Strategic capacity shortage in global sourcing: A new rationale for onshore production

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Abstract

Recently, U.S. manufacturers are increasingly interested in bringing back their manufacturing production to onshore or near-shore suppliers. In this paper, we show that onshoring creates, on top of the typical cost-flexibility trade-off, a strategic value. We cast our analysis in a stylized model where a downstream firm adopts a dual-sourcing strategy for production capacity, while interacting with an upstream monopoly supplier for acquiring a critical component. We assume away demand uncertainty and document the possibility of strategic capacity shortage, i.e., the phenomenon that the downstream firm intentionally sets out offshore capacity limit upfront before contracting with the upstream supplier, even though eventually he has to bear the more expensive ex post onshore capacity expansion. Improving forecasting accuracy does not help mitigate this deadweight loss (for establishing the expensive onshore capacity). Counter-intuitively, even if the downstream firm is entitled to reduce his cost of ex post onshore capacity expansion, he may intentionally opt not to do so; accordingly, the offshore cost on a rise may not necessarily be detrimental for the downstream firm. In addition, when the onshore production becomes less expensive, under strategic capacity shortage the downstream firm tends to increase his ex ante offshore capacity and expand less onshore capacity ex post.

Keywords: capacity, outsouricng, onshoring

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1 Introduction

Very recently, U.S. manufacturers are increasingly concerned about their global sourcing strategies. In the past decade, outsourcing the critical manufacturing business to the *offshore* suppliers in China, Malaysia, and India has been the dominant and default option due to the pronounced cost saving. Nevertheless, in a trend of rapidly rising labor rates abroad, loftier materials and shipping costs, deep-discount tax incentives from U.S. states, these cost calculations seem no longer in absolute favor of offshoring ((Bussey (2011))). Christian Murck, president of the Beijing-based American Chamber of Commerce in China, publicly offered his warning in Washington Tuesday that "China's low-wage advantage will disappear over the next five years," as "[i]n many sectors, annual wage growth (in China) is running at 15% or more" ((Bussey (2011))). In addition, the inflations in the tab for energy, raw materials, real estate, and shipping are all on the rise, significantly cutting into the cost advantage of "cheap" Chinese manufacturing. Analysts see a clear trend and have reportedly suggested to take the production near-shore or *on-shore*,[1] as exemplified by the re-shoring fair in May 2010 co-sponsored by the National Tooling and Machining Association and the Precision Metals Association. As of July 2011, four Northern California companies have chosen the onshore Wright Engineered Plastics over their default option China. Vaniman Manufacturing has pulled back part of its sheet metal fabrication production from Chinese suppliers, NCR has been switching its production of ATM machines back to a facility in Columbus, Georgia, and All-Clad Metalcrafters is bringing the manufacturing of the lids back to its main factory in Canonsville, Pennsylvania (Collins (2010) and Singleton (2011)).

Global sourcing strategy – whether to produce off-shore or on-shore – has been a central topic in the operations management literature. The majority of academic papers focuses on the trade-off between cost and *flexibility* in the presence of *demand uncertainty*. Stemming from the classical newsvendor problem, it is well perceived that when the capacity must be established prior to the demand realization, it may fall short if the stochastic demand turns out to be sufficiently high. In such a scenario, the newsvendor shall benefit from the quick response option, and this option is facilitated by an expedite source that is typically expensive. Putting this in our global sourcing context, the offshore supplier provides a cheap yet inflexible source, and it is complemented by the expensive but flexible onshore supplier if supply/demand mismatch occurs. This rationale has been elaborated in numerous papers on multi-sourcing and inventory/capacity hedging (see van

[1] According to Harold Sirkin, senior partner at Boston Consulting Group, since 2008 various client manufacturers have considered to put the incremental plant in the U.S. as opposed to China in the near future. In a recent survey by **?**, "40 percent of manufacturing executives report experiencing a staggering increase of 25 percent or more in core direct costs on off-shored supply [...] over the last three years", and "[a]lmost 90 percent expect further significant ongoing price increases of 10 percent or more over the next 12 months of 10 percent or more."

Mieghem (2003) for a comprehensive survey).

The above trade-off, without doubt, is related to the current trend of backshoring "manufacturing renaissance," since it is evidentially true that the cost discrepancy between offshoring and onshoring shrinks nowadays after accounting all the hidden costs and expenditure. Even though the cost calculations are tedious, they are straightforward and conceptually simple (**?**). In light of this, it seems rather puzzling that the global sourcing strategy remains a challenging task from the perspectives of analysts and practitioners (e.g., **?** and **?**). Our primary goal in this paper is to provide a novel rationale for the current trend of onshoring. Through this study, we hope to shed some light on the critical question that consulting analysts posited for the U.S. manufacturers (Ferreira and Prokopets (2009)):: "Having offshored our operations and supply networks, which ones should be returned on-shore or near-shore, and when?"

We argue that even if there is no demand uncertainty, offshoring is unambiguously less expensive than onshoring, both sourcing strategies are available and non-exclusive, onshoring may still be adopted due to its strategic value in global supply chains. Thus, our results indicate that the "tipping point" from re-initiating the onshoring/ near-shoring business shall be earlier than what the analysts have suggested. To formalize our ideas, we construct a stylized model in which a monopolistic downstream firm supplies a finished good to the end consumers. There are two sources for the downstream firm to acquire his capacity: the offshore supplier that is relatively inexpensive but requires a long lead time, and the onshore supplier that delivers quickly at a higher cost. Confronted with these two sourcing options with heterogeneous lead times, a natural solution for the downstream firm is to adopt the hybrid dual-sourcing strategy: establish an ex ante production capacity way aforehand via the offshore supplier, and expand the capacity via the onshore supplier ex post. In between these two stages, the downstream firm acquires a critical component from an upstream firm for converting the intermediate good to the finished good. This assumption is intended to capture the idea that most firms that adopt global sourcing assemble the components from both foreign and domestic contract manufacturers.[2] Notably, although we cast our analysis in the context of global sourcing, it can be alternatively interpreted as the buyer-seller relationship without any materialistic difference.[3]

[2]For example, the dental and industrial equipment manufacturer Vaniman Manufacturing outsources only their sheet metal fabrication to Chinese vendors, and the creation of micro-sandblasting, dust collection and air purification products apparently requires other business partners such as Cosney Corporation. To manufacture very high-end cookware, All-Clad Metalcrafters needs not only the regular non-bonded components such as lids from Chinese suppliers but also the metals only from U.S. suppliers.

[3]In addition, these ex ante and ex post capacity investments appear in various contexts, not necessarily restricted to the offshoring and onshoring scenarios. For example, the ex ante production capacity may refer to the downstream firm's own production line when he must pre-block some time frames and resources for this particular production process; it may also correspond to the downstream firm's purchase order of other components that are also required

We document the possibility of *strategic capacity shortage*, i.e., the phenomenon that the downstream firm intentionally sets out a capacity limit upfront before contracting with the upstream firm. The term capacity shortage is borrowed from the classical newsvendor setting to better articulate the tight connection between our offshore/onshore sourcing and the conventional regular/expedite productions. In our context, it refers to the scenario that the downstream firm is induced to use the "expedite" sourcing ex post. Under this strategy, the downstream firm benefits from a lower wholesale price from the upstream firm. Thus, the painful restriction ex ante on his own is made in exchange of the ex post benefit from his partner. This illustrates the downstream firm's trade-off by committing to a limited capacity upfront. On one hand, he can induce the upstream firm to give him a favorable wholesale price out of her incentive to boost the downstream firm's production; on the other hand, since the downstream firm eventually is encouraged to expand his capacity ex post, he has to absorb the higher capacity cost. Our result suggests that showing the weakness to the business partner has a strategic effect, as the upstream firm, despite being a relentless profit maximizer, willingly cuts back her profit share to facilitate the business transactions.

Our analysis identifies a less explored benefit for going on-shore even if the demand uncertainty is absent, thereby suggesting a new rationale for the pervasive consideration of re-shoring. Since the downstream firm's strategic concern does not hinge on the conventional supply/demand mismatch, improving forecasting accuracy does not help mitigate this deadweight loss. In addition, we show that this strategic capacity shortage occurs only when the cost discrepancy between ex ante and ex post capacity investments is relatively small. This echoes the analysts' observations and explanations for the current onshoring wave as exemplified by Wright Engineered Plastics, Vaniman Manufacturing, NCR, and All-Clad Metalcrafters ((Collins (2010))).

We further find that, even if the downstream firm is entitled to reduce his cost of ex post capacity expansion, he may intentionally opt *not* to do so. This is because an inflated capacity expansion cost serves as a commitment device that induces a lower wholesale price by the upstream firm. In this sense, the downstream firm turns his self-sabotage weakness to his advantage in the contractual relationship, and this is made possible due to the peculiar supply chain collaboration. Our result therefore documents a novel source of supply chain inefficiency. Put differently, if we interpret the capacity expansion cost as the cost differential between ex ante and ex post capacity investments, our analysis suggests that the offshore cost on a rise may not necessarily be detrimental for the downstream firm. The underlying reason is that the increased offshore cost may occasionally

for this assembly system. Accordingly, the ex post capacity expansion could result from the expensive quick response option via any sort of expedite sourcing. Numerous dual-sourcing settings exhibit the features of having a low-cost supplier with a long transportation lead time and a high-cost supplier with a short lead time (relative to the order fulfillment).

strengthen the downstream firm's ability to claim a higher profit share vis-a-vis the upstream firm, thereby overturning the downside of this seeming business crisis.

