesale prices are seldom dictated by the supplier. There is usually a back-and-forth process going on between the two parties in which the retailer attempts to obtain a lower price. Walmart, for example, is well known for using its market power to squeeze the margins of its suppliers. Second, it is a widely-adopted assumption in the outsourcing literature that the wholesale price is not determined solely by the manufacturer, but through some type of profit-sharing mechanism, such as bargaining (Feng and Lu, 2012; Benjaafar et al., 2007; Cachon and Harker, 2002; Ülkü et al., 2005). We follow the literature by explicitly modeling the bargaining process between manufacturers and brands, and looking for the Nash Bargaining Solution of the problem.

Following Iyer and Villas-Boas (2003) and Guo and Iyer (2013), we assume that bargaining takes place in two stages – an ex-ante bargaining stage and an ex-post bargaining stage. This assumption is made for two reasons. The first reason, as noted in Guo and Iyer

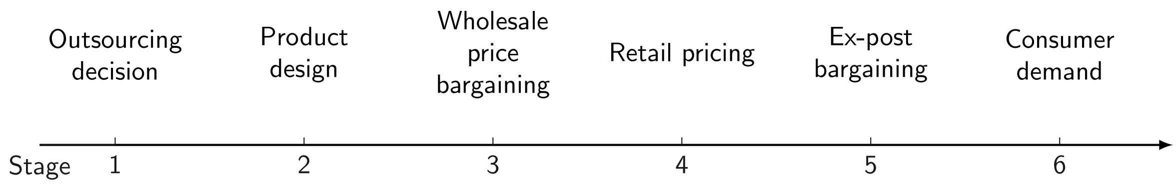

Figure 2: Game Structure and Timeline

(2013), is that consumer purchases sometimes occur before brands place order with suppliers. In this case, brands and manufacturers will have an opportunity to renegotiate about the wholesale price after demand for the product has been realized. Second, because looking for the Nash Bargaining Solution of the bargaining process involving solving the first-order condition of an objective function with fractional exponents, the problem can easily become unsolvable if the profit functions of the brand and the manufacturer are not sufficiently simplified. Without the ex-post bargaining stage, the expected profits of the two parties as a function of the wholesale price at the ex-ante bargaining stage are too complicated to obtain a close-form solution. With ex-post bargaining, however, the problem is simplified enough to ensure analytical tractability yet still able to capture the tension between the two parties during the negotiation process. We therefore restrict our attention to the situation in which late ordering and ex-post bargaining are present.

4 Channel with exclusive ODMs

We will first look at the situation in which each firm deals with an exclusive ODM in the channel. In this situation, if both firms decide to outsource product design, the two products will be designed by competing ODMs. We will solve the model through backward induction. We first examine the purchase decision of consumers as well as the ex-post bargaining at the last stage of the model. Note that consumers' purchase decisions are not affected by the wholesale price of a product. Thus the analysis of product demand can be conducted independent of the outcome of the ex-post bargaining.

Denote the locations of the two products as x_i $(i = 1, 2)$ and their prices p_i. Without loss of generality, we assume $x_2 \geq x_1$ because firms' profits depend only on the distance between the two products, not on their specific locations. For consumers located between x_1 and x_2, their payoff of buying product 1 is $V - t(x - x_1) - p_1$ and that of product 2 is $V - t(x_2 - x) - p_2$. The indifferent consumer is located at $x^* = \frac{t(x_1+x_2)-(p_1-p_2)}{2t}$. For those with $x < x_1$, purchasing product 1 and product 2 deliver a payoff of $V - t(x_1 - x) - p_1$ and $V - t(x_2 - x) - p_2$ respectively. They either all prefer to buy product 1, or all prefer to buy product 2. Similarly, consumers with $x > x_2$ also have homogeneous preference over the two products – they either all prefer product 1 or all prefer product 2.

4.1 Ex-post bargaining

At the beginning of the ex-post bargaining between brands and manufacturers, two possible outcomes may arise in the market: 1) The market between x_1 and x_2 is fully covered, and 2) the market between x_1 and x_2 is not fully covered. The first scenario arises when the indifferent consumer obtains non-negative payoff, i.e., when $p_1 + p_2 \leq 2V - (x_2 - x_1)t$, and the second scenario occurs when $p_1 + p_2 > 2V - (x_2 - x_1)t$. The Nash Bargaining Solution of the negotiation between brand i and manufacturer i is the solution to the following problem.

$$\max_{w_i} \quad [\pi_{mi}(w_i) - \pi_{mi}^0]^w [\pi_{fi}(w_i) - \pi_{fi}^0]^{1-w} \tag{1}$$

$$s.t. \quad \pi_{mi}(w_i) \geq \pi_{mi}^0 \; and \; \pi_{fi}(w_i) \geq \pi_{fi}^0 \tag{2}$$

In these equations, $\pi_{mi}(w_i)$ and $\pi_{fi}(w_i)$ are the expected profit of manufacturer i and brand i when the wholesale price is equal to w_i. π_{mi}^0 and π_{fi}^0 are the expected profit of manufacturer i and brand i if the negotiation between them breaks down.

We first analyze the bargaining problem when the market in between the two products is not fully covered. In this scenario, both brands act as a local monopoly in the market and obtain a demand of $d_i^{nf} = \frac{2(V-p_i)}{t}$, $i = 1, 2$. If the negotiated wholesale price is w_i, brand i and manufacturer i will earn a profit of $\pi_{fi}(w_i) = (1 - w_i)d_i^{nf}$ and $\pi_{mi}(w_i) = w_i d_i^{nf}$ respectively regardless of the outcome of the negotiation in the other channel. If the negotiation between brand i and manufacturer i breaks down, both companies obtain zero profit. So $\pi_{mi}^0 = \pi_{fi}^0 = 0$. Substituting these values into Equation (1) and solving the first-order condition, we obtain the equilibrium wholesale price $w_i^* = wp_i$.

We then proceed to the scenario in which the market in between the two products is fully covered. In this scenario, the demand for product i is given by $d_i^f = \frac{2V+(x_2-x_1)t+p_{3-i}-3p_i}{2t}$, $i = 1, 2$. However, note that the aforementioned demand is realized only when the negotiation succeeds in both channels. If the negotiation between either brand and its supplier fails to reach an agreement, the other product will become a local monopoly in the market and face a different demand function. So when analyzing the bargaining problem faced by brand i and manufacturer i, we need to take into account the possible bargaining outcome between the other brand and manufacturer. Specifically, if the bargaining between brand $(3 - i)$ and manufacturer $(3 - i)$ breaks down, brand i will become the only product in the market and earn a demand of d_i^{nf}. The bargaining problem therefore reduces to the one we have solved earlier when the market in between is not fully covered, and the equilibrium wholesale price is wp_i. If the bargaining between brand $(3 - i)$ and manufacturer $(3 - i)$ succeeds, brand i and manufacturer i will earn a profit of $\pi_{fi}(w_i) = (1-w_i)d_i^f$ and $\pi_{mi}(w_i) = w_i d_i^f$ respectively if the negotiated price is w_i and 0 if no agreement is reached. Solving the problem, we find that the equilibrium wholesale price is still wp_i.

At the ex-post bargaining stage, we find that the agreed wholesale price between brands and manufacturers is always equal to wp_i, regardless of the market outcome at the previous stage of the model. That is to say, the brand and the manufacturer essentially split the total channel profit according to their respective bargaining power in the channel. This result is not surprising because both parties will have to exit the market with zero profit if the negotiation breaks down. No party has a better outside option which could put them in a more favorable position during the negotiation. As a result, each of them will simply get a share of the profit that reflects their power in the channel.

4.2 Retail pricing

At the retail pricing stage, each firm will get a positive share of the market segment between x_1 and x_2 ("the middle segment" hereafter), i.e., $x_1 < x^* < x_2$. Otherwise one of the firms will get zero market share and profit. The middle segment will be fully covered If $V - t(x^* - x_1) - p_1 > 0$. Firms' demands from the middle segment are $x^* - x_1$ and $x_2 - x^*$ respectively when it is fully covered. If $V - t(x^* - x_1) - p_1 < 0$, the indifferent consumer prefers not to purchase any product and hence the middle segment will not be fully covered. In this scenario, demands for the two products from the middle segment are $\frac{V-p_2}{t}$ and $\frac{V-p_1}{t}$ respectively. For consumers located to the left of x_1 ("the left segment" hereafter), they will purchase product 1 as long as the payoff of buying is non-negative. This means consumers with $x \geq \frac{tx_1-V+p_1}{t}$ will buy product 1 and those with $x < \frac{tx_1-V+p_1}{t}$ will not buy any product. Similarly, for consumers located to the right of x_2 ("the right segment" hereafter), those with $x \leq \frac{tx_2+V-p_2}{t}$ will purchase product 2 and those with $x > \frac{tx_2+V-p_2}{t}$ will not purchase any product.

