

Strategic Partial Outsourcing in the Presence of Bottleneck Components

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Abstract

We study the sourcing decision of a manufacturer for an intermediate good, with multiple sources available under different efficiency levels, in choosing between sole sourcing and multi-sourcing. In our model, the manufacturer can produce in-house or outsource the intermediate good, and in-house production is more efficient. There is no demand uncertainty or ex-ante capacity constraint with in-house production. We find that the manufacturer may establish only limited in-house capacity to create ex-post capacity constraint, and eventually outsource to less efficient external providers. Such partial outsourcing is purely strategic and is due to the existence of bottleneck components, with which the manufacturer solely relies on key suppliers with great market power. Partial outsourcing enables the manufacturer to mitigate the pricing power of key suppliers, and is optimal to the manufacturer so long as the associated efficiency loss is not too pronounced. Moreover, an increase in outsourcing cost may lead the manufacturer to outsource a larger proportion and may boost the manufacturer's profitability.

Keywords: outsourcing, capacity, supply chain

JEL Classification: D4, L1, L2

1 Introduction

While the configuration of the supply of indispensable production components is always crucial to manufacturers, nowadays it is witnessed many complex sourcing decisions involving multiple suppliers. For example, as a cell phone manufacturer, Samsung uses Google for its platforms and services, and also partnered with Nokia to develop its maps and location services for Galaxy

smartphones.¹ In many situations, such multi-sourcing strategy involves an intermingle of internal and external sources in the supply chain. For example, Ford Motor Co. uses Mexican suppliers and also its own facility in Ohio and Michigan for work on the F-650 and F-750 truck models, the Fusion midsize model and its EcoBoost engine.² Apple continues with some manufacturing outsourced to Asian suppliers, but it also has its manufacturing on the United States including manufacturing its new Mac Pros in a Texas plant and an AppleCare repairs facility in Pennsylvania.³ In the recent years, while continuing with outsourcing, General Electric revived its principal U.S. appliance manufacturing facility in Kentucky, and opened in U.S. assembly lines to make low-energy water heaters.⁴

Various rationales could underlie such multi-sourcing strategy, as have been reported by media and studied in literature. For example, in the presence of demand uncertainty, manufacturers may use the most efficient supplier as the main source while cue up other suppliers in case demand is usually high. Multi-sourcing could also be the result of production capacity constraint or dis-economies of scale in the supply side, or due to manufacturers' pursue for a better risk/quality control or the benefit of staying close to emerging big markets.

While all these elements could be at play and determine firms' sourcing policies, in this paper, we intend to provide a strategic point of view to manufacturers' multi-sourcing. In particular, we bring to light the strategic considerations in supply chain configuration when manufacturing requires "bottleneck" components. To focus on the central message, we abstract out any market uncertainty or dis-economies of scale in production, so that we can identify the operational region wherein strategic considerations play the pivotal role for outsourcing.

To this end, we note that producing a final good normally requires multiple intermediate goods. For some of them, production could require specific resources or technology know-how, hence manufacturers rely on single source for procurement and are subject to suppliers' large market power. For example, Samsung is the sole supplier of micro processors for Apple's iPhone and iPad; Ford exclusively uses several key suppliers for the parts, including NHK Spring, Japan for suspension stabilizer linkages and Autoliv, Spain for side airbags; Land Rover buys more than 90

¹Forbes, Aug 29, 2014. Samsung Shuns Google by Offering Nokia's Here Maps on Galaxy Phones.

²MNET, Jun 12th, 2015. Reshoring In-Depth: Ford, Caterpillar, GE, GM Among Top Reshoring Companies.

³CNET, Nov. 4th, 2013. Apple to build made-in-the-USA manufacturing plant in Arizona.

⁴Forbes, Dec 6th, 2012. Why Apple Is Bringing Manufacturing Back To The United States.

percent of components from single suppliers (Lester (2002)). We denote such components as *bottleneck components* and powerful providers of the bottleneck components as *key suppliers*. These key suppliers, because of their superior quality, cutting-edge technology or exclusive property rights, become vital in the supply chain and possess huge market power in transactions with the manufacturer. It is reported that some large and well-known electronics contract manufacturers issue essentially “take-it-or-leave-it” contract to perspective OEM (original equipment manufacturer) customers regarding per unit price with little room for negotiating on price (Gray et al. (2009)).

We show that in the presence of bottleneck components, manufacturers may intentionally create sourcing inefficiency with non-bottleneck components, for which manufacturers have flexibility selecting among various available sources. By involving inefficient sources in the supply chain, manufacturers inflate future cost and therefore can induce the key suppliers to offer more favorable deals in the market of bottleneck components. As long as inefficiency of multi-sourcing is not too severe, the incentive for manufacturers to mitigate key suppliers’ market power could dominate and lead multi-sourcing to occur in equilibrium.

To formalize our idea, we consider a stylized model in which a manufacturer needs one unit of a bottleneck component and one unit of a non-bottleneck component to produce one unit of a final good. The manufacturer relies on a key supplier for quality supply of the bottleneck component. For the non-bottleneck component, the manufacturer can either outsource to a competitive fringe or produce in-house via irreversible capacity investment. As mentioned above, there is no market uncertainty or strictly convex production cost in our model. To focus on the strategic aspect of outsourcing, we also assume that per unit in-house production is cheaper than outsourcing for the non-bottleneck component. We consider the sequence that the manufacturer first chooses in-house capacity level for the production of the non-bottleneck component, then the key supplier quotes price for the bottleneck component. After that, the manufacturer determines the quantity to produce for the final good. If his need of the non-bottleneck component exceeds his in-house capacity, he uses the competitive fringe to fulfill his residual demand.

Our central finding of the model indicates that the manufacturer adopts partial outsourcing as long as the cost advantage of in-house production is not substantial. If so, the manufacturer restrains his in-house capacity upfront to create ex post capacity constraint after the price of the bottleneck component is decided. On the other hand, given that his in-house capacity is low enough, his key supplier will willingly cut back price of the bottleneck component to motivate

the manufacturer to expand his quantity beyond his in-house capacity level. We also find that, ironically, if the manufacturer is empowered to reduce the outsourcing cost, he may intentionally choose not to do so. Moreover, an increase in the procurement cost from outsourcing may not necessarily be detrimental for the manufacturer. In fact, this cost increase would induce the manufacturer to outsource a larger proportion, as the increased cost may strengthen the manufacturer's ability to claim a higher profit share vis-à-vis his key supplier, thereby overturning the downside of this seeming business crisis. Our result therefore documents a novel source of supply chain inefficiency. As a consequence to the efficiency loss, partial outsourcing reduces both producer surplus and consumer surplus.

Since the purpose of strategic partial outsourcing is to secure favorable transaction deals with key suppliers, the argument applies to situations when contract incompleteness deems signing long-term contracts to lock in prices implausible (see Spencer (2005) for a survey on contractual incompleteness in outsourcing). As documented in Quelin and Duhamel (2003), in reality many manufacturing contracts are written only for a specific time of period. With worldwide fast technology progress, it is often impossible to pre-specify in a price contract every attributes of a product including quality, compatibility and duration. If long-term price contract cannot prevent suppliers' ex post opportunistic behavior, partial sourcing provides the manufacturer the potential to eat into key suppliers' profit margin in their spot transactions.

In the context of global sourcing, our results provide insights to the increasing concern about the prevalence of U.S. manufacturers' offshore outsourcing. In recent years, a trend of increasing outsourcing cost due to rapidly rising labor rates abroad,⁵ loftier materials and shipping costs, together with deep-discount tax incentives from U.S. states, has to some extent deemed offshore outsourcing no longer a default option to U.S. manufacturers.⁶ However, our findings highlight

⁵According to the International Labor Organization, real wages in Asia between 2000 and 2008 rose by 7.1-7.8% a year. Pay for senior management in several emerging markets, such as China, Turkey and Brazil, now either matches or exceeds pay in America and Europe, according to a recent study by the Hay Group, a consulting firm. Pay in advanced economies, on the other hand, rose by just 0.5% to 0.9% a year between 2000 and 2008, says the McKinsey Global Institute. In manufacturing, the financial crisis actually reduced pay: real wages in American manufacturing have declined by 2.2% since 2005. (The Economist, Jan 19th, 2013. A growing number of American companies are moving their manufacturing back to the United States.)

⁶In 2012, the Massachusetts Institute of Technology looked at 108 American manufacturing firms with multinational operations and found that 14% of them had firm plans to bring some manufacturing back to America and one-third were actively considering such a move (The Economists, Jan 19th, 2013). Cost savings due to reshoring have been reported by these manufacturers. For example, since 2012, General Electric (GE) has opened in U.S. assembly lines to make low-energy water heaters. As a result of reshoring, GE was able to save around 20% of its production cost of water heater (Forbs, Dec 6th, 2012. Why Apple Is Bringing Manufacturing Back To The United States).

potential pitfalls in the re-shoring progress when manufacturers are subject to key suppliers with great market power. First, our findings indicate that outsourcing cost on a rise to exceed on-shore cost may not naturally attract more production on-shore, as strategic considerations of manufacturers can lead to sourcing inefficiency. Second, tax relief provided by government to load dice against outsourcing may not be efficacious as it is meant to be. In the presence of key suppliers, policies to encourage sourcing diversification to relieve key suppliers' market power could be complementary to tax relief for the purpose of re-shoring.