In addition, this new rationale also gives rise to some unintended implications of the capacity investment strategies. When the expedite capacity on-shore becomes less expensive, under strategic capacity shortage the downstream firm tends to *increase* his ex ante capacity and expand *less* capacity ex post. This finding has an intriguing policy implication, as it suggests that blindly providing the grants and tax relief may not necessarily attract more production (and therefore more job opportunities) back in town. This somehow goes against the premise of the recent $1.3 billion financial expenditure by New York for the semiconductor plants (Bussey (2011)). Put it differently, a wage increase of offshore suppliers in China may actually *impede*, rather than accelerate, the move-back of manufacturing to the United States. The logic behind this can be articulated as follows. Although the capacity expansion is now more expensive and certainly painful for the downstream firm, it also leads to a strong commitment effect. Because the downstream firm is now very vulnerable ex post, the upstream firm will significantly reduce the wholesale price to facilitate the capacity expansion. Notably, the entire supply chain suffers from the more costly expedite capacity expansion a priori; additionally, the downstream firm's inefficient capacity decision exacerbates this inefficiency because he retains a larger portion of the profit by doing so.

Finally, we extend our analysis to incorporate alternative information structure and alternative contract form. When the downstream firm's capacity investment is not observable by the upstream firm, we show that the downstream firm has the incentive to *voluntarily reveal* his ex ante capacity to the upstream firm. The underlying economic force remains the same: strategic capacity shortage allows the downstream firm to clinch a higher revenue, and the downstream firm has every reason to disclose his capacity investment decision to capitalize on this strategic benefit. This revelation can be facilitated by allowing the downstream firm to decide, after establishing his ex ante capacity, whether to disclose this information to the upstream firm. In addition, we investigate an alternative contract form: *revenue sharing contract,* where we allow for arbitrary revenue sharing proportion and the wholesale price contract can therefore be regarded as a special case. We find that strategic capacity shortage prevails under this alternative contract form, and all the qualitative results aforementioned apply equally well to arbitrary revenue sharing contract. A higher revenue sharing proportion reduces the downstream firm's share of selling the finished good; thus, his incentive to create strategic capacity shortage is weakened, but never completely eliminated. On the other hand, the upstream firm now has a *stronger* incentive to cut back her price in order to foster the finished good selling.

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 Firm D's capacity decisions. Section 4 investigates some alternative model characteristics, and Section 5 concludes. All proofs are in the appendices.

2 Model

We posit a stylized model in which a monopolistic downstream firm, denoted as firm D, supplies a finished good F to the end consumers. Firm D invokes a dual-sourcing strategy for his production capacity via offshoring and onshoring (which is appropriate as in reality all the aforementioned producers only bring back a portion of their manufacturing to the United States). As the results are equally applicable to other contexts, in the sequel we will emphasize the *ex ante* and *ex post* capacity investments to make general statements and predictions, and at times refer the readers to the offshoring/onshoring examples that motivate this study.

Intermediate and finished goods. The end consumers' willingness to pay for the finished good F is captured by an inverse demand function $P(q)$, where q denotes the ultimate quantity of good F. The inverse demand satisfies $P(q) > 0$ for q not too large, and $P'(\cdot) < 0$. To produce good F, an intermediate good I is needed, and firm D cannot produce good I by himself. There exists an upstream firm U, who produces good I at a constant unit production cost denoted as $v > 0$.

Ex ante capacity investment. In order to convert the intermediate good I to the finished good F, firm D has to establish a production capacity denoted as $K \geq 0$ beforehand. This ex ante capacity is built through the offshore supplier in our motivating example. Nevertheless, as mentioned in the introduction, this production capacity may also refer to firm D's own production line when he must pre-block some time frames and resources for this particular production process. As another example, the capacity constraint may correspond to firm D's purchase order of other components that are also required for this assembly system. In such a scenario, firm D assembles the components (including the one acquired from firm U) into the finished goods, and has to first determine how much to order from other manufacturers before contacting firm U in question. Thus, one can interpret our setting as a reduced form of the underlying game, as firm U in the later stage may deal with firm D who has already committed to some capacity constraint before entering the contracting process.

Ex post capacity expansion. In addition, firm D is allowed to *expand* the capacity K ex post, at a higher expedite cost, should he find this profitable after interacting with firm U. In our motivating example, this corresponds to the onshore supplier that has a shorter lead time but is typically more expensive than the offshore one. As indicated by Allon and van Mieghem (2010), the lead time of offshoring (in China) could be five to ten times longer than that of onshoring/ nearshoring (in Mexico). As another example, while outsourcing to China, the Outdoor GreatRoom Co. ought to order fire pits nine months in advance so that it fits into the offshore suppliers' production schedule and accommodates the shipping time. In contrast, with onshoring in the United States, the lead time is cut down to three months (Davidson (2010)). Heterogeneous lead times are widely observed nowadays as "North American and European firms are faced with longer procurement lead times" while oursourcing production to lower-cost countries such as China, whereas domestic suppliers typically have shorter lead times (Wang and Tomlin (2009)). For the alternative interpretation of our model, this expensive capacity expansion may arise from the fact that additional capacity may be originally assigned for other production processes; thus, firm D needs to take extra effort and cost to clear out the inventory and personnel allocation before releasing it to the production in question. Likewise, if firm D assembles the components from multiple providers, the capacity expansion may require firm D to find a new provider to fulfill this additional capacity. Thus, the variable cost necessarily incorporates this search cost and consequently is higher than the original one.

We normalize the unit capacity cost in the ex ante stage to zero. The unit ex post capacity expansion cost is $m > 0$, which measures the *cost differential* between ex ante and ex post capacity investments. This assumption is made to encapsulate the phenomenon that the offshore supplier, as exemplified by China, has been able to offer prices 25 to 40 percent lower than those available onshore (e.g., in North America) due to low labor costs, cheap commodities, and favorable exchange rates (Ferreira and Prokopets (2009)); see also Allon and van Mieghem (2010) for more detailed descriptions on the discrepancy between the China and Mexico sourcing options. Note that this cost differential shall account not only the traditional cost of goods sold (material, labor, and overhead) but also the transportation, customs, duties, and taxes.

Recollect that K denotes the ex ante capacity constraint set by firm D. Thus, firm D does not incur any ex post capacity cost if eventually he produces no more than K units of good F. If he produces more than K units, he pays $m(q - K)$ for capacity expansion, where q denotes the ultimate quantity of good F.

Finished-good production. In addition to the capacity cost, firm D incurs the production cost of converting good I into good F, and this production cost is denoted by $C(q)$. We assume that $C(\cdot)$ satisfies $C(0) = 0$ and $C'(\cdot) > 0$.

Timing. We model the interaction between firm D and firm U as a three-stage game. The sequence of events is as follows:

- *Stage 1* – The capacity-building stage: firm D establishes his production capacity K, which guarantees that quantity K can be produced for good F at no capacity cost.
- *Stage 2* – The contracting stage: firm U announces her wholesale price w of good I, at which she is willing to supply firm D.
- *Stage 3* – The production stage: firm D determines his quantity q to produce for good F. If $q > K$, firm D expands his capacity by building capacity onshore at scale $q - K$.

From the above description, we implicitly assume that the capacity investment in stage 1 is publicly observable. It is directly applicable if such ex ante capacity is established through firm D's own production facility (e.g., his foreign direct investment (FDI)), because in this case firm U may directly observe the upper-bound of the size of firm D's offshore production. In Section 4, we remove this common knowledge assumption and show that firm D will voluntarily disclose his capacity investment. Thus, all the results apply immediately to this alternative scenario. Incidentally, we use the wholesale price contract to model the transactions between firm U and firm D regarding good I. This contract form and the bargaining power are adopted mainly for simplicity, as in essence firm D's sourcing should lead to some sort of transfers between firm U and firm D. 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 show that our results are unaltered if we instead adopt the revenue sharing contract to take care of alternative bargaining powers between firm U and firm D.

We adopt the subgame perfect Nash equilibrium (SPNE) as our solution concept (Fudenberg and Tirole (1991)), and derive the equilibrium of this game in the next section.

3 Equilibrium analysis

In this section, we investigate firm D's capacity strategy by doing backward induction to solve the game. Thus, we shall start with stage 3 in which firm D makes his production decision. Afterwards, we move to firm U's wholesale price decision in the contracting stage (stage 2). Finally, we return to the capacity building stage (stage 1) and examine firm D's capacity decision. Our primary result demonstrates the possibility of *strategic capacity shortage* – i.e., firm D voluntarily chooses a capacity limit upfront even though he has to bear a more expensive ex post capacity expansion cost. We first keep the utility and cost functions general and derive the necessary and sufficient conditions for strategic capacity shortage. Following this, we then impose additional structure for more transparent regimes and comparative statics.

3.1 Production stage

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

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

In the production stage, firm D's marginal cost depends on whether his quantity q exceeds the ex ante established capacity K. For ease of exposition, we call the case $q \leq K$ as the scenario *without capacity shortage*, and the case $q > K$ as the scenario *with capacity shortage*. In the former scenario, firm D's marginal cost is given by $w + C'(q)$; in the latter scenario, his marginal cost is $w + m + C'(q)$, which is strictly larger due to the positive marginal cost of capacity expansion.

We make the following assumption to guarantee that the profit functions of firm D satisfy the second-order condition either with or without capacity shortage. Intuitively, this assumption is more likely to hold when the inverse demand function does not explode too fast, the production cost and/or the capacity cost is sufficiently convex.