In the equilibrium, whether the middle segment will be fully covered depends on the distance between the two products. Intuitively, when the two products are located far apart from each other, the middle segment will not be fully covered, and each brand can enjoy being a local monopoly in the market. When the two products are located close enough, the middle segment will be fully served, and the equilibrium prices will be determined by competitive forces. We will outline the analysis of the competitive case. The analysis of other cases is analogous. When the market in between the two products is fully covered, we can write out the profit functions of the two firms.

$$\pi_1 = p_1(1-w)(\frac{V-p_1}{t} + x^* - x_1)$$

$$\pi_2 = p_2(1-w)(\frac{V-p_2}{t} + x_2 - x^*)$$

Solving the first-order conditions of the two equations together, we obtain the following solution for retail prices.

$$p_1^c = p_2^c = \frac{2}{5}V + \frac{1}{5}t(x_2 - x_1)$$

In order for the equilibrium to hold, we need to verify that the indifferent consumer indeed obtains a non-negative payoff at p_1^c and p_2^c. This implies $x_2 - x_1 \leq \frac{6V}{7t}$. Therefore, p_1^c and p_2^c are the equilibrium retail prices when $x_2 - x_1 \leq \frac{6V}{7t}$. The complete equilibrium results are given in Lemma 1.

Lemma 1. *When $0 \leq |x_2 - x_1| \leq \frac{6V}{7t}$, the equilibrium retail prices are $p_1^c = p_2^c = \frac{2}{5}V + \frac{1}{5}t|x_2 - x_1|$. The middle segment is fully covered and the indifferent consumers obtains positive payoff in the equilibrium. When $\frac{6V}{7t} < |x_2 - x_1| \leq \frac{V}{t}$, the equilibrium prices are $p_1^{cm} = p_2^{cm} = V - \frac{t|x_2-x_1|}{2}$. The middle segment is fully covered and the indifferent consumer obtains zero payoff in the equilibrium. When $|x_2 - x_1| > \frac{V}{t}$, the equilibrium prices are $p_1^m = p_2^m = \frac{V}{2t}$. The middle segment is not fully covered. Firms' and manufacturers' profits in each case are given in the Appendix.*

Proof. See the Appendix. □

Lemma 1 characterizes the equilibrium at the retail pricing stage. The equilibrium depends only on the distance between the two products, but not on the specific locations. When they are relatively close to each other ($0 \leq |x_2 - x_1| \leq \frac{6V}{7t}$), firms will compete fiercely for the consumers in the middle segment. As a result, prices will be low enough to ensure the indifferent consumer gets positive payoff in the equilibrium (*"competitive case"* hereafter). When the two products are relatively far away from each other ($|x_2 - x_1| > \frac{V}{t}$), the middle segment will not be fully covered, because firms will have to price extremely low to induce all consumers to buy, which hurts their profits (*"local monopoly case"*). When the distance between the two products is in an intermediate range ($\frac{6V}{7t} < |x_2 - x_1| \leq \frac{V}{t}$), the middle segment is fully covered, but the indifferent consumer will get zero payoff in the equilibrium (*"competitive monopoly case"*). In this case, firms do not want to deviate to a higher price because they will lose demand from the middle segment, and do not want to deviate to a lower price either, because the additional demand is not sufficient to offset the foregone revenue.

4.3 Product design

Because wholesale prices will be renegotiated at the ex-post bargaining stage, there is no need to solve for the wholesale prices at the ex-ante bargaining stage. Therefore, we can skip the third stage of the model and solve for the optimal product locations at the second stage. We need to consider three different subgames: (1) both products are designed by firms; (2) both products are designed by ODMs; (3) one of the products is designed by the firm and the other by the ODM. We will provide the analysis of the subgame in which both products are designed by firms. The analysis of the other two subgames is given in the Appendix. Note that in the equilibrium, the locations of the two products must satisfy $x_1 \leq 0 \leq x_2$. This is because when both products are located on the same side of the market, e.g., $0 < x_1 \leq x_2$, firm 2 can strictly increase its profit by relocating its product to $2x_1 - x_2$. It earns the same revenue from the product at the new location, but incurs strictly lower product design cost.

We will solve for the equilibrium locations by first examining the best response of each firm to the other firm's location and then solving the two best response functions together. Since the two firms are symmetric, we only need to look at the best response of firm 2 to x_1. Firm 1's best response to x_2 follows analogously. According to Lemma 1, when the two products are more than V/t apart, the equilibrium prices are $p_1^m = p_2^m = V/2$. Each firm is a local monopoly in this case and firm 2's profit is equal to $\pi_2^m = \frac{V^2(1-w)}{2t} - \frac{cx_2^2}{2}$. Since π_2^m decreases with $|x_2|$, firm 2 can increase its profit by moving closer to firm 1 if $x_1 \geq -\frac{V}{t}$. If $x_1 < -\frac{V}{t}$, firm 2's optimal location is at the zero point. However, when product 2 is located at the zero point, firm 1 will respond by moving to $x_1 \geq -\frac{V}{t}$. So we can restrict our analysis to $-V/t \leq x_1 \leq 0 \leq x_2 \leq V/t$. Under this condition, firm 2's best response to firm 1's location must satisfy $x_2 - x_1 \leq V/t$.

When $x_2 - x_1 \leq V/t$, firm 2's profit function is $\pi_2^{cm} = (1-w)(2V - tx_2 + tx_1)(x_2 - x_1) - cx_2^2/2$ in the competitive monopoly case, and $\pi_2^c = \frac{3(1-w)(2V+tx_2-tx_1)^2}{50t} - \frac{cx_2^2}{2}$ in the competitive case. Solving the first-order condition of π_2^{cm} and π_2^c with respect to x_2, we obtain the following results.

$$x_2^{bcm}(x_1) = \frac{(1-w)(V+tx_1)}{t(1-w)+c} \tag{3}$$

$$x_2^{bc}(x_1) = \frac{3(1-w)(V-tx_1)}{3t(1-w)-25c} \tag{4}$$

x_2^{bcm} is the solution of the first-order condition in the competitive case, while x_2^{bc} is the solution of the competitive case. The best response of firm 2 is either in the internal regions of the competitive and competitive monopoly case (x_2^{bcm} or x_2^{bc}), or at the boundary between different cases ($x_1 + \frac{V}{t}$ or $x_1 + \frac{6V}{7t}$). Comparing firm 2's profit at these four points, we obtain the result in Lemma 2.

Lemma 2. *Assume $-V/t \leq x_1 \leq 0$. When both products are designed by firms, firm 2's best response to firm 1's location x_1 is as follows, where $x_2^{bcm}(x_1)$ and $x_2^{bc}(x_1)$ are defined in Equation 3 and 4.*
(1) If $c \leq \frac{t(1-w)}{6}$, firm 2's best response is $x_2^{bcm}(x_1)$.
(2) If $\frac{t(1-w)}{6} < c \leq \frac{2t(1-w)}{5}$, firm 2's best response is $x_2^{bcm}(x_1)$ when $x_1 \leq \frac{V(t-tw-6c)}{7tc}$ and $x_1 + \frac{6V}{7t}$ when $x_1 > \frac{V(t-tw-6c)}{7tc}$.
(3) If $c > \frac{2t(1-w)}{5}$, firm 2's best response is $x_2^{bcm}(x_1)$ when $x_1 \leq \frac{V(t-tw-6c)}{7tc}$, $x_1 + \frac{6V}{7t}$ when $\frac{V(t-tw-6c)}{7tc} < x_1 \leq \frac{6V(2t-2tw-5c)}{35tc}$, and $x_2^{bc}(x_1)$ when $x_1 > \frac{6V(2t-2tw-5c)}{35tc}$.

Proof. See the Appendix. □

Whether firm 2's best response is in the competitive case or the competitive monopoly case depends on firm 1's location and the product design cost. As firm 2 moves away from firm 1, the market outcome at the retail pricing stage will change from the competitive case to the competitive monopoly case, and then to the local monopoly case. If firm 1 is located far away from the zero point, the best response of firm 2 lies in the internal region of the competitive monopoly case. When firm 1 moves closer to the zero point, firm 2's best response will move to the boundary between the competitive and competitive monopoly case. When firm 1 gets very close to the zero point, firm 2 will optimally locate its product in the internal region of the competitive case. Firm 1 has a more favorable position against firm 2 when it is located closer to the zero point, because firm 1 incurs less cost to design the product but firm 2 has to invest more in product design in order to differentiate its product from firm 1's. Consequently, as firm 1 gets closer to the zero point, firm 2 will choose to differentiate its product less and the market will get more competitive. Following a similar procedure, one can derive firm 1's best response to firm 2's location. The equilibrium product locations can then be found by solving the two best response functions together. Lemma 3 gives the results.

