Timing the Price Agreement in High-Tech Component Procurement

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We consider a high-technology supply chain wherein a manufacturer is sourcing a new component from a monopolistic supplier who has limited production capacity. We focus on a setting wherein the manufacturer has decided to adopt the component but has not introduced the end product to the market and the manufacturer's task is to negotiate with the supplier for the procurement price before a deadline. The only uncertainty is the number of manufacturers adopting this component, which determines the supplier's outside option. With this uncertainty, delaying the agreement could be preferable because the manufacturer may receive a price cut if the supplier's outside option turns out to be weak. However, delay could also be costly as the supplier may refuse to sell or ask for a high price if many adopters show up. Thus, the timing of agreement for the manufacturer is a trade-off between the benefit of collecting more information and the risk of losing the limited supply (or paying a high price). Given that the firms are rational, information is symmetric, and the manufacturer's outside option is to use older technologies, we derive the manufacturer's optimal timing strategy—how to set the deadline and whether to delay the agreement. Interestingly, we find that the manufacturer can benefit more from waiting when there is a greater chance that other higher-value buyers exist. Furthermore, in certain circumstances, we find that the manufacturer should commit to a tighter deadline, even though it is optimal to delay the agreement.

1. Introduction

In high-technology industries, manufacturers such as Apple and Huawei are constantly upgrading their products by incorporating components based on innovative technologies (e.g., OLED screens and microprocessors). When a novel technology/component is first introduced to the market by a supplier, downstream manufacturers decide whether to adopt the component for their final products by evaluating its performance and compare it with the existing mature ones. If a manufacturer decides to adopt the novel component, it then offers a quantity based on the sales plan and negotiates with the supplier about the price. Such price negotiations are important because component costs can be quite significant for

manufacturers. For example, technical components of iPhone 5 (excluding packaging, production, licensing fees, research and development, and all other costs) contribute about 66.6% of the total manufacturing and operating cost (Sherman 2013). In this study, we focus on a manufacturer's bargaining strategy when sourcing a novel component.

A common bargaining tactic used by large buyers like Apple is to let suppliers compete against each other (Mickle 2020). Such a tactic is effective when sourcing standard components which competing suppliers can all produce. However, this tactic may lose its power when sourcing novel components which only the innovative supplier can produce. For example, VIAVI Solutions Inc., the company that enabled Apple's Face ID function, was the only supplier of

optical filters needed for the 3D sensing modules in smartphones (Rai and Nellis 2018). Although it is possible that the innovative component has standard substitutes based on mature technologies, the component normally has additional value over its mature substitutes due to superior performance (e.g., speed, power consumption) which makes the supplier effectively a monopoly in selling the differentiated novel component. For example, in the period around late 2018 and early 2019, Samsung was the only supplier of processors with the 5-nanometer process technology (TSMC started 5-nanometer volume production only from the end of 2019). Though a buyer can use processors based on mature process technology (such as the 7-nanometer process) made by other suppliers such as TSMC, the novel 5-nanometer process technology does bring additional value to the buyer due to its better performance.

The supplier of a novel component has a strong bargaining power for its monopoly position in selling the differentiated innovative component. But it also has the cost in that the market prospect of a novel component is usually uncertain. When a novel component is first introduced to the market, it remains unclear which manufacturers will choose to adopt the new component. One tactic that some end-product manufacturers use when negotiating with a monopolistic novel component supplier is to leverage such uncertain market prospect of the new component by strategically managing the timing of reaching a price agreement. However, how such a tactic should be designed and implemented in the procurement of high-technology components has not yet been well studied in the literature.

In this work, we study a bilateral negotiation between a monopolistic supplier of a novel-technology-based component and a focal buyer (an end-product manufacturer). Our goal is to examine whether and when the buyer should delay the price agreement with the supplier, given that the technical uncertainties associated with the component (e.g., performance and yield) have all been resolved and the buyer has decided to adopt it. We consider the following unique features of price negotiation in the procurement of such high-technology components.

The Supplier. To develop new technologies and build production capacity, component suppliers face long lead times and high fixed costs. To mitigate risks, these suppliers engage with end-product manufacturers during their development cycles. Engineers from both sides may participate in each other's design efforts. Such relationships allow suppliers to collect some information about the market prospects of new technologies in the design stage. Nevertheless, these component suppliers have to commit to capacity levels and introduce new components to the market before they have full information. Once a new component is introduced, the technical specifications are certain and published, and the supplier wait for manufacturers' adoption decisions. In the microprocessor industry, the number of buyers (i.e., the industry acceptance) for a new processor is normally uncertain, and the average selling price of a processor is correlated with the number of buyers after controlling for the brand (i.e., market segment) and the process technology (i.e., the technical performance). In Figure 1, we present two examples with the data we collected from a major microprocessor supplier. In each example, we plot with a linear trend line the average price against the number of buyers for all the processor products of the same brand and the same process technology. We can see that the average price of a product is higher when there are more buyers for the product. Hence, the supplier's bargaining position is strengthened as more buyers adopt a new component.

The Buyer. Buyers commence design and production planning of new versions of their products in anticipation of the new component technologies. The adoption decisions are normally made by buyers after uncertainties are resolved regarding the new components' yield and technical performance. When a buyer decides to incorporate a new component into a new/upgraded end product, it offers to buy a certain quantity from the supplier and then the price negotiation starts. Note that the component is one of a large bill of materials for the end product, for which the component procurement quantities are set by the production or sales plans (Zhang et al. 2016). Hence, the price negotiation will not affect the total sourcing quantity.[1] According to our communications with practitioners from the high-technology industries, a buyer may offer to buy other components from the supplier—which we call side payments—rather than to change the quantity of the focal component, so as to settle the price agreement. In order to launch the new product in time, a price agreement must be reached with the supplier before the production begins. Given this time window, the buyer can make decisions on two aspects: one is to decide whether to accept the price proposed by the supplier (or to propose a price that is acceptable to the supplier), and the other is to commit to a deadline (e.g., by announcing the introduction date of the new product).

Information Structure. In high-technology (such as the microprocessor) markets, firms along the supply chain normally form deep cooperations which allow efficient communications. In addition, buyers' adoption decisions are often publicly announced or reported by the media (e.g., Ungureanu 2016), so both the buyer and supplier are able to learn about the industry acceptance of the new component.

Figure 1   Relationship between Number of Buyers and Average Product Price [Color figure can be viewed at wileyonlinelibrary.com]
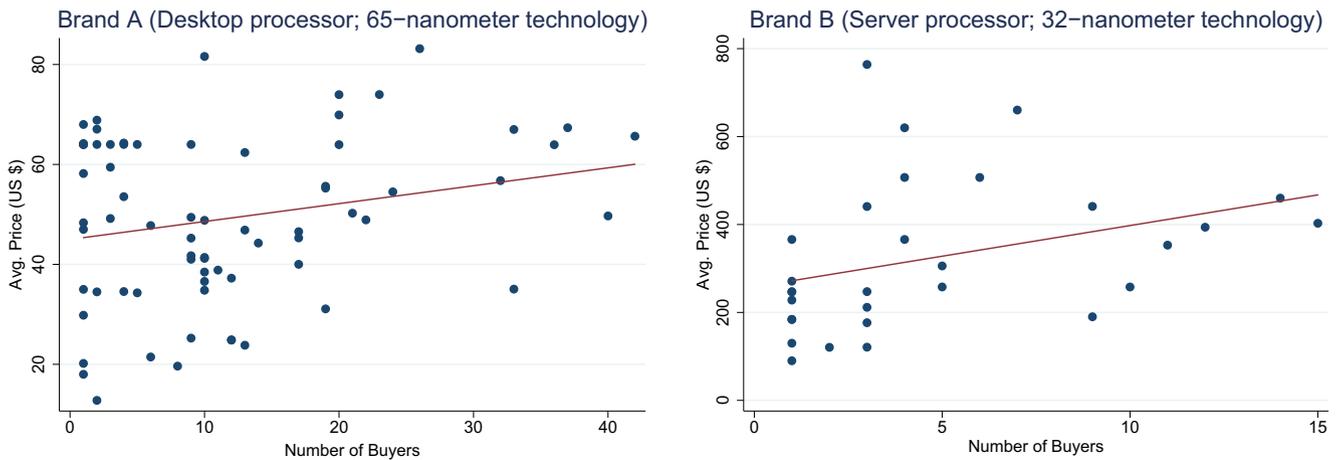
Therefore, it is reasonable to assume that information is symmetric between the manufacturer and supplier.

Hence, in this bilateral negotiation, there could be big uncertainty associated with the monopolistic supplier's outside option (i.e., the number of buyers), while the buyer's outside option is to continue using an existing component, for which the procurement cost is certain. If the supplier's outside option turns out to be strong, the supplier may refuse to sell or ask for a high price; otherwise, the buyer may receive a price cut if the supplier's outside option is weakened while they wait. Therefore, the timing of agreement for the buyer is a trade-off between the benefit of collecting more information about the industry acceptance of the new component and the risk of losing the limited supply (or paying a high price) when many other high-value buyers show up. Admittedly, sometimes delay of price agreement could be driven by other factors such as the uncertainty associated with the demand of the end product. Hence, to clearly test whether delaying the price agreement could benefit the buyer, we focus on the situation wherein the buyer cannot learn about the demand of the end product during the price negotiation. This is plausible because no additional demand information could be collected before the end product is launched.