The message of our work resonates the theory of "second best" in Lipsey and Lancaster (1957). From the perspective of final-good producers, market distortion from perfect competition in the bottleneck segment results in distortion from efficient sourcing in the non-bottleneck segment. Bulow et al. (1985) show that for firms operate in multiple downstream markets, situation in one market can have ramifications in the second market through a horizontal channel due to competitors' response to the strategy taken by the multi-market firm. Our work considers multiple upstream markets, and situation in one market influences sourcing decision in the second market through a vertical channel, due to upstream suppliers' response to the downstream manufacturer's strategy.

Literature on firms' make-or-buy decision provides several explanations to the practice of partial outsourcing. Shy and Stenbacka (2005) argue that partial outsourcing can result from the tradeoff entailed by outsourcing: a cost deduction on the production side and an occurrence of monitoring cost for the need of management. Taking into consideration the same tradeoff, Alvarez and Stenbacka (2007) use a real options approach to explain partial outsourcing under uncertain market conditions. Gray et al. (2009) show that the existence of learning-by-doing in production can make partial outsourcing the optimal sourcing mode for manufacturers. In a setting where supplier's bargaining power increases in the fraction of the production outsourced, Stenbacka and Tombak (2012) find that partial outsourcing emerges to balance the cost advantages associated with outsourcing against the increased bargaining power of the supplier. Du et al. (2006) argue that partial outsourcing helps mitigate holdup problem as well as secure quality supply, thereby improving efficiency. Our work complements the literature by showing that in the presence of powerful key suppliers, partial outsourcing can be a valuable device for the manufacturer to constrain key suppliers' pricing power.

Our paper falls in the broad research streams on multi-sourcing/second sourcing. Among

them, Choi and Davison (2004) identify a strategic reason for multinationals to engage in both outsourcing and foreign direct investment (FDI). The similarity between Choi and Davison (2004) and our work is that in both papers, committing to the second source serves the purpose of raising the firm's marginal cost while keeping his average cost low, which leads to strategic advantage. However, there are major differences between these two papers. The strategic advantage in Choi and Davison (2004) occurs in a horizontal setting where the enhanced marginal cost softens downstream competition by leading competing multinationals to increase prices of final goods. Instead, our work examines a vertical setting wherein the enhanced marginal cost helps drive down prices charged by upstream suppliers. Moreover, the analysis in Choi and Davison (2004) is built upon cost uncertainty entailed by FDI of the multinational, where strategic consideration adds to the option value of second sourcing in an uncertain world. Our work rules out any format of uncertainty, which allows us to focus on strategic aspects and identify the operational region wherein strategic considerations are the sole driver for outsourcing.

Other literature in this strand includes Farrell and Gallini (1988) and Shepard (1987), who illustrate the commitment value of second sourcing in fostering future competition between sellers, thereby preventing ex post opportunistic behavior of a monopolist seller and increasing industry demand. In the context of procurement, Laffont and Tirole (1988), Anton and Yao (1989) and Riordan and Sappington (1989) focus on the advantage/disadvantage of second sourcing when it is linked to ex ante innovative behavior of an incumbent supplier. Inderst (2008) shows that single sourcing could not be optimal when suppliers face strictly convex costs unless the buyer is with significantly strong market power. In addition, Kogut and Kulatilaka (1994) and Li and Debo (2009) illustrate the option value of second sourcing under cost uncertainty.

The rest of this paper is organized as follows. Section 2 introduces our model setup. In Section 3, we carry out the equilibrium analysis and articulate the manufacturer's in-house capacity decision. Section 4 discusses various extensions of our model characteristics to examine the robustness of our central message. Section 5 concludes. All proofs are in the appendix.

2 Model

We posit a stylized model in which a manufacturer, denoted as firm M , is a monopolist for a final good (we consider final good competition in Section 4). The inverse demand function of the final

good is $P(q)$, where q denotes the produced quantity. The market price satisfies $P(q) > 0$ for q not too large and $P'(\cdot) < 0$.

To produce the final good, firm M needs two intermediate goods, with which he has different market powers. For one intermediate good, firm M cannot produce in-house and relies exclusively on an external supplier. To highlight the exclusivity in firm M 's sourcing with this intermediate good, we call it a *bottleneck* component and denote it as component B . On the other hand, for the other intermediate good, firm M has flexibility as he can either produce in-house or order from a competitive fringe. We denote this "non-bottleneck" intermediate good as component N . The unique supplier for component B is denoted as firm S , who incurs a constant average cost $v > 0$ to produce component B . While both firm M and the competitive fringe can produce component N , we assume that firm M is more efficient, which allows us to focus on the strategic aspect of outsourcing. The unit cost to produce component N for firm M is normalized to zero, whereas it is $m > 0$ for the competitive fringe. Without loss of generality, we assume that one unit of component B and one unit of component N in combination can be converted into one unit of the final good. Firm M incurs production cost $C(q)$ for converting these components into the final good, which satisfies $C(0) = 0$ and $C'(\cdot) > 0$.

To produce component N in-house, firm M needs to establish in-house production capacity. Since capacity building acquires a longer lead time, firm M makes decision on capacity building before he contacts suppliers to fulfill his demand of intermediate goods. For simplicity, we assume that building production capacity $K > 0$ entails a fixed cost $F > 0$, and correspondingly firm M is able to produce in-house K units of component N .⁷ Instead if $K = 0$, no fixed cost is entailed and firm M resorts to the competitive fringe for his whole demand of component N . After the capacity decision, firm M purchases component B and also component N if he wants to expand quantity beyond his in-house capacity. We assume that the transaction on component B is conducted before the transaction on component N , which captures the flexibility firm M has with his order quantity of component N upon observing the transaction terms of component B .⁸ We use a wholesale price

⁷To make in-house production a feasible choice, we assume that the fixed cost F is not too big, such that for firm M , his optimal profit when he produces component N fully in-house is no less than his optimal profit when he establishes zero in-house capacity and fully outsources component N .

⁸The timing can naturally arise considering that firm M endeavors to settle down his transaction with firm S , whom firm M fully relies on for component B . In contrast, the purchase of component N is less painful to firm M as there are competing suppliers available, therefore can be postponed till a later stage. However, our central results do not rely on this particular timing and will continue to hold if these transactions are conducted in a simultaneous manner.

contract to model the transaction of component B , and firm S has full power determining the wholesale price w of component B .⁹ Observing the price of component B , firm M then determines its quantity q of the final good. If $q \leq K$, the implication is that q units of component N are fully produced in-house; otherwise if $q > K$, firm M outsources $q - K > 0$ units of its residual demand of component N to the competitive fringe by paying price m . The interaction between firm M and firm S is summarized into a three-stage game as follows:

- *Stage 1* – The **capacity-building** stage: Firm M establishes his production capacity K , which guarantees that K units of component N can be produced in-house.
- *Stage 2* – The **contracting** stage: Firm S announces her wholesale price w of component B , at which she is willing to supply firm M .
- *Stage 3* – The **production** stage: Firm M determines his quantity q to produce for the final good. If $q > K$, firm M outsources his residual demand $q - K$ units of component N to the competitive fringe.

We impose the following assumptions on the demand and cost functions of Firm M :

Assumption 1. $P''(q)q + 2P'(q) - C''(q) < 0$.

Assumption 2. $P'''(q)q + 3P''(q) - C'''(q) \leq 0$.

Assumption 1 is the standard assumption, which guarantees that the profit maximization problem of firm M has a unique interior solution. Similarly, Assumption 2 guarantees that the profit maximization of firm S has a unique interior solution. Assumption 2 is meant to simplify our analysis; it also applies to a wide variety of demand and cost functions. For example, it is satisfied when both $P(q)$ and $C(q)$ are linear; with quadratic $C(q)$, it is satisfied when $P(q)$ is linear, or when $P(q)$ is constant elastic with elasticity $\epsilon \geq -1$. We adopt the subgame perfect Nash equilibrium (SPNE) as our solution concept. In the next section, we derive the equilibrium behaviors in this manufacturer–supplier relationship.

⁹This contract form and the bargaining power are adopted mainly for simplicity; nevertheless, the wholesale price contract is commonly adopted in practice and has been widely recognized as a good workhorse in the academic literature. In Section 4, we discuss the robustness of our results if instead a Nash bargaining framework is used to determine the wholesale price.

3 Equilibrium analysis

In this section, we solve the game by doing backward induction to investigate equilibrium strategies of firm M and firm S . Our primary result demonstrates the possibility of *strategic partial outsourcing* – i.e., firm M voluntarily restrains his in-house capacity upfront even though outsourcing is more costly relative to in-house production.

3.1 Production stage

At the terminal nodes of the game tree, the profit of firm M is

$$\pi_m(K, w, q) = \begin{cases} P(q)q - wq - C(q) & \text{if } q \leq K \\ P(q)q - wq - C(q) - m(q - K) & \text{if } q > K \end{cases}. \quad (1)$$

Firm M 's marginal cost depends on whether his quantity q exceeds his established capacity K . For ease of exposition, we call the case $q \leq K$ as the scenario *with in-house production*, and the case $q > K$ as the scenario *with partial outsourcing*. In the former scenario, firm M 's marginal cost is $w + C'(q)$; in the latter scenario, his marginal cost is strictly larger and is given by $w + m + C'(q)$.