Lemma 3. *When both products are designed by firms, the equilibrium product locations are* $x_1^{BB} = -\frac{V(1-w)}{2t(1-w)+c}$ *and* $x_2^{BB} = \frac{V(1-w)}{2t(1-w)+c}$ *if* $c \leq \frac{t(1-w)}{3}$*;* $x_1^{BB} = -\frac{3V}{7t}$ *and* $x_2^{BB} = \frac{3V}{7t}$ *if* $\frac{t(1-w)}{3} < c \leq \frac{4t(1-w)}{5}$*; and,* $x_1^{BB} = -\frac{6V(1-w)}{25c-6t(1-w)}$ *and* $x_2^{BB} = \frac{6V(1-w)}{25c-6t(1-w)}$ *if* $c > \frac{4t(1-w)}{5}$*. The equilibrium profits of firms and manufacturers are given in the Appendix.*

Proof. See the Appendix. □

The superscript BB stands for the subgame in which both products are designed by brands. Not surprisingly, the equilibrium product locations depend on the cost of designing a product. The equilibrium locations of the two firms are always symmetric around zero and $x_2^{BB} - x_1^{BB}$ is a non-increasing function of c. This means the distance between the two products decreases when product design cost increases, because it is more costly to differentiate a product from the competitor's. Also note that when c is in an intermediate range, the equilibrium location choices do not depend on c. That is, when the cost of designing a product increases, firms will not respond by cutting their investment in product design. This is because the equilibrium locations in this region are on the boundary between the competitive case and the competitive monopoly case. Firms do not want to move farther away because the cost is too high, and do not want to move closer either, because the market will become too competitive at the retail pricing stage that ensues. Following similar steps, we can also solve for the equilibrium product locations in the other two subgames. The results are given in Lemma 4.

Lemma 4. *When both products are designed by ODMs, the equilibrium product locations are* $x_1^{DD} = -\frac{Vw}{2tw+c}$ *and* $x_2^{DD} = \frac{Vw}{2tw+c}$ *if* $c \leq \frac{tw}{3}$; $x_1^{DD} = -\frac{3V}{7t}$ *and* $x_2^{DD} = \frac{3V}{7t}$ *if* $\frac{tw}{3} < c \leq \frac{4tw}{5}$; *and,* $x_1^{DD} = -\frac{6Vw}{25c-6tw}$ *and* $x_2^{DD} = \frac{6Vw}{25c-6tw}$ *if* $c > \frac{4tw}{5}$.

When product 1 is designed by the ODM and product 2 is designed by the firm, the equilibrium product locations are $x_1^{DB} = -\frac{Vw}{t+c}$ *and* $x_2^{DB} = \frac{V(1-w)}{t+c}$ *if* $c \leq \frac{t}{6}$; $x_1^{DB} = -\frac{6Vw}{7t}$ *and* $x_2^{DB} = \frac{6V(1-w)}{7t}$ *if* $\frac{t}{6} < c \leq \frac{2t}{5}$; *and,* $x_1^{DB} = -\frac{6Vw}{25c-3t}$ *and* $x_2^{DB} = \frac{6V(1-w)}{25c-3t}$ *if* $c > \frac{2t}{5}$. *The equilibrium profits of firms and manufacturers in these two subgames are given in the Appendix.*

Proof. See the Appendix. □

The subgame in which product 1 is designed by the firm and product 2 is designed by the ODM is symmetric to the one in which product 2 is designed by the firm. Given the results in Lemma 3 and 4, we can compare the level of differentiation between the two products across different subgames. The result is presented in Proposition 1.

Proposition 1. *When* $w > 1/2$*, the differentiation between the two products is the largest when both products are designed by ODMs, and smallest when both products are designed by firms. The opposite is true when* $w < 1/2$*. When* $w = 1/2$*, the distance is the same no matter a product is designed by the firm or the ODM.*

Proof. Through direct comparison of the results in Lemma 3 and 4. □

According to Proposition 1, the result depends on how channel profit is split between the firm and the manufacturer. When the manufacturer is more powerful in the channel and gets a larger share of profit, product differentiation is larger when more ODMs are involved in the product design process. When the firm is more powerful and gets a larger share, the differentiation level is larger when more products are designed by firms. This result is very intuitive. Because it is costly to differentiate a product from the competitor's, the more powerful party in the channel is willing to invest more in product design. Therefore, when a product is designed by the more powerful party in the channel, product differentiation will increase. When the firm and the manufacturer split the profit equally, the equilibrium product locations are identical no matter who designs the product, because firms and manufacturers have exactly the same profits and investment incentives.

4.4 Outsourcing decision

Now we can turn to the analysis of firms' outsourcing decisions at the first stage of the model. Intuitively, the outsourcing decision should be affected by c and w. When deciding whether to outsource product design, a firm is essentially trading off the cost saving with the potential change in product design when the design process is outsourced. The findings in Proposition 1 indicate that the firm should have higher incentive to outsource design when w is large, because the ODM will invest more in product design and develop a better differentiated product. This in turn will lead to higher channel profit.

Conventional wisdom suggests that firms should outsource when the potential cost saving is large (See, for example, McMillan, 1990; Venkatesan, 1992; Qu and Brocklehurst, 2003). In our model, this implies firms should be more eager to outsource design when the design cost is high. Using the result in Lemma 3 and 4, as well as the profit functions in the Appendix, we compare firms' profits in the three subgames and derive the outsourcing equilibrium. The equilibrium outsourcing outcome depends only on w and c/t, but not on V. So we define $c_t = c/t$ to simplify the notation in the rest of the paper.

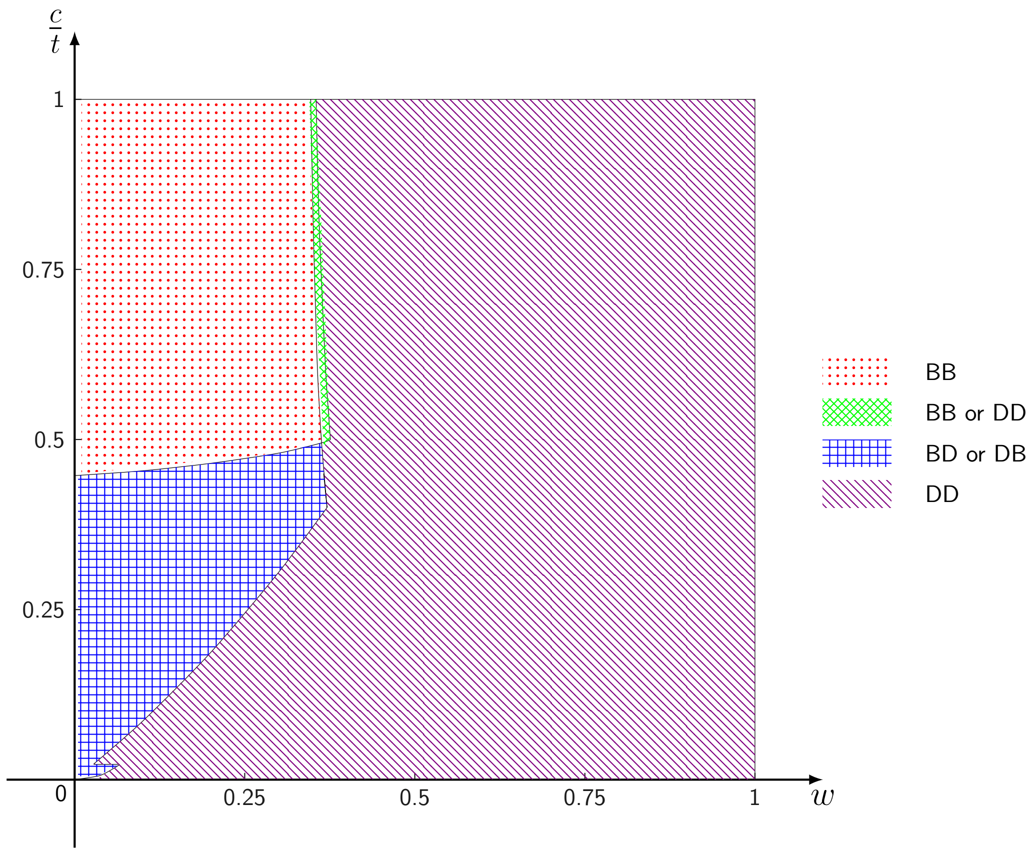

Figure 3: Equilibrium Outsourcing Decisions with Exclusive ODMs

Proposition 2. *Both symmetric and asymmetric equilibria exist at the outsourcing stage. Both firms outsource product design when w is relatively large. One firm outsources product design and the other insources when both w and c_t are relatively small. Both firms insource product design when w is relatively small and c_t is relatively large.*

Proof. Follows directly from comparing firms' profits in Lemma 3 and 4. □

We omit the specific equilibrium conditions here due to extreme complexity of their functional form, but instead depict the equilibrium outsourcing outcome in Figure 3. Since the outsourcing outcome is only affected by w and c_t, Figure 3 completely characterizes the outsourcing equilibrium of the model. All three types of equilibrium can be observed – both firms outsource product design (DD), both firms insource product design (BB), and one of the firms outsources design (BD or DB). Consistent with the intuition discussed earlier, both firms will outsource product design when the manufacturer has a relatively large bargaining power in the channel. When the manufacturer's bargaining power is relatively small, the equilibrium outcome depends on the cost ratio c_t. Notably, the asymmetric equilibrium in which one of the firms outsources product design and the other insources may arise in our model even though firms and manufacturers are assumed to be perfectly symmetric. Also note from Figure 3 that multiple equilibria may exist in some area. When w is in an intermediate range and c_t is relatively large, neither firm outsourcing and neither firm insourcing can both arise as the equilibrium outcome. In this area, firms have more bargaining power than manufacturers, but the difference is not large enough to completely deter outsourcing. When one firm outsources, the best response of the other firm is also to outsource to save the product design cost. When one firm designs the product by itself, the best response of the other firm is also to insource in order to increase product differentiation and avoid direct price competition.