In such a setting, we are interested in the following questions. How should a manufacturer formulate the timing strategy when negotiating with a supplier over the price of a new-technology-based component, given that there are no other factors that motivate agreement delay? Specifically, how much should the manufacturer delay the agreement with the potential existence of other high-value buying firms? Should the manufacturer commit to a tight or loose negotiation deadline? Should a manufacturer further delay the price agreement or push for an earlier agreement when there is a higher chance that the industry

acceptance of the new component is strong? Based on the aforementioned context, we build a stylized, dynamic bargaining model and obtain the following findings.

First, we characterize conditions under which the manufacturer and supplier should delay their price agreement and analyze factors affecting the joint value of delaying the agreement. Interestingly, we find that the manufacturer may find it more attractive to delay the agreement when the chance of strong adoptions of the new component increases but still within the range that warrants the firms' participations in the negotiation. This result is somewhat against the intuition, because we often see that buyers and sellers take the likelihood of higher-value buyers showing up as a pressure (for buyers) or an excuse (for sellers) to reach an agreement as soon as possible.

Second, we show that extending the deadline can hurt the manufacturer, even when it is optimal for the manufacturer to delay the agreement. In particular, when (1) the manufacturer has a low bargaining power, (2) learning is fast, (3) side payments (i.e., the payment made to induce participation in the negotiation) are not permitted, and/or (4) the chance of other higher-value buyers showing up is relatively low, the manufacturer faces inconsistency between the two levers to control the timing of agreement: a tighter deadline and a delayed agreement. This is because learning in such circumstances mainly benefits the supplier, and a tighter deadline weakens the value of learning as well as the supplier's bargaining position (and thus should be preferred by the manufacturer). Once the deadline is set, it is optimal for the manufacturer to delay the agreement because the supplier has a strong interest to learn and is not willing to make concessions at the beginning. Therefore, the two bargaining tactics—committing to a deadline and delaying the agreement—have to be combined wisely.

Lastly, by extending our base model and allowing the firms to change the target quantity, we show that firms can avoid a breakdown of the negotiation by increasing the order quantity significantly when other higher-value buyers are likely to show up. However, this strategy works only when the magnitude of quantity change is large enough and the value of the new technology for the manufacturer is significantly different under different market conditions.

The remainder of the study is organized as follows. We first review the related literature and summarize our theoretic contribution in Section 2. Then we introduce the model preliminaries in Section 3 and analyze the negotiation in Section 4. In Section 5, we extend our base model in a number of ways to demonstrate the robustness of our results. Finally, we present our conclusions in Section 6.

2. Related Literature

This study is related to two streams of research in the literature: vertical bargaining in supply chains and bargaining with delay of agreements. To the best of our knowledge, our study is the first to explicitly model business-to-business (B2B) bargaining for the procurement of a new component technology.

Existing literature on B2B or supply chain bargaining focuses on how the bargaining game structure (rather than the timing of agreements) affects the profits and profit allocation among supply chain members. Depending on the game structure considered, two main streams of research exist. One stream assumes that multilateral bargaining happens sequentially among supply chain members and bargaining outcomes depend on the position of each firm in the sequence. In an assembly-chain setting, Nagarajan and Bassok (2008) consider suppliers who form multilateral bargaining coalitions and compete for a position in the bargaining sequence. Zhang et al. (2016) use a stochastic sequential bargaining model to study how prices depend on the procurement quantities in the microprocessor market. In the other stream of research, simultaneous multilateral-negotiation models (e.g., Aydin and Heese 2015, Dukes et al. 2006, Feng and Lu 2013, Guo and Iyer 2013, Lovejoy 2010) focus on the static equilibrium in which the profit allocation is determined by a negotiator's contribution to the entire system. These studies do not consider the timing of agreements. We contribute to this literature by showing how learning about the seller's outside option affects the timing of agreement and how the timing affects the profit allocation between two supply chain partners.

Delay in reaching agreements has been frequently observed in practice and studied in the literature. Thus far, five causes of delay have been identified:

information asymmetry, random delay of price offers, history-dependent preference, multi-person sequence game, and externalities among buyers. Cramton (1984) is among the earliest to study the phenomenon that trade often occurs after costly delay and attributed the delay to the need for participants to learn (or signal) each other's valuation under incomplete information. Later, several researcher explored the impact of asymmetric information on bargaining delay in a variety of settings (e.g., Admati and Perry (1987), Cramton (1992), Damiano et al. (2012), and Feng et al. (2015)). Fuchs and Skrzypacz (2010) study a model that combines information asymmetry and the arrival of new buyers. They assume that the seller has full pricing power and the seller's outside option is fixed. But the main feature of our context is the uncertainty in supplier's outside option. Roth et al. (1988) consider bargaining with deadlines and document some experimental evidence of last-minute agreements. Based on this observation, Ma and Manove (1993) propose a continuous-time, alternating-offer model with a deadline and symmetric information. They assume that players can decide when to make an offer or counteroffer but only after a period of exogenous, random delay due to information transmission and processing. Their model predicts that players adopt strategic delay early in the game and reach an agreement late in the game if at all. Because the player who makes an offer closer to the deadline is less likely to be rejected, the delay in the model is driven by the desire to obtain a stronger bargaining power. However, long and random communication lead time is not an appropriate assumption in high-technology industries. Under the assumption of symmetric information, the models proposed by Fershtman and Seidmann (1993) and Li (2007) both predict delay of agreement; however, their models deviate from the assumption of rational behavior and rely on history-dependent commitment or preferences. Jéhiel and Moldovanu (1995) showed that, under complete information, positive or negative externalities between buyers can induce delay in negotiations between a seller and several buyers. Cai (2000) studies delay of agreement in multilateral bargaining with symmetric information. In their model, agreements must be reached with all players in the game and the sequence matters. If weak players who reach agreements earlier can be forced to accept much smaller shares than tough players who reach agreements later, then delay can arise. Assuming symmetric (or complete) information, we contribute to this literature by offering a new explanatory factor for delay: learning about the seller's (or the buyer's) outside option. In addition, while nearly all of the previous studies argue that delay is inefficient, we offer a counter argument that delay can benefit both negotiating parties.

More importantly, our theory is the only one that can explain delayed price agreements in high-technology markets where players are rational, information is symmetric, negotiation may break down, and the adoption of a new component may not generate significant externalities among the manufacturers.

3. The Base Model

For the ease of presentation, we perform our initial analysis using a model that has a few simplifying assumptions. Subsequently, in Section 5, we relax these assumptions and show that the insights we gain from our base model remain intact.

Consider a high-technology manufacturer $\mathscr{B}$ (the buyer) who decides to adopt a new component (or process technology) from supplier $\mathscr{S}$ (the seller). The buyer $\mathscr{B}$ produces a final product made of a large number of components, including the one sourced from the seller $\mathscr{S}$. Motivated by the practices in the semiconductor industry, we first consider the case that $\mathscr{B}$ requests a fixed target quantity Q (according to the planned bill of materials) and negotiates with $\mathscr{S}$ for the unit price. Later, in Section 5.2, we shall generalize our results by allowing the buyer and supplier to change the quantity by incurring a fixed cost. Without loss of generality, we assume that $\mathscr{B}$ is the first adopter of this new technology and starts the price negotiation with $\mathscr{S}$ in period 1. Because the end product made by $\mathscr{B}$ must be launched on time, $\mathscr{B}$ has to reach an agreement with $\mathscr{S}$ by period $T \geq 1$; otherwise, $\mathscr{B}$ must give up the new technology and receive a fixed payoff (by using a mature technology) that is normalized to zero, while $\mathscr{S}$ may continue the selling. Thus, there is a fixed negotiation deadline: period T.

$\mathscr{S}$ has a fixed production capacity due to long construction lead times and heavy investments. As discussed earlier in the introduction, we assume that the monetary value of each unit of the capacity depends on N, the total number of adopters including $\mathscr{B}$. However, N is unknown to either $\mathscr{B}$ or $\mathscr{S}$ at the beginning. The larger N is, the higher the average price $\mathscr{S}$ can charge in equilibrium. For the sake of tractability, we consider a simplified model with two possible market conditions: an average market, wherein $N = N_L = 1$, and a good market, wherein $N = N_H > N_L$. (We consider a more general setting by allowing $N_L > 1$ in the numerical explorations.) We denote the outside-option value of each unit of the target quantity to the seller in a good (average) market as π_H (π_L). Note that π_H (π_L) is a net value which captures the loss for not satisfying $\mathscr{B}$. Without loss of generality, we assume $\pi_H > 0$ and normalize π_L to zero. Denote as v the value of each unit of the component for $\mathscr{B}$. This value depends on its impact on the performance of the end product (relative to alternative components based on mature technologies)

and/or the cost savings in productions. In the base model, we assume that the value v is independent of the market condition. In Section 5.1, we will show that the results are robust even if v depends on the market condition. Without loss of generality, we normalize the marginal production costs for both $\mathscr{B}$ and $\mathscr{S}$ to zero.

