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 more likely to outsource product design when there is a common ODM in the channel than when there are exclusive ODMs.

Keywords: Original Design Manufacturer, 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 that do not have their own manufacturing facilities typically contract the production process to an external manufacturer[1]. The most commonly cited reason for production outsourcing is the cost advantage that external manufacturers possess over brands[2]. Over the past two decades, however, some external 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 and selling the product under its own name.

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 by the company but sold under the names of lighting firms with well-known products. Less than 20% of their profit comes from pure manufacturing contracts that require the company to make products according to the specifications of the brand.[3]

At the same time, firms with big-name products 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

[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 the intellectual property rights, 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.

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 increase cooperation with ODMs instead of using contract manufacturers. Many firms with similar strategies are now found in different industries. 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]

Whether to outsource product design along with manufacturing in an outsourcing strategy is a crucial strategic decision for today's supply chain managers, because the design of a product is of paramount importance to its market success, a point that has been substantiated by the stories of many products. 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 share of the global 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 this ignores the strong network externality of operating systems. The company is reported to be developing two new smartphones with the Android operating system, to keep up with market trends and revitalize the business[8]. For Apple, on the other

[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.

[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/

[8]"BlackBerrys Android Phone Confirmed: Company Registers 2 Secured Android Domains," available at http://www.ibtimes.com/blackberrys-android-phone-confirmed-company-registers-2-secured-android-domains-2005074

hand, the success of its iPhone in the smartphone market is largely due to its successful product design. Interviewed by the online news website Cult of Mac, 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[9].

Firms face many challenges when designing their products, including how to find the right product positioning to 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, is still an attractive design to others, including President Barack Obama [10]. The TrackPoint design of laptops that was popularized by ThinkPad is yet another feature that receives 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 [11]. 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.’”[12] Since it is hard to appeal to all consumers, the challenge faced by firms is to create a design that attracts the right group of consumers and brings the largest profit.

Despite the importance of product design 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 under competition. We adopt a competitive framework because competition is common in industries where ODMs are most often found, such as lighting,

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

[10]“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/

[11]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/

[12]“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

computers, digital audio players, cameras, cellphones and TVs (Haksöz et al., 2011). In both outsourcing strategies, firms will outsource production to an 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 in the presence of competition.

To analyze firms' outsourcing decisions, we develop an analytical model of duopoly competition in a market with heterogeneous consumer tastes. Consumers are assumed to be distributed uniformly on a straight line that represents heterogeneous consumer preferences, and they incur a disutility from purchasing a product that is different from their ideal. The two 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 itself choose to locate the product on the straight line. If it outsources, the ODM will determine the location of the product. A product development cost will inevitably be incurred by the designer of the product, and that cost is determined by how much the product differs from a prototype product. 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. We look at firms' outsourcing decisions in both situations and investigate how the outsourcing equilibrium might differ between the two situations.

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 profit share 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 profit share 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' profit share 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 sales. This effect – better product differentiation by companies with larger channel power – 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 is larger when the two products are designed by a common ODM than by competing ODMs. Increasing the investment in product design on either product leads to higher product differentiation and benefits both products, because firms will compete less fiercely on price. 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. As a result, products designed by the common ODM will be better differentiated. The finding that product differentiation is larger when designed by the common ODM leads to different results in the common-ODM channel than in the exclusive-ODM channel. We find that outsourcing is more 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 only one firm outsources design in the exclusive-ODM channel sees both firms outsourcing in the common-ODM channel. We also discuss the possibility that firms are allowed to choose which ODM to outsource to when there are multiple ODMs in the market, and conclude that they will optimally outsource to the same ODM.

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 then concludes the paper.