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

In Stage 3, firm D maximizes his profit given by (1) to determine his optimal quantity q for good F. As anticipated, we shall differentiate two scenarios in Stage 3 depending on whether firm D faces ex ante capacity shortage. First, consider the case when firm D has ex ante established a very large capacity so that his production does not subject to any capacity constraint. In this case, the optimal quantity of firm D solves the following first-order condition:

$$f_1 \equiv P'(q)q + P(q) - C'(q) - w = 0. \tag{2}$$

Let $q^*(w)$ be the solution to firm D's problem without capacity shortage. Second, suppose firm D has established a small ex ante capacity and produces by expanding his capacity, the optimal q solves the first-order condition:

$$f_2 \equiv P'(q)q + P(q) - C'(q) - w - m = 0. \tag{3}$$

Let $\bar{q}(w)$ be the solution to firm D's problem with capacity shortage. In the sequel, we shall use upper bar and asterisk to indicate whether the term is associated with the scenario with or without capacity shortage. It is verifiable that $q^*(w)$ and $\bar{q}(w)$ decrease in w. Thus there exists unique values of $w_1(K) : [0, \bar{q}(0)] \to \mathbb{R}^+$ and $w_2(K) : [0, q^*(0)] \to \mathbb{R}^+$, defined by

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

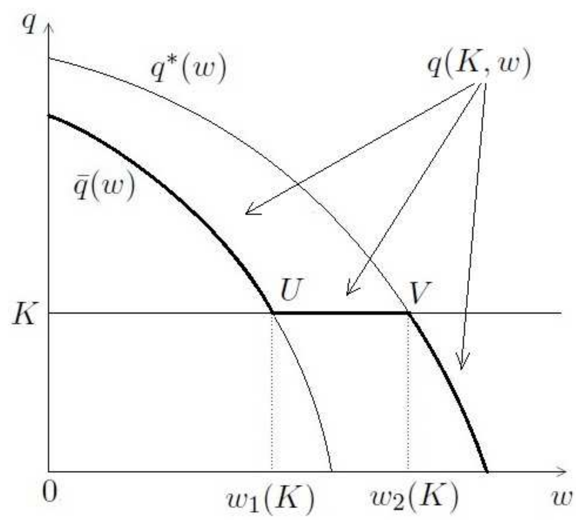

Figure 1: Firm D's optimal quantity in the production stage

Figure 1 gives a graphical illustration of the two optimal quantities of firm D with and without capacity shortage. We allow $q - K$ to be negative in (3) in order to get the whole graph of $\bar{q}(K, w)$. As shown in Figure 1, $w_1(K)$ is the critical value of w such that firm D finds it optimal to produce exactly quantity K given that his marginal cost is $w + m + C'(K)$ (with capacity shortage). Likewise, $w_2(K)$ is the value of w such that the same is true given that firm D's marginal cost is $w + C'(K)$ (without capacity shortage). Since firm D's marginal cost is higher with capacity shortage, for $K \in [0, q^*(0))$, it holds that $w_1(K) < w_2(K)$ (see the proof of Lemma 1). In addition, for $K \in [0, \bar{q}(0))$ the following holds (see the proof of Lemma 1):

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

That is, at a given wholesale price w of good I, firm D produces a larger quantity of good F when he faces no capacity shortage vis-a-vis his quantity with capacity shortage. Intuitively, since firm D bears a higher marginal cost when he expands capacity in the production stage, it is optimal for firm D to produce less. Consequently, there exist three cases in the production stage: 1) $w < w_1(K)$, 2) $w \geq w_2(K)$, and 3) $w \in [w_1(K), w_2(K))$. These three cases lead to different optimal production strategies of firm D for $K \in [0, q^*(0)]$, elaborated in the following lemma and is also shown by the heavy kinked curve in Figure 1.

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

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

Lemma 1 characterizes firm D's optimal production decision in stage 3 at given ex ante capacity K and wholesale price w. For K large enough, there is no capacity constraint to firm D and he always produces $q^*(w)$, his optimal quantity without capacity shortage. Instead, when K is not large enough, Lemma 1 says that w is going to affect firm D's marginal cost therefore determine the optimal quantity of firm D. First, if $w < w_1(K)$, firm D's aggregate marginal cost is relatively low and he is willing to expand the capacity to $\bar{q}(w)$. This is shown by the heavy part on $\bar{q}(w)$ in Figure 1. At the other extreme, when $w \geq w_2(K)$, firm U's wholesale price largely increases firm D's perceived marginal cost. In such a scenario, firm D is better off leaving some capacity unused. This leads to the equilibrium quantity $q^*(w)$ shown by the heavy part on $q^*(w)$ in Figure 1. In the intermediate region, however, it is best for firm D to settle down with the established capacity K from the marginal cost-benefit analysis.

3.2 Contracting stage

We are now ready to move back to Stage 2, where firm U determines her wholesale price w upon observing firm D's ex ante capacity K. We focus on $K \in [0, q^*(0))$ as this is the case of interest. Anticipating that firm D orders $q = q(K, w)$ for good I, firm U chooses her wholesale price w to maximize her profit

$$\pi_c(K, w) = (w - v)q(K, w). \tag{5}$$

The following assumption is needed to ensure the second-order conditions for the profit of firm U:

Assumption 2. *$P'''(q)q + 2P''(q) - C'''(q)$ are sufficiently small.*

The precise bounds are somewhat complicated and therefore are provided in the appendix (see the proof of Lemma 2). We later verify that this technical assumption is naturally satisfied if the above functions are linear. Under Assumption 2, there exists a unique value of w that maximizes $\pi_c(w, K)$ given that firm D produces either $q^*(w)$ or $\bar{q}(w)$. Let the optimal value of w be w^* in the former case and $\bar{w}$ in the latter case. That is, w^* solves the first-order condition

$$q^*(w) + (w - v)q^{*\prime}(w) = 0, \tag{6}$$

and $\bar{w}(K)$ solves the first-order condition

$$\bar{q}(w) + (w - v)\bar{q}'(w) = 0. \tag{7}$$

Figure 2 illustrates firm U's profit maximization problem. To this end, we draw firm U's *iso-profit* line, where the movement of the iso-profit towards the northeast corner represents a larger profit of firm U. The equilibrium can be interpreted via the Edgeworth box argument. Specifically, when firm D produces $\bar{q}(w)$ in Stage 3, the tangency point of firm U's iso-profit line to $\bar{q}(w)$ is point A, which gives the optimal wholesale price $\bar{w}(K)$ for firm U. Similarly, if firm D instead produces $q^*(w)$ in Stage 3, the tangency point of firm U's iso-profit line to $q^*(w)$ is point B; the corresponding optimal wholesale price is w^*.

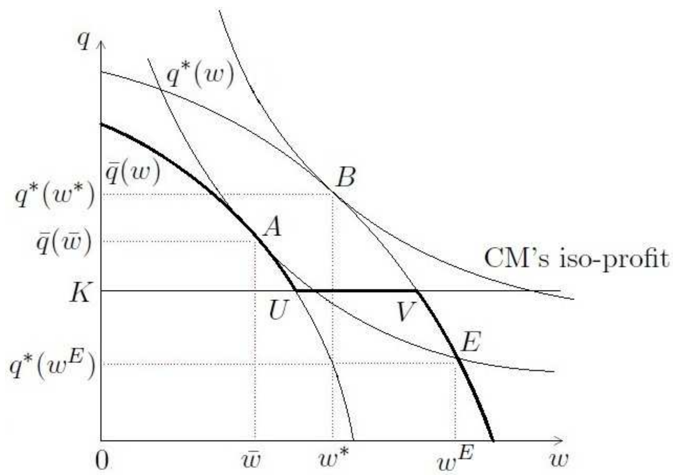

Figure 2: firm U's profit maximization problem in the contracting stage.

Let firm U's iso-profit line which passes point A intersect $q^*(w)$ from below at point E (the structural properties and relative positions of points A, B, and E are discussed in the appendix). It is helpful to focus on the wholesale price at point E, denoted as w^E and is defined by

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

Note that according to the definition, it must be $\bar{q}(\bar{w}) > q^*(w^E)$. Equation (8) indicates that w^E is the wholesale price at which firm U is indifferent between two strategies: on the left-hand side of (8), firm U sets the wholesale price relatively low as $\bar{w}$, so that firm D produces $\bar{q}(\bar{w})$ by expanding his ex ante capacity. On the right-hand side of (8), firm U sets the wholesale price relatively high as w^E at which firm D produces $q^*(w^E)$ within his ex ante capacity. If firm U is indifferent between setting w as $\bar{w}$ and $w = w^E$, we assume that firm U sets $w = w^E$ so that firm D produces within his ex ante capacity. The following lemma characterizes firm U's optimal pricing strategy in Stage 2.

Lemma 2. *In the contracting stage, firm U's optimal wholesale price, denoted as $w(K)$, is given below:*

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

Lemma 2 suggests that firm U's optimal wholesale price crucially depends on Firm D's ex ante capacity. When Firm D's ex ante capacity is relatively small ($K < q^*(w^E)$), firm U shall set a relatively how wholesale price $w = \bar{w}$ such that firm D expands his capacity by the scale $\bar{q}(\bar{w}) - K$ in the production stage. In other words, under the limited capacity built upfront, firm U intends to *compensate* Firm D so as to induce capacity expansion. In this sense, firm D benefits from showing his weakness to firm U, as it leads to a low wholesale price quote. This result follows because with a limited ex ante capacity, firm D convinces firm U that he will suffer from a high marginal cost upon expanding his capacity. Understanding the (possible) inefficiency of firm D, firm U faces a battle between two strategies. First, she can set a high wholesale price $w = w_2(K)$ (that corresponds to point V in Figure 2) and lead to a low production quantity (K) ordered by Firm D. Second, she can accommodate firm D's capacity expansion cost and set a low price $w = \bar{w}$ to boost firm D's order quantity. By credibly committing to a sufficiently low ex ante capacity ($K < q^*(w^E)$), firm D successfully "forces" firm U to reduce the wholesale price in exchange of a higher order quantity. On the other hand, if the ex ante capacity is sufficiently large ($K > q^*(w^E)$), firm U's wholesale price should induce firm $D$to produce within his capacity so as to avoid the expensive capacity expansion. By Lemma 1, his quantity is either given by K for $K \in [q^*(w^E), q^*(w^*))$, or given by $q^*(w^*)$ for $K \geq q^*(w^*)$.