Given the above model setting, it is important for both $\mathscr{B}$ and $\mathscr{S}$ to learn about the market condition by observing whether there is a second adopter, which signals a strong market. Due to heterogeneity in development cycles, manufacturers may decide to adopt the new technology at different times. While $\mathscr{S}$ and $\mathscr{B}$ negotiate, a design-win may or may not be achieved with another major buyer. Denote as α the probability that a new design-win is achieved in each period t (starting from period 2) in a good market. We assume that there can be at most one design-win in each period. This assumption is less restrictive than it appears because we can set the length of each period to be very short.[2]

The negotiation between $\mathscr{S}$ and $\mathscr{B}$ proceeds as follows. In each period, both parties first check whether a new design-win has been achieved and update their common belief about the market condition. Then one party is randomly selected to propose a price; if the other party accepts the price, an agreement is reached; otherwise, both parties wait until the next period and the process repeats. Such a random-proposer bargaining game is commonly used in the literature. Similar settings can be found in Fershtman and Seidmann (1993) and Muthoo (1999). In this game, $\mathscr{B}$'s relative power of bargaining is measured by $\beta \in (0, 1)$, where β represents the probability that $\mathscr{B}$ proposes the price in each period. This is because the proposer can set the price to the reservation price of the other party when an agreement is possible and thus seize a larger share of the surplus. We can also model the bargaining powers and splits of surplus using Nash bargaining (Nash 1950), under which our results continue to hold. Readers are referred to the online supplement for more details. Given that delaying the agreement could be costly for both the seller and buyer, we assume that it costs the seller $c_S \geq 0$ and the buyer $c_B > 0$ per period unless an agreement has been reached or the bargaining breaks down. For the ease of exposition, we define $c_* = c_S + c_B$ as the joint cost of delaying per period.

It is a common prior belief that $\Pr\{N = N_H\} = \gamma \in (0, 1)$. Let N_t denote the number of adopters that have appeared by period t. We have $N_1 = 1$ and $\Pr\{N = N_H | N_t > 1\} = 1$. According to the Bayes' rule, we know that

$$\Pr\{N = N_H | N_{1+t} = 1, t \geq 0\} = \frac{\gamma(1-\alpha)^t}{1 - \gamma + \gamma(1-\alpha)^t}. \quad (1)$$

Hence, the belief about the market condition in period t depends on the history, $\{N_k\}_{k=1}^t$. Let $\theta_t = \Pr\{N = N_H | \{N_k\}_{k=1}^t\}$ be the common belief in period t and thus the expected per-unit opportunity cost for seller $\mathscr{S}$ in period t is $\theta_t \pi_H$.

Finally, the negotiation terminates when either an agreement is achieved or the negotiation breaks down. The negotiation breaks down when (i) the deadline is reached or (ii) the market condition is known yet an agreement is not achieved (because any additional delay is unnecessary). Another possible scenario for a breakdown of the negotiation is if continuing the negotiation results in negative expected payoffs for one of the parties. However, we will show that, if the firms decide to participate in the negotiation and side payments are allowed, quitting can always be avoided through side payments unless the deadline is reached or a strong market is confirmed. We allow side payments in our model because rational decision makers will try to avoid an inefficient breakdown of the negotiation. In practice, side payments may take various forms such as future business opportunities and priorities. Side payments have been widely studied in the supply chain literature as a means of increasing channel profits (Tsay and Agrawal 2004).

In Figure 2, we illustrate the timeline of events. We summarize in Table 1 all the model parameters, which are public information. All the proofs are presented in the supplement.

4. Model Analysis

This is a non-stationary, strategic bargaining model with symmetric information, the result of which depends on the bargaining powers, the value of trade, and the outside option values. The bargaining powers (i.e., β and $1 - \beta$) and the value of trade (i.e., vQ) are fixed in this game, but the seller's outside option value may change as the players learn about the market condition. As described in the previous section, the buyer's outside option value is 0 and the seller's expected per unit outside option value is $\theta_t \cdot \pi_H$. Clearly, an agreement can be reached in period t only if $v \geq \theta_t \cdot \pi_H$; however, an agreement may not be
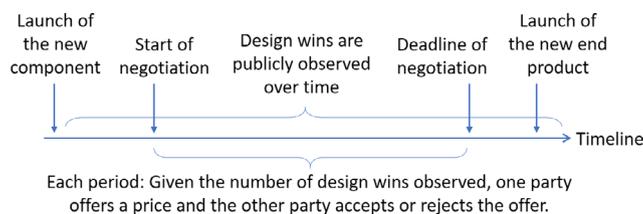
Table 1   Summary Table of Notations used in the Main Model

Notation	Meaning
α	The probability of having a design-win in each period conditional on $N_t < N$.
v	The value of each unit of component to the buyer.
Q	The selling quantity in the negotiation.
$\mathscr{S}$ ($\mathscr{B}$)	The focal seller (buyer).
T	The total number of periods in the negotiation.
β	The buyer's bargaining power (probability of proposing the price).
c_s (c_B)	The fixed bargaining and delaying cost per period for the seller (buyer).
N_H (N_L)	The total number of adopters in a good (average) market.
N_t	The number of adopters who have appeared by period t.
π_H	The seller's per unit opportunity cost of selling to the buyer in a good market.
γ	The common prior belief of a good market.
θ_t	The belief of a good market in period t.
U_t^S (U_t^B)	The expected payoff for the seller (buyer) of not reaching an agreement in period t.
$\hat{U}_t^S$ ($\hat{U}_t^B$)	The expected payoff for the seller (buyer) for continuing the negotiation.
δ_t	The joint value of delay in period t ($\delta_t = U_t^B + U_t^S + c_S + c_B - vQ$).
u_0	The joint expected payoff of a negotiation ($u_0 = U_0^B + U_0^S$).

reached even if $v \geq \theta_t \cdot \pi_H$. Our goal in this section is to understand when an agreement should be reached. Because the bargaining has a deadline, we will use a backward induction to solve this dynamic game.

First, notice that θ_t is a function of $\{N_k\}_{k=1}^t$ and from the firms' perspective the evolution of $\{N_k\}_{k=1}^t$ in turn depends on θ_t. Hence, define the state in period t as $\{N_t, \theta_t\}$, and the state transition takes the following form:

$$N_{t+1} = \begin{cases} N_t + 1 & \text{w.p. } \alpha\theta_t \\ N_t & \text{w.p. } 1 - \alpha\theta_t \end{cases} \text{ and } \theta_{t+1} = \begin{cases} 1 & \text{if } N_{t+1} > N_L \\ \frac{(1-\alpha)\theta_t}{1-\alpha\theta_t} & \text{if } N_{t+1} = N_L \end{cases}.$$

(2)

Let U_t^B and U_t^S be the expected payoff for the buyer and seller, respectively, in period t (≥ 1) given that no agreement is reached. Note that the worst case for either $\mathscr{S}$ or $\mathscr{B}$ is to receive the outside option value, so we have $U_t^B \geq 0$ and $U_t^S \geq \pi_H \gamma Q$. Accordingly, the lowest price acceptable for the seller in period t is U_t^S / Q and the highest price acceptable for the buyer is $v - U_t^B / Q$. Thus, an agreement can be reached in period t if and only if $U_t^S \leq vQ - U_t^B$ or, equivalently,

$$U_t^S + U_t^B \leq vQ. \tag{3}$$

We now derive the explicit forms of U_t^B and U_t^S. If an agreement cannot be reached by period T, the buyer will receive a payoff of 0 in period $T + 1$ and the seller will receive an expected payoff of $\theta_T \cdot \pi_H \cdot Q$. Hence, we have $U_T^B = 0$ and $U_T^S = \theta_T \cdot \pi_H \cdot Q$. In any

Figure 2   The Timeline of Events [Color figure can be viewed at wileyonlinelibrary.com]

Launch of the new component | Start of negotiation | Design wins are publicly observed over time | Deadline of negotiation | Launch of the new end product

→ Timeline

Each period: Given the number of design wins observed, one party offers a price and the other party accepts or rejects the offer.

period $t+1$ where $t \leq T-1$, either the negotiation breaks down or one firm is randomly selected to offer a price. If the buyer makes the offer, the best price is $\min\{v - U_{t+1}^B/Q, U_{t+1}^S/Q\}$ and the buyer's payoff is $\max\{U_{t+1}^B, vQ - U_{t+1}^S\}$. If the seller makes the offer, the buyer's payoff is always U_{t+1}^B because the price offered by the seller (i.e., $\max\{v - U_{t+1}^B/Q, U_{t+1}^S/Q\}$) will not be lower than $\mathscr{B}$'s highest acceptable price (i.e., $v - U_{t+1}^B/Q$). Therefore, the expected payoff for $\mathscr{B}$ in period t conditional on continuing the negotiation is

$$\hat{U}_t^B(N_t, \theta_t) = \mathbf{E}\big[\beta \max\{U_{t+1}^B, vQ - U_{t+1}^S\} + (1-\beta)\,U_{t+1}^B | N_t, \theta_t\big] - c_B. \tag{4}$$

Similarly, the expected payoff for $\mathscr{S}$ in period t conditional on continuing the negotiation is

$$\hat{U}_t^S(N_t, \theta_t) = \mathbf{E}\big[\beta U_{t+1}^S + (1-\beta)\max\{U_{t+1}^S, vQ - U_{t+1}^B\} | N_t, \theta_t\big] - c_S. \tag{5}$$

Note that we have $U_t^B = \max\{0, \hat{U}_t^B\}$ and $U_t^S = \max\{\pi_H \theta_t Q, \hat{U}_t^S\}$.