In the production stage, firm M determines his optimal quantity q for good F to maximize his profit given by (1). First, consider the case of in-house production, i.e., when $q \leq K$. In this case, the optimal quantity of firm M solves the first-order condition:

$$P'(q)q + P(q) - C'(q) - w = 0. \quad (2)$$

Let $q^*(w)$ be the solution to the above problem. Second, consider the case of partial outsourcing, i.e., when $q > K$. The optimal q solves the first-order condition:

$$P'(q)q + P(q) - C'(q) - w - m = 0. \quad (3)$$

Let $\bar{q}(w)$ be the solution to firm M 's problem with partial outsourcing.¹⁰ For $K \in [0, \bar{q}(0))$ the following holds (see the proof of Lemma 1):

$$q^*(w) > \bar{q}(w). \quad (4)$$

¹⁰In the sequel, we shall use upper bar and asterisk to indicate whether the term is associated with the scenario of partial outsourcing or in-house production.

That is, at a given price w of component B , firm M produces a larger quantity of the final good with in-house production vis-a-vis his quantity with partial outsourcing. Clearly, this is because that with partial outsourcing firm M bears a higher marginal cost for component N . It is verifiable that

$$\frac{d\bar{q}(w)}{dw} < 0, \quad \frac{dq^*(w)}{dw} < 0. \quad (5)$$

There exist unique values of $w_1(K) : [0, \bar{q}(0)] \rightarrow \mathbb{R}^+$ and $w_2(K) : [0, q^*(0)] \rightarrow \mathbb{R}^+$, defined by

$$\bar{q}(w_1(K)) = K, \quad q^*(w_2(K)) = K.$$

These are the values of w at which firm M is optimal producing quantity K given that its marginal cost is $w + m + C'(q)$ and $w + C'(q)$ respectively. By (4) and (5), it follows that

$$w_1(K) < w_2(K). \quad (6)$$

The following lemma characterizes firm M 's optimal production strategies at different values of w .

Lemma 1. *In Stage 3, firm M 's optimal quantity of the final good is $q^*(w)$ if $K \geq q^*(0)$. Instead, if $K \in [0, q^*(0))$, Firm M 's optimal quantity is $q(K, w)$, given by*

$$q(K, w) = \begin{cases} \bar{q}(w) & \text{if } w < w_1(K) \\ K & \text{if } w \in [w_1(K), w_2(K)] \\ q^*(w) & \text{if } w > w_2(K) \end{cases} .$$

For K large enough ($K \geq q^*(0)$), firm M faces no capacity constraint on component N and he always produces $q^*(w)$, his optimal quantity with in-house production. When K is not that big ($K < q^*(0)$), whether or not firm M outsources part of his demand of component N depends on the level of w . Lemma 1 says that according to w , there are three different production levels of firm M , which is illustrated by the heavy kinked curve in Figure 1: First, if $w < w_1(K)$, firm M 's aggregate marginal cost is relatively low so that he finds it optimal expanding his quantity to $\bar{q}(w)$ through partial outsourcing component N . Second, when $w > w_2(K)$, firm S finds his marginal cost high and he correspondingly produces strictly below his established capacity, reflected by $q^*(w) < K$. Third, for w in the intermediate region ($w \in [w_1(K), w_2(K)]$), the optimal quantity of firm M is given exactly by his established capacity K . For our following analysis, we focus on the case $K \in [0, q^*(0))$.

3.2 Contracting stage

In Stage 2, firm S determines her wholesale price w upon observing firm M 's capacity K . Anticipating that firm M produces quantity $q(K, w)$, firm S chooses w to maximize her profit

$$\pi_s(K, w) = (w - v)q(K, w). \quad (7)$$

Define

$$\bar{w} = \arg \max_w (w - v)\bar{q}(w), \quad w^* = \arg \max_w (w - v)q^*(w).$$

Thus \bar{w} is the value of w maximizing $\pi_s(K, w)$ when firm M produces $\bar{q}(w)$, his quantity with partial outsourcing; and w^* is the value of w maximizing $\pi_s(K, w)$ when firm M produces $q^*(w)$, his quantity with in-house production.

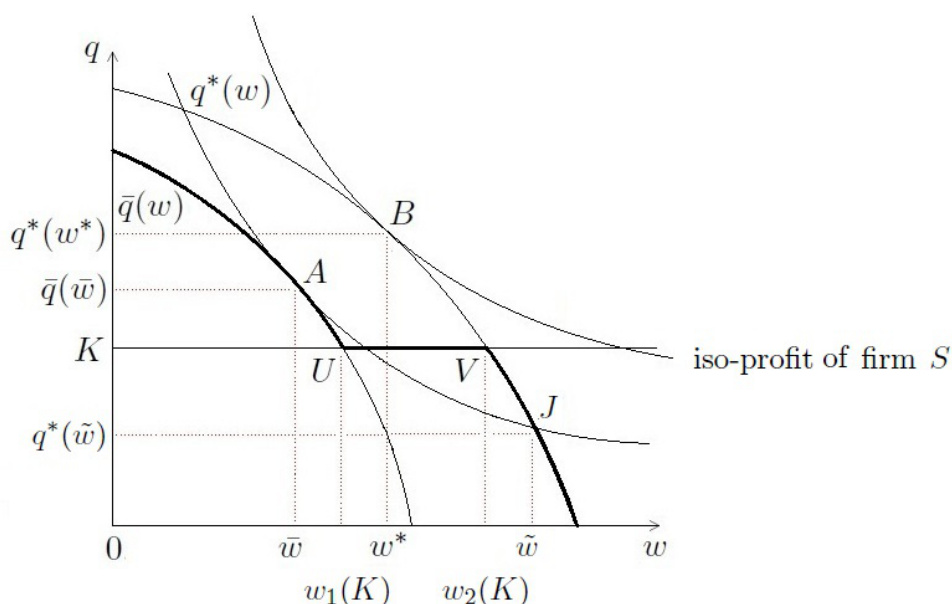


Figure 1: Profit maximization of firm S in the contracting stage

Figure 1 illustrates the profit maximization problem of firm S using $q(K, w)$ and *iso-profit* curves of firm S . The movement of the iso-profit towards the northeast corner represents a higher profit of firm S . Assumption 2 guarantees the uniqueness of tangency point of iso-profit curve to firm M 's optimal quantities. In Figure 1, point A is the tangency point of iso-profit to $\bar{q}(w)$, which gives the price \bar{w} . Similarly, point B is the tangency point of iso-profit to $q^*(w)$, which gives the price w^* . We compare \bar{w} and w^* below.

Lemma 2. $w^* > \bar{w}$.

Lemma 2 gives an essential but intuitive result to profit maximization of firm S : when firm S is convinced that future production efficiency of firm M is low (due to his outsourcing of component N), firm S may willingly cut back her price w of component B in order to boost the production of firm M , therefore maximizing her profit from selling component B . Since firm M 's sourcing decision depends on both w and his in-house capacity K , whether firm S should cut back w or not hinges on the capacity established by firm M , and it is profitable doing so only when the in-house capacity of firm M is sufficiently low. This critical level of K , below which firm S will cut back her price w , is given by point J in Figure 1, which is the intersection of $q^*(w)$ and the iso-profit of firm S which passes point A . The corresponding value of w at point J is denoted as \tilde{w} and is defined by

$$\begin{aligned} (\tilde{w} - v)\bar{q}(\tilde{w}) &= (\tilde{w} - v)q^*(\tilde{w}) \\ \text{s.t. } \tilde{w} &> \bar{w}. \end{aligned} \tag{8}$$

According to the definition, it is clear that

$$\bar{q}(\tilde{w}) > q^*(\tilde{w}). \tag{9}$$

Equation (8) shows that firm S is indifferent between two scenarios: The left-hand side of (8) is the situation when firm S sets w relatively low at \bar{w} , so that firm M produces $\bar{q}(\bar{w})$ (a relatively high quantity) through outsourcing component N . The right-hand side of (8) is the situation when firm S sets w relatively high at \tilde{w} , so that firm M produces $q^*(\tilde{w})$ (a relatively low quantity) using only in-house capacity of component N . Here $q^*(\tilde{w})$ gives the cutoff level of in-house capacity K , such that as long as K does not exceed $q^*(\tilde{w})$, firm S will favor the low price strategy. The following lemma summarizes the result.

Lemma 3. *In the contracting stage, firm S 's optimal wholesale price, denoted as $w(K)$, is given below:¹¹*

$$w(K) = \begin{cases} \bar{w} & \text{if } K \leq q^*(\tilde{w}) \\ w_2(K) & \text{if } K \in (q^*(\tilde{w}), q^*(w^*)) \\ w^* & \text{if } K \geq q^*(w^*) \end{cases} .$$

Given a pre-established in-house capacity of firm M , firm S has two choices: she may charge a low price to induce quantity expansion of firm M , or maintain a high price which eventually leads firm M to produce within his capacity. The central message of Lemma 3 is that when firm M 's in-house capacity is sufficiently small ($K \leq q^*(\tilde{w})$), the low-price strategy is optimal to firm S . In what follows, we examine the capacity choice of firm M .

¹¹For ease of exposition, when firm S is indifferent between a low price \bar{w} and a high price $w_2(K)$, we assume that firm S chooses the low price \bar{w} .

