Deadline Credibility and Trade Efficiency*

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Abstract

Many real-world negotiations are persistently delayed, yet imposing deadlines is costly because it induces inefficient separations. Do all deadlines in one-on-one market transactions need to be perfectly credible? To improve trade efficiency, I propose a mechanism that introduces an intermediate, imperfectly credible deadline to facilitate agreement. Using a canonical seller--buyer dynamic bargaining model with a credible deadline, I analytically characterize the optimal degree of credibility of such a deadline that maximizes trade efficiency, leading to early agreements without triggering separations. Under a non-zero risk of separation, the seller is tempted to discount the price to secure a payoff, while the buyer is more likely to accept at the intermediate deadline because pricing resembles ultimatum offers. A laboratory experiment provides direct evidence of the mechanism's effects that extend beyond the theoretical benchmark.

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1 Introduction

Many negotiations are persistently delayed, and therefore inefficient. A classical institution used to limit endless delay is a credible deadline. Typical labor disputes close within several months, often followed by an institutional deadline of strikes or lockouts.[1] Many civil and criminal pretrial disputes are settled at the eleventh-hour, just before a legal deadline for filing suit.[2] Sovereign debt renegotiations also often come to a close just before a debt repayment deadline.[3] At first glance, deadlines have the virtue of enforcing agreements within a time limit (see Roth (1995) for "deadline effects" in lab experiments). By contrast, however, the same deadlines can be fatal if agreements are not reached. About 12 percent of labor disputes end in strikes and lockouts (Cramton and Tracy (1992)). Civil and criminal cases often enter costly formal trials after pre-trial disputes. Sovereign debt renegotiations sometimes end in catastrophic default by debtor countries.

Motivated by the substantial costs of deadline-induced agreement breakdowns, I propose a bargaining mechanism that introduces an intermediate, stochastic deadline to improve trade efficiency in one-on-one bargaining. I start with a seller–buyer bargaining model with one-sided, incomplete information under a deadline (Sobel and Takahashi (1983)).[4] Consider a seller (he) who bargains for a durable good with a buyer (she) with a private value under an exogenous N-period credible deadline. The seller knows that the buyer's private value ranges from 0 to 1, and both know that the seller's marginal cost is 0. The seller offers a price in every period, and the buyer accepts or rejects. Bargaining continues until the buyer accepts; when the deadline arrives, both fall back to outside options of 0. In a unique equilibrium, the price falls over time without any commitment to a single price (reflecting intrapersonal price competition, or simply, "self-competition"; see, e.g., Güth (1994)), and a delay occurs as a result of screening private information: buyers with lower private values take longer to reach an agreement, and some buyers reject all offers, leading to inefficient breakups.

[1] Using data on labor contract disputes from 1970–1989, Cramton and Tracy (1992) document that holdouts are the most common form of dispute, lasting about two months.

[2] See Williams (1983) for last-minute agreements in civil litigation and Spier (1992) and Sieg (2000) for cases in plea bargaining.

[3] In 2015, Greece faced a July 20 deadline to repay its debts to international creditors. Negotiations were narrowly concluded eight days before the deadline. See Benjamin and Wright (2009) for a history of sovereign debt renegotiations and defaults.

[4] This bargaining framework with deadlines has been widely applied to real-world bargaining scenarios, including Tracy (1987), Hart (1989), and Cramton and Tracy (1992) for labor disputes, Bebchuk (1984) and Silveira (2017) for plea bargaining, and Bai and Zhang (2012) for sovereign debt renegotiations.