4.1. The Condition for Participation

We now study when it is profitable for the firms to enter the negotiation and to continue the process. To prepare, define U_0^S and U_0^B as the expected payoffs associated with the target capacity for the seller and buyer, respectively, at the beginning of period 1 given that the firms enter the negotiation. The outside payoffs associated with the target capacity at the beginning of period 1 are $\gamma \pi_H Q$ for the seller and 0 for the buyer. Hence, the firms would enter negotiation as long as $U_0^S \geq \gamma \pi_H Q$ and $U_0^B \geq 0$. Alternatively, if $U_0^S + U_0^B \geq \gamma \pi_H Q$ and side payments can be made, firms would also negotiate. To ensure that the firms do not quit, similar conditions are required during the negotiation. In particular, if side payments cannot be made, participation and delay would be beneficial and voluntary if $\hat{U}_t^B \geq 0$ and $\hat{U}_t^S \geq \theta_t \pi_H Q$ for all possible t, wherein we define $\hat{U}_0^B = U_0^B$ and $\hat{U}_0^S = U_0^S$. The following lemma gives sufficient conditions for both firms to participate at the outset and to continue the negotiation.

LEMMA 1. *If one of the following conditions is satisfied, firms will participate in negotiation at the outset and the negotiation will not break down in period t unless the deadline is reached or the market condition is known:*

1. *firms can make side payments to each other and $vQ \geq \gamma \pi_H Q + c_*$;*
2. *$vQ \geq \gamma \pi_H Q + \rho c_*$ wherein*

$$\rho = \max\left\{\frac{1 + \alpha\gamma - (1-\alpha\gamma)^{T-1}}{\alpha\beta\gamma(1-\alpha\gamma)^{T-1}} \cdot \frac{c_B}{c_*}, \frac{T}{1-\beta} \cdot \frac{c_S}{c_*}\right\}. \tag{6}$$

Therefore, when condition for agreement (8) given below is not met but one of the conditions listed in Lemma 1 is satisfied, delaying the agreement would be beneficial for the two firms and thus quitting will not happen unless the deadline is reached or the market condition is known.

4.2. The Condition for Agreement

Combining (2) and (3), we have

$$\hat{U}_t^B + \hat{U}_t^S = \mathbf{E}\big[\max\{U_{t+1}^B + U_{t+1}^S, vQ\} | N_t, \theta_t\big] - c_*. \tag{7}$$

If the participation conditions given in Lemma 1 are satisfied, we have $U_t^B + U_t^S = \hat{U}_t^B + \hat{U}_t^S$.

Using the iteration formula (7), we can derive the following lemma, which suggests that if bargaining is too costly for either party or the new component is of high value to the buyer, the agreement should be reached immediately. Otherwise, delay should occur unless the deadline is reached or the market condition is known.

LEMMA 2. *The agreement will be reached in period $t < T$ if and only if*

$$c_* \geq \mathbf{E}\big[\max\{0, U_{t+1}^B + U_{t+1}^S - vQ\} | N_t, \theta_t\big]. \tag{8}$$

We then derive a necessary condition for the delay of agreement and present it in Proposition 1. This gives us an easy guideline regarding when delay may occur. We also learn from Proposition 1 that, if buyer $\mathscr{B}$ is strategically important to seller S such that the net outside-option value π_H is low, then the agreement will never be delayed.

PROPOSITION 1. *If $vQ \geq \pi_H Q - c_*$, the agreement should never be delayed.*

Therefore, to explore when and why the buyer should delay the agreement, we focus on the interesting case wherein $vQ < \pi_H Q - c_*$ for the rest of our analysis. In addition, we assume that the conditions given in Lemma 1 is satisfied to ensure participation.

4.3. The Value of Delaying the Agreement

In this section, we define and analyze the value of delaying the agreement. To start, define

$$\begin{aligned}\delta_t(N_t, \theta_t) &= U_t^B(N_t, \theta_t) + U_t^S(N_t, \theta_t) + c_* - vQ \\ &= \mathbf{E}\big[\max\{0, U_{t+1}^B + U_{t+1}^S - vQ\} | N_t, \theta_t\big] = \mathbf{E}[\max\{0, \delta_{t+1} - c_*\} | N_t, \theta_t].\end{aligned} \tag{9}$$

Then we have that $U_t^B + U_t^S = vQ - c_* + \delta_t$ and $\delta_t(N_t, \theta_t) \geq 0$ for period $t \leq T-1$. In light of Lemma 2, *an agreement should be reached in period t if and*

only if $\delta_t \leq c_*$. Hence, δ_t can be viewed as the *joint value of delay* (JVD) in period t.

In order to understand the dynamics of the bargaining process, the key is to determine the JVD for each period t. However, it is difficult to determine the values directly. Note that δ_t depends on $U_t^B + U_t^S$, and $U_t^B + U_t^S$ can be determined iteratively from Equation (7). Thus, we perform a backward induction on $U_t^B + U_t^S$, starting from period T, and the procedures are illustrated in Table S1 in the supplement. Based on inductions, we next derive some structural properties of δ_t and the bargaining process.

Because the driving force for the delay of agreement in our problem is the learning about the seller's outside option value πQ, our intuition is that the JVD should be increasing in the level of uncertainty associated with π, holding the mean of π and other parameters constant. In our model, π follows a two-point distribution, with its variance in period t being $\mathbf{V}[\pi] = \pi_H \theta_t (1 - \theta_t)$ and its mean being $\mathbf{E}[\pi] = \pi_H \theta_t$. If we set the mean to be a constant C, then we need to set $\pi_H = C/\theta_t$. Hence, the variance becomes $\mathbf{V}[\pi | \pi_H \theta_t = C] = C(1 - \theta_t)$ and thus the level of uncertainty associated with π decreases with θ_t. Accordingly, we expect that the JVD decreases with the chance of a strong market if the seller's expected outside option value is held to be a constant. The following proposition confirms this logic.

PROPOSITION 2. *Assuming $vQ < \pi_H Q - c_*$, the participation conditions hold, and keeping the seller's expected outside option value $\pi_H \theta_t$ constant, then the value of delay is increasing in the uncertainty of the seller's outside option, that is, the joint value of delay $\delta_t(N_t, \theta_t)$ decreases in θ_t for any possible t and N_t.*

Nevertheless, without the constraint of $\pi_H \theta_t = C$, we find that the result regarding the impact of θ_t is the opposite, which is presented in Proposition 3 below.

PROPOSITION 3. *Assuming $vQ < \pi_H Q - c_*$ and the participation conditions hold, the joint value of delay $\delta_t(N_t, \theta_t)$ increases with the chance of strong adoption (θ_t) and the seller's highest possible unit opportunity cost (π_H) given any possible t and N_t.*

Proposition 3 suggests that, given a higher prior belief γ, it is more likely that the price agreement should be delayed; if no more adopters were observed over time (i.e., as θ_t decreases), it would be more and more likely over time that the price agreement should be reached. (Of course, if γ or θ_t is too high, the seller will not participate in the negotiation. But we focus on cases wherein participations are warranted.) This is somewhat against the intuition. It is

often observed in daily life that buyers and sellers take the chance of higher-value buyers showing up (γ) as a pressure (for buyers) or an excuse (for sellers) to reach an agreement. Fearing the existence of higher-value buyers, the focal buyer may be forced to accept a higher price and reach an agreement. However, our analysis shows that, for rational negotiators, a greater probability of higher-value buyers showing up could be interpreted as a higher incentive to wait and see for both the buyer and seller. The incentive for the seller is easier to understand, whereas for the buyer, the incentive comes from a potential big price cut if the higher-value buyers do not show up eventually. In theory, if the condition listed in Lemma 2 holds, then both the buyer and seller should voluntarily further delay the agreement even if side payments cannot be made. If side payments are possible but voluntary delay is not warranted, then the party that benefits the most from learning should consider (and also benefits from) subsidizing the other party in order to continue the negotiation for a longer period.

The impact of θ_t offers a partial explanation to the delay of agreement between Apple and TSMC. According to *The Wall Street Journal*, since July of 2014, Apple and TSMC have collaborated on designing and testing the 14/16-nanometer A9 processor that would power 2015 iPhones and iPads (Luk 2014). Hundreds of TSMC engineers were sent to Apple headquarters to work on the project. It was reported, however, that the price was still unsettled for this deal even in August of 2015 when TSMC already had its 14/16-nanometer FinFET Process capacity ready and the new iPhone was due to be launched soon (Lien and Shen 2015). According to our model, the reason for this delay could be a high value of learning for both Apple and TSMC, given that the 16-nanometer FinFET process technology was believed to be popular in the market. From Apple's perspective, it was better to wait and see if the belief could be weakened in the end; from TSMC's perspective, it was better to wait and see if a strong market and a higher payoff could be confirmed.