3.3 Capacity building stage

In stage 1, firm M determines his in-house capacity K for component N while foreseeing that future transaction terms may hinge on K . According to Lemma 3, there is a tradeoff to firm M by restraining his capacity. On the one hand, a limited production capacity may induce firm S to lower her price of component E . On the other hand, firm M eventually needs to absorb an increased cost of component N when he outsources his residual demand of component N . Instead, if firm M builds a sufficiently large in-house production capacity, he will have to pay a relatively high price w for component B but his cost of component N is kept low. To compare these two different strategies, note that the equilibrium profit of firm M when he solely uses in-house production for component N (gross of the fixed capacity cost F) is

$$\pi_m^* \equiv P(q^*(w^*))q^*(w^*) - C(q^*(w^*)) - w^*q^*(w^*).$$

Instead, if firm M establishes zero in-house capacity and therefore fully outsources component N , his equilibrium profit is

$$\bar{\pi}_m \equiv P(\bar{q}(\bar{w}))\bar{q}(\bar{w}) - C(\bar{q}(\bar{w})) - \bar{w}\bar{q}(\bar{w}) - m\bar{q}(\bar{w}).$$

Our presumption on F is that $\pi_m^* - F \geq \bar{\pi}_m$, so that for firm M , fully using in-house production is never worse than fully outsourcing component N with zero in-house capacity. If firm M establishes an in-house capacity $q^*(\bar{w})$, his profit (gross of the fixed capacity cost F) is

$$\bar{\pi}_m + mq^*(\bar{w})$$

since for each unit of component N produced in-house, he saves the cost m . The proof of the following theorem reveals that when choosing his optimal in-house capacity, firm M compares his profit when he fully produces component N in-house and when he partly outsources component N with $K = q^*(\bar{w})$. Partial outsourcing occurs in equilibrium if and only if the following condition is satisfied:

$$\bar{\pi}_m + mq^*(\bar{w}) - F > \pi_m^* - F. \quad (10)$$

The message of the following theorem is that when m is not too big, in equilibrium firm M adopts a partial outsourcing strategy.

Theorem 1. *Strategic partial outsourcing arises for m close to 0. If so, in the unique equilibrium firm M establishes production capacity $K = q^*(\bar{w})$ for component N ; then firm S quotes $w = \bar{w}$ for component B . Correspondingly, firm M outsources quantity $\bar{q}(\bar{w}) - q^*(\bar{w}) > 0$ for component N and produces quantity $q^*(\bar{w})$ of the final good.*

Theorem 1 suggests that whenever outsourcing is not too expensive relative to in-house production, firm M is better off intentionally creating himself a weakness through restraining his in-house capacity for component N . The purpose of doing so is purely strategic: a limited in-house capacity enables firm M to commit to a high future marginal cost so that firm S , despite being a relentless profit maximizer, will willingly cut back her profit share to facilitate quantity expansion by firm M . In addition, firm M is able to keep his average cost of component N relatively low through using more efficient in-house production to meet part of his demand. The aggregate effect is that the advantage of partial outsourcing dominates the associated disadvantage. Our results thus formalizes a strategic reason for firm M to use partial outsourcing as a way of self-sabotaging.

We note that the result is derived under the assumption that in-house capacity building faces only fixed cost, which could be restrictive. We now consider relaxing the assumption by assuming that in-house capacity building entails a non-negative cost $f(K)$ for firm M , which strictly increases in the capacity scale K :

Assumption 3. *The capacity building cost $f(K)$ of firm M satisfies $f(0) = 0, 0 < f'(K) < m$.¹²*

Our our message is only strengthened when there is variable cost associated with capacity building, as shown below.

Corollary 1. *Under Assumption 3, strategic partial outsourcing stated in Theorem 1 arises in equilibrium for a larger range of m .*

The intuition is that when capacity building is costlier for a larger K , full in-house production becomes less attractive to firm M . As a consequence, partial outsourcing will arise in equilibrium for a larger range of parameter. As the fixed cost assumption is innocuous to our analysis, we stick to it in what follows and provide several companion results to our central message.

Corollary 2. *If in the capacity building stage (stage 1) firm M is empowered to determine his outsourcing cost (m) of component N , in equilibrium his outsourcing cost is larger than his in-house production cost (i.e., $m > 0$).*

The above message says that when firm M is entitled to choose his outsourcing cost of component N , he may actually favor an *inefficient* one. In a situation when firm M is able to reduce his

¹²The assumption $f'(K) < m$ is to guarantee that average capacity building cost is not too big such that firm M finds it optimal to give up in-house production and fully rely on outsourcing. This allows us to focus on the strategic aspect of outsourcing.

outsourcing cost through a more extensive supplier search, or labor training or technology transfer to his current suppliers, he may choose not to do so. Instead, there is the incentive for him to inflate this cost in order to mitigate the pricing power of his key supplier firm S . In the context of global sourcing, the result indicates that offshore outsourcing cost on a rise may not necessarily be detrimental to firm M . For example, an increased labor cost in offshore production base for some components may strengthen firm M 's ability to claim a higher profit share vis-à-vis his suppliers of bottleneck components.

3.4 Welfare effects

In this section, we investigate the impacts of strategic partial outsourcing on producers' surplus and consumers' surplus. We consider the scenario when firm M fully produces component N in-house by establishing capacity $K \geq q^*(w^*)$ as the status quo. This is the case of standard double marginalization, in which both firm S and firm M get positive profit margin from selling their products above marginal costs.

When firm M engages in strategic partial outsourcing for component N , several factors can reduce social welfare. First, according to Theorem 1, firm M bears the more expensive outsourcing cost, which reduces producers' surplus. Second, in the production stage, the marginal cost of firm M is given by $\bar{w} + m$ under partial outsourcing, whereas it is w^* in the status quo. As $\bar{w} + m > w^*$ (see the proof of Corollary 3 in the Appendix), firm M ends up producing a smaller quantity of the final good ($\bar{q}(\bar{w}) < q^*(w^*)$). This reduces consumers' surplus; moreover, it also reduces producers' surplus since the quantity under partial outsourcing is downward distorted from the level in status quo (which is below the quantity of a vertically integrated monopolist). The result thus follows.

Corollary 3. *Strategic partial outsourcing reduces both producers' surplus and consumers' surplus.*

Whenever strategic partial outsourcing arises in equilibrium, firm M and firm S as an aggregate suffer from a lowered quantity of the final good and the outsourcing inefficiency. Clearly, it is firm M who gains a larger slice out of a smaller pie. At the same time, consumers are worse off due to the lowered quantity of the final good. Considering social welfare as the summation of producers' surplus and consumers' surplus, strategic partial outsourcing unambiguously reduces social welfare. Thus when strategic consideration is the central driver for outsourcing, the welfare

implication goes against the conventional wisdom that outsourcing either exploits cost efficiency among suppliers or mitigates supply uncertainty that ultimately benefits consumers.

3.5 A linear example

We use an example to further illustrate our message and to derive more characterizations of strategic partial outsourcing. In our example, market demand and production cost of firm M for the final good are linear and give as below.

Assumption 4. $P = \max\{a - q, 0\}$, $C(q) = cq$, where $a > 0$, $c > 0$, and $a > c + v + m$.

Under Assumption 4, Assumptions 1 and 2 are automatically satisfied. In Assumption 4, the condition $a > c + v + m$ ensures that the market size is big enough that justifies the business. If this condition is violated, the optimal production is trivially zero. The aforementioned solution approach is applied to the analysis of the example to obtain equilibrium results.

Define

$$\bar{m} \equiv \frac{2(7 - 4\sqrt{2})}{17}(a - c - v), \text{ and } m^* \equiv \frac{31 - 5\sqrt{33}}{34}(a - c - v).$$

Note that $m^* \in (0, \bar{m})$. The following proposition gives precise characterization on the regime within which strategic partial outsourcing arises in equilibrium. In addition, it provides the optimal outsourcing cost m of firm M , if m is endogenously chosen by firm M before the game unfolds.

Proposition 1. *Under Assumption 4, strategic partial outsourcing arises if and only if $m < \bar{m}$. Moreover, if firm M is entitled to determine his outsourcing cost m at the beginning of the game, he sets $m = m^* > 0$.*

Assumption 4 leads to a clear cutoff value of m , below which firm M strategically utilizes partial outsourcing to benefit in the contractual relationship with firm S . Moreover, it enables us to characterize the optimal gap between the interior and exterior costs of component N , under which firm M can maximize profit through partial outsourcing. The intuition is that when firm M outsources component N , an increase in m has two-sided effects on his profit. On the one hand, a higher m means lower outsourcing efficiency; on the other hand, a higher m leads to a lower cost of component B . If the outsourcing inefficiency is relatively small (m is close to zero), the positive effect of an increase in m dominates, and the optimal profit for firm M is achieved at the level $m = m^*$. Instead if the outsourcing inefficiency is relatively big ($m > m^*$), the negative effect of an increase in m dominates and firm M 's profit under partial outsourcing starts to decrease in m .

When $m > \bar{m}$, partial outsourcing becomes disadvantageous for firm M compared to the situation of in-house production.

The next corollary documents an intriguing phenomenon on how firm M adjusts his in-house capacity in response to the outsourcing cost.