3.3 Capacity building stage

We are now ready to move back to stage 1 for firm D's optimal capacity decision. In this stage, firm D determines the capacity K to build ex ante before the pricing decision of firm U and his own production of good F. Lemma 2 shows that by alternating his established capacity K, firm D anticipates three possible wholesale prices $\bar{w}$, w^* and $w_2(K)$ to arise in stage 2. In the appendix, we show that $w_2(K)$ is suboptimal for firm D, i.e., point B strictly dominates point V for firm D in Figure 2. To see the intuition, recollect that if $K > q^*(w^E)$, firm D never produces more than his ex ante capacity. In anticipation of no capacity expansion, firm D shall set the ex ante capacity large enough for an interior solution, namely, to obtain the maximum profit without being subject to capacity shortage in the production stage. Technically, this implies that in Figure 2, along $q^*(w)$ point B dominates point V from firm D's perspective (since point B implies a lower wholesale price by firm U).

The above observation leads us to simply compare firm D's optimal profit without capacity shortage (at point B) to that with capacity shortage (at point A). Without loss of generality, if firm D is just indifferent between establishing a limited capacity such that he ends up getting point A in equilibrium and establishing a full capacity such that he achieves point B in equilibrium, we assume that firm Dsets a limited capacity for his profit at point A. This simplifies the presentation of our equilibrium outcomes and has no qualitative influence.

Our main result provides a concrete regime in which strategic capacity shortage arises, i.e., firm D voluntarily sets a limited capacity ex ante and expands his capacity ex post even if ex ante capacity comes at no cost. To specify the condition, it is useful to define firm D's optimal profit without capacity shortage (i.e., $K \geq q^*(w^*)$). This profit is denoted by π_o^*, corresponds to point B in Figure 2, and can be expressed as

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

Firm D's equilibrium profit at point A can be derived as follows. Let us denote firm D's optimal profit with zero ex ante capacity as $\bar{\pi}_o$, with the following expression:

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

Nevertheless, if firm D intends to create capacity shortage in the production stage, he should optimally set the ex ante capacity as $K = q^*(w^E)$; accordingly, the maximum cost saving is $mq^*(w^E)$. Thus firm D's optimal profit under capacity shortage is at $K = q^*(w^E)$ and is given by

$$\bar{\pi}_o + mq^*(w^E).$$

The optimal ex ante capacity of firm D depends on the comparison between his optimal profit with and without capacity shortage given above. If and only if the optimal profit of firm D under capacity shortage exceeds his profit without capacity shortage, i.e.,

$$\pi_o^* < \bar{\pi}_o + mq^*(w^E), \tag{9}$$

firm D will adopt a limited ex ante capacity and expand his capacity ex post. The following theorem summarizes our main results by giving the condition for (9) to be satisfied and capacity shortage to arise.

Theorem 1. *In the capacity building stage,*

1. *Strategic capacity shortage arises if and only if* m *is sufficiently small. In this case, firm* D*'s ex ante capacity is* $K = q^*(w^E)$*; firm* U *sets the wholesale price* $w = \bar{w}$*, and firm* D *expands his capacity by the scale* $\bar{q}(\bar{w}) - q^*(w^E) > 0$.

2. *for* m *relatively large, firm* D *sets the ex ante capacity* $K \geq q^*(w^*)$*; firm* U *selects the wholesale price* $w = w^*$*, and there is no capacity expansion in the production stage.*[4]

Note that in our global outsourcing context, m serves as a proxy of the cost differential between onshore and offshore productions. We show that in equilibrium firm D strategically creates capacity shortage in exchange of a low wholesale price from firm U as long as ex post capacity expansion is not too costly. Our result suggests a new rationale for the frequently observed capacity shortage in business practice. The conventional wisdom typically relates the observed capacity shortage to the inevitable imprecision of demand forecasting. This demand uncertainty is completely abstracted away in our context; yet, we document a strong incentive for Firm D to intentionally create capacity shortage even if ex post capacity expansion is absolutely more expensive. The primary driver for this result is purely strategic. Deviating from the integrated single decision-making problem, here firm Dtakes into account the subsequent transactions with his business partner. Foreseeing that firm U will willingly recede in her profit sharing, firm Dnow intentionally creates such a weakness through his limited ex ante capacity. Putting this result in our global sourcing context, Theorem 1 identifies a less explored benefit for going on-shore, thereby suggesting a new rationale other than demand uncertainty for the pervasive consideration of re-shoring. Since this OEM's strategic concern does not hinge on the conventional supply/demand mismatch, improving forecasting accuracy does not help mitigate this deadweight loss. Our results also indicate that due to strategic reasons, the tipping point from re-initiating the onshoring/ near-shoring business can be earlier than what the analysts have suggested.

We also observe an essential ingredient for this strategic capacity shortage, as presented in the following corollary.

Corollary 1. *Whenever strategic capacity shortage arises,* $\bar{w} < w^*$.

Corollary 1 asserts that for firm D to strategically limit his ex ante capacity, he must benefit from a lower wholesale price from firm U. Thus, the painful restriction ex ante on his own is made in exchange of the ex post benefit from his partner. This illustrates Firm D's trade-off by committing

[4]Notice that $K > q^*(w^*)$ can arise in equilibrium because we normalize the ex ante unit capacity cost to zero. For any nonzero unit ex ante capacity cost of firm D, the SPNE when m is large is unique, where $K = q^*(w^*)$ and $w = w^*$, and there is no capacity expansion in the production stage.

to a limited capacity upfront. On one hand, he can induce firm U to give him a favorable wholesale price out of her incentive to boost Firm D's production; on the other hand, since firm Deventually is encouraged to expand his capacity ex post, he has to absorb the higher capacity cost. Condition (9) provides the regime in which the former force dominates the latter. In this sense, our result suggests that showing the weakness to the business partner has a strategic effect, as firm U, despite being a relentless profit maximizer, willingly cuts back her profit share to facilitate the business transactions.

Theorem 1 echoes the insights via the analysts' observations and explanations aforementioned in the introduction, and it formalizes the economic rationale for the current onshoring wave as exemplified by Wright Engineered Plastics, Vaniman Manufacturing, NCR, and All-Clad Metalcrafters (**?**). Namely, firm U always lowers her wholesale price for a less efficient downstream producer firm D. Thus, by strategically choosing to be weak, firm D is able to force firm U to surrender a higher profit share to firm D. This strategic weakness ultimately benefits firm D, even though he has to absorb the expensive capacity expansion cost in the production stage. As a companion result of this observation, if firm D is entitled to choose the cost of ex post capacity expansion, he is in favor of an inefficient one.

Corollary 2. *If in the capacity building stage (Stage 1) firm D is empowered to determine the cost of his ex post capacity expansion* (m)*, in equilibrium his ex post capacity expansion cost is larger than his ex ante capacity building cost (i.e.,* $m > 0$*).*

The above corollary reasserts our finding, and suggests an intriguing rationale for firm D to intentionally inflate his capacity expansion cost. This is because an inflated capacity expansion cost serves as a commitment device that induces a lower wholesale price of firm U. In this sense, firm D turns his self-sabotage weakness to his advantage in the contractual relationship, and this is made possible due to the peculiar supply chain collaboration. Our result therefore documents a novel source of supply chain inefficiency. Recollect that we can also interpret the capacity expansion cost as the cost differential between ex ante and ex post capacity investments. Thus, in our global sourcing context, our analysis suggests that the offshore cost on a rise may not necessarily be detrimental for firm D: it may occasionally *strengthen* firm D's ability to claim a higher profit share vis-a-vis firm U, thereby overturning the downside of this seeming business crisis.

Insofar we have obtained the operating regime for strategic capacity shortage. Nevertheless, it remains to quantify this effect and articulate how this phenomenon is affected by firm D's and CM's production efficiencies. To this end, in the next section we provide a concrete example for which clear-cut characterizations can be presented.

3.4 The linear example

In this section, we consider the following example where in addition to a linear capacity expansion cost, the market demand and the production cost of good F are both linear to Firm D. Specifically, we assume that

Assumption 3. *$P = \max\{a - q, 0\}$, $C(q) = cq$,, where $a > 0$, $c > 0$, and $a > c + v + m$.*

Under Assumption 3, it is verifiable that Assumptions 1 and 2 are both satisfied. Thus, we can apply the aforementioned solution approach to obtain the market equilibrium. In our context, m measures the inefficiency of ex post capacity building, and c and v indicate the production efficiencies of firm $D$and firm U, respectively. The condition $a > c + v + m$ ensures that the potential market size is high enough that justifies the business. If this condition is violated, the optimal production is trivially zero.

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 precisely characterizes the operating regime for strategic capacity shortage and the optimal endogenous capacity expansion cost of Firm D.