2 Related Literature

This paper is related to several streams of research in marketing and operations research. First, there are several studies on product design outsourcing that this paper is most closely related to. 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 has been 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 economy 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). Our paper adopts a horizontal differentiation framework with endogenous product design, but is different from the aforementioned studies in three important ways. First, although we explicitly model product design in our study, we are not looking at product line design 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, while most of the studies on product line design examine a monopoly firm's decision on the optimal number and specifications of products to offer, we take a different perspective by investigating whether the design process should be completed in-house or outsourced to an ODM. Third, most studies with horizontal differentiation focus more on the number of products to offer than on 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 is also related 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). 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 straight 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 product 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 then 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 adopted in the literature (e.g., Raju et al., 1995; Jain and Srivastava, 2000). Without loss of generality, we normalize the density of consumers on the straight 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. Some consumers may prefer a cellphone with a larger screen so that they can see the content more clearly. Others may prefer a smaller one that is easier to carry around. Some consumers may have a preference for Android operating system, while others may like iOS or Windows system better. When shopping for a particular type of product, consumers may not always be able to find the product with the exact features they are looking for. For example, a consumer looking for a cellphone with iOS operating system and a physical keyboard is unlikely to find such a product, and will have to compromise with a less-than-ideal product. Her valuation for the less-than-ideal product will inevitably be lower, because it does not match her preference perfectly.

By changing the design of its product, a firm also change its position in the market, 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 prototype product that costs the least amount of effort to design. Any modification of the prototype incurs additional design cost and the cost depends on how much the product differs from the prototype. A prototype product may exist for several reasons. One possible reason is that the prototype is a product with standardized features that all companies know how to design. Adding unique features to the product to cater to a specific group of consumers requires additional investment. For example, in the design of laptops, the prototype product 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

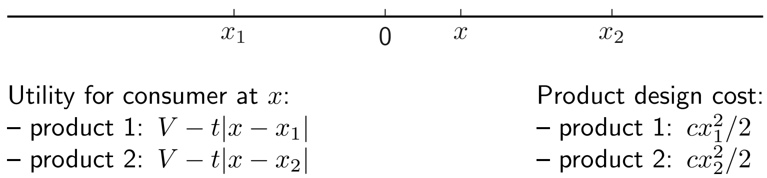

Figure 1: Consumer Utility and Product Design Cost

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 prototype product 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 point in the design of new products. In such industries as cellphones and tablets, where new products are frequently introduced in the form of upgrade, the design cost is largely determined by how much the new product differs from the old one. To capture this idea, we normalize the cost of designing the prototype product to 0 and without loss of generality, assume that the prototype product is located at the zero point. 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 an external manufacturer (contract manufacturer or ODM). With regard to the cost of manufacturing, 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 choices. 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 to insource 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.

No matter firm i outsources to a contract manufacturer or an ODM, we assume that it is able to acquire the finished product at a cost wp_i, where p_i is the retail price of product i and w ($0 < w < 1$) is an exogenous parameter that captures how channel profit is divided between the manufacturer and the firm. Instead of assuming that the manufacturer makes a take-it-or-leave-it offer to the firm, we assume that the manufacturer and the firm split channel profit according to their respective power in the channel. In a distribution channel, usually the party who owns the intellectual property right of the product has more influence on the wholesale price. In the outsourcing context, brands are usually believed to be more powerful than the manufacturers, because they own the trademark of the products. No matter the production process is outsourced to a contract manufacturer or an ODM, the initiative of the outsourcing process is likely to be taken by the brand. Therefore, the brand must be actively involved in the entire outsourcing process, including the determination of the wholesale price. A Stackelberg framework does not realistically capture the interaction between the brand and the manufacturer in this context. In fact, in the outsourcing literature, it is a widely-adopted assumption that the wholesale price is determined not by the manufacturer, but by 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). In light of this, we adopt the aforementioned assumption on wholesale price that is capable of capturing the relative power of the two trading parties, yet simple enough to ensure analytical tractability. w is larger if the manufacturer has more power in the channel and smaller if the brand has more power. Note that the parameter w is the same for contract manufacturers and ODMs, which means the firm is able to acquire the final product at a constant per-unit price. The only difference

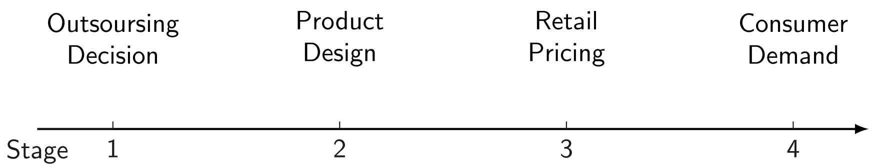

Figure 2: Game Structure and Timeline

between the two outsourcing options is who designs the product. By making this assumption, we are able to rule out the asymmetry between different types of manufacturers and focus exclusively on the strategic effect of product design.