To understand the existence of asymmetric equilibria, consider a numeric example in which $V = 10$, $w = 1/10$ and $c_t = 1/4$. Under these parameter values, the distance between the two products is 8.78 when both products are designed by firms, 8.57 when one of the products is designed by the firm, and 2.12 when both products are designed by ODMs. The differentiation between products decreases when products are designed by ODMs because in this example, manufacturers only obtain 1/10 of the channel profit and therefore, they have much lower incentive to invest in product differentiation than firms do. However, the change in product differentiation varies dramatically across different subgames. When one firm changes from designing its own product to outsourcing design, the distance between the two products does not drop too much, because the competitor's product is still designed by the firm who is willing to invest a large amount of money in product design. When the second firm also changes its strategy from insourcing to outsourcing product design, the level of product differentiation declines drastically, causing a huge decrease in both firms' profits.

This is because when both products are designed by ODMs, neither of them has a strong motive to invest in product differentiation. As a result, there will be very little differentiation between the two products in the equilibrium. Regarding how the outsourcing equilibrium changes with the cost factor c_t, we have the following finding.

Proposition 3. *The outsourcing outcome is not monotonic in* c_t *and may be inversely related to* c_t*, i.e. fewer firms outsource when the design cost increases.*

Proof. Follows directly from comparing the results in Lemma 3 and 4. □

The result in Proposition 3 is somewhat surprising. As discussed earlier, conventional wisdom suggests that firms should be more likely to outsource when the potential cost saving is high. However, this is not what we find. As Figure 3 shows, when firms obtain a relatively large profit share, it is possible that both firms outsource design when the design cost is low, one firm outsources design when the cost is in an intermediate range, and neither firm outsources design when the cost is very high. This counter-intuitive result occurs when $w < 1/2$ because in this region, product differentiation decreases when a firm outsources its product design to an ODM. So when deciding whether to outsource, the firm needs to consider two effects this move will have on its profit. On one hand, by outsourcing product design, it can save the design cost. On the other hand, when the design process is outsourced to the ODM, the firm should expect lower product differentiation as well as lower revenue. The potential cost saving depends on both the cost parameter c and the equilibrium location of the product when the firm designs the product by itself. As the design cost increases, the firm will adjust its strategy by moving the product closer to the zero point. Consequently, the actual design cost incurred by the firm will not increase significantly when the cost parameter increases. However, when the ODM designs the product, product differentiation decreases remarkably with the cost parameter, because the ODM responds to the higher cost by reducing its investment in product design. Therefore, a higher design cost deters the firm from outsourcing design rather than encourages it.

The equilibrium outsourcing outcome is not affected by consumers' valuation, but is affected by consumers' disutility from product mismatch, because the cost factor c_t is a function of the disutility parameter t. t captures the heterogeneity of consumer tastes. In the extreme case of $t = 0$, consumers do not care about what type of product they are buying. As a result, the market is completely homogeneous. According to Proposition 3, when manufacturers have relatively large power in the channel, both firms will outsource product design no matter how heterogeneous consumers are. When firms are more powerful in the channel, the result is not monotonic, but roughly speaking, design outsourcing is more likely to occur when t is larger. The intuition is that when the market is more homogeneous, price competition between the two firms becomes more intense. It is more important for firms to attenuate price competition through product differentiation, and a larger differentiation is achieved when firms insource product design. Therefore, firms are less likely to outsource design to the ODM when t decreases.

5 Channel with a Common ODM

In the previous section, we analyzed firms' design outsourcing decisions in an exclusive–ODM channel. We showed that asymmetric outsourcing outcome exists in the equilibrium, and that firms' outsourcing incentive may be inversely related to product design cost. In this section, we will look at another commonly-observed channel structure in which a common ODM partners with both firms.

Consider a model with two competing firms and a common ODM. When both firms decide to outsource product design, the two products will be designed by the same ODM. The rest of the model is the same as in Section 4. The analysis of this model is similar to that in Section 4. In particular, the subgame in which both firms insource product design and that in which one firm outsources design are the same as in the previous model. As a result, we can directly borrow the results in Lemma 3 and 4. The only subgame that calls for additional analysis is the one in which both products are designed by the common ODM. We present the analysis of this subgame in the following sections.

5.1 Ex-post bargaining with a common ODM

When both brands outsource product design, the ex-post bargaining problem changes because both firms must bargain with the same manufacturer. We still consider two different market outcomes that might have arisen from the previous stage: 1) the market in between the two products is not fully covered, and 2) the market in between the two products is fully covered. Recall that in the first scenario, demand for each product is given by $d_i^{nf} = \frac{2(V-p_i)}{t}$, $i = 1, 2$, while in the second scenario, it is given by $d_i^f = \frac{2V+(x_2-x_1)t+p_{3-i}-3p_i}{2t}$, $i = 1, 2$. We still look to solve the following problem.

$$\max_{w_i} \quad [\pi_{mi}(w_i) - \pi_{mi}^0]^w [\pi_{fi}(w_i) - \pi_{fi}^0]^{1-w}$$
$$s.t. \quad \pi_{mi}(w_i) \geq \pi_{mi}^0 \; and \; \pi_{fi}(w_i) \geq \pi_{fi}^0$$

First consider the scenario in which the market in between the two products is not fully covered. In the negotiation between brand i and the manufacturer, the brand will earn a profit of $\pi_{fi}(w_i) = (1-w_i)d_i^{nf}$ if the negotiation reaches an agreement of w_i and $\pi_{fi}^0 = 0$ if the negotiation fails. For the manufacturer, its profit now depends on the bargaining outcome with both brands. Suppose the bargaining with brand $(3-i)$ fails. In the bargaining with brand i, the manufacturer will obtain a profit of $w_i d_i^{nf}$ if the agreed wholesale price is w_i and 0 if no agreement is reached. Then suppose the bargaining with brand $(3-i)$ succeeds with an agreed price of w_{3-i}. In the bargaining with the current brand, the manufacturer can expect a total profit of $w_i d_i^{nf} + w_{3-i} d_{3-i}^{nf}$ if the current negotiation yields a wholesale price of w_i and $w_{3-i} d_{3-i}^{nf}$ if the current negotiation fails. In either case, the incremental profit the manufacturer can earn in the negotiation with brand i is equal to $w_i d_i^{nf}$. This will lead to the same equilibrium wholesale price as in the model with exclusive ODMs: wp_i.

When the market in between the two products is fully covered, however, the bargaining problem becomes more complicated, especially when the negotiations with brand 1 and brand 2 are both expected to succeed. In this case, $\pi_{mi}(w_i) = w_i d_i^f + w_{3-i} d_{3-i}^f$ and $\pi_{fi}(w_i) = (1-w_i)d_i^f$. If the negotiation between brand i and the manufacturer breaks down, the manufacturer will generate profit only from product $(3-i)$. So $\pi_{mi}^0 = w_{3-i} d_{3-i}^{nf}$ and $\pi_{fi}^0 = 0$. Substituting these values into the problem and solving the first-order condition for $i = 1$ and $i = 2$ simultaneously, we obtain the following solution.

$$w_i^* = \frac{w(2V + t\Delta x + p_i - 3p_{3-i})[p_i(3p_i - 2V - t\Delta x) + p_{3-i}(1-w)(p_{3-i} - 2V + t\Delta x) + wp_1p_2]}{w(w-2)[p_s^2 - 4V(p_s - V) + t^2\Delta x^2] + 2t\Delta x(w^2 - 2w + 2)(p_s - 2V) + 4\Delta p^2},$$

$$where\ \Delta x = x_2 - x_1,\ \Delta p = p_2 - p_1,\ p_s = p_1 + p_2,\ i = 1, 2 \quad (5)$$

When $p_1 = p_2 = p$, the above solution simplifies to a symmetric one: $w_1 = w_2 = w^* = \frac{w(2V-2p+t\Delta x)p}{2w(V-p)+t(2-w)\Delta x}$. It can be verified that $w^* > wp$. That is, the manufacturer is able to secure a larger share of the total channel profit when bargaining with both brands than when bargaining with only one brand. This is because when bargaining with two competing brands, the manufacturer can effectively utilize the negotiation with one brand as a threat to the other. To see this, note that if both products are sold in the market, a larger market will be covered but the demand is split between the two products. If only one product is available in the market, total product demand will be lower than in the competitive situation but demand for this particular product will increase due to the absence of competition. So compared to dealing with only one brand, when dealing with both brands together, the manufacturer essentially has to sacrifice some business from one brand in exchange for business from the second brand. This gives the manufacturer an edge over the brands during the negotiation because the brands have to offer the manufacturer higher prices to compensate it for its potential loss of profit.