Proposition 1. *Under Assumption 3, strategic capacity shortage arises whenever $m \leq \bar{m}$. Moreover, if firm D is entitled to determine his ex post capacity expansion cost, he sets $m = m^*$.*

Assumption 3 leads to a clear cutoff value of m (the unit cost of firm D's ex post capacity expansion), below which firm Dstrategically utilizes capacity shortage to profit in the supply chain. To see the intuition, note that in (9), the left-hand side is independent of m; on the right-hand side, an increase in m reduces $\bar{\pi}_o$, which is firm D's equilibrium profit with zero ex ante capacity. Moreover, it also reduces $q^*(w^E)$ (this can be clearly viewed in Figure 2 as when $\bar{q}(w)$ shifts inside, firm U's iso-profit line tangency to $\bar{q}(w)$ will intersect $q^*(w)$ at a lower point, leading to a reduced $q^*(w^E)$). To elaborate, let us consider the effect of cost increase from $m = 0$ (where π_o^* equals $\bar{\pi}_o + mq^*(w^E)$). For m small, although a cost inflation of m has a negative effect on the right-hand side ($\bar{\pi}_o + mq^*(w^E)$), the positive effect dominates and the optimal profit with capacity shortage is achieved for firm Dat $m^* > 0$. Nonetheless, when the cost becomes sufficiently high ($m > m^*$), the negative effect dominates and the right-hand side decreases in m. Ultimately, when $m > \bar{m}$, capacity shortage becomes disadvantageous for firm D.

As aforementioned, this linear example allows us to articulate how firm D determines the capacities in response to the change of market size and production efficiencies.

Corollary 3. *Under Assumption 3, strategic capacity shortage occurs more likely when the market size is large, and firm D and firm U are highly efficient in production.*

Corollary 3 shows that when the business is more profitable, Firm D has a stronger incentive to restrict himself in establishing the ex ante capacity. This is because in such a scenario, the benefit from "threatening" the partner to offer a favorable deal is amplified. As aforementioned, in the absence of demand uncertainty, our analysis suggests that, quite ironically, the profitability of the business creates an endogenous capacity shortage.

The next corollary documents an intriguing phenomenon on how firm D changes his capacity decisions according to the capacity expansion cost.

Corollary 4. *Under Assumption 3, whenever strategic capacity shortage arises, firm D's ex ante capacity ($q^*(w^E)$) decreases in the cost of capacity expansion (m), whereas the ex post capacity expansion ($\bar{q}(\bar{w}) - q^*(w^E)$) increases in the cost of capacity expansion.*

According to Corollary 4, when the expedite capacity becomes less expensive, under strategic capacity shortage Firm D tends to *increase* his ex ante capacity and expand *less* capacity ex post. As aforementioned in the introduction, the policy implication of this corollary is that blindly providing the grants and tax relief may not necessarily attract more production back in town, and a wage increase of offshore supplier in China may actually impede the move-back of manufacturing to the United States. To understand this result, observe that a more expensive capacity expansion gives rise to a strong commitment effect for Firm D's "self-sabotage" behavior. Because Firm D is now very vulnerable ex post, firm U will significantly reduce the wholesale price to facilitate the capacity expansion. Notably, the entire supply chain suffers from the more costly expedite capacity expansion a priori; additionally, Firm D's inefficient capacity decision exacerbates this inefficiency because he retains a larger portion of the profit by doing so.

We now examine how the change of profitability affects Firm D's capacity decisions. This is provided in the next corollary.

Corollary 5. *Under Assumption 3, whenever strategic capacity shortage arises, firm D's ex ante capacity ($q^*(w^E)$) and the ex post capacity expansion ($\bar{q}(\bar{w}) - q^*(w^E)$) increase in the market size (a) and decrease in the costs of good I and good F (v and c).*

Unlike the capacity expansion cost, the implications of other profitability measures on Firm D's capacity decisions are monotonic. As long as the business opportunity is more profitable (either because the market size is larger or because firm $D$and firm U are more efficient in production), Firm D builds a higher capacity ex ante and also expands more ex post. These results confirm the intuition that the total capacity of firm Dincreases when the market is more profitable.

4 Discussions

Our analysis points out that as long as the inefficiency associated with ex post capacity expansion is not too substantial for firm D, in equilibrium firm D strategically limits his ex ante capacity. A natural question is whether these results are driven by our specific model setup. To address this issue, we in this section explore some alternative scenarios to examine the robustness of our predictions.

4.1 Observability of firm D's capacity investment

In our basic framework, we assume that firm U can observe firm D's ex ante capacity investment. This assumption is made mainly for ease of exposition. In this subsection, we consider the alternative scenario wherein firm D's capacity investment is not observable by firm U. This is the case when, e.g., the ex ante capacity is built through firm D's contracting with offshore suppliers in the global sourcing context.

We note that while in general the contracts between firm D and his offshore suppliers are not directly observable to firm U, firm D has the incentive to *voluntarily reveal* his ex ante capacity to firm U for the strategic benefits presented above. This revelation can be facilitated by allowing firm $D$to decide, after establishing his ex ante capacity, whether to disclose this information to firm U. Below, we articulate the rationale for this voluntary revelation.

If firm D chooses not to reveal his ex ante capacity, then firm U sets the wholesale price w according to her belief regarding Firm D's established capacity. firm U's only rational belief is that firm Dhas established a full capacity ex ante. Correspondingly, firm U charges the optimal wholesale price w^* assuming that no capacity shortage arises. As a consequence, firm D's incentive to hold any ex ante capacity shortage diminishes. To see this, suppose instead that in firm U's belief, firm D establishes a limited ex ante capacity. In this case, firm U will set $w = \bar{w}$ to firm D. This is because under capacity shortage, it is optimal for firm D to establish $K = q^*(w^E)$; by Lemma 2, firm U chooses $w = \bar{w}$ to induce firm D to expand his quantity to $\bar{q}(\bar{w})$. However, given this price, in stage 1 firm D is better off deviating from $K = q^*(w^E)$ to $K = \bar{q}(\bar{w})$, since this avoids the expensive ex post capacity expansion cost. Therefore, such a belief does not satisfy sequential rationality. In equilibrium, it must be that firm D establishes $K \geq q^*(w^*)$, his full capacity; accordingly, firm U charges $w = w^*$, her optimal price in the absence of firm D's capacity shortage.

Now we consider the scenario when firm D discloses a limited ex ante capacity. In this case, firm D can restore the aforementioned strategic benefit, as this forces firm U to give away a higher portion of revenue in the intermediate goods. Therefore, in equilibrium, firm D's capacity revelation decision hinges on the comparison between his profits in these two scenarios: one is with the optimal ex ante capacity shortage and the other is with full ex ante capacity. It is then clear that whenever strategic capacity shortage arises in our benchmark model, it must be that firm D adopts the limited ex ante capacity, then reveals his ex ante capacity to firm U before contracting with firm U for good I. Therefore, we conclude that our results are not prone to this common knowledge assumption.

4.2 Revenue sharing contract

Our basic framework considers a linear wholesale price contract between firm U and firm Don the transaction of good I. In this subsection, we investigate an alternative contract form: *revenue sharing contract.* This contract allows firm U to also share the profit from selling the finished good F at a proportion α. Under this revenue sharing contract, firm U's profit is

$$\tilde{\pi}_c(K, w, q) = (w - v)q + \alpha\pi_o(K, w, q) \tag{10}$$

with $\pi_o(K, w, q)$ given in (1). The first part of CM's profit stands for her profit from selling good I to firm D, and the second part corresponds to her revenue share of selling the finished good F. Correspondingly, firm D's profit becomes

$$\tilde{\pi}_o(K, w, q) = (1 - \alpha)\pi_o(K, w, q). \tag{11}$$

This contract form is more general than the wholesale price contract, and it incorporates the relative bargaining power in this buyer-seller relationship; see **?** and the references therein for the prevalent use of this contract. The proportion α reflects firm U's market power. When $\alpha = 0$, the contract coincides with the wholesale price contract considered in our basic framework, wherein firm U only makes a profit from the intermediate goods. At the other extreme, when $\alpha = 1$, firm U fully extracts the profit from the finished good market; one can verify that this is equivalent to the scenario with a two-part tariff. In this degenerate case, firm D's decision is irrelevant because he earns zero profit anyway. Thus, we exclude this trivial case. In the intermediate case ($\alpha \in (0, 1)$), this revenue sharing contract allows possible coordination between firm U and firm D on the finished good F. [5]

[5] α might be determined through the ex ante bargaining between firm U and firm D. Recall that our interest is to explore whether our major results are affected by the alternative market power of firm U and by the possible coordination between firm U and firm D. Thus, we treat α as an exogenous proportion.

Our main observation is the following. Although the revenue sharing factually alters firm U's pricing incentive for the intermediate good I, the key driver for firm D's ex ante capacity shortage persists. Define

$$\bar{m}_\alpha \equiv \frac{2(2-\sqrt{2})(1-\alpha)}{6+\sqrt{2}-4\alpha}(a-c-v),$$

and

$$m^*_\alpha \equiv \frac{(1-\alpha)(31-18\alpha-\sqrt{825-1060\alpha+452\alpha^2-64\alpha^3})}{2(17-7\alpha-16\alpha^2+8\alpha^3)}(a-c-v).$$

Note that $\bar{m}_\alpha > m^*_\alpha$ for $\alpha < 1$, both $\bar{m}_\alpha$ and m^*_α decrease in α, and $\bar{m}_\alpha = m^*_\alpha = 0$ at $\alpha = 1$. We formally state our finding in the next proposition.