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 will choose the location of the product. At the third stage, both firms simultaneously set the retail prices of their products. 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.

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. First, we will examine the purchase decision of consumers given the locations of products 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 Retail pricing

At the retail pricing stage, each firm should 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 follows analogously. 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, 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.

4.2 Product design

Now we will solve for the optimal product locations at the second stage of the model. 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.

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

$$x_2^{bc}(x_1) = \frac{3(1-w)(V-tx_1)}{3t(1-w)-25c} \tag{2}$$

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 1 and 2.*

(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 firms. 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 the 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 distance 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.

4.3 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

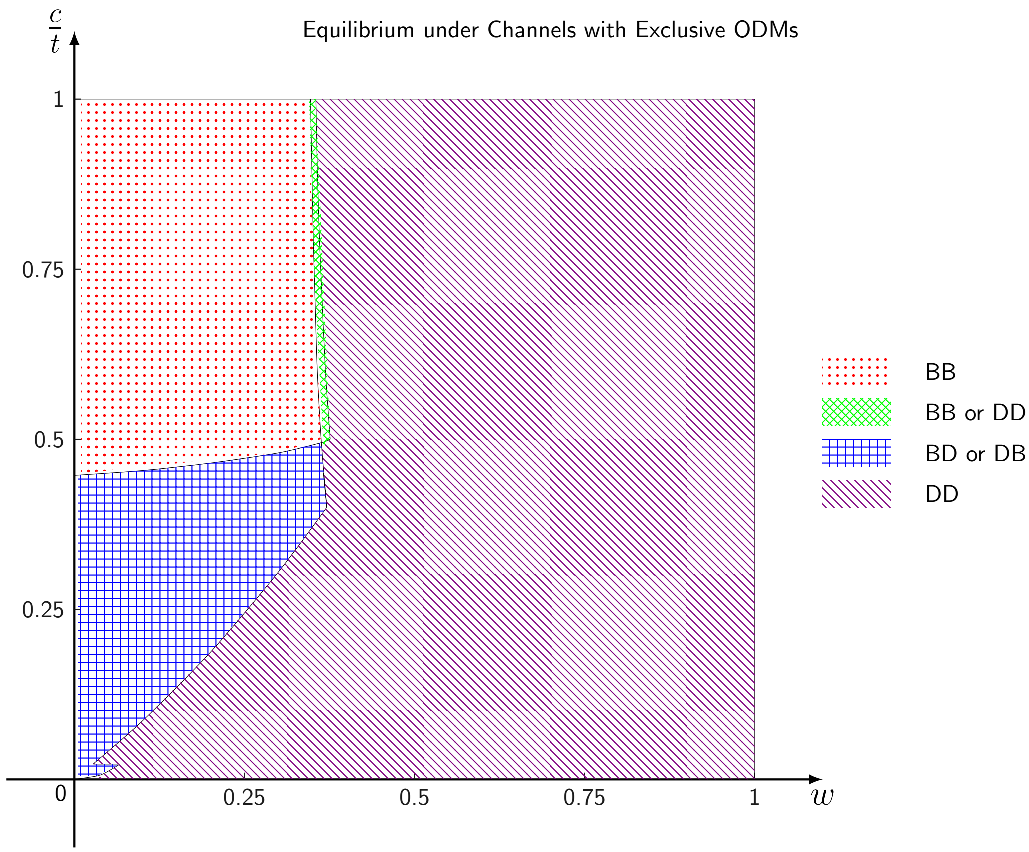

Figure 3: Equilibrium under Channels with Exclusive ODMs

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.

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, both firms insource product design, and one of the firms outsources design. Consistent with the intution discussed earlier, both firms will outsource product design when the manufacturer is able to obtain a relatively large share of channel profit. When the manufacturer's profit share 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 channel 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 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 larger 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 the firm insources product design. Therefore, the firm is less likely to outsource design to the ODM when t decreases.

5 Channel with a Common ODM

In the previous section, we analyzed the design outsourcing decisions of firms 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 an alternative situation in which a common ODM partners with both firms. Both channel structures are widely observed in the the manufacturing industry.