Corollary 4. *Under Assumption 4, whenever strategic partial outsourcing arises, firm M 's in-house capacity ($q^*(\bar{w})$) decreases in the outsourcing cost (m), whereas his outsourcing quantity ($\bar{q}(\bar{w}) - q^*(\bar{w})$) increases in the outsourcing cost.*

Therefore, whenever firm M partly outsources component N , the quantity he outsources *increases* in the outsourcing cost whereas the quantity he produces in-house decreases in the outsourcing cost. This counter-intuitive result comes from the fact that an ex-post more vulnerable firm M due to stronger outsourcing inefficiency is undesirable to firm S . Thus for m larger, to give firm S incentive to cut back her price of component B thereby leading firm M to outsource, firm M has to further reduce his in-house production capacity, which consequently leads to a larger quantity outsourced for component N .

The policy implication of this result is that when strategic considerations dominate, grants and tax relief provided by government to encourage re-shoring could result in more production outsourced. This unintended consequence occurs when efficiency edge of on-shore production is only mild (corresponding to $m < \bar{m}$ in our model) and when firms are subject to powerful suppliers with bottleneck components. If so, they have strategic incentive to utilize (or even create) mild inefficiency in other component markets to mitigate pricing power of key suppliers. In such a situation, policies taken to foster competition or to encourage manufacturers to vertically integrate with key suppliers¹³ could be helpful relieving such sourcing inefficiency.

Below we provide more results regarding the occurrence and the scale of partial outsourcing.

Corollary 5. *Under Assumption 4, there is more strategic partial outsourcing when the market size (a) is larger, or when firm M and firm S are more efficient in production (c and v are smaller).*

Corollary 6. *Under Assumption 4, whenever strategic partial outsourcing arises, firm M 's in-house production capacity ($q^*(\bar{w})$) and the outsourcing quantity ($\bar{q}(\bar{w}) - q^*(\bar{w})$) increase in the market size (a) and decrease in the costs of component B and the final good (v and c).*

Corollary 5 says that when the business opportunity is more profitable (either due to a larger market size or better production efficiency between firm M and firm S), firm M is more willingly

¹³de Fontenay and Gans (2005) provide an analysis about the impact of vertical integration on the supply chain profit, and also on different parties' bargaining power under upstream monopoly and competition.

adopting partial outsourcing to entice firm S to offer a favorable deal on component B . According to Corollary 6, these are also situations where firm M builds larger in-house capacity and also outsource more of component N given that he adopts partial outsourcing.

4 Discussions

Our analysis points out that inefficient partial outsourcing of component N could occur due to firms' strategic incentive to mitigate market distortion in component B . In this section, we explore some alternative scenarios to examine the robustness of our results. We first relax the assumption of the full market power of firm S through Nash bargaining, then we examine the situation of downstream competition, and when the supplier of component N has pricing power.

4.1 Nash bargaining

Consider that firm M and firm S engage in Nash bargaining to determine the price w of component B . We use $\alpha \in [0, 1]$ to denote firm M 's bargaining power and accordingly $1 - \alpha$ for firm S . Thus $\alpha = 0$ corresponds to our basic framework where firm S provides a take-it-or-leave-it offer on w . Below, we analyze the equilibrium outcome of this Nash bargaining game.

In Stage 3, given the capacity K and w , firm M 's optimal quantity is $q(K, w)$ as given in Lemma 1. In Stage 2, firm M and firm S bargain on the wholesale price w by solving the following problem:

$$\max_w NB = \begin{cases} NB_1 \equiv [(P(\bar{q}(w)) - w)\bar{q}(w) - C(\bar{q}(w))]^\alpha [(w - v)\bar{q}(w)]^{1-\alpha} & \text{if } w < w_1(K) \\ NB_2 \equiv [(P(K) - w)K - C(K)]^\alpha [(w - v)K]^{1-\alpha} & \text{if } w \in [w_1(K), w_2(K)] \\ NB_3 \equiv [(P(q^*(w)) - w)q^*(w) - C(q^*(w))]^\alpha [(w - v)q^*(w)]^{1-\alpha} & \text{if } w > w_2(K) \end{cases} . \quad (11)$$

Finally, in Stage 1 firm M chooses his in-house capacity K to maximize his profit. Because it is difficult to obtain a closed-form expression of the solution to (11), we instead use numerical examples to demonstrate the robustness of our major results. We adopt Assumption 4 and use the following parameters: $a = 10$, $c = v = 0$, and $m = 0.6$.¹⁴

¹⁴These parameters are chosen to be representative; we have tried various combinations of parameters and observe similar patterns.

α	\bar{w}_{NB}	$\bar{q}(\bar{w}_{NB})$	w_{NB}^*	$q^*(w_{NB}^*)$	$\bar{\pi}_m + mK$	π_m^*
0.02	4.620	2.390	4.900	2.550	6.732	6.503
0.04	4.539	2.431	4.800	2.600	6.928	6.760
0.06	4.456	2.472	4.700	2.650	7.130	7.023
0.08	4.373	2.514	4.600	2.700	7.339	7.290
0.10	4.288	2.556	4.500	2.750	7.553	7.563
0.12	4.202	2.599	4.400	2.800	7.774	7.840
0.14	4.116	2.642	4.300	2.850	8.002	8.123

Table 1: Equilibrium outcomes under Nash bargaining

Define

$$\bar{w}_{NB} = \arg \max_w NB_1, \quad w_{NB}^* = \arg \max_w NB_3.$$

In Table 1, we compare firm M 's optimal profits under full in-house production and under partial outsourcing, where we impose $K = 1.7$ to facilitate numerical calculation. In the former situation, the Nash bargaining result is w_{NB}^* for w ; the corresponding profit of firm M is π_m^* . In the latter situation, the Nash bargaining result is \bar{w}_{NB} for w and the profit of firm M is $\bar{\pi}_m + mK$.

Table 1 shows that strategic partial outsourcing can again arise as the equilibrium sourcing pattern. With $K = 1.7$, as long as firm M 's bargaining power is relatively small, partial outsourcing with limited in-house capacity dominates the strategy of full in-house production for firm M . Moreover, consistent with intuition, the profit of firm M increases when he acquires a larger bargaining power against firm S .

4.2 Multiple downstream manufacturers

Downstream competition is of interest because it can weaken the incentive for firm M to partial outsource, considering that a lowered price w consequential of his outsourcing will strengthen his competitors in the final good market. Nonetheless, our central message is preserved provided that downstream competition is not too intensified.

To see this, we posit a duopoly downstream market wherein two manufacturers, M_1 and M_2 , compete with each other in their final goods. Firm M_1 corresponds to firm M in our basic framework. For simplicity, we assume that firm M_2 has full in-house capacity for producing component N , therefore outsourcing is not a relevant question to firm M_2 . Both firms acquire the key compo-

ment B from firm S at the wholesale price w .¹⁵ We impose a linear demand function for the final goods:

$$p_i = a - q_i - \gamma q_j, \quad i, j = 1, 2, i \neq j. \quad (12)$$

Here $\gamma \in (0, 1)$ represents the degree of product differentiation. A larger γ indicates a closer substitution between the final goods of M_1 and M_2 , implying a harsher competition between the two firms. The production cost of each firm is $C(q_i) = cq_i$ for each $M_i, i = 1, 2$. To ensure that each firm produces a positive quantity irrespective of the sourcing mode of firm M_1 , we assume that $a > 0, c > 0, m \in (0, \frac{2(2-\gamma)}{6+\gamma}(a - c - v))$. The game among firms S, M_1 , and M_2 unfolds in the same sequence as in our basic framework, while the only difference is that in stage 3 (the production stage) firms M_1 and M_2 simultaneously choose quantities q_1 and q_2 , respectively.

Analysis of the linear example indicates that as long as downstream competition is not too fierce ($\gamma < 0.781$ is the condition needed), downstream competition imposes no qualitative impact on our results. Although firm M_1 is now subject to the concern that a low price of component B due to his outsourcing will strengthen firm M_2 , still the benefit of outsourcing can dominate the disadvantage for firm M_1 . As a result, strategic partial outsourcing again is the equilibrium sourcing pattern whenever m is relatively small.

4.3 Endogenous price of component N

In our baseline model, the existence of a competitive fringe for component N means that the outsourcing cost of component N is not a strategic element. Here we relax this assumption to see how our results depend on a non-strategic outsourcing cost m . We adopt Assumption 4 and assume that there is a unique external supplier, firm S_0 , to provide component N . The unit production cost of firm S_0 is m_0 , which satisfies $0 < m_0 < \bar{m}$, to keep the case of interest. We assume that firm S_0 has full power determining her price m for component N . The timing of the game is give as below. In stage one, firm M establishes his in-house capacity K for the production of component N . In stage two, these two suppliers S and S_0 simultaneously choose prices w and m for components B and N , respectively. After observing the prices, in stage three firm M chooses his quantity q to produce for the final good. If $q > K$, $q - K$ units of component N is ordered from firm S_0 .