Suppose that a stochastic deadline is exogenously imposed on a particular interim day $n^* < N$.[5] This complementary deadline acts as a stochastic "time bomb": if the agreement is not reached on that day, the pair may break up with a conditional probability of $\alpha \in [0,1]$ and receive outside options of 0, and otherwise bargaining continues.[6] The implications of imposing a "time bomb" for the efficiency—defined as the sum of both parties' ex ante payoffs—are ambiguous. If the "time bomb" is realized, efficiency is clearly harmed by foregone gains from trade. In contrast, the stochastic deadline can improve trade efficiency by acting as a catalyst for earlier agreement. In a well-designed "time bomb" regime, I show that the latter dominates the former. In particular, when both parties are sufficiently patient, I demonstrate that there exists an interior deadline credibility $\alpha^* \in (0,1)$ that maximizes ex ante efficiency.

To understand the mechanics behind this, first consider the buyer's simple response to the stochastic deadline: she is likely to buy earlier due to the risk of separation. A parameterized model shows that agreements are disproportionately likely to occur at the stochastic deadline (see Figure 2a for a purchase schedule over a variety of α). One could view this as a stochastic analog of the canonical deadline effect (Güth, Schmittberger and Schwarze (1982)).

What is nontrivial is the seller's price discounting: the price schedule may involve early discounts, starting from a lower opening price. The key mechanism is that a stochastic deadline allows low-valuation buyers—who typically delay agreement—to credibly signal their low valuation when the deadline passes without being realized. To understand this, suppose that a rejection occurs at the stochastic deadline with a reasonably large α. Then, the seller infers that the buyer's private value is not high enough to induce a purchase, and his belief about the buyer's valuation becomes substantially lower than when $\alpha = 0$. Therefore, the forward-looking seller is forced to discount from the start, which would further facilitate earlier agreements through "self-competition" between pre- and post-bomb periods. This seller's discount is perhaps surprising in light of a standard ultimatum game, where the seller is typically expected to exploit the buyer.

My theoretical insight, based on a mathematically equivalent formulation of multi-buyer

[5] A stochastic deadline system could function as a discipline to complement a conventional deadline. In civil litigation, a private or public arbitrator (e.g., insurance companies or courts) could intervene sometime before the deadline as a preliminary injunction. Prior to labor contract disputes, each party could formulate an ex ante bargaining rule that an intermediary (e.g., stakeholders) could potentially settle at an earlier negotiation. In sovereign debt negotiations, a group of creditors and a debtor could join a commitment in which a third party (e.g., the International Court of Justice) could intervene in the negotiations.

[6] α is a conditional probability of separation if a price is rejected in period n^*. If $\alpha = 0$, this is nothing more than an initial setting. If $\alpha = 1$, this becomes shorter-horizon bargaining with a deadline at $N = n^*$.

markets in durable goods monopoly, revisits the accepted wisdom surrounding the famous Coase (1972) conjecture on bargaining horizons and market efficiency.[7] Coase argued that one-sided asymmetric information without a deadline leads to an immediate agreement favorable to the informed buyers. Thus, as the bargaining horizon lengthens, efficiency is restored. Two polar cases succinctly characterize this intuition. In a one-shot ultimatum game,[8] bargaining suffers from the greatest efficiency loss under maximum monopolist power. In contrast, under an infinite horizon, as Coase conjectured, the monopolistic market achieves full efficiency with an immediate agreement. A stochastic deadline breaks the conventional link: the horizon appears *shorter*, yet efficiency may improve in expectation.

To provide proof of concept, I conducted a controlled laboratory experiment to empirically test the validity of the stochastic deadline. Building on the experimental literature on a multi-period bargaining experiment for sellers and buyers (*à la* Reynolds (2000)), I implemented a simplified model in a computer laboratory and collected approximately 1,200 bargaining observations from 62 subjects. Subjects were randomly assigned to a bilateral bargaining game ($N = 6$) under different levels of credibility at a predetermined stochastic deadline ($n^* = 3$).