The symmetric wholesale price solution w^* is a decreasing function of Δx and when

$\Delta x = 0$, $w^* = p$. To understand this, note that when both products are located at exactly the same point and also priced the same, the manufacturer is able to cover the same market no matter it sells through brand 1 or brand 2. This creates a perfect "competition" between brands when negotiating with the manufacturer and as a result, their profits will be squeezed to zero. As the two products move farther apart, there is less overlapping between the covered market of the two products, so the existence of a second brand adds more value to the manufacturer. This puts the brands in a more favorable position in the bargaining and allows them to negotiate a lower price.

5.2 Retail pricing with a common ODM

The retail-pricing stage of the subgame in which both brands outsource to the same ODM can be solved in a similar way to Section 4.2. One first writes out the profit functions of the two brands, then solve the first-order conditions together, and finally, check the boundary conditions. When the market in the middle of the two products is not fully covered, the equilibrium wholesale prices at the ex-post bargaining stage of the model are the same as in the model with exclusive ODMs. As a result, the equilibrium retail prices and boundary conditions should also be the same: $p_1^m = p_2^m = \frac{V}{2t}$ when $|x_2 - x_1| \geq \frac{V}{t}$.

When the market in the middle of the two products is fully covered, however, the problem is different from the one solved in Section 4.2, because the equilibrium wholesale prices at the next stage of the model have changed. In this case, the profit functions of the two brands are given by Equation (6) and (7), where w_1^* and w_2^* are defined in Equation (5).

$$\pi_1 = \frac{(p_1 - w_1^*)(2V - 3p_1 + p_2 + x_2 t - x_1 t)}{2t} \tag{6}$$

$$\pi_2 = \frac{(p_2 - w_2^*)(2V - 3p_2 + p_1 + x_2 t - x_1 t)}{2t} \tag{7}$$

Solving the first-order conditions of Equation (6) and (7) together, we find that $p_1^c =$

$p_2^c = p_c$, where p_c is the solution to the following equation s.t. $0 \le p_c \le V$.

$$f_4 p_c^4 + f_3 p_c^3 + f_2 p_c^2 + f_1 p_c + f_0 = 0 \tag{8}$$

$$\begin{aligned}
where \quad & f_4 = 32w^2 \\
& f_3 = 8w(52t\Delta x - 14Vw - 12t\Delta x) \\
& f_2 = 144V^2w^2 - 96Vw^2t\Delta x + 240Vwt\Delta x + 80t^2\Delta x^2 + 20w^2t^2\Delta x^2 - 64wt^2\Delta x^2 \\
& f_1 = 2(wt\Delta x - 2Vw - 2t\Delta x)(20V^2w - 8Vwt\Delta x + 28Vt\Delta x + wt^2\Delta x^2 + 4t^2\Delta x^2) \\
& f_0 = (2V + t\Delta x)(2Vw - wt\Delta x + 2t\Delta x)(4V^2w - 4Vwt\Delta x + wt^2\Delta x^2 + 8Vt\Delta x) \\
& \Delta x = x_2 - x_1
\end{aligned}$$

The price pair $p_1^c = p_2^c = p_c$ is supported in the equilibrium when the boundary condition $V - \frac{1}{2}t\Delta x - p_c$ is satisfied, i.e., the market in between the two products is indeed fully covered at these prices. In between the competitive case and local monopoly case, the equilibrium prices are $p_1^{cm} = p_2^{cm} = V - \frac{t|x_2 - x_1|}{2}$. The middle segment is fully covered, but the indifferent consumer gets zero payoff in the equilibrium. When the set of parameter values $\{V, t, w, \Delta x\}$ is known, an exact solution of p_c can be easily obtained. However, a general closed-form solution of p_c is too complicated to derive since Equation (8) involves a higher-degree polynomial of p_c. Consequently, numeric analysis is required when solving for the optimal product design and outsourcing choices at previous stages of the model.

5.3 Product design with a common ODM

We will now solve for the optimal product locations at the second stage of the model. When the ODM designs both products, it should optimally locate them symmetrically around the zero point in order to minimize the design cost. So the problem faced by the ODM can be simplified into choosing the optimal $\Delta x \ge 0$ such that $x_2 = \Delta x/2$ and $x_1 = -\Delta x/2$.

When choosing the optimal product locations, the manufacturer is trading off between several considerations. As the two products become more differentiated, there will be less competition between products, but the manufacturer needs to incur higher design cost. A third consideration, which stems from the unique dynamics at the ex-post bargaining stage when both brands bargain with the same ODM, is that a smaller differentiation between products gives the manufacturer a bigger advantage during the negotiation and allows it to negotiate higher prices with the brands. The third consideration was not present in the model with exclusive ODMs and causes the manufacturer to design products with smaller differentiation.

A fully analytical solution of the optimal Δx using first-order conditions calls for knowledge of the specific functional form of expected retail prices as well as the boundary conditions. However, this is not plausible in our model due to the complexity of Equation (8). Instead, we solve for the optimal Δx numerically. The equilibrium product design is characterized in Figure 4.

The figure describes the different types of equilibrium outcome as a function of w and c/t. The optimal product differentiation chosen by the manufacturer increases as the manufacturer possesses more power in the channel or as the cost of product design decreases. Recall that as the differentiation between the two products increases, the market outcome changes from the competitive case to the competitive monopoly case, and eventually, to the local monopoly case. When the bargaining power of the manufacturer is relatively small, the manufacturer will optimally locate both products at the zero point, i.e., there is minimal differentiation between the two products. As the bargaining power of the manufacturer becomes higher, the optimal product locations will gradually move to the competitive case, the boundary between the competitive and competitive monopoly case, and the internal region of the competitive monopoly case. It is optimal for the manufacturer to locate both products at the zero point because it allows the manufacturer to grab the entire profit of the channel regardless of its bargaining power. When the two products are not identical, the

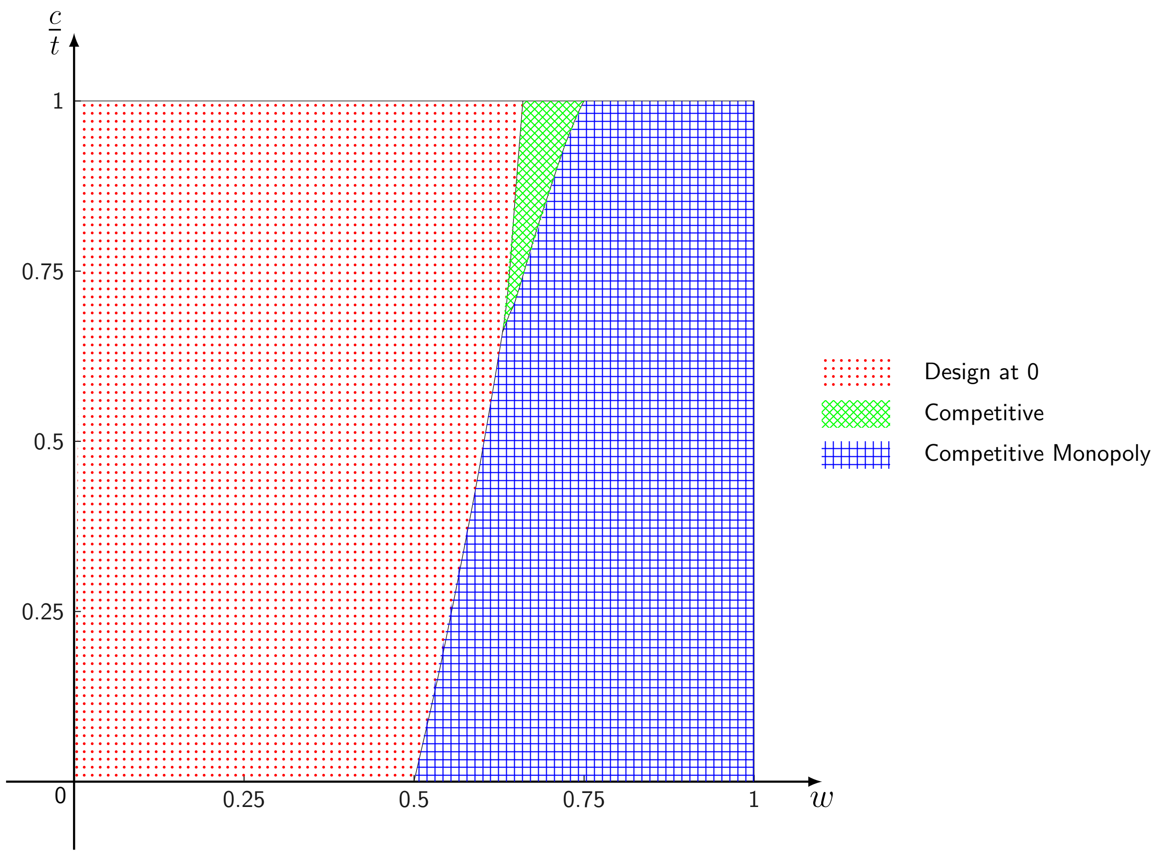

Figure 4: Equilibrium Product Locations when Manufacturers Outsource to a Common ODM

manufacturer will have to share the channel profit with the brand in a way that is in line with its power in the channel. So it is desirable for the manufacturer to differentiate the two products only when its bargaining power is large enough.