Proposition 2. *Under Assumption 3 and revenue sharing contract, strategic capacity shortage arises whenever $m \leq \bar{m}_\alpha$. Moreover, if firm D is entitled to determine his ex post capacity expansion cost, he sets $m = m^*_\alpha$.*

Proposition 2 verifies that our main message – strategic capacity shortage – prevails under *arbitrary* non-linear (revenue sharing) contract. It holds that $\bar{m}_\alpha > 0$ for all $\alpha < 1$. Thus, as long as firm U cannot fully extract Firm D's profit from the finished good F, there always exists a non-empty range of parameter m under which in equilibrium firm D adopts a limited ex ante capacity and then further expands his capacity ex post. The underlying economic forces remain the same. By limiting his ex ante capacity, firm Dcan benefit from a lower price in the intermediate good market. A higher revenue sharing proportion α reduces firm D's share of selling the finished good; thus, his incentive to create strategic capacity shortage is weakened, but never completely eliminated. On the other hand, firm U now has a *stronger* incentive to cut back her price in order to foster the finished good selling. The aggregate is that while firm D continues to bear ex ante capacity shortage, the upper bound of m for ex ante capacity shortage as an equilibrium decreases when α becomes larger.

We also find that whenever there is strategic capacity shortage, the patterns of the change in firm D's ex ante capacity and ex post capacity expansion in market size (a) and production costs (c and v) are unaltered.

Corollary 6. *Under Assumption 3 and the revenue sharing contract, the results in Corollaries 3-5 continue to hold. Moreover, whenever strategic capacity shortage arises, firm D's ex ante capacity increases in α; the ex post capacity expansion first increases in α and then decreases in α.*

The first message from Corollary 6 demonstrates that the alternative contract form results in no materialistic differences in our managerial implications. The second message provides some guidelines for how the relative market power affects firm D's capacity decisions. To contrast the ex ante and ex post capacity decisions, below we center our discussions around the situation where strategic capacity shortage occurs. Corollary 6 shows that when firm U's market power increases (α is larger), firm D's ex ante capacity becomes larger. Recollect that firm D sets his ex ante capacity according to the highest capacity level at which firm U is willing to cut back her price of good I. Therefore, this result verifies the intuition that when α becomes larger, firm U is more willing to undercut her price in exchange for a larger quantity produced by firm D.

Moreover, we observe a non-monotonic pattern of firm D's ex post capacity expansion, which can be explained as follows. First, the optimal wholesale price w decreases in α due to firm U's incentive to favor the production of good F. As a result, firm D's production quantity (of the finished good F) increases in α. Second, firm D's ex ante capacity increases in α. Since the ex post capacity expansion is the difference between firm D's total quantity and his ex ante capacity, the result encapsulates a tradeoff between firm D and firm U's incentives. When α is relatively small, firm D's incentive to expand his production dominates firm U's incentive to bear the cost of OEM's capacity shortage. Consequently, ex post capacity expansion increases in α. However, when α is relatively large, firm D only appropriates a small revenue proportion from the finished good F. In this case, the latter becomes more significant and it leads to a reduction of capacity expansion.

5 Conclusion

In this paper, we provide a novel rationale for the current trend of onshoring. We argue that even if there is no demand uncertainty, offshoring is unambiguously less expensive than onshoring, both sourcing strategies are available and non-exclusive, onshoring may still be adopted due to its strategic value in global supply chains. Thus, our results indicate that the tipping point from re-initiating the onshoring/ near-shoring business shall be earlier than what the analysts have suggested. In accordance, the offshore cost on a rise may not necessarily be detrimental for the downstream firm, and the downstream firm therefore may not aggressively seek for more efficient onshore suppliers. In addition, this new rationale also gives rise to some unintended implications of the capacity investment strategies. When the expedite capacity becomes less expensive, under strategic capacity shortage the downstream firm tends to increase his ex ante capacity and expand less capacity ex post. This finding has an intriguing policy implication, as it suggests that blindly providing the grants and tax relief may not necessarily attract more production (and therefore more job opportunities) back in town. We further show that our results are robust against the observability of capacity investment, and the implications are qualitatively similar under arbitrary revenue sharing contracts. Overall, our results speak to the sophisticated strategic interactions in the global supply chains and the dynamic capacity investment decisions.

A Proofs of main results

In this appendix, we provide the detailed proofs of the main results.

Proof of Theorem 1. We first show that firm Dstrictly prefers setting $K \geq q^*(w^*)$ so that $w = w^*$ to setting $K \in (q^*(w^E), q^*(w^*))$ so that $w = w_2(K)$. By Lemma 2, for $K \geq q^*(w^*)$, $w = w^*$ in stage 2 and firm Dwill produce $q^*(w^*)$; the corresponding OEM's profit is π_o^*. On the other hand, for $K \in (q^*(w^E), q^*(w^*))$, $w = w_2(K)$ in stage 2 and firm Dproduces $q = q^*(w_2(K)) = K$. Firm D's profit is then given by

$$\pi_o^V \equiv P(K)K - C(K) - w_2(K)K.$$

In either case, there is no capacity expansion in stage 3. We use $\pi_o(w, q^*(w))$ to denote Firm D's profit when she produces $q^*(w)$ at given w without expanding capacity, where

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

By the envelope theorem, we obtain that

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

Since $w^* \leq w_2(K)$, it follows that $\pi_o^* \geq \pi_o^V$; the equality holds only at $K = q^*(w^*)$, in which case point B overlaps point V. In other words, $K \geq q^*(w^*)$ dominates $K \in (q^*(w^E), q^*(w^*))$ for Firm D, and in Figure 2, point B strictly dominates point V for Firm D. The theorem follows from the above result and Lemma 1. □

Proof of Theorem ??. First, with a linear function $f(\cdot)$, $\bar{q}(w)$ solves the following first-order condition:

$$P'(q)q + P(q) - C'(q) - w - m = 0,$$

and $q^*(w)$ solving the first-order condition:

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

Note that $\bar{q}(w) = q^*(w)$ at $m = 0$. Thus, if we allow $w^E = \bar{w}$ in (8) for $m = 0$, it holds that $\bar{w} = w^* = w^E$ at $m = 0$.

Second, to show that $w^* > \bar{w}$, it is sufficient to verify that $\frac{d\bar{w}}{dm} < 0$. Since $\bar{w}$ solves the first-order condition $\bar{q}(w) + (w - v)\frac{d\bar{q}(w)}{dw} = 0$, we obtain that

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

The second equality follows the implicit function theorem. The implicit function theorem also implies that

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

By (16), $\frac{d\bar{w}}{dm} < 0$. The continuity of $\bar{w}$ then suggests that $w^* > \bar{w}$.

Third, by Theorem 1, capacity shortage arises in equilibrium if and only if (9) holds. Note that at $m = 0$, $\pi_o^* = \bar{\pi}_o + f(\bar{q}(\bar{w})) - f[\bar{q}(\bar{w}) - q^*(w^E)]$. To prove the rest of Theorem **??**, it is sufficient of show that $\frac{d}{dm}\left\{\bar{\pi}_o + f(\bar{q}(\bar{w})) - f[\bar{q}(\bar{w}) - q^*(w^E)]\right\}|_{m=0} > 0$. Since

$$\bar{\pi}_o + f(\bar{q}(\bar{w})) - f[\bar{q}(\bar{w}) - q^*(w^E)] = P(\bar{q}(\bar{w}))\bar{q}(\bar{w}) - C(\bar{q}(\bar{w})) - \bar{w}\bar{q}(\bar{w}) - m[\bar{q}(\bar{w}) - q^*(w^E)],$$

we obtain that

$$\begin{aligned}
& \frac{d}{dm}\left\{\bar{\pi}_o + f(\bar{q}(\bar{w})) - f[\bar{q}(\bar{w}) - q^*(w^E)]\right\}|_{m=0} \\
= \; & \frac{\partial rhs}{\partial m} + \frac{\partial rhs}{\partial \bar{w}}\frac{d\bar{w}}{dm} + \frac{\partial rhs}{\partial w^E}\frac{dw^E}{dm} \quad \text{by the envelope theorem} \\
= \; & -[\bar{q}(\bar{w}) - q^*(w^E)] - \bar{q}(\bar{w})\frac{d\bar{w}}{dm} + \frac{\partial rhs}{\partial q^*(w^E)}\frac{dq^*(w^E)}{dw^E}\frac{dw^E}{dm} \\
= \; & -\bar{q}(\bar{w})\frac{d\bar{w}}{dm} + m\frac{dq^*(w^E)}{dw^E}\frac{dw^E}{dm} \quad \text{by } \bar{q}(\bar{w}) = q^*(w^E) \text{ at } m = 0 \\
> \; & 0 \quad \text{since } \frac{d\bar{w}}{dm} < 0;\ m = 0 \text{ and } \frac{dq^*(w^E)}{dw^E}\frac{dw^E}{dm} \text{ is bounded}
\end{aligned}$$

Here $\frac{dq^*(w^E)}{dw^E} = \frac{1}{P''(q)q + 2P'(q) - C''}$ is regulated by Assumption 1. Recall that w^E solves the function $f : (\bar{w} - v)\bar{q}(\bar{w}) - (w - v)q^*(w) = 0$ subject to $w > \bar{w}$. Using the implicit function theorem and the envelope theorem, we obtain that

$$\frac{dw^E}{dm} = -\frac{\frac{df}{dm}}{\frac{df}{dw}} = \frac{(\bar{w} - v)\frac{d\bar{q}(\bar{w})}{dm}}{q^*(w^E) + w^E\frac{dq^*(w^E)}{dw^E}}.$$

Note that the denominator is non-zero by $w^E > w^*$ and the optimality of w^*. Therefore, $\frac{dq^*(w^E)}{dw^E}\frac{dw^E}{dm}$ is bounded. We conclude that for m sufficiently small, $\pi_o^* < \bar{\pi}_o + f(\bar{q}(\bar{w})) - f[\bar{q}(\bar{w}) - q^*(w^E)]$ and strategic capacity shortage arises. □

Proof of Proposition 1. To proceed, we shall invoke the backward induction as in the general case to characterize the market equilibrium.