The experiment broadly supports the effectiveness of a stochastic deadline. Consistent with the key predictions of the model, I find that imposing a stochastic deadline increases trade efficiency, restrains pricing, and favors the buyer. Intriguingly, even when the stochastic deadline approaches full credibility, these effects remain pronounced, contrary to the model's predictions. To illustrate this pattern, I compare submitted prices and buyers' decisions with their theoretical benchmarks. Under the conventional deadline regime ($\alpha = 0$), most (89%) of buyers' reactions are theoretically reasonable, but notably, 59% of prices are categorized as "demanding"—sometimes exceeding the ultimatum price.[9] Such "demanding" pricing has been documented by previous bargaining experiments (Rapoport, Erev and Zwick (1995); Reynolds (2000)).

I find that sellers discount prices at the stochastic deadline much more prominently than predicted by the model—a novel finding in the literature that is nevertheless reminiscent of the long-standing, firmly established evidence from ultimatum game experiments (see e.g.,

[7]This conjecture is formulated as "durability (or extended bargaining horizon) attenuates monopolistic distortions". See, e.g., Güth and Ritzberger (1998).

[8]My model with $N = 1$ can be framed as a variant of an ultimatum-offer game under incomplete information.

[9]Prices are classified as "demanding" if they are at least 20% above the theoretical price. Buyer decisions are considered "reasonable" if they follow the model-implied cutoff rule (see Section 4 for detailed classification criteria).

Güth and Kocher (2014)).[10] As a result, a significant fraction of sellers' pricing, especially on the stochastic deadline, becomes theoretically reasonable, or even excessively discounted. Based on the discussion of potential behavioral forces at play (see Section 4), I conclude that a stochastic deadline mitigates the upward bias in sellers' pricing under conventional deadlines and encourages buyers to agree earlier; consequently, it enhances trade efficiency.

Related literature: This paper proposes a bargaining mechanism to complement the conventional deadline. First, by enriching the deadline structure, my paper theoretically and experimentally extends existing work on last-minute agreements before a deadline ("deadline effects") in one-on-one bargaining. My finite-horizon bargaining model builds on Sobel and Takahashi (1983) and Fudenberg and Tirole (1983), although the role of deadlines in trade efficiency is not explicitly considered.[11] For pretrial civil litigation, Spier (1992) uses a model similar to mine and derives an agglomeration of trade at the trial deadline.[12] More recently, Fuchs and Skrzypacz (2013) theoretically explore the impact of outside options after breakups on deadline effects in continuous time limits. Compared to Fuchs and Skrzypacz (2013), my model normalizes outside options and highlights the efficiency implications of the proposed pre-deadline mechanism in discrete time, which I directly test in the laboratory.

On the empirical side, my paper contributes to the experimental bargaining literature on deadlines, surveyed by Roth (1995), with more recent studies including Gneezy, Haruvy and Roth (2003), Haruvy, Katok and Pavlov (2020), and Karagözoğlu and Kocher (2019).[13] Indeed, deadline effects are firmly established across time horizons, diminishing-pie environments, and alternating-role protocols (Roth, Murnighan and Schoumaker (1988); Güth, Levati and Maciejovsky (2005)). My experiment confirms that the deadline effect emerges even when a deadline is stochastic: as the stochastic deadline becomes more credible, a larger fraction of

[10]On average, ultimatum game experiments show that proposers offer between 30% and 50% of the money, and more than half of the opponents reject proposals with their share below 20% (see Camerer (2003)).

[11]Some theoretical work on deadlines explores the effect of strategic use of deadlines (Ma and Manove (1993); Fershtman and Seidmann (1993); Özyurt (2023)). In contrast, my paper seeks to improve the institutional role of deadlines, which are typically set by a market designer.

[12]For different protocols with two-sided incomplete information, Ponsati (1995) and Damiano, Li and Suen (2012) derive an atom of trade at the deadline in concession games.