Compared to the exclusive-ODM model, product differentiation in the current model may be larger or smaller when both brands outsource design. Consider the following numeric examples. When $V = 1$, $t = 1$, $w = 0.8$ and $c = 0.2$, the optimal product design is in the interior of the competitive monopoly case no matter the products are designed by the same ODM or different ODMs. When they are designed by different ODMs, the distance between the two products is 0.8889. When they are designed by the same ODM, the optimal product differentiation is 0.9412. The reason for this increase is that when the market outcome is in the competitive monopoly case, the manufacturer(s) obtains the same share of channel profit in bargaining in both the exclusive-ODM and common-ODM model. However, the common ODM takes into account the revenue increase of both products into account when designing the products and therefore, has a stronger motive to invest in product differentiation. Exclusive ODMs, in contrast, takes into account only the benefit of higher product differentiation on their own product. As another example, when $V = 1$, $t = 1$, $w = 0.2$ and $c = 0.8$, product differentiation is smaller in the common-ODM model. Under these parameter values, the distance between the two products is 0.1277 when they are designed by different ODMs and 0 when designed by the same ODM. Product differentiation decreases in this case because when the bargaining power of manufacturers is relatively small, they do not have high incentives to invest in product design and consequently, the market outcome will be in the competitive case in both models. When the market outcome is determined by competitive forces, the common ODM benefits from making the two products more similar in order to negotiate a higher price in bargaining.

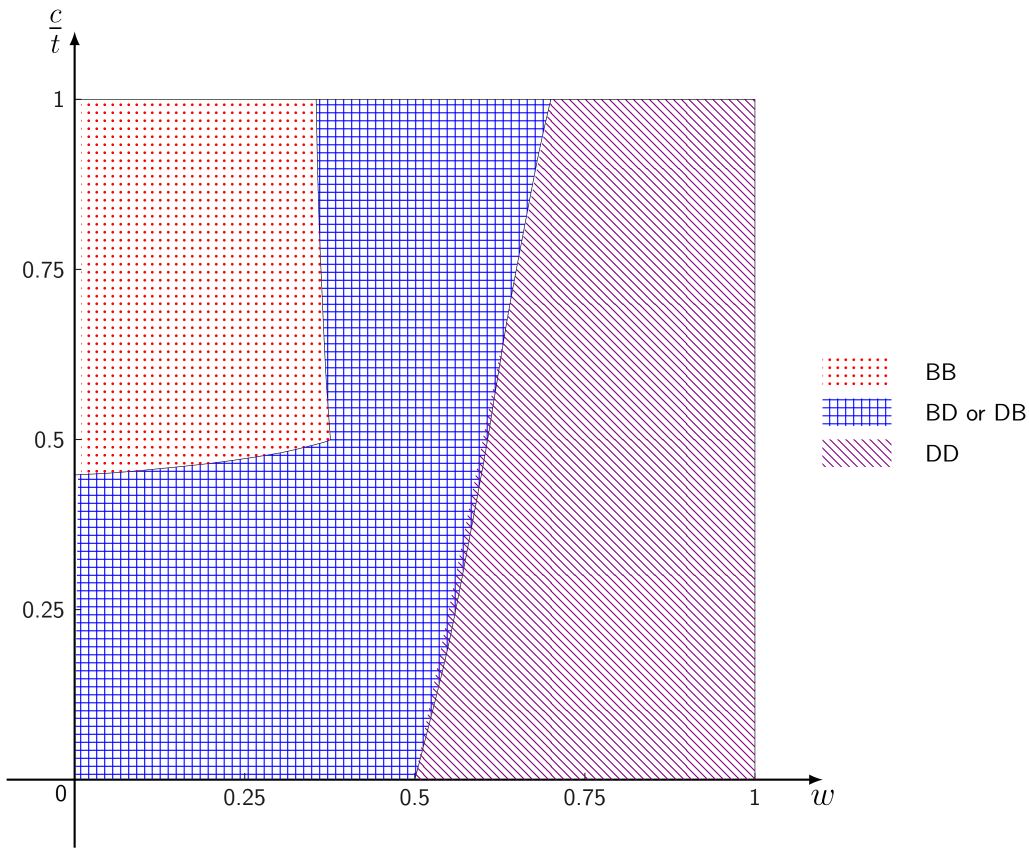

Figure 5: Equilibrium Outsourcing Strategies with a Common ODM

5.4 Outsourcing decision

We will now investigate the equilibrium outsourcing decisions of firms when there is a common ODM in the channel. The equilibrium outsourcing outcome in which both brands insource product design can be solved by directly comparing brands' profits across subgame BB and DB, because these two subgames are identical to the ones in the previous model and have been solved analytically. The outsourcing outcome in which one or more brands outsource design, however, needs to be examined numerically, because no analytical solution for the subgame DD is available. So the analytical solution of subgame DB will be compared to the numerical solution of subgame DD to derive the equilibrium conditions. The equilibrium outsourcing decisions are described in the following figure.

Figure 5 characterizes the equilibrium outsourcing outcome with respect to w and c_t. As can be seen from the figure, the equilibrium outsourcing outcome is akin to that in the exclusive–ODM model. Roughly speaking, when manufacturers' power in the channel is large enough, both firms will choose to outsource product design. When firms' power is relatively large, firms outsource design when the design cost is low but do not outsource when the cost is high. Same as the exclusive–ODM model, we find that firms' outsourcing motives may be inversely related to the design cost – both firms outsource design when the design cost is low, one of the them outsources design when the cost is in an intermediate range, and neither of them outsources when the cost is high. Comparing the results in the two figures, we also have the following finding.

Proposition 4. *Firms are less likely to outsource product design when there is a common ODM in the channel than when there are exclusive ODMs.*

Proof. Follows directly from comparing the equilibrium outsourcing outcome of the two models. □

The area in which both firms insource in the equilibrium is the same across the two scenarios. However, when there is a common ODM in the channel, the area in which one firm outsources design and the other insources in the equilibrium is larger, and the area in which both firms outsource design in the equilibrium is smaller. Overall, design outsourcing is less likely to occur when there is a common ODM than when there are exclusive ODMs. The intuition lies in the fact that the common ODM will develop less differentiated products when both firms outsource design in order to gain a more favorable position in bargaining, which increases the expected benefit of outsourcing.

6 Discussion and Conclusion

Outsourcing product design in addition to production represents a new supply chain strategy in today's dynamic market. Understanding what drives firms to choose this new form of outsourcing is a first step towards answering many other questions. In this paper, we developed an analytic model that accounts for both product and price competition in the end consumer market, and studied firms' outsourcing decisions in two different channel structures. Firms and manufacturers are assumed to split the channel profit according to their respective power in the channel. The party responsible for designing the product bears the design cost that increases quadratically as the product diverges more from the zero point.

Examining the product design decisions of firms and manufacturers, we found that product differentiation is larger when a product is designed by the party with higher channel power. Incorporating this result into firms' outsourcing decisions, we found that all three types of outsourcing outcomes can arise in the equilibrium. In particular, one firm outsourcing product design and the other insourcing could be an equilibrium outcome even though the two firms in the model are assumed to be completely symmetric. Investigating how the equilibrium outcome changes with the model parameters, we found the counter-intuitive result that firms could be less willing to outsource design as the design cost increases or as the consumer market becomes more homogeneous. These results are robust to alternative specifications of channel structure. Comparing the results under different channel structures, we found that outsourcing is less likely to occur in the equilibrium in the channel with a common ODM.

To reveal the most important market forces that impact firms' strategic outsourcing decisions, we adopted some simplifying assumptions in the model. First, we assumed that channel power is independent of outsourcing format. That is, the bargaining power of a firm is the same when it outsources only production and when it outsources both production and design. In reality, the firm may lose some bargaining power as it outsources more functions to external suppliers. This suggests that ODMs may be able to obtain a larger share of channel profit than contract manufacturers. Compared with the main model, this alternative assumption will affect firms' incentives to outsource product design in two different ways. On one hand, because ODMs are more willing to invest in product design than in the main model, firms should have a higher incentive to outsource design. On the other hand, because firms obtain a smaller profit share when partnering with ODMs, they may be more reluctant to outsource design. Although the overall effect is not clear, as long as the difference in bargaining power between ODMs and contract manufacturers is small enough, we should obtain the same results as in the main model, because the underlying forces that drive the results remain the same. We decided to analyze the simplified model to tease out the strategic forces and focus better on the intuition.