Our central message is preserved when the external price of component N is strategically

¹⁵This implies that firm S cannot discriminate against any manufacturer, presumably due to the fairness concern or the Robinson-Patman Act.

chosen by firm S_0 . To see the intuition, note that since firm S_0 is the less efficient producer of component B compared to firm M , she can benefit from supplying firm M only when the strategic consideration dominates for firm M in his sourcing decisions. In other words, she can only practice her pricing power subject to the constraint $m < \bar{m}$, with \bar{m} the maximum outsourcing cost below which firm M is willing to order from firm S_0 . Under this constraint, the problem of firm S_0 is to maximize her profit $(m - m_0)[\bar{q}(\bar{w}) - K]$ upon observing the established capacity K of firm M . The key insight is that, so long as $m_0 < \bar{m}$, which holds true according to our assumption, firm S_0 is able to quote her price m within the range (m_0, \bar{m}) , such that firm M will find partial outsourcing more profitable compared to full in-house production. Understanding this, firm M establishes in stage one limited in-house capacity, low enough to entice firm S to cut back her price w in order for firm M to produce beyond his capacity. Consequently, firm M outsources to firm S_0 his residual demand of component N .

5 Conclusion

In this paper, we consider a manufacturer who needs multiple components in order to produce his final good. Suppliers of some components (denoted as bottleneck components) possess monopoly power, which leads to the well-known double marginalization problem. We show that the manufacturer may adopt, or even intentionally create, sourcing inefficiency with his demand of non-bottleneck components, and his sole purpose of doing so is to mitigate pricing power of key suppliers in the bottleneck segments. In our context, the manufacturer has flexibility choosing between producing in-house or outsourcing the non-bottleneck component, while outsourcing is less efficient than in-house production. Our model rules out any market uncertainty, thereby allowing us to identify the operational region wherein strategic consideration is the pivotal driver of outsourcing. We show that as long as outsourcing inefficiency is not too pronounced, it is optimal for the manufacturer to establish limited in-house capacity, then resort to the expensive outsourcing for additional demand of the non-bottleneck component. Furthermore, if the manufacturer is empowered to choose his outsourcing cost, there is an optimal level which lies above his in-house production cost. Consequential to the inefficiency and also the reduced quantity of the final good, strategic partial outsourcing reduces both consumer surplus and producer surplus.

From the perspective of global sourcing, our results indicate that outsourcing cost on a rise may not naturally lead manufacturers to bring production on-shore. If there are indispensable

key suppliers with large market power, ironically, a mild and increasing on-shore cost advantage over outsourcing for non-bottleneck components may literally lead a manufacturer to outsource a larger proportion. In this situation, government's grants and tax relief aimed at production re-shoring may not be as efficacious as it is meant to be, and fostering competition in bottleneck segments could be a complementary policy for achieving such purpose.

We consider several model variations to examine the robustness of our results, including Nash bargaining on the price of the bottleneck component, the presence of downstream competition, and when a unique external supplier strategically determines the price of the non-bottleneck component. Our central message is well preserved under these variations. On the other hand, our results are derived based on a linear wholesale price of the bottleneck component. If the supplier is able to adopt a two-part tariff to appropriate the whole surplus from the manufacturer, full outsourcing of the non-bottleneck component will now become optimal to the manufacturer, so that he can avoid non-negative in-house capacity cost. However, if non-linear pricing like quantity discount is adopted by the supplier of the bottleneck component, the strategic consideration identified here could continue to drive the manufacturer to adopt partial outsourcing. Namely, by establishing a limited in-house capacity, the manufacturer may entice the key supplier of the bottleneck component to provide a favorable quantity discount, which eventually leads the manufacturer to expand his quantity through outsourcing.

Appendix

Proof of Lemma 1. First, we show that $q^*(w)$ and $\bar{q}(w)$ decrease in w . By (2), (3) and the implicit function theorem, it holds that

$$\frac{dq^*(w)}{dw} = \frac{d\bar{q}(w)}{dw} = \frac{1}{P''(q)q + 2P'(q) - C''(q)} < 0. \quad (13)$$

Second, we show that $q^*(w) > \bar{q}(w)$. By Assumption 1, $P'(q)q + P(q) - C'(q)$ decreases in q . By (2) and (3), $P'(q^*(w))q^*(w) + P(q^*(w)) - C'(q^*(w)) = w$, and $P'(\bar{q}(w))\bar{q}(w) + P(\bar{q}(w)) - C'(\bar{q}(w)) = w + m > w$. Thus $q^*(w) > \bar{q}(w)$.

Third, note that $w_1(K)$ and $w_2(K)$ are well defined due to the monotonicity of $\bar{q}(w)$ and $q^*(w)$. By (4) and (5), it holds that $w_1(K) < w_2(K)$.

Forth, we derive firm M 's optimal quantity by discussing different cases. Since $w_1(K) <$

$w_2(K)$, there exist three cases: 1) $w < w_1(K)$, 2) $w \geq w_2(K)$, and 3) $w \in [w_1(K), w_2(K))$. We discuss each of them below.

Case i) $w < w_1(K)$: By the definition of $w_1(K)$, (4) and (5), we have $\bar{q}(w) > K$ and $q^*(w) > K$. firm M maximizes $P(q)q - C(q) - wq - m(q - K)$ subject to $q > K$, and his equilibrium quantity is $\bar{q}(w)$ (given by the heavy part of $\bar{q}(w)$ in Figure 1).

Case ii) $w > w_2(K)$: By the definition of $w_2(K)$, (4) and (5), we have $\bar{q}(w) < K$ and $q^*(w) < K$. firm M maximizes $P(q)q - c(q) - wq$ subject to $q < K$. His equilibrium quantity is $q^*(w)$ (given by the heavy part of $q^*(w)$ in Figure 1).

Case iii) $w \in [w_1(K), w_2(K)]$: By the definitions of $w_1(K)$ and $w_2(K)$, (4) and (5), we have $\bar{q}(w) \leq K \leq q^*(w)$. The optimal quantity of firm M when he outsources component N shall never exceeds K . Thus, firm M maximizes $P(q)q - c(q) - wq$ subject to $q \leq K$. The constraint is binding since $K \leq q^*(w)$ and firm M 's equilibrium quantity is K . The lemma then follows. \square

Proof of Lemma 2. First, note that \bar{w} satisfies the first-order condition

$$\bar{q}(w) + (w - v)\bar{q}'(w) = 0, \quad (14)$$

and w^* satisfies the first-order condition

$$q^*(w) + (w - v)q^{*'}(w) = 0. \quad (15)$$

Let the optimal quantity produced by firm M by $q(w)$, suppressing $q(w) = q^*(w)$ or $q(w) = \bar{q}(w)$. By (14) and (15), the second order condition of firm S 's profit maximization requires that

$$2\frac{dq(w)}{dw} + (w - v)\frac{d^2q(w)}{dw^2} < 0. \quad (16)$$

By (13), we have

$$\frac{d^2q(w)}{dw^2} = -\frac{1}{H^2}[P'''(q)q + 3P''(q) - C''']\frac{dq(w)}{dw} \leq 0, \quad (17)$$

with $H \equiv P''(q)q + 2P'(q) - C''$. The above is guaranteed by Assumption 2. Thus (16) is satisfied, showing that w^* and \bar{w} exist and are unique to the profit maximization problem of firm S .

Second, we prove that $w^* > \bar{w}$. By (2) and (3), $\bar{q}(w) = q^*(w)$ at $m = 0$. Therefore, $\bar{w} = w^*$ at $m = 0$. To show that $w^* > \bar{w}$, it is sufficient to verify that $\frac{d\bar{w}}{dm} < 0$ since $\frac{dw^*}{dm} = 0$. Note that by the implicit function theorem, we have

$$\frac{d\bar{q}(w)}{dm} = \frac{1}{P''(q) + 2P'(q) - C''} < 0.$$

By (14) and the implicit function theorem, we have

$$\frac{d\bar{w}}{dm} = -\frac{\frac{d\bar{q}(w)}{dm} + (w-v)\frac{d^2\bar{q}(w)}{dw dm}}{2\frac{d\bar{q}(w)}{dw} + (w-v)\frac{d^2\bar{q}(w)}{dw^2}} < 0. \quad (18)$$

by (16) and $\frac{d^2\bar{q}(w)}{dw dm} = 0$ (by (5)). The continuity of \bar{w} in m suggests that $w^* > \bar{w}$.

Proof of Lemma 3. We first establish some structural properties of w^* and \bar{w} before we proceed to prove the lemma.

1) Structural properties of firm S 's wholesale prices:

(i). $(w^* - v)q^*(w^*) > (\bar{w} - v)\bar{q}(\bar{w})$: observe that

$$\begin{aligned} (w^* - v)q^*(w^*) &\geq (\bar{w} - v)q^*(\bar{w}) && \text{by optimality of } w^* \\ &> (\bar{w} - v)\bar{q}(\bar{w}) && \text{by (4).} \end{aligned}$$

(ii). \bar{w} exists and is unique: The slope of the iso-profit of firm S is $\frac{dq}{dw} = -\frac{q}{w-v} < 0$ (since $w - v \geq 0$), which goes to zero when w goes to infinity. Since $q^*(w)$ strictly decreases in w , the iso-profit passing point A must intersect $q^*(w)$ from below, i.e., there exists $\tilde{w} > \bar{w}$ such that (8) holds. In addition, the iso-profit of firm S is convex since $\frac{d^2q}{dw^2} = \frac{q}{(w-v)^2} > 0$, and $q^*(w)$ is concave since $\frac{d^2q^*(w)}{dw^2} \leq 0$ by (17). Thus the intersection of these two at which $w > \bar{w}$ is unique.