[13]Karagözoğlu and Kocher (2019) show that deterministic deadlines under severe time pressure (90 seconds) *increase* disagreement rates in an unstructured bargaining experiment, particularly when parties hold conflicting fairness reference points and expect an opponent to concede. By contrast, my setting features a structured environment with one-sided offers and no time pressure. Instead, I introduce a stochastic termination hazard, which reduces the value of delay and thereby increases agreement rates.

negotiations is completed at the stochastic deadline, consistent with the model.[14]

Second, and more substantively, the paper theoretically revisits the conventional wisdom of the Coase conjecture (Coase (1972)) in durable-goods monopoly with a continuum of buyers (from Stokey (1981) and Bulow (1982); later formalized by Gul, Sonnenschein and Wilson (1986), Ausubel and Deneckere (1992), and Thépot (1998)).[15] The conjecture essentially states that "durability hurts monopoly power," suggesting a positive relationship between the time horizon (interpretable as durability) and market efficiency in monopolistic markets (see Güth and Ritzberger (1998) or Sobel and Takahashi (1983) Theorem 6).[16] A general consensus in the literature is that efficiency is significantly greater for longer bargaining rounds (or, at the extreme, under an infinite horizon) compared to a snapshot ultimatum game. The stochastic deadline proposed in this paper challenges the conventional link: seemingly shorter bargaining periods may generate higher ex ante trade efficiency (see Proposition 2).

Third, a stochastic deadline is mathematically equivalent to the classical idea of random breakdown in discrete periods (e.g., Binmore, Rubinstein and Wolinsky (1986); Rubinstein and Wolinsky (1985)). Early models assume perfect information and no equilibrium delay, and thus cannot account for real-world bargaining delay. Recent bargaining models use random breakdown to introduce a stochastic deadline to generate delay, and show that random breakdown can facilitate trade, albeit through mechanisms different from mine. Using an analogous seller-offer model with one-sided incomplete information and an infinite horizon, Fuchs and Skrzypacz (2010) embed the stochastic arrival of outside options as random breakdown and show that a larger arrival rate can increase the efficiency. Using the Abreu and Gul (2000) model with incomplete information about behavioral types, Fanning (2016) rationalizes the deadline effect by mimicking the behavior of stubborn types to build reputation until the deadline. However, the one-sided incomplete information in Fanning (2016)'s model generates no delay and yields full efficiency in contrast to my model.[17] Simsek and Yildiz (2016) introduce optimism for future bargaining power after some events (e.g., elections) as a source of delay.

[14] Contrast a theoretical purchase schedule on Figure 2a with the lab agreements in Table 1.

[15] The departure from the conjecture is also a deep theoretical topic (e.g.; Bagnoli, Salant and Swierzbinski (1989); Fuchs and Skrzypacz (2010); Board and Pycia (2014)). Most of these papers assume an infinite horizon without deadlines. Once a deadline is imposed, monopoly power is restored.

[16] Bond and Samuelson (1984) show that the Coase conjecture can be circumvented if the good depreciates faster, thereby restoring monopoly power.

[17] See the "Related Literature" section in Fanning (2016) for a discussion of the differences between the Fanning model and standard one-sided incomplete-information models, including mine (e.g., Spier (1992); Fuchs and Skrzypacz (2013)).

They explain that a lower continuation value after a given event (analogous to a "time bomb" in my model) induces both parties to agree before the event, thereby creating a deadline effect. These models assume that the *arrival* of the deadline is stochastic, whereas in my model, the *realization* of breakdown is stochastic, while the timing is externally imposed by market designers.

Fourth, this paper borrows from and extends the experimental literature on durable goods monopoly trades between sellers and buyers (Rapoport, Erev and Zwick (1995); Reynolds (2000)).[18] For the most part, sellers' prices in these experiments systematically deviate from model predictions, often being higher than predicted, which is also observed in my results. In particular, opening prices are generally higher than the predicted level and in some cases exceeds the static monopoly benchmark (Rapoport, Erev and Zwick (1995)). As a novel finding, my experiment documents a behavioral regularity that has not been reported before but echoes the long-standing tradition of ultimatum game experiments (for a survey, see Camerer (2003) and Güth and Kocher (2014)): as a stochastic deadline becomes more credible, the seller's "demanding" price adjusts to a "reasonable"—or even "cooperative"—level.[19] I find that when deadline credibility is below 40%, increases in credibility do not significantly reduce prices. Once credibility reaches 50% or higher, however, sellers begin to make salient concessions: 61% of opening prices (versus 74%) and 51% of all prices (versus 59%) are classified as "demanding," relative to the no-stochastic-deadline cases (see Figure B.5 in the Supplementary Material). These results suggest that the stochastic deadline mitigates the systematic bias toward "demanding" pricing observed under deterministic, credible deadlines.