The result regarding the impact of π_H is intuitive, because a larger π_H means both a higher level of uncertainty and a larger mean value of the seller's outside option. Note that π_H may carry the influence from several factors, including the size of the target quantity relative to the seller's capacity level, the scale of adoption in a good market, other buyers' valuation of the component, and their bargaining powers. A larger π_H not only means a larger value of learning for the seller, but from the buyer's perspective, there is also a high incentive to learn as well. This is because, when π_H is high, the joint surplus (i.e., $(v - \pi_H \theta_t)Q$) is small if they agree immediately, and thus the buyer has to pay a high price. Therefore, the downside of

delay is limited but the upside is high for the buyer when π_H is high.

In the following, we study how the value of delay depends on the delaying cost c_*. We show that its impact is negative on $\delta_t(N_t, \theta_t)$. Therefore, as the bargaining and delaying costs increase, it is less likely to have $\delta_t(N_t, \theta_t) > c_*$ and thus agreement delay will be less likely.

PROPOSITION 4. *Assuming $vQ < \pi_H Q - c_*$ and the participation conditions hold, the joint value of delay $\delta_t(N_t, \theta_t)$ decreases with the total bargaining and delaying cost (c_*) for any given θ_t, $t < T$.*

4.4. The Impact of the Deadline

Due to inflexible production schedules, deadlines often exist for price negotiations. Now we consider the case wherein the buyer has the ability to commit to a certain deadline. Then should the buyer commit to a tighter or looser deadline? In the economics literature, committing to a deadline is a commonly used bargaining tactic to avoid stalling or delay of agreements (e.g., Karagözoğlu and Kocher 2019). However, based on our previous analyses, we know that firms could benefit from delay by collecting more information about the market condition while keeping the possibility of agreement. Hence, a tighter deadline may hurt the firms. In this section, we examine how a change in the deadline will affect the firms' expected payoffs.

In preparation, let $u_0(T, N_L, N_H, \gamma) = U_0^S + U_0^B$ denote the joint expected payoff of a bargaining game given that the deadline is period T, the number of adopters is N_L (N_H) in an average (a good) market, and the prior belief about a good market is γ. Recall that $U_0^S + U_0^B = \max\{U_1^B + U_1^S, vQ\} - c_*$ and that $U_1^B + U_1^S = \mathbf{E}[\max\{U_2^B + U_2^S, vQ\}] - c_*$, wherein the expectation is on $\{N_2, \theta_2\}$. If we treat the bargaining game starting from period 2 as a new bargaining game, then the joint expected payoff of this new bargaining game is thus $u_0(T', N_L', N_H', \gamma') = \max\{U_2^B + U_2^S, vQ\} - c_*$, wherein the deadline is $T' = T - 1$, prior belief is $\gamma' = \theta_2$, the total number of adopters is $N_L' = N_L - N_2 + 1$ in an average market, and $N_H' = N_H - N_2 + 1$ in a good market. Thus, we have $u_0(T, N_L, N_H, \gamma) = \max\{\mathbf{E}[u_0(T - 1, N_L - N_2 + 1, N_H - N_2 + 1, \theta_2)], vQ\} - c_*$. In particular, for any $T \geq 2$,

where $x^+ = \max\{0, x\}$. Now we can analyze how u_0 changes with T, using the above iterative relationship (10) and induction. It reveals that the closer the deadline, the lower the expected payoff a firm can obtain from participating in the negotiation, which confirms our conjecture. The next proposition presents this result.

PROPOSITION 5. *The closer the deadline is, the lower the expected payoff a firm can obtain from participating in the negotiation, that is, $u_0(T + 1, N_L, N_H, \gamma) \geq u_0(T, N_L, N_H, \gamma)$ for $\forall N_L, N_H, \gamma$ and $T \geq 1$.*

We then compare our result with those from the literature. On one hand, our model suggests that the existence of a finite deadline brings inefficiency to the bargaining game and component procurement. In this regard, our result is consistent with the literature. On the other hand, our model offers a new insight regarding how a change in deadline affects firm payoffs. Most studies (e.g., Fershtman and Seidmann 1993, Ma and Manove 1993, and Damiano et al. 2012) suggest that extending a deadline hurts the players because delay is costly and players tend to reach an agreement close to the deadline without bringing additional benefits to the system. However, our model indicates that extending the deadline benefits the system by better allocating the production capacity among buyers with different valuations. Therefore, both negotiating parties can be better off by extending the deadline if side payments can be made.

But what if the deadline has to be determined before any side payments can be made? In particular, when will the buyer suffer from a looser deadline in this case? Let $U_0^B(T)$ denote the buyer's expected payoff given a general deadline T. We compare $U_0^B(T)$ with $U_0^B(T - 1)$. We find that the impact of T on $U_0^B(T)$ depends on the buyer's bargaining power, the arrival rate of new adopters conditional on the existence of additional adopters, and the seller's outside option.[3]

PROPOSITION 6. *For any $T > 1$ and $\pi_H \gamma < v < \pi_H$, then the buyer prefers a tighter deadline, that is, $U_0^B(T) < U_0^B(T - 1)$, if*

$$u_0(T, N_L, N_H, \gamma) = -c_* +$$

$$\max\left\{\begin{array}{c}\left(1 - \alpha \cdot \gamma^{(2-N_L)^+}\right) \cdot u_0(T - 1, N_L, N_H, \gamma) + \\ \alpha \cdot \gamma^{(2-N_L)^+} \cdot u_0\left(T - 1, (N_L - 2)^+ + 1, N_H - 1, \dfrac{(1-\alpha)^{(2-N_L)^+} \cdot \gamma}{(1-\alpha)^{(2-N_L)^+} \cdot \gamma + 1 - \gamma}\right)\end{array}, vQ\right\}, \quad (10)$$

$$\pi_H Q \cdot \frac{\alpha\gamma(1-\gamma)}{1-\alpha\gamma} \le \frac{c_B - \beta c_*}{\beta}. \qquad (11)$$

It is immediately observed that the right hand side of (11) is decreasing in β. Hence, given all other parameters, extending the deadline will hurt the buyer *ex ante* if β is small enough. The intuition is as follows. When β is too small, the buyer will either pay a very high price (close to v) to purchase the component or receive the outside payoff of zero. In this case, the cost of delay will outweigh the benefit of learning for the buyer. However, this logic does not apply to the seller because learning is valuable as long as the outside option value of in a strong market (π_H) is much higher than that of v.

Furthermore, extending the deadline can hurt the buyer *ex ante* when the seller has a weak outside option, because the left hand side of (11) is increasing in γ when γ is small.[4] Hence, even if the buyer has a decent bargaining power, learning is not worthwhile when the seller's expected outside option value is too low. This is because the buyer can benefit from learning only when the seller's opportunity cost ($\gamma\pi_H Q$) can be greatly weakened through learning. Given that $\gamma\pi_H Q$ is low in the first place, the benefit of learning will be marginal for the buyer and thus will be outweighed by the cost of delay.

Another observation is that extending the deadline can hurt the buyer *ex ante* when learning is too slow (i.e., α is small). This is because the cost of learning is high (or is time consuming) when the arrival rate of new adopters is low. However, note that agreement delay may not occur if learning is very slow and/or the chance of strong adoption is low. Therefore, even if the agreement will be reached immediately, extending the deadline can still hurt the buyer *ex ante*.

Given the above results, an interesting question is: if the buyer prefers a tighter deadline and side payments are not allowed, is it possible that the buyer delays the agreement voluntarily? If this is true, then the buyer will have time-inconsistent interests regarding the timing of agreement. Using numerical examples, we can show that there exist such possibilities. Here we just give one example. Consider $T = 2$ and $N_1 = N_L$. To ensure that the agreement will be delayed, we need $U_1^S + U_1^B > vQ$ and it suffices to have $\alpha\gamma Q(\pi_H - v) > c_*$. To ensure that the buyer opts to delay (but not to quit), we need $U_1^B > 0$ and it suffices to have $\beta Q(v - \gamma\pi_H) > c_B$. To ensure that the buyer prefers a tighter deadline, we need condition (11). It is easy to verify that the three conditions can all be satisfied when $c_S = 0$, $\alpha = 0.7$, $\beta = 0.2$, $\gamma = 0.2$, $Qv = 20c_B$, and $Q\pi_H = 30c_B$. In sum, we find that the buyer will have time-inconsistent interests regarding the timing of agreement when the buyer has a weak

bargaining power, learning is fast enough, and/or the chance of strong adoption for the new component is relatively low. The reason is as follows. When learning is sufficiently fast, the value of learning is high for both parties; When the chance of strong adoption is low enough, the buyer will always participate because a large enough surplus can be obtained from the agreement even with a weak bargaining power and a delayed agreement; When the buyer has a weak bargaining power and knows that the agreement is likely to be reached in the last minute anyway, extending the deadline will make the buyer worse off because the cost of delay outweighs the share of additional surplus obtained. Hence, the fact that the buyer can benefit from the delay does not necessarily mean that the buyer should commit to a looser deadline.