(iii). $\bar{w} > w^*$: Suppose by negation that $\bar{w} \leq w^*$. Define $q^A(w)$ as the solution to $(w - v)q = (\bar{w} - v)\bar{q}(\bar{w})$ at given w . Thus $(w, q^A(w))$ is on the iso-profit of firm S which passes point A . Since point J is the intersection of this iso-profit and $q^*(w)$ when the iso-profit is getting flattened, it holds that for $w \geq \bar{w}$, we have $q^*(w) \leq q^A(w)$. Thus at w^* , $(w^* - v)q^A(w^*) = (\bar{w} - v)\bar{q}(\bar{w})$. Since $(w^* - v)q^A(w^*) \geq (w^* - v)q^*(w^*)$, it follows that $(\bar{w} - v)\bar{q}(\bar{w}) \geq (w^* - v)q^*(w^*)$. A contradiction to (i). We conclude that $\bar{w} > w^*$.

2) Firm S 's optimal wholesale price decisions:

At any given K , in Stage 2 firm S can modify w to induce firm M to produce any quantity along the kinked curve given by $q(K, w)$. Since $q^*(\bar{w}) < q^*(w^*)$ by (5) and (iii), there can be three cases according to the established capacity K . We discuss each of them in what follows.

Case 1) $K \leq q^*(\bar{w})$. In this case, $w_2(K) \geq \bar{w}$ by the definition of $w_2(K)$ and the fact that $q^*(w)$ decreases in w . firm M 's equilibrium quantity $q(K, w)$ passes point A but not point B . Along $\bar{q}(w)$, point A maximizes firm S 's profit; it is also achievable for firm S at $w = \bar{w}$. Along $q^*(w)$,

the optimal point achievable for firm S is point V at $w = w_2(K)$. Along UV , firm S 's profit is $(w - v)K$, which is maximized at $w = w_2(K)$. Thus, firm S shall compare two prices: $w_2(K)$ and \bar{w} . Since firm S 's profit along $q^*(w)$, given by $(w - v)q^*(w)$, decreases in w for $w > w^*$, we have $(w_2(K) - v)K = (w_2(K) - v)q^*(w_2(K)) \leq (\tilde{w} - v)q^*(\tilde{w}) = (\bar{w} - v)\bar{q}(\bar{w})$, where equality holds only at $K = q^*(\tilde{w})$. It follows that \bar{w} is optimal for firm S .

Case 2) $K \in (q^(\tilde{w}), q^*(w^*))$.* It holds that $w^* < w_2(K) < \tilde{w}$. There are two subcases: a) $q^*(w^*) \leq \bar{q}(\bar{w})$, and b) $q^*(w^*) > \bar{q}(\bar{w})$.

2a) $q^(w^*) \leq \bar{q}(\bar{w})$:* When $q^*(w^*) \leq \bar{q}(\bar{w})$, $q(K, w)$ passes point A but not point B . Along $q^*(w)$ and segment UV on $q(K, w)$, point V is optimal for firm S . Thus, firm S again compares two prices: $w_2(K)$ and \bar{w} . Since $(w - v)q^*(w)$ decreases in w for $w > w^*$, we have $(w_2(K) - v)K = (w_2(K) - v)q^*(w_2(K)) > (\tilde{w} - v)q^*(\tilde{w}) = (\bar{w} - v)\bar{q}(\bar{w})$. It follows that $w_2(K)$ is optimal for firm S .

2b) $q^(w^*) > \bar{q}(\bar{w})$:* If $K \leq \bar{q}(\bar{w})$, $q(K, w)$ passes point A but not point B . The proof is the same as in 2a). Consider the case when $K > \bar{q}(\bar{w})$. Now neither point A nor point B is on $q(K, w)$. Along $\bar{q}(w)$, it is optimal for firm S to set $w = w_1(K)$ at point U ; along $q^*(w)$, setting $w = w_2(K)$ is optimal (at point V). As $w_2(K) > w_1(K)$, point V strictly dominates point U for firm S since $(w_2(K) - v)K > (w_1(K) - v)K$. Thus, $w_2(K)$ is optimal for firm S .

Case 3) $K \geq q^(w^*)$:* There are again two subcases: a) $K \leq \bar{q}(\bar{w})$ and b) $K > \bar{q}(\bar{w})$.

3a) $K \leq \bar{q}(\bar{w})$: Both points A and B are on $q(K, w)$. Firm S sets $w = \bar{w}$ for her profit at point A along $\bar{q}(w)$ and $w = w^*$ for her profit at point B along $q^*(w)$. Since $(w^* - v)q^*(w^*) > (\bar{w} - v)\bar{q}(\bar{w})$, $w = w^*$ is optimal for firm S .

3b) $K > \bar{q}(\bar{w})$: Point B is on $q(K, w)$ but not point A . Along $\bar{q}(w)$, firm S shall set $w = w_1(K)$ to maximize her profit (at point U); along $q^*(w)$, firm S then sets $w = w^*$ to arrive at point B . Since $(w^* - v)q^*(w^*) > (\bar{w} - v)\bar{q}(\bar{w})$, and point A dominates point U along $\bar{q}(w)$, $w = w^*$ is optimal for firm S .

Collectively, the optimal w for firm S is as expressed in the lemma. \square

Proof of Theorem 1. First, we show that firm M strictly prefers $K \geq q^*(w^*)$ to $K \in (q^*(\tilde{w}), q^*(w^*))$. By Lemma 3, for $K \geq q^*(w^*)$, $w = w^*$ in stage 2 and firm M will produce $q^*(w^*)$ and get profit $\pi_m^* - F$. On the other hand, for $K \in (q^*(\tilde{w}), q^*(w^*))$, $w = w_2(K)$ in stage 2 and firm M produces

$q = q^*(w_2(K)) = K$. firm M 's profit is given by $\pi_m^V - F$, with

$$\pi_m^V \equiv \pi_m(w_2(K), q^*(w_2(K))) = P(K)K - C(K) - w_2(K)K.$$

In either case, there is no outsourcing in stage 3. We use $\pi_m(w, q^*(w)) - F$ to denote firm M 's profit when he produces $q^*(w)$ at given w without outsourcing, where

$$\pi_m(w, q^*(w)) = P(q^*(w))q^*(w) - C(q^*(w)) - wq^*(w).$$

By the envelope theorem, we obtain that

$$\frac{d\pi_m(w, q^*(w))}{dw} = \frac{\partial\pi_m(w, q^*(w))}{\partial w} = -q^*(w) < 0.$$

Since $w^* < w_2(K)$ for $K < q^*(w^*)$, it follows that $\pi_m^* > \pi_m^V$. Thus $K \geq q^*(w^*)$ dominates $K \in (q^*(\tilde{w}), q^*(w^*))$ for firm M .

Second, by Lemma 3, any $K \leq q^*(\tilde{w})$ leads firm M to produce $\bar{q}(\tilde{w})$ and firm M engages in partial outsourcing in the production stage. It is optimal for firm M to set $K = q^*(\tilde{w})$ to minimize his outsourcing cost $m(\bar{q}(\tilde{w}) - K)$. Accordingly, firm M 's equilibrium profit under partial outsourcing is at $K = q^*(\tilde{w})$ and is given by

$$\bar{\pi}_m + mq^*(\tilde{w}) - F.$$

Therefore, when firm M chooses K , he compares his profit at $K \geq q^*(w^*)$ (with full in-house production) to his profit at $K = q^*(\tilde{w})$ (with partial outsourcing). In equilibrium he engages in partial outsourcing whenever (10) is satisfied, which is reduced to

$$\bar{\pi}_m + mq^*(\tilde{w}) > \pi_m^*. \quad (19)$$

Third, note that π_m^* does not depend on m and at $m = 0$, $\bar{\pi}_m + mq^*(\tilde{w}) = \pi_m^*$. To prove the theorem, it is sufficient to show that the left-hand-side of (19) strictly increases in m at $m = 0$. We obtain that

$$\begin{aligned} & \frac{d}{dm} \{ \bar{\pi}_m + mq^*(\tilde{w}) \} |_{m=0} \\ = & \frac{\partial lhs}{\partial m} + \frac{\partial lhs}{\partial \bar{w}} \frac{d\bar{w}}{dm} + \frac{\partial lhs}{\partial \tilde{w}} \frac{d\tilde{w}}{dm} && \text{by the envelope theorem} \\ = & -[\bar{q}(\tilde{w}) - q^*(\tilde{w})] - \bar{q}(\tilde{w}) \frac{d\bar{w}}{dm} + \frac{\partial lhs}{\partial q^*(\tilde{w})} \frac{dq^*(\tilde{w})}{d\tilde{w}} \frac{d\tilde{w}}{dm} \\ = & -\bar{q}(\tilde{w}) \frac{d\bar{w}}{dm} + m \frac{dq^*(\tilde{w})}{d\tilde{w}} \frac{d\tilde{w}}{dm} && \text{by } \bar{q}(\tilde{w}) = q^*(\tilde{w}) \text{ at } m = 0 \\ > & 0 && \text{since } \frac{d\bar{w}}{dm} < 0 \text{ by (18)}. \end{aligned}$$

We conclude that for m sufficiently close to 0, $\pi_m^* < \bar{\pi}_m + mq^*(\tilde{w})$. The rest of the theorem follows immediately. \square

Proof of Corollary 1. Under Assumption 3, Lemma 1 through Lemma 3 are preserved since capacity building cost is sunk cost in stage 3 and does not affect the quantity decision of firm M . We need to check the validity of the proof of Theorem 1. First, for $K \geq q^*(w^*)$, firm M is optimal setting $K = q^*(w^*)$ when $f'(K) > 0$. His profit is $\pi_m^* - f(q^*(w^*))$.