5.1 Product design

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 also 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 borrow the results in Lemma 3 and 4 directly. The only subgame that calls for additional analysis is the one in which both products are designed by the common ODM. We outline the analysis below.

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 x_2 such that $x_2 \geq 0$ and $x_1 = -x_2$. When x_2 decreases, the market will change from the local monopoly case to the competitive monopoly case, and eventually, to the competitive case. Same as in the other two subgames, the equilibrium location x_2 will be either in the interior of the competitive monopoly case, in the interior of the competitive case, or at the cutoff points between different cases. When $x_1 = -x_2$, the ODM's profit function is

$$\pi_D = \begin{cases} 4wx_2(V - tx_2) - cx_2^2, & \text{if } \frac{3V}{7t} < x_2 \leq \frac{V}{2t} \\ \frac{12w(V+tx_2)^2}{25t} - cx_2^2, & \text{if } x_2 \leq \frac{3V}{7t} \end{cases} \tag{3}$$

Maximizing Equation 3 with respect to x_2, we find that the optimal x_2 is $x_2 = \frac{2Vw}{4tw+c}$ when $c \leq \frac{2tw}{3}$, $x_2 = \frac{3V}{7t}$ when $\frac{2t}{3w} < c \leq \frac{8V}{5t}$, and $x_2 = \frac{12Vw}{25c-12tw}$ when $c > \frac{8tw}{5}$. This result is formally stated in Lemma 5.

Lemma 5. *When both products are designed by the same ODM, the equilibrium product locations are* $x_1 = -\frac{2Vw}{4tw+c}$ *and* $x_2 = \frac{2Vw}{4tw+c}$ *when* $c \leq \frac{2tw}{3}$, $x_1 = -\frac{3V}{7t}$ *and* $x_2 = \frac{3V}{7t}$ *when* $\frac{2tw}{3} < c \leq \frac{8tw}{5}$, *and,* $x_1 = -\frac{12Vw}{25c-12tw}$ *and* $x_2 = \frac{12Vw}{25c-12tw}$ *when* $c > \frac{8tw}{5}$. *The equilibrium profits* *of firms are given in the Appendix.*

Proof. Follows from the analysis in the main text. □

Comparing the results in Lemma 4 and 5, we have the finding in Proposition 4.

Proposition 4. *Products are more differentiated when designed by the same ODM than when designed by different ODMs.*

Proof. Follows directly from comparing the results in Lemma 4 and 5. □

Competing firms are usually expected to produce more-differentiated products in order to alleviate price competition. However, Proposition 4 shows that it is the opposite. We observe higher product differentiation when products are designed by the common ODM than by competing ODMs. This reason is as follows. When products are designed by competing ODMs, each ODM takes into account only the benefit of higher product differentiation for their own product. Nevertheless, when one product moves away from the other, both products can enjoy higher revenue due to softened competition. When the common ODM designs the products, it takes the revenue increase of both products into account and therefore, has a stronger motive to invest in product differentiation.

5.2 Outsourcing decision

We will now investigate the equilibrium outsourcing decisions of firms when there is a common ODM in the channel. Same as the model with exclusive ODMs, the equilibrium outsourcing decisions can be derived by directly comparing brands' profits across different subgames. Figure 4 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