We also assumed the existence of an ex-post bargaining stage in which the wholesale price is determined. The adoption of this assumption greatly simplifies the analysis of the model. An alternative way to model the determination of wholesale price is to assume away the ex-post bargaining stage so that the wholesale price would be determined through bilateral bargaining before retail prices are set. Although the specific split of channel profit between the manufacturer and the brand would be different in this model, all the important forces underlying the main results of the previous model should carry over to this alternative setting. For instance, a larger bargaining power of the manufacturer would increase its share of profit in the channel and encourage the brands to outsource design. When both brands bargain with the same ODM instead of different ODMs, the common ODM would have incentive to reduce product differentiation when designing the two products to obtain a better position in bargaining. This will deter the brands from outsourcing design. In light of this, we expect the main results of the paper to continue to hold under this alternative assumption.

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Appendices

A Proof of Lemma 1

The result for $|x_2 - x_1| \leq \frac{6V}{7t}$ (competitive case) has already been proven in the main text. We will prove the result for the other two cases: $\frac{6V}{7t} < |x_2 - x_1| \leq \frac{V}{t}$ and $|x_2 - x_1| > \frac{V}{t}$. Suppose the market in between x_1 and x_2 is not fully covered in the equilibrium. Each product is a local monopoly in the market and can be analyzed separately. Without loss of generality, consider the pricing problem of product 1. Denote the distance between product 1 and the consumers who are indifferent between buying product 1 and not buying anything by Δx. The price of the product is equal to $V - t\Delta x$, and firm 1's profit is $\pi_1^m = 2\Delta x(V - t\Delta x)(1-w)$. Solving the first-order condition of π_1 with respect to Δx, we obtain the optimal Δx of product 1: $\Delta x = \frac{V}{2t}$. We need to verify that the market in between x_1 and x_2 is indeed not covered in the equilibrium, which requires $\frac{V}{2t} < |x_2 - x_1|/2$, or $|x_2 - x_1| > \frac{V}{t}$. When $\Delta x = \frac{V}{2t}$, the price of the product is equal to $V/2$. This proves the result for $|x_2 - x_1| > \frac{V}{t}$ in the lemma.

When $\frac{6V}{7t} < |x_2 - x_1| \leq \frac{V}{t}$, internal solution cannot be obtained in either the competitive case or the local monopoly case. The equilibrium must be on the boundary between the two cases – the market is fully covered, but the indifferent consumer gets zero payoff. Since the two firms are symmetric, we look for symmetric equilibrium that satisfies these conditions. This means the consumer located halfway between x_1 and x_2 should get zero payoff and the prices of both products should be equal to $p_1^{cm} = p_2^{cm} = V - \frac{t|x_2 - x_1|}{2}$. To verify that this is indeed the equilibrium price, we need to show that firms do not want to deviate to any other price. Without loss of generality, we will show that firm 1 will not deviate to any price above p_1^{cm} or any price below p_1^{cm}. If firm 1 charges a price higher than p_1^{cm}, the market will be in the local monopoly case. firm 1's profit function in the local monopoly case is $\pi_1 = \frac{2p_1(V-p_1)(1-w)}{t}$. Since π_1 is a quadratic function of p_1, it is sufficient to check that the derivative of π_1 w.r.t. p_1 is negative at the aforementioned price. When $p_1 = V - \frac{t|x_2 - x_1|}{2}$, the derivative is equal to $\frac{2(1-w)[t(x_2-x_1)-V]}{t}$, which is negative when $|x_2 - x_1| \leq \frac{V}{t}$, so firm 1 does not finds it profitable to deviate to a higher price. Following similar steps, it can be shown that firm 1 does not want to deviate to the competitive case by lowering the price from p_1^{cm}, either. So $p_1^{cm} = p_2^{cm} = V - \frac{t|x_2-x_1|}{2}$ are indeed the equilibrium prices in this region. This proves the result for $\frac{6V}{7t} < |x_2 - x_1| \leq \frac{V}{t}$ in the lemma.

Denote firms' profits in the competitive case, competitive monopoly case and local monopoly case by π_{bi}^c, π_{bi}^{cm} and π_{bi}^m $(i = 1, 2)$ respectively. Denote manufacturers' profits in the corresponding cases by π_{si}^c, π_{si}^{cm} and π_{si}^m $(i = 1, 2)$ respectively. firms' and manufacturers' profits in each case are given below.

$$\pi_{b1}^c = \pi_{b2}^c = \frac{3(1-w)(2V - tx_1 + tx_2)^2}{50t} \tag{A.1}$$

$$\pi_{s1}^c = \pi_{s2}^c = \frac{3w(2V - tx_1 + tx_2)^2}{50t} \tag{A.2}$$

$$\pi_{b1}^{cm} = \pi_{b2}^{cm} = \frac{1}{2}(1-w)(x_2 - x_1)(2V - tx_2 + tx_1) \tag{A.3}$$

$$\pi_{s1}^{cm} = \pi_{s2}^{cm} = \frac{1}{2}w(x_2 - x_1)(2V - tx_2 + tx_1) \tag{A.4}$$

$$\pi_{b1}^m = \pi_{b2}^m = \frac{(1-w)V^2}{2t} \tag{A.5}$$

$$\pi_{s1}^m = \pi_{s2}^m = \frac{wV^2}{2t} \tag{A.6}$$

B Proof of Lemma 2

As discussed in the main text, firm 2 strictly prefers to move to $x_2 = x_1 + V/t$ in the local monopoly case. So we only need to examine firm 1's profit change in the competitive and competitive monopoly case. We first look at the competitive monopoly case ($\frac{6V}{7t} < x_2 - x_1 \leq \frac{V}{t}$). firm 2's profit in this region is equal to $\pi_{b2}^{cm} = \frac{1}{2}(1-w)(x_2 - x_1)(2V - tx_2 + tx_1) - \frac{cx_2^2}{2}$. Note that it is different from Equation A.3 because at the product design stage, firms need to incorporate design cost into their profit function. π_{b1}^{cm} is a quadratic function of x_2 with the second-term coefficient $\frac{1}{2}(-t + tw - c) < 0$. So the maximum point is obtained at $x_2 = \frac{(1-w)(V+tx_1)}{t(1-w)+c}$, which is an internal solution when $x_1 < \frac{V(t-tw-6c)}{7tc}$ and is smaller than $x_1 + \frac{6V}{7t}$ otherwise.

We then look at the competitive case $x_2 - x_1 \leq \frac{6V}{7t}$. firm 2's profit in this region is equal to $\pi_{b2}^c = \frac{3(1-w)(2V-tx_1+tx_2)^2}{50t} - \frac{cx_2^2}{2}$, which is a quadratic function of x_2 with the second-term coefficient equal to $-\frac{25c-3t(1-w)}{50}$. When $c < \frac{3t(1-w)}{25}$, $-\frac{25c-3t(1-w)}{50} > 0$, so the maximum point obtained is at the boundary $x_2 = x_1 + \frac{6V}{7t}$. When $c > \frac{3t(1-w)}{25}$, $-\frac{25c-3t(1-w)}{50} < 0$, so the maximum point is obtained at $x_2 = \frac{3(1-w)(2V-tx_1)}{25c-3t(1-w)}$, which is an internal solution when $x_1 > \frac{6V(2t-2tw-5c)}{35tc}$ and is larger than $x_1 + \frac{6V}{7t}$ otherwise.

When $c \leq \frac{t(1-w)}{6}$, $x_1 \leq 0 \leq \frac{V(t-tw-6c)}{7tc} < \frac{6V(2t-2tw-5c)}{35tc}$. So the maximum point is obtained internally in the competitive monopoly case while the maximum point of the competitive case is obtained at the boundary $x_2 = x_1 + \frac{6V}{7t}$. Since firm 2's profit is continuous in x_2, the best response of firm 2 to firm 1's location is the internal solution of the competitive monopoly case: $x_2 = \frac{(1-w)(V+tx_1)}{t(1-w)+c}$. This proves the first point of the lemma. The second and third points of the lemma can be proven in a similar way.

C Proof of Lemma 3

We first write out the best response of firm 1 to firm 2's location based on the results in Lemma 2 and the fact that the two firms are symmetric.

$$x_1^{bcm}(x_2) = \frac{(1-w)(V-tx_2)}{-t(1-w)-c}$$

$$x_1^{bc}(x_2) = \frac{3(1-w)(V+tx_2)}{25c-3t(1-w)}$$

$x_2 - \frac{6V}{7t}$ is also firm 1's best response under conditions similar to the ones defined in Lemma 2. The equilibrium locations can be obtained by solving the best response functions of the two firms simultaneously while verifying the boundary conditions are satisfied. Theoretically, since both firms have three potential best responses to the other firm's location, we need to examine nine different scenarios. However, most of these scenarios can be easily eliminated once we take into account the fact that in the equilibrium, the best responses of the two firms must be of the same type, i.e., if the best response of firm 1 is in the competitive monopoly case, the best response of firm 2 must also be in the competitive monopoly case. This reduces the number of scenarios to be examined to three: (1) $x_1 = x_1^{bcm}(x_2)$ and $x_2 = x_2^{bcm}(x_1)$; (2) $x_1 = x_1^{bc}(x_2)$ and $x_2 = x_2^{bc}(x_1)$; (3) $x_1 = x_2 - \frac{6V}{7t}$ and $x_2 = x_1 + \frac{6V}{7t}$.