Lastly, we study how the value of delay is affected by the length of the negotiation window. The following proposition shows that the joint value of delay in any period increases as the deadline is extended.

PROPOSITION 7. *Given $vQ < \pi_H Q - c_*$ and that the participation conditions hold, the joint value of delay $\delta_t(N_t, \theta_t)$ is an increasing function of T given any possible t, N_t, and θ_t.*

This result suggests that the longer the negotiation window, the more valuable delay is. This is because extending the negotiation window by one period allows a longer period of learning and thus higher expected payoffs.

4.5. The Optimal Timing of Agreement
Based on our previous findings, we now discuss about the structural property of the optimal timing of agreement between the buyer and seller. Propositions 3 and 7 indicate that there exists a threshold in time such that it is optimal for the firms to wait until the time threshold and reach agreement afterwards, unless the negotiation time window is over or a strong market has been confirmed by a critical signal. We formally state the result in the following corollary.

COROLLARY 1. *Assuming $vQ < \pi_H Q - c_*$ and the participation conditions hold, if it is optimal for the seller (and/or buyer) to reach an agreement in the present period (i.e., period t), the same decision remains optimal for the next period (i.e., period $t + 1$) as long as the negotiation does not break down.*

The reasons are twofold. First, as the deadline approaches and other factors are held constant, the JVD decreases. Second, the JVD is monotonic in the belief of a strong market which is weakened over time unless a second adopter appears. Hence, this result is robust even if some of our assumptions are

relaxed. For one, if $N_L > 1$, the belief of a strong market will not be updated until $N_t = N_L$, but the JVD will still decrease over time as the time window becomes shorter. For another, if the arrival probability of new design-wins depends on the market condition even when $N_t < N_L$, then the belief of a strong market could increase over time as new design-wins are observed; however, as long as the increases of belief cause smaller changes in the JVD than the time window does, the JVD would still decrease over time.

4.6. Numerical Explorations

Our analysis shows how the joint value of delay depends on various factors. Given that we are more interested in the buyer's payoff, now we use extensive numerical examples to explore how various factors affect the net value of delay for the buyer. The net value of delay, assuming no side payments, is defined as $U_1^B|_{T=T_0} - U_1^B|_{T=1}$, where $U_1^B|_{T=1}$ stands for the buyer's expected no-agreement payoff in period 1 when delay is not allowed and $U_1^B|_{T=T_0}$ stands for the buyer's expected no-agreement payoff in period 1 when the agreement is delayed until an agreement is reached or the market condition is known. Hence, given $T_0 > 1$, the difference $U_1^B|_{T=T_0} - U_1^B|_{T=1}$ represents how much the buyer's payoff is affected by delaying.

In our numerical examples, the default parameter values in Part I are as follows: $\pi_H = 5$, $v = 3$, $\alpha = 0.7$, $\beta = 0.5$, $\gamma = 0.4$, $Q = 1$, $N_L = 5$, $c_S = 0.01$, and $c_B = 0.02$. Note that when $N_L > 1$, the firms have to observe $N_L - 1$ additional design-wins before confirming a strong market. In Part II, we set $c_S = 0.03$ and other parameter values are the same. The results are summarized in Figure 2 and 3, from which we have several observations.

First, the net value of delay for the buyer can depend on the negotiation time window in a nonmonotonic way. In particular, when the time window is too narrow, delay does not occur because there is insufficient time for learning.[5] When the negotiation time window is longer, the value of delay will start to increase with the time window and it will become optimal for the buyer to commit to an extended deadline. However, when the time window is too wide, further extending the deadline may start to hurt the buyer if the buyer's bargaining power is not high enough. This is because, when the time window is too wide, the buyer will either lose the capacity if higher-value buyers show up or suffer a large cost of delay without obtaining much value from additional information. If the buyer's bargaining power is sufficiently high, the benefit of learning will mainly go to the buyer and extending the deadline is always good for the buyer.

Second, the net value of delay for the buyer is increasing with the belief of a strong market for the seller (γ). This observation confirms our discussion related to Proposition 3. In Part I (Figure 3), when the market is unlikely to be strong, the net value of delay for the buyer is negative and extending the deadline will hurt the buyer unless the buyer's bargaining power is very high. This is because the buyer cannot expect to cut the price much through learning given that the seller has a weak outside option at the beginning; on the contrary, the buyer may lose the buying opportunity if other high-value buyers show up. When the chance of strong adoptions is high, the net value of delay for the buyer will become positive because the buyer may be able to force the seller to cut the price a lot if the belief of strong adoptions is weakened through learning.

In Part II (Figure 4), learning is more costly for the seller. In this case, even when the chance of strong adoptions is low, the buyer can also benefit from learning. This is because the seller will suffer a lot from learning without benefiting much given that higher-value buyers are very unlikely to show up. Hence, a wider negotiation time window will strengthen the buyer's bargaining position and force the seller to accept a lower price.

In Part III, we present more numerical examples to show the existence of time-inconsistent interests for the buyer. To this end, we set $\pi_H = 1.5$, $v = 1$, $\gamma = 0.5$, $\beta = 0.2$, $c_B = 0.02$, and $c_S = 0.01$, so the costs of delay are relatively high (compared to π_H and v). Other parameter values are the same as those in Parts I and II. In Figure 5, we plot the buyer's expected no-agreement payoff in period 1 in the upper two panels, and we plot the optimal time of agreement in the lower two panels. We can see from the upper panels that, in most cases, a wider time window is always worse for the buyer, except when the buyer has a very high bargaining power ($\beta = 0.8$ in the upper right panel); however, the lower panels show that, when the time window is large enough, it is optimal to delay the agreement, except when the prior belief of a strong market is too low ($\gamma = 0.1$ or 0.3 in the lower left panel). Note that in the bottom-right panel, when $\gamma = 0.5$, the delay pattern is identical for three different values of the bargaining power β. These numerical examples demonstrate the buyer's time-inconsistent interest; that is, the buyer prefers a tighter deadline *ex ante* but would choose to delay if the negotiation time window is wide. This is because, when the buyer is not too powerful, learning not only allows the buyer to achieve a significantly lower price (by weakening the belief of a strong market for the component) although delay is costly, but it also allows the seller to ask for a very high price at the beginning; hence, *ex ante*, it is better for the buyer to commit to a tighter

Figure 3   The Net Value of Delay for the Buyer (Part I: $c_S = 0.01$) [Color figure can be viewed at wileyonlinelibrary.com]
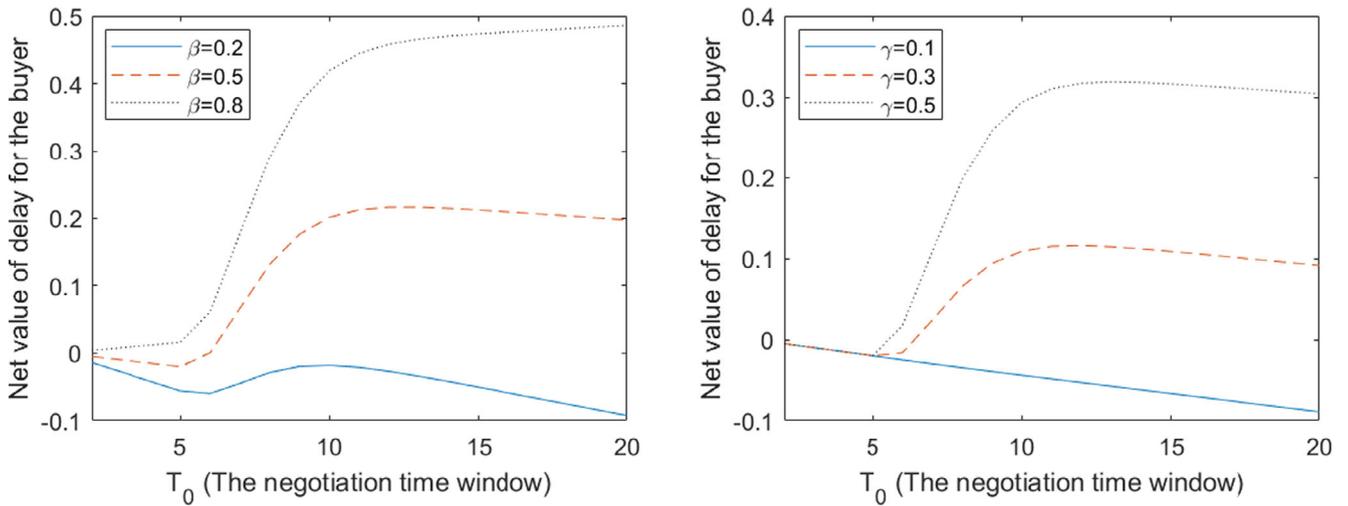
deadline so that the seller would ask for a lower price and the cost of delay can be saved.