1) The production stage:

We first solve for Firm D's quantity decision in the production stage (Stage 3). Without capacity shortage, firm Dmaximizes his profit $(a-q)q-cq-wq$ and the optimal quantity is

$$q^*(w)=\frac{1}{2}(a-c-w). \tag{12}$$

Instead, if firm Dproduces with capacity shortage, his problem is to maximize profit $(a-q)q-cq-wq-m(q-K)$ and the optimal quantity is

$$\bar{q}(w)=\frac{1}{2}(a-c-w-m). \tag{13}$$

firm Dproduces less when he faces the capacity shortage in the production stage and has to expand his capacity by paying a higher cost.

2) The contracting stage:

In Stage 2, firm U chooses w to maximize her profit. When firm U anticipates that firm Dchooses the optimal quantity in the absence of capacity shortage, 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 U anticipates that firm Dwill produce with capacity shortage, firm U 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 $w^*>\bar{w}$. In this linear example, firm Dcan always induce firm U to set a lower wholesale price of good I by ex ante establishing a limited capacity such that he will face capacity shortage in the production stage. Note that there exists a level of the ex ante capacity such that in Stage 2, firm U is indifferent between setting $\bar{w}$ while anticipating Firm D's capacity expansion and setting w^E while anticipating that firm Dproduces under the ex ante established capacity. Here, w^E solves

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

subject to $w^E>\bar{w}$, and is given by

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

The corresponding capacity which makes firm U to be indifferent between $\bar{w}$ and w^E is

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

According to Proposition 2, if and only if $K \le q^*(w^E)$, firm U finds it optimal to set $w = \bar{w}$, a lower price of good I.

3) The capacity building stage:

In Stage 1, firm Destablishes his ex ante capacity for the production of good F. By establishing $K \ge q^*(w^*)$, he is able to produce without capacity constraint in the production stage and his profit is

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

Whereas at $K = 0$, Firm D's profit is

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

Instead, by establishing $K = q^*(w^E)$, firm Danticipates that firm U will set $w = \bar{w}$ so that in Stage 3, firm Dfaces a capacity shortage and has to expand his capacity by

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

In this case, Firm D's profit is

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

Firm D's problem in Stage 1 is to compare π_o^* to $\bar{\pi}_o + mq^*(w^E)$ in order to determine the optimal capacity. Whenever Condition (9) is satisfied, firm Dfinds it optimal to set $K = q^*(w^E)$, a limited capacity, to induce firm U to charge a lower wholesale price of good I; following this, he then expands his capacity in the production stage. We find that for m within a certain range, i.e., the cost of capacity expansion in the production stage is not too large, Condition (9) is satisfied. This gives rise to the condition for strategic capacity shortage in the proposition. The rest of the proposition follows the fact that $\bar{\pi}_o + mq^*(w^E)$ is maximized at $m = m^*$. $\square$

Proof of Proposition 2. Since the procedure is similar to the proof for Proposition 1, we only sketch the major steps following the backward induction.

In the production stage, at given (K, w), firm Dmaximizes $\tilde{\pi}_o(K, w, q)$. Thus, his optimal quantity is $q(K, w)$, the same as in Lemma 1. In the contracting stage, firm U chooses w to maximize $\tilde{\pi}_c(K, w, q(K, w))$. When $q(K, w)$ is $q^*(w)$ in the absence of ex ante capacity shortage, the optimal w is

$$w_\alpha^* = \frac{(1-\alpha)(a-c)+v}{2-\alpha};$$

whereas when $q(K, w)$ is $\bar{q}(w)$ in the presence of ex ante capacity shortage, the optimal w is

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

Again, at given K, there exists $w_\alpha^E > w_\alpha^*$ such that firm U is indifferent between two strategies: setting $w = \bar{w}_\alpha$, a relatively low price, such that firm Dwill ex post expand his capacity to produce more; or setting $w = w_\alpha^E$, a relatively high price, such that firm Dwill produce within his ex ante capacity. Thus w_α^E solves the equation which corresponds to (8):

$$\begin{aligned}&(\bar{w}_\alpha - v)\bar{q}(\bar{w}_\alpha) + \alpha[(a-c-\bar{w}_\alpha)\bar{q}(\bar{w}_\alpha) - m(\bar{q}(\bar{w}_\alpha) - K)] = (w-v)q^*(w) + \alpha[(a-c-w)q^*(w)]\\ &\text{s.t.} \quad w > w_\alpha^*.\end{aligned}$$

Moreover, let K_α^E denote the unique solution to $q^*(w_\alpha^E) = K_\alpha^E$, where

$$K_\alpha^E = \frac{a-c-v-m\alpha - \sqrt{m(1-\alpha)(2(a-c-v)-m(1+\alpha))}}{2(2-\alpha)}.$$

The optimal pricing $w_\alpha(K)$ of firm U is summarized in Lemma 2, with $\bar{w}, w^*, q^*(w^E)$ substituted by $\bar{w}_\alpha, w_\alpha^*, K_\alpha^E$, respectively.

In the capacity building stage, firm Dchooses his ex ante capacity K to maximize $\pi_c(K, w_\alpha(K), q(K, w_\alpha(K))$. From Firm D's perspective, setting $K \in (K_\alpha^E, q^*(w_\alpha^*))$ such that $w = w_2(K)$ is suboptimal relative to setting $K \geq q^*(w_\alpha^*)$ such that $w = w_\alpha^*$. Thus, firm Dsimply compares his profit at $K = K_\alpha^E$ (with capacity shortage) to his profit at $K \geq q^*(w_\alpha^*)$ (with full ex ante capacity). We find that the following condition is satisfied:

$$(1-\alpha)[(a-c-\bar{w}_\alpha)\bar{q}(\bar{w}_\alpha) - m(\bar{q}(\bar{w}_\alpha) - K_\alpha^E)] \geq (1-\alpha)[(a-c-w_\alpha^*)q^*(w_\alpha^*)]$$

if and only if $m \leq \bar{m}_\alpha$. Moreover, the left-hand-side is maximized at $m = m_\alpha^* \leq \bar{m}_\alpha$. We conclude that in equilibrium, firm Destablishes ex ante capacity shortage as long as $m \leq \bar{m}_\alpha$; moreover, it is optimal for firm $D$to set $m = m_\alpha^*$. Proposition 2 follows immediately. □

B Proofs of auxiliary results

We now provide the proofs for auxiliary results (lemmas and corollaries).

Proof of Lemma 1. The proof proceeds as follows. We first show that $q^*(w)$ and $\bar{q}(w)$ decrease in w, and then prove that $q^*(w) > \bar{q}(w)$. Next, we verify that $w_1(K)$ and $w_2(K)$ are well defined and $w_1(K) < w_2(K)$. Finally, we build upon these findings and discuss Firm D's quantity decisions case by case.

1) Some preliminary results:

i) $q^*(w)$ and $\bar{q}(w)$ decrease in w:

By the implicit function theorem, it holds that

$$\frac{dq^*(w)}{dw} = -\frac{df_1/dw}{df_1/dq} = \frac{1}{P''(q)q + 2P'(q) - C''(q)} < 0. \tag{14}$$

Also, the following holds by the implicit function theorem:

$$\frac{d\bar{q}(w)}{dw} = -\frac{df_2/dw}{df_2/dq} = \frac{1}{P''(q)q + 2P'(q) - C''(q) - f''(q)} < 0. \tag{15}$$

ii) $q^*(w) > \bar{q}(w)$*:*

By Assumption 1, $P'(q)q+P(q)-C'(q)$ decreases in q. By the two first-order conditions given in (2) and (3), $P'(q^*(w))q^*(w)+P(q^*(w))-C'(q^*(w)) = w$, and $P'(\bar{q}(w))\bar{q}(w)+P(\bar{q}(w))-C'(\bar{q}(w)) = w + f'(\bar{q}(w) - K) > w$. Thus, $q^*(w) > \bar{q}(w)$.

iii) $w_1(K)$ *and* $w_2(K)$ *are well defined and* $w_1(K) < w_2(K)$*:*

Due to the monotonicity of $\bar{q}(w)$ and $q^*(w)$, $w_1(K)$ uniquely solves $\bar{q}(w) = K$ and $w_2(K)$ uniquely solves $q^*(w) = K$. Therefore, we have $q^*(w_2(K)) = \bar{q}(w_1(K))$. Since $q^*(w)$ decreases in w and $q^*(w) > \bar{q}(w)$, it follows immediately that $w_1(K) < w_2(K)$.

2) OEM's production decision:

For a given ex ante capacity K, there exist three cases in Stage 3 according to the wholesale price w, and we discuss each of them below.