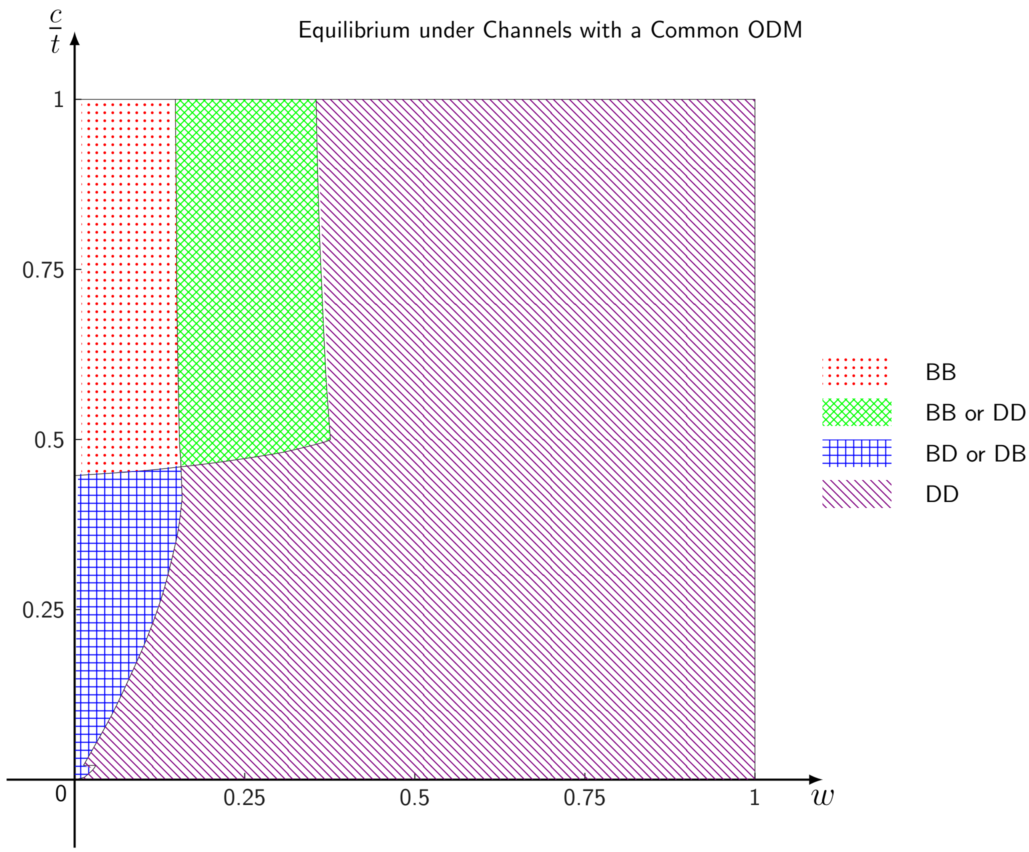

Figure 4: Equilibrium under Channels with a Common ODM

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 result in Figure 3 and 4, we also have the following observation.

Proposition 5. *firms are more 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 smaller, and the area in which both firms outsource design in the equilibrium is bigger. Overall, outsourcing is more 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 better differentiated products when both firms outsource design, which increases the expected benefit of outsourcing. Note that our model does not consider scale of economy in product design, i.e., the design cost does not decrease when both products are designed by the same company. If we were to incorporate scale of economy by assuming cost reduction opportunities when products are designed by the same company, the result in Proposition 4 and 5 would be even stronger, because scale of economy incentivizes the ODM to develop even more differentiated products than in the current model setup.

6 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 prototype product.

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 observed larger product differentiation when the two products are designed by the common ODM than by competing ODMs. As a result, outsourcing is more 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 both firms and manufacturers have the same cost structure in product design. If one party has cost advantages, it will be more likely to take the responsibility of product design than the other party. Second, we assumed that the channel power is independent of contract format. Relaxing this assumption to allow either the ODM or the contract manufacturer to have a larger channel power will also change the firms' strategic incentives in choosing one outsourcing format versus the other. Third, we focused on identifying the strategic forces behind firms' decision to outsource product design in a competitive environment. There are other aspects of design outsourcing that we did not study due to the scope of the current research. For example, the long term impact of design outsourcing is an important issue because an ODM strategy is likely to be a no-turning-back solution in the long run. In addition, our model made predictions about the drivers and economic consequences of design outsourcing. An interesting direction of research in the future is to empirically test the model predictions using outsourcing data across different industries.

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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

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

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.

E Equilibrium Profits of firms in Lemma 5

When $x_1 = -\frac{2Vw}{4tw+c}$ and $x_2 = \frac{2Vw}{4tw+c}$ in the equilibrium, the equilibrium profits of the two firms are

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

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

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

When $x_1 = -\frac{12Vw}{25c-12tw}$ and $x_2 = \frac{12Vw}{25c-12tw}$ in the equilibrium, the equilibrium profits of the two firms are

$$\pi_{b1} = \pi_{b2} = \frac{150V^2c^2(1-w)}{t(12tw-25c)^2}$$