In the supplement file, we use a three-dimensional plot to show how the optimal time for the firms to reach agreement depends on β and γ. We find that the optimal timing does not depend on β because β only affects the allocation of the surplus, and the possibility of reaching an agreement is not affected by β. Besides, the optimal timing increases with γ, which echoes the findings in Figure 3 and 4.

5. Extensions and Robustness

In this section, we discuss three extensions of our base model to incorporate a number of complicating factors. We will see that the results will not be qualitatively different from what is offered by the base model. Hence, the robustness of the base model will be supported by the analyses of these extensions.

5.1. State-Dependent Value of Technology

Due to positive externalities associated with adoptions of a new technology in the high technology markets, it is likely that the value per unit of the seller's capacity for the buyer is v_H in a good market and is v_L in an average market, where $v_H > v_L$. In such a setting, the expected per unit value in period t, given information $\{N_t, \theta_t\}$, is $v_t^e = \theta_t v_H + (1 - \theta_t) v_L = v_L + (v_H - v_L)\theta_t$. Therefore, an agreement can be reached in period t if and only if $U_t^S + U_t^B \le v_t^e Q$, or equivalently, $U_t^S + U_t^B - (v_H - v_L)\theta_t Q \le v_L Q$. Based on this criterion, we can define the following equivalent bargaining game.

Consider a bargaining game wherein the value of a unit of the capacity for buyer $\mathscr{B}$ is fixed at v_L and the seller's opportunity loss for a unit of the target

capacity in a good market is $\pi_* = \pi_H - (v_H - v_L)$. All of the other settings are the same as those in the base model. Denote as $\tilde{U}_t^S$ and $\tilde{U}_t^B$ the no-agreement payoffs in period t. We can prove that, in terms of the time when an agreement can be achieved, this bargaining game is completely equivalent to bargaining with state-dependent product value. Consequently, all the results in the base model can apply.

PROPOSITION 8. $U_t^S + U_t^B \le v_t^e Q$ given $\{\pi_H, v_t^e\}$ is equivalent to $\tilde{U}_t^S + \tilde{U}_t^B \le v_L Q$ given $\{\pi_*, v_L\}$ and $U_t^S + U_t^B = \tilde{U}_t^S + \tilde{U}_t^B + (v_H - v_L)\theta_t Q$ for every possible t.

5.2. Changing the Quantity in Negotiation

In high-technology industrial markets, a buyer has to purchase all components (e.g., chips, screens, memories, etc.) proportionally. Therefore, the purchase quantity is unlikely to change because of the negotiation with one supplier. In the case where the buyer purchases the same component from several suppliers (e.g., TSMC, Samsung, etc.), the division of the order quantity between these suppliers is also driven by strategic considerations such as diversifying supplier base or maintaining long-term relationships with suppliers. That is, shifting the order quantity from other suppliers to the focal supplier is costly and the buyer would not be willing to do so unless the benefit is large enough.

To generalize our results, we now consider a case wherein either the buyer or the supplier can change the quantity in the negotiation. Suppose that the firms (either one) can choose to change the quantity from Q to one of K possible quantity levels by incurring a total fixed cost $L_k = L(Q_k) > 0$, wherein $Q_k \in \{Q_1, Q_2, \ldots, Q_K\}$ (e.g., the buyer may need to shift some quantities from/to other suppliers and the
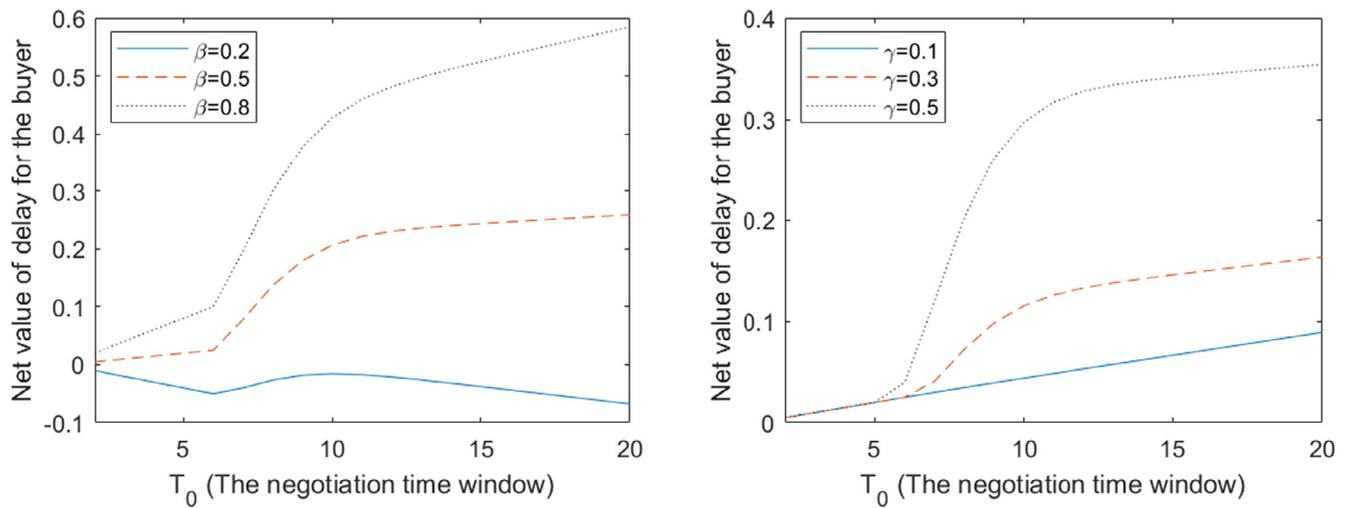
seller may adjust the capacity allocation or even the total capacity, both of which can be costly). We allow side payments such that the two parties will want to increase the quantity if such a change can increase the total profit. Due to the *positive externalities* associated with adoptions of a new technology, it is likely that the value of a unit of capacity for the buyer is v_H in a good market and is v_L in an average market, where $v_H > v_L$. In such a setting, the expected product value for the buyer in period t, given information $\{N_t, \theta_t\}$, is $v_t^e = \theta_t v_H + (1 - \theta_t) v_L = v_L + (v_H - v_L)\theta_t$. In each period, there are four alternatives for the two firms: delaying, reaching an agreement, delaying after increasing the quantity to $Q' \in \{Q_1, Q_2, \ldots, Q_K\}$, or reaching an agreement after increasing the quantity to Q'. Our analysis leads to the following result.

PROPOSITION 9.   *The firms never reduce the quantity and it is only possible to have $Q_k > Q$ for all k. Define $\theta_k = \frac{L_k - v_L(Q_k - Q)}{(v_H - v_L)(Q_k - Q)}$, and $\theta_* = \min\{\theta_1, \theta_2, \ldots, \theta_K\}$. In period t, the firms never change the quantity if the probability of strong market θ_t is lower than a threshold θ_*, and never reach an agreement at Q if θ_t is higher than θ_*.*

Note that our base model is a special case of this extended model where the fixed cost L_k is large. When $L_k > v_L(Q_k - Q)$ for all $k \in \{1, 2, \ldots, K\}$ and $v_H \to v_L$, we have $\theta_* \to +\infty$ and thus the firms never change the quantity even if they are allowed to do so, because the fixed cost L_k is too large. However, this extended model is more general and allows the change of quantity, which happens only when (1) L_k's are low enough, (2) the positive externalities (i.e, $v_H - v_L$) is strong enough, (3) the magnitude of change (i.e., $Q' - Q$) is large is enough, and (4) the probability of a strong market is higher than a

threshold. When the conditions are satisfied, either the buyer or the seller can initiate the change as long as the aggregate benefit of agreeing at a larger quantity is larger than no agreement.

5.3. The Leader–Follower Effect
It is possible that in the high-tech industry, the adoption decision of a market leader could influence those of other firms in the same market segment. Here we study the situation wherein the state of demand depends on whether an agreement is reached between $\mathscr{A}$ and $\mathscr{B}$. In particular, if the market condition is initially good, the agreement will have no effect; however, if the market is initially average, the agreement between $\mathscr{A}$ and $\mathscr{B}$ in any period can turn the market into a good one with probability ϕ. Let γ denote the original probability of a good market and θ_t the probability of a good market in period t without an agreement. After an agreement is reached in period t, the probability of a good market becomes $\theta_t + (1 - \theta_t)\phi$. Accordingly, the value of an agreement between $\mathscr{A}$ and $\mathscr{B}$ is twofold. First, the value of Q units of the capacity for the buyer is vQ. Second, the agreement can increase the probability of a good market and thus the probability of selling the extra capacity of $K - Q$ units is raised from θ_t to $\theta_t + (1 - \theta_t)\phi$ in period t. Let π_e denote the value of the extra capacity for the seller in a good market when it is sold to other buyers. Hence, the total value of the agreement is $vQ + (1 - \theta_t)\phi\pi_e$, and an agreement can be reached in period t if and only if $U_t^S + U_t^B \leq vQ + (1 - \theta_t)\phi\pi_e$, or equivalently, $U_t^S + U_t^B + \frac{\pi_e\phi}{Q}\theta_t Q \leq \left(v + \frac{\pi_e\phi}{Q}\right)Q$. Based on this criterion, we can define the following equivalent bargaining game in a way similar to Section 5.1.