Second, for $K \in (q^*(\tilde{w}), q^*(w^*))$, firm M produces $q = q^*(w_2(K)) = K$ and his profit is $\pi_m^V - f(K)$. Since

$$\frac{d[\pi_m(w, q^*(w)) - f(K)]}{dw} = \frac{\partial \pi_m(w, q^*(w))}{\partial w} - f'(K) \frac{dq^*(w)}{dw} = -q^*(w) - f'(K) \frac{dq^*(w)}{dw},$$

the sign is ambiguous and it is not determined whether $K = q^*(w^*)$ or $K \in (q^*(\tilde{w}), q^*(w^*))$ is optimal for firm M . In either case, firm M does not outsource.

Third, for $K \leq q^*(\tilde{w})$, firm M produces $\bar{q}(\tilde{w})$ and his profit is denoted as $\bar{\pi}_m + mK - f(K)$. It is still true that firm M is optimal setting $K = q^*(\tilde{w})$ since $\frac{d[\bar{\pi}_m + mK - f(K)]}{dK} = m - f'(K) > 0$. Accordingly, firm M 's equilibrium profit under partial outsourcing is

$$\bar{\pi}_m + mq^*(\tilde{w}) - f(q^*(\tilde{w})).$$

Thus when firm M chooses K , he compares his profit with partial outsourcing to the profit with full in-house production. There can be two cases:

Case 1. Firm M is optimal setting $K = q^*(w^*)$ under full in-house production. If so, condition (10) is rewritten as

$$\bar{\pi}_m + mq^*(\tilde{w}) - f(q^*(\tilde{w})) > \pi_m^* - f(q^*(w^*)). \quad (20)$$

Condition (20) is weaker than condition (10) since $f(q^*(\tilde{w})) < f(q^*(w^*))$.

Case 2. Firm M is optimal setting $K \in (q^*(\tilde{w}), q^*(w^*))$ under full in-house production. If so, condition (10) is rewritten as

$$\bar{\pi}_m + mq^*(\tilde{w}) - f(q^*(\tilde{w})) > \pi_m^V - f(K). \quad (21)$$

Again, condition (21) is weaker than condition (10) since $\pi_m^V < \pi_m^*$ and $f(q^*(\tilde{w})) < f(K)$ for $K > q^*(\tilde{w})$.

We conclude that there is more partial outsourcing in equilibrium under Assumption 3. \square

Proof of Corollary 2. The corollary directly follows from the proof of Theorem 1. \square

Proof of Corollary 3. To prove the result, consider

$$P'(q)q + P(q) - C'(q) = \theta. \quad (22)$$

Then $q^*(w^*)$ solves (22) at $\theta = w^*$ and $\bar{q}(\bar{w})$ solve (22) at $\theta = \bar{w} + m$. Let \tilde{q} solves (22) at $\theta = v$. Thus \tilde{q} is firm M 's monopoly quantity when he vertically integrate with firm S and produces the final good under full capacity. By Assumption 1, the left-hand-side of (22) decreases in q . Since $w^* > v, \bar{w} + m > v$, we have $q^*(w^*) < \tilde{q}, \bar{q}(\bar{w}) < \tilde{q}$.

At $m = 0$, it holds that $w^* = \bar{w} + m$. By (18) and $\frac{d^2\bar{q}(w)}{dwdm} = 0$, we have

$$\frac{d(\bar{w} + m)}{dm} = 1 - \frac{\frac{d\bar{q}(w)}{dm}}{2\frac{d\bar{q}(w)}{dw} + (w - v)\frac{d^2\bar{q}(w)}{dw^2}}.$$

Since $\frac{d\bar{q}(w)}{dw} = \frac{d\bar{q}(w)}{dm} = \frac{1}{P''(q)+2P'(q)-C''}$, reorganizing gives

$$\frac{d(\bar{w} + m)}{dm} = \frac{d\bar{q}(w)}{dw} \frac{1 - (w - v)(P'''(q)q + 3P''(q) - C''')/H^2}{2\frac{d\bar{q}(w)}{dw} + (w - v)\frac{d^2\bar{q}(w)}{dw^2}}.$$

By Assumption 2, $w - v \geq 0$, $\frac{d\bar{q}(w)}{dw} < 0$ and $\frac{d^2\bar{q}(w)}{dw^2} \leq 0$, it holds that $\frac{d(\bar{w}+m)}{dm} > 0$. Thus $\bar{w} + m > w^*$ for $m > 0$, implying that $\bar{q}(\bar{w}) < q^*(w^*)$. We conclude that firm M produces a lower quantity for the final good under strategic partial outsourcing, leading to lower consumers' surplus.

In addition, producers' surplus under strategic partial outsourcing is

$$\overline{PS} = P(\bar{q}(\bar{w}))\bar{q}(\bar{w}) - C(\bar{q}(\bar{w})) - v\bar{q}(\bar{w}) - m(\bar{q}(\bar{w}) - q^*(\bar{w})),$$

and producers' surplus in status quo is

$$PS^* = P(q^*(w^*))q^*(w^*) - C(q^*(w^*)) - vq^*(w^*).$$

By Assumption 1 and $\bar{q} > q^*(w^*) > \bar{q}(\bar{w}) > q^*(\bar{w})$, it follows that $PS^* > \overline{PS}$.

Proof of Proposition 1. Since the proof is the same as for Theorem 1, we give only the sketch of the procedure of backward induction.

1) *The production stage:* Without partial outsourcing, firm M maximizes his profit $(a - q)q - cq - wq$ and the optimal quantity is

$$q^*(w) = \frac{1}{2}(a - c - w). \quad (23)$$

Instead, if firm M produces with partial outsourcing, his problem is to maximize profit $(a - q)q - cq - wq - m(q - K)$ and the optimal quantity is

$$\bar{q}(w) = \frac{1}{2}(a - c - w - m). \quad (24)$$

2) *The contracting stage:* In Stage 2, firm S chooses w to maximize her profit. When firm S anticipates that firm M fully uses in-house production for component N , she maximizes $(w - v)q^*(w)$ and the optimal wholesale price is

$$w^* = \frac{1}{2}(a - c + v).$$

On the other hand, when firm S anticipates that firm M will produce with partial outsourcing, firm S maximizes $(w - v)\bar{q}(w)$ and the optimal wholesale price is

$$\bar{w} = \frac{1}{2}(a - c - m + v).$$

It is clear that $w^* > \bar{w}$. There exists a level of the in-house capacity such that in Stage 2, firm S is indifferent between setting \bar{w} while anticipating that firm M outsources his residual demand and setting \tilde{w} while anticipating that firm M produces within his in-house capacity. Here, \tilde{w} satisfies

$$(\bar{w} - v)\bar{q}(\bar{w}) = (\tilde{w} - v)q^*(\tilde{w})$$

subject to $\tilde{w} > \bar{w}$. It is uniquely solved as

$$\tilde{w} = \frac{1}{2}(a - c + v + \sqrt{m[2(a - c - v) - m]}).$$

The corresponding capacity which makes firm S to be indifferent between \bar{w} and \tilde{w} is

$$q^*(\tilde{w}) = \frac{1}{4}(a - c - v - \sqrt{m[2(a - c - v) - m]}).$$

According to Proposition 3, if and only if $K \leq q^*(\tilde{w})$, firm S finds it optimal to set $w = \bar{w}$, a lower price of component B .

3) *The capacity building stage:* In Stage 1, by establishing $K \geq q^*(w^*)$, firm M is able to produce without capacity constraint in the production stage and his profit is

$$\pi_m^* = \frac{1}{16}(a - c - v)^2.$$

Whereas at $K = 0$, firm M 's profit is

$$\bar{\pi}_m = \frac{1}{16}(a - c - v - m)^2.$$

Instead, by establishing $K = q^*(\bar{w})$, firm M anticipates that firm S will set $w = \bar{w}$ so that in Stage 3, firm M outsources quantity

$$\bar{q}(\bar{w}) - q^*(\bar{w}) = \frac{1}{4}(\sqrt{m[2(a - c - v) - m]} - m).$$

In this case, firm M 's profit is

$$\bar{\pi}_m + mq^*(\bar{w}) = \frac{1}{16}(a - c - v - m)^2 + mq^*(\bar{w}).$$

firm M 's problem in Stage 1 is to compare π_m^* to $\bar{\pi}_m + mq^*(\bar{w})$ in order to determine the optimal capacity. We find that for $m < \bar{m}$, Condition (10) is satisfied. In this case, firm M finds it optimal setting $K = q^*(\bar{w})$ to induce firm S to charge \bar{w} , then outsourcing quantity $\bar{q}(\bar{w}) - q^*(\bar{w})$ for component N . The rest of the proposition follows the fact that $\bar{\pi}_m + mq^*(\bar{w})$ is maximized at $m = m^*$. \square

Proof of Corollaries 4-6. The results follow from straightforward calculations and thus the details are omitted. \square

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