Case i) $w < w_1(K)$*:*

By the definition of $w_1(K)$, the fact that $\bar{q}(w)$ decreases in w, and $q^*(w) > \bar{q}(w)$, we have $\bar{q}(w) > K$ and $q^*(w) > K$. Thus, it is optimal for firm $D$to produce a quantity exceeding his ex ante capacity. firm Dmaximizes $P(q)q-c(q)-wq-f(q-K)$ 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) $w \geq w_2(K)$*:*

By the definition of $w_2(K)$, the fact that $q^*(w)$ decreases in w, and $q^*(w) > \bar{q}(w)$, we have $\bar{q}(w) < K$ and $q^*(w) \leq K$. In this case, firm Dnever produces more than his ex ante capacity. firm Dmaximizes $P(q)q - c(q) - wq$ subject to $q \leq K$, and 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 $w_2(K)$, the fact that $\bar{q}(w), q^*(w)$ decrease in w, and $q^*(w) > \bar{q}(w)$, we have $\bar{q}(w) \leq K < q^*(w)$. It is optimal for firm $D$to produce no larger than K if he expands his ex ante capacity K. Thus, in this case firm Ddoes not expand his capacity and he maximizes $P(q)q - c(q) - wq$ subject to $q \leq K$. The constraint is binding since $K < q^*(w)$. Firm D's equilibrium quantity is K, given by the heavy horizontal line between $\bar{q}(w)$ and $q^*(w)$ in Figure 1.

Collectively, at given value of K, Firm D's equilibrium quantity $q(K, w)$ in Stage 3 is kinked in the value of w, as shown by the heavy kinked curve in Figure 1. We then obtain the results as summarized in the lemma. □

Proof of Lemma 2. Before proving the lemma, we first provide the precise characterization of the conditions in Assumption 2. Next, we establish some structural properties of the wholesale prices for firm U. Finally, we return to the lemma.

1) Precise characterization of Assumption 2:

We first show that under Assumption 2, the second-order condition is satisfied for firm U's profit maximization. Let the optimal quantity produced by firm $D$by $q(w)$, suppressing $q(w) = q^*(w)$ or $q(w) = \bar{q}(w)$. By (6) and (7), second order condition requires

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

By (14) and (15), we have

$$\frac{dq^2(w)}{dw^2} = -\frac{1}{H_1^2}[P'''(q)q + 3P''(q) - C''']\frac{dq(w)}{dw}$$

with $H_1 \equiv P''(q)q + 2P'(q) - C''$ if $q(w) = q^*(w)$, and

$$\frac{dq^2(w)}{dw^2} = -\frac{1}{H_2^2}[P'''(q)q + 3P''(q) - C''' - f''']\frac{dq(w)}{dw}$$

with $H_2 \equiv P''(q)q + 2P'(q) - C'' - f''$ if $q(w) = \bar{q}(w)$. Reorganizing the second-order condition gives

$$P'''(q)q + 3P''(q) - C''' < \frac{2H_1^2}{w - v} \tag{17}$$

for $q(w) = q^*(w)$ and

$$P'''(q)q + 3P''(q) - C''' - f''' < \frac{2H_2^2}{w - v} \tag{18}$$

for $q(w) = \bar{q}(w)$. As long as the left-hand sides of (17) and (18) are small as assumed by Assumption 2, these two inequalities hold and the existence and uniqueness of w^* and $\bar{w}$ are guaranteed.

2) Structural properties of firm U's wholesale prices:

1) $(w^* - v)q^*(w^*) > (\bar{w} - v)\bar{q}(\bar{w})$:

To prove this, observe that

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

Therefore, we obtain that

$$(w^* - v)q^*(w^*) > (\bar{w} - v)\bar{q}(\bar{w}).$$

2) $w^E > w^*$:

To show that $w^E > w^*$, we use the negation argument. Suppose by negation that $w^E \leq w^*$. By the definition of w^E, $\bar{w} < w^E \leq w^*$. Recall that firm U's profit is $(w - v)q^*(w)$ when $q^*(w)$ is produced in Stage 3. Thus, by (6) and Assumption 2, firm U's profit increases in w for $w \leq w^*$. Therefore,

$$(w^E - v)q^*(w^E) > (\bar{w} - v)q^*(\bar{w}) > (\bar{w} - v)\bar{q}(\bar{w}),$$

where the second inequality follows from (4). This, however, contradicts (8), and thus it must be $w^E > w^*$. Note that this asserts that point B lies above point E on the curve $q^*(w)$ in Figure 2. By (14), it follows that $q^*(w^E) < q^*(w^*)$.

3) CM's optimal wholesale price decisions:

Now we proceed to prove the lemma. At any given K, in Stage 2 firm U can modify w to induce firm $D$to produce any quantity along the kinked curve $q(K, w)$ in Stage 3. Since $q^*(w^E) < q^*(w^*)$, there are three cases according to the ex ante established capacity K. We discuss each of them in what follows.

Case 1) $K \leq q^*(w^E)$*:*

In this case, $w_2(K) \geq w^E$ by the definition of $w_2(K)$ and the fact that $q^*(w)$ decreases in w. Firm D's equilibrium quantity $q(K, w)$ passes point A but not point B. Along $\bar{q}(w)$, point A maximizes Firm U's profit and is achievable for Firm U at $w = \bar{w}$. Along $q^*(w)$, the optimal point achievable for Firm U is point V at $w = w_2(K)$. Moreover, along segment UV on $q(K, w)$, point V is optimal for Firm U. This is because along UV, Firm U's profit is $(w - v)K$, which is maximized at $w = w_2(K)$. Thus, Firm U shall compare two prices: $w_2(K)$ for her profit at point V, and $\bar{w}$ for her profit at point A. By Assumption 2 and the optimality of w^*, Firm U's profit along $q^*(w)$, given by $(w - v)q^*(w)$, decreases in w for $w > w^*$. Thus,

$$(w_2(K) - v)K = (w_2(K) - v)q^*(w_2(K)) \leq (w^E - v)q^*(w^E) = (\bar{w} - v)\bar{q}(\bar{w}),$$

where the equality holds only when $K = q^*(w^E)$. It follows that $\bar{w}$ is optimal for Firm U.

Case 2) $K \in (q^*(w^E), q^*(w^*))$:

We have $w^* < w_2(K) < w^E$. 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 $\bar{q}(w)$, Firm U finds it optimal to set $w = \bar{w}$ for her profit at point A. On the other hand, along $q^*(w)$, Firm U optimally sets $w = w_2(K)$ for her profit at point V. Along segment UV on $q(K, w)$, point V is optimal for Firm U. Thus, Firm U again compares two prices: $w_2(K)$ and $\bar{w}$. Since $(w - v)q^*(w)$ decreases in w for $w > w^*$, we have

$$(w_2(K) - v)K = (w_2(K) - v)q^*(w_2(K)) > (w^E - v)q^*(w^E) = (\bar{w} - v)\bar{q}(\bar{w}).$$

It follows that $w_2(K)$ is optimal for Firm U.

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 U to set $w = w_1(K)$ at point U; along $q^*(w)$, setting $w = w_2(K)$ is optimal (at point V). We observe that point V strictly dominates point U for Firm U since $(w_2(K)-v)K > (w_1(K)-v)K$ as $w_2(K) > w_1(K)$. Thus, $w_2(K)$ is optimal for Firm U.

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 U 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 $(w^* - v)q^*(w^*) > (\bar{w} - v)\bar{q}(\bar{w})$, Firm U sets $w = w^*$.

3b) $K > \bar{q}(\bar{w})$:

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

Collectively, Firm U's optimal wholesale price decision is as expressed in the lemma. □

Proof of Corollary 1. We prove this by contradiction. Suppose under (9), $w^* \leq \bar{w}$. At w^*, due to the optimality of $q^*(w)$, we have

$$\begin{aligned}\pi_o^* &= P(q^*(w^*))q^*(w^*) - C(q^*(w^*)) - w^*q^*(w^*) \\ &> P(\bar{q}(w^*))\bar{q}(w^*) - C(\bar{q}(w^*)) - w^*\bar{q}(w^*).\end{aligned}$$

By (3), we have

$$\begin{aligned}&\frac{d}{dw}[P(\bar{q}(w))\bar{q}(w) - C(\bar{q}(w)) - w\bar{q}(w)] \\ = &\frac{\partial[P(\bar{q}(w))\bar{q}(w) - C(\bar{q}(w)) - w\bar{q}(w)]}{\partial q}\frac{d\bar{q}(w)}{dw} + \frac{\partial[P(\bar{q}(w))\bar{q}(w) - C(\bar{q}(w)) - w\bar{q}(w)]}{\partial w} \\ = &-f'(\bar{q}(w))\frac{d\bar{q}(w)}{dw} - \bar{q}(w) \\ < &\ 0.\end{aligned}$$

Hence,

$$\begin{aligned}&P(\bar{q}(w^*))\bar{q}(w^*) - C(\bar{q}(w^*)) - w^*\bar{q}(w^*) \\ \geq\ &P(\bar{q}(\bar{w}))\bar{q}(\bar{w}) - C(\bar{q}(\bar{w})) - \bar{w}\bar{q}(\bar{w}) \\ >\ &P(\bar{q}(\bar{w}))\bar{q}(\bar{w}) - C(\bar{q}(\bar{w})) - \bar{w}\bar{q}(\bar{w}) - f[\bar{q}(\bar{w}) - q^*(w^E)] \\ =\ &\bar{\pi} - f(\bar{q}(\bar{w}) - q^*(w^E)),\end{aligned}$$

where the first inequality follows from $w^* \leq \bar{w}$ and the second inequality is because $f[\bar{q}(\bar{w}) - q^*(w^E)] > 0$. It then holds that $\pi_o^* > \bar{\pi}_o - f(\bar{q}(\bar{w}) - q^*(w^E))$, which contradicts Condition (9). Therefore, we conclude that $\bar{w} < w^*$ whenever (9) is true. □

Proof of Corollary 2. The corollary directly follows from the proof of Theorem **??**. □

Proof of Corollaries 3-6. The results follow from straightforward calculations and thus the details are omitted. □

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