Figure 5   The Buyer's Time-Inconsistent Interests [Color figure can be viewed at wileyonlinelibrary.com]
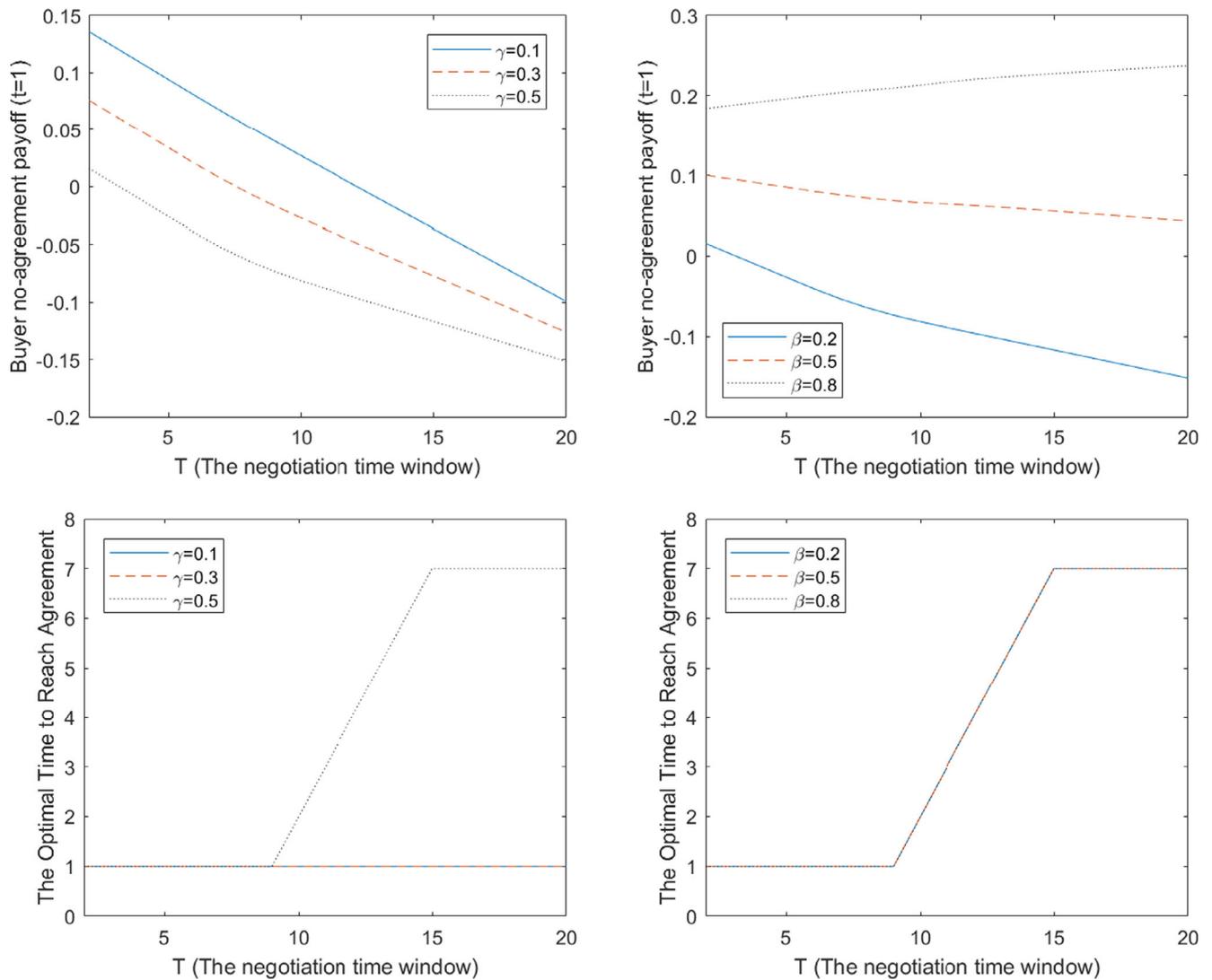
Consider a bargaining game wherein the value of a unit of the capacity for buyer $\mathcal{B}$ is fixed at $v_{lfe} = v + \frac{\pi_e \phi}{Q}$ and the seller's opportunity loss for a unit of the target capacity in a good market is $\pi_{lfe} = \pi_H + \frac{\pi_e \phi}{Q}$. All of the other settings are the same as those used in the base model. Using the same logic as in Proposition 8, we can show that, in terms of the time when an agreement can be achieved, this bargaining game is completely equivalent to the bargaining game with the leader-follower effect. The proof is omitted. All of the results in the base model can apply.

6. Concluding Remarks

We study the negotiation process between a manufacturer and a supplier of a new component product in the high-technology industry. We focus on a setting wherein the manufacturer decides to adopt the new component technology for the next generation of product but has not introduced the end product equipped with this new component to the end market. The manufacturer's task is to negotiate with the supplier for the purchase price before a given deadline. Our goal is to find the optimal timing of agreement that can maximize the expected payoff of the manufacturer as well as the supply chain.

We build a dynamic bargaining model with random price proposers, uncertain seller outside option, symmetric information, fixed delay costs, and a deadline. In this model, the strategic delay of agreement is driven by the incentive to learn about the market condition of the new technology, which determines the seller's opportunity cost of selling the fixed capacity. Contrary to most existing theories, delay in our model can benefit both the seller and buyer and the joint expected payoff always weakly increases as the

deadline is extended. This logic holds even if we extend the model in various ways.

Our model gives several interesting findings. First, the firms should consider delaying the agreement even when the chance of higher-value buyers showing up later is high but still within the range that warrants participations. The reason is that, as this chance increases, it becomes less sure whether reaching agreement immediately is better for the firms, although the level of uncertainty associated with the seller's outside option value may decrease. From the buyer's perspective, it is better to wait and see if the belief could be weakened in the end; from the seller's perspective, it is better to wait and see if a strong market and a higher payoff could be confirmed. This result is somewhat against the intuition, because we often see that buyers and sellers take the likelihood of higher-value buyers showing up as a pressure (for buyers) or an excuse (for sellers) to reach an agreement.

Second, we point out that extending the deadline could hurt the buyer if side payments are not allowed. Although extending the deadline can improve the joint payoff, tighter deadlines are preferred by the buyer when the buyer has a sufficiently low bargaining power. In addition, when learning is fast enough and/or the chance of higher-value buyers showing up (in a strong market) is relatively low, the buyer will sometimes have time-inconsistent interests regarding the timing of agreement: although the buyer prefers a tighter deadline *ex ante*, delaying the agreement may be optimal for the buyer once the negotiation starts. This is because learning in this case mainly benefits the seller, and a tighter deadline weakens the value of learning as well as the seller's bargaining position; with a loose deadline, it is difficult for the buyer to achieve an agreement on a low price in early periods. Therefore, the two bargaining tactics—committing to a deadline and delaying the agreement—should be combined wisely.

At last, by allowing the firms to increase the order quantity during the negotiation, we find that the firms will increase the order quantity only when the magnitude of quantity change is large is enough, the value of the new technology is significantly different under different market conditions, and the probability of strong adoptions is high enough. The reason is that the surplus of the agreement can be significantly increased only if the purchase quantity is increased significantly and the value of the component is sufficiently higher in a good market to warrant a high enough price even when higher-value buyers exist. This finding is consistent with observations in the high-technology industry.

Notes

[1]When buying standard components from competing suppliers, the buyer may shift some quantity between competing suppliers. But for an innovative component with one supplier, the quantity depends on the demand forecast of the final product and remains independent of the sourcing price.

[2]When the length of each period is short enough (e.g., one day), then the probability of having multiple design-wins happening in each period is negligibly small. This assumption is mainly for technical convenience. Our main insights would also hold without this assumption, except that the math will be unnecessarily much messier.

[3]We proceed as follows. First, we set $T = 1$ and do not allow delay. Because delaying the agreement is not allowed given $T = 1$, we have $U_1^B = 0$ and $U_1^S = \pi_H \gamma Q$. The transaction price is expected to be $\bar{p} = \beta \min\{v, \pi_H \gamma\} + (1 - \beta) \max\{v, \pi_H \gamma\} = \beta \pi_H \gamma + (1 - \beta) v$ and thus the buyer's (*ex ante*) expected payoff is $U_0^B = (v - \bar{p})Q - c_B = \beta Q(v - \pi_H \gamma) - c_B$. Next, we allow delay by setting $T > 1$.

[4]Although (11) can be also satisfied when γ approaches 1, this is not relevant because the condition $\pi_H \gamma < v < \pi_H$ will be violated.

[5]Note that delay never occurs when $U_1^B|_{T=T_0} - U_1^B|_{T=1} < 0$, in which case the buyer either accepts a high price or quit (if quitting is allowed).

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

S1. Technical Proofs.
S2. A Nash Bargaining Model.
S3. The Optimal Timing.