Solving the two equations in scenario (1) together, we find $x_1 = -\frac{V(1-w)}{2t(1-w)+c}$ and $x_2 = \frac{V(1-w)}{2t(1-w)+c}$. In order for these prices to hold in the equilibrium, we need to verify the boundary conditions given in Lemma 2. It is sufficient to check the boundary conditions for x_1: $x_1 \leq \frac{V(t-tw-6c)}{7tc}$. This leads to the condition $c \leq \frac{t(1-w)}{3}$. So when $c \leq \frac{t(1-w)}{3}$, $x_1^{BB} = -\frac{V(1-w)}{2t(1-w)+c}$ and $x_2^{BB} = \frac{V(1-w)}{2t(1-w)+c}$ are the equilibrium locations. The equilibrium profits of the two firms are

$$\pi_{b1} = \pi_{b2} = \frac{V^2(1-w)^2(3c+4t-4tw)}{2(c+2t-2tw)^2}$$

Solving the two equations in scenario (2) together, we find $x_1 = -\frac{6V(1-w)}{25c-6t(1-w)}$ and $x_2 = \frac{6V(1-w)}{25c-6t(1-w)}$. In order for these prices to constitute an equilibrium, we need to verify the boundary condition $x_1 > \frac{6V(2t-2tw-5c)}{35tc}$, which requires $c > \frac{4t(1-w)}{5}$. So when $c > \frac{4t(1-w)}{5}$, $x_1^{BB} = -\frac{6V(1-w)}{25c-6t(1-w)}$ and $x_2^{BB} = \frac{6V(1-w)}{25c-6t(1-w)}$ are the equilibrium locations. The equilibrium profits of the two firms are

$$\pi_{b1} = \pi_{b2} = \frac{6V^2c(1-w)(25c-3t+3tw)}{t(25c-6t+6tw)^2}$$

For scenario (3), the distance between x_1 and x_2 needs to equal to $\frac{6V}{7t}$. Since the two firms are symmetric, we look for symmetric equilibrium, which implies $x_1 = -\frac{3V}{7t}$ and $x_2 = \frac{3V}{7t}$. Solving the boundary conditions $\frac{V(t-tw-6c)}{7tc} < x_1 \leq \frac{6V(2t-2tw-5c)}{35tc}$ leads to the following requirement: $\frac{t(1-w)}{3} < c \leq \frac{4t(1-w)}{5}$. The equilibrium profits of the two firms are

$$\pi_{b1} = \pi_{b2} = \frac{3V^2(16t-16tw-3c)}{98t^2}$$

This completes the proof of the lemma.

D Proof of Lemma 4

When both products are designed by ODMs, the subgame is exactly the same as the one in which both products are designed by firms except for the profit share of the companies. So the results in Lemma 3 can be used directly here when we substitute $1-w$ with w in the corresponding places. This proves the first part of the results in the lemma when both products are designed by ODMs. When $x_1^{DD} = -\frac{Vw}{2tw+c}$ and $x_2^{DD} = \frac{Vw}{2tw+c}$, the equilibrium profits of the two firms are

$$\pi_{b1} = \pi_{b2} = \frac{2V^2 w(1-w)(c+tw)}{(c+2tw)^2}$$

When $x_1^{DD} = -\frac{3V}{7t}$ and $x_2^{DD} = \frac{3V}{7t}$, the equilibrium profits of the two firms are

$$\pi_{b1} = \pi_{b2} = \frac{24V^2(1-w)}{49t}$$

When $x_1^{DD} = -\frac{6Vw}{25c-6tw}$ and $x_2^{DD} = \frac{6Vw}{25c-6tw}$, the equilibrium profits of the two firms are

$$\pi_{b1} = \pi_{b2} = \frac{150V^2c^2(1-w)}{t(6tw-25c)^2}$$

When one product is designed by the firm and the other by the ODM, the results in Lemma 3 no longer apply, because the two decision makers in the subgame are now asymmetric. We will still solve for the equilibrium by first writing out the best response of each company to the other company's location and then solving the two best response functions together. Since product 2 is designed by the firm, its best response to x_1 is given in Lemma 2. Product 1's best response to x_2 can be obtained by substituting the results in Lemma 2 with the appropriate notations. Define the following variables.

$$x_1^{scm}(x_2) = -\frac{w(V - tx_2)}{tw + c}$$

$$x_1^{sc}(x_2) = \frac{3w(V + tx_2)}{25c - 3tw}$$

The best response of x_1 to x_2 is given below.

(1) When $c \leq \frac{tw}{6}$, firm 2's best response is $x_1^{scm}(x_2)$.

(2) When $\frac{tw}{6} < c \leq \frac{2tw}{5}$, firm 2's best response is $x_1^{scm}(x_2)$ if $x_2 \geq \frac{V(6c-tw)}{7tc}$ and $x_2 - \frac{6V}{7t}$ if $x_2 < \frac{V(6c-tw)}{7tc}$.

(3) When $c > \frac{2tw}{5}$, firm 2's best response is $x_1^{scm}(x_2)$ if $x_2 \geq \frac{V(6c-tw)}{7tc}$, $x_2 - \frac{6V}{7t}$ if $\frac{6V(5c-2tw)}{35tc} \leq x_2 < \frac{V(6c-tw)}{7tc}$, and $x_1^{sc}(x_2)$ if $x_1 < \frac{6V(5c-2tw)}{35tc}$.

Same as the subgame in which both products are designed by firms, in this subgame, the best responses of the two companies must also be of the same type in the equilibrium. This means we need to solve three sets of best response functions: (1) $x_1 = x_1^{scm}(x_2)$ and $x_2 = x_2^{bcm}(x_1)$; (2) $x_1 = x_1^{sc}(x_2)$ and $x_2 = x_2^{bc}(x_1)$; (3) $x_1 = x_2 - \frac{6V}{7t}$ and $x_2 = x_1 + \frac{6V}{7t}$. Solving the two best response functions in scenario (1) and checking the boundary conditions, we find $x_1^{DB} = -\frac{Vw}{t+c}$ and $x_2^{DB} = \frac{V(1-w)}{t+c}$ when $c \leq \frac{t}{6}$. The equilibrium profits of the two firms at these prices are

$$\pi_{b1} = \frac{V^2(1-w)(2c+t)}{2(c+t)^2}$$

$$\pi_{b2} = \frac{V^2(1-w)(c+t+wc)}{2(c+t)^2}$$

Solving the two best response functions in scenario (2) and checking the boundary conditions, we find $x_1^{DB} = -\frac{6Vw}{25c-3t}$ and $x_2^{DB} = \frac{6V(1-w)}{25c-3t}$ when $c > \frac{2t}{5}$. The equilibrium profits of the two firms at these prices are

$$\pi_{b1} = \frac{150V^2c^2(1-w)}{t(25c-3t)^2}$$

$$\pi_{b2} = \frac{6V^2c(1-w)(25c-3t+3tw)}{t(25c-3t)^2}$$

In scenario (3), since the two conditions essentially reduces to the same condition $x_2 - x_1 = \frac{6V}{7t}$, multiple equilibria exist. After checking the respective boundary conditions for x_1 and x_2, we find that all pairs of prices that satisfy $x_2 - x_1 = \frac{6V}{7t}$ and $\max\{\frac{V(t-tw-6c)}{7tc}, -\frac{12Vw}{35c}\} \leq x_1 \leq \min\{-\frac{Vw}{7c}, \frac{6V(2t-2tw-5c)}{35tc}\}$ are supported in the equilibrium. Furthermore, it can be shown that $\min\{-\frac{Vw}{7c}, \frac{6V(2t-2tw-5c)}{35tc}\} > \max\{\frac{V(t-tw-6c)}{7tc}, -\frac{12Vw}{35c}\}$ when $\frac{t}{6} < c < \frac{2t}{5}$. We need to select an equilibrium to be used in the analysis of firms' outsourcing decision in the first stage of the model. We look for the equilibrium that satisfies two natural criteria in the selection process: (a) the equilibrium product locations and firms' profits are continuous for all parameter values; (b) the selected equilibrium product locations reflect the respect power of the two decision makers. These two criteria lead to the following pair of prices: $x_1^{DB} = -\frac{6Vw}{7t}$ and $x_2^{DB} = \frac{6V(1-w)}{7t}$. Note that the equilibrium locations of the two products are proportional to the power of the decision maker. The equilibrium profits of the two firms at these prices are

$$\pi_{b1} = \frac{24V^2(1-w)}{49t}$$

$$\pi_{b2} = \frac{6V^2(1-w)(4t-3c+3wc)}{49t^2}$$

This completes the proof of the lemma.