Layout: The paper is organized as follows: Section 2 presents a stochastic deadline bargaining framework under a conventional deadline and characterizes the unique equilibrium. It then examines overall trade efficiency and the sensitivity of the distributional outcome to higher

[18] Cason and Reynolds (2005) study a two-period special case of my framework, find little sensitivity of opening prices to continuation probabilities, and develop boundedly rational models to explain these deviations (see "Related Experiments" in the Supplementary Material for details). Outside of durable goods trades, Sterbenz and Phillips (2001) introduce random delays to proposals in their pie-split game experiments, rather than random breakdowns of trades, as in my setting. Bolton and Karagözoğlu (2016) study pie-split games with varying commitment capabilities, featuring hard leverage (binding commitment) in the ultimatum game versus stochastic leverage (appealing to a focal point) in unstructured negotiations. Other related experiments include Güth, Ockenfels and Ritzberger (1995), Cason and Sharma (2001), Srivastava (2001), and Güth, Kröger and Normann (2004).

[19] We classify prices as demanding: $> +20\%$; reasonable: $\pm 20\%$; and cooperative: $< -20\%$ relative to the theoretical benchmark. See Section 4 for details.

levels of deadline credibility. Comparative statics of the ex ante separation probability and the delay to agreement are provided. Next, Section 3 presents the design and results of the laboratory experiments. The actions of both players are compared with their theoretical benchmarks and behavioral interpretations are provided to reconcile the gap. Section 4 concludes the paper. The Appendix contains the proofs of the main theoretical results.

2 Model

This section formalizes a stochastic deadline (or, for generality, a series of stochastic deadlines) on a seller–buyer bargaining model with one-sided incomplete information under a deterministic deadline.

2.1 Setup

A seller ("he") sells an indivisible durable good to a buyer ("she") with an unknown private value $v \in [0,1]$ for the good. I assume that v is distributed according to a publicly shared cumulative distribution function $F(v) = v^{\sigma}$ $(\sigma > 0)$.[20] The durable good has a zero marginal cost, which is commonly known. Assume that both the seller and the buyer are rational and risk neutral.

Time is measured by discrete and finite periods with $n \in \{1,2,3,\cdots,N\}$, with an exogenous institutionally set deadline is set at period $N < \infty$. At the beginning of the period n, the seller makes an offer P_n. The buyer then immediately accepts or rejects the offer. If the buyer accepts the price at the end of period n, the game ends: the seller gets $\delta^{n-1}P_n$, and the buyer gets $\delta^{n-1}(v - P_n)$, where $\delta \in (0,1)$ is a periodic discount factor. If the buyer continues to reject the price until $n = N$, the game also ends: both receive 0 as an outside option. The seller's strategy in period n, $p(\{P_t\}_{t=1}^{t=n-1}, N)$, is a mapping from the history of $n-1$ rejected prices, $\{P_t\}_{t=1}^{t=n-1}$, and the given horizon N, to the current period offer P_n.[21] The buyer's strategy for type v in period n, $q(\{P_t\}_{t=1}^{t=n-1}, v, N)$, maps the history of prices (including the current one), type v, and horizon N to a binary accept–reject decision.

[20] This distributional assumption is often made for analytical convenience to solve a dynamic bargaining game (see Ausubel and Deneckere (1992); Fuchs and Skrzypacz (2013)).

[21] At $n = 1$, no history is available, so an opening price is simply $p(\emptyset,\ N-1)$, where $\emptyset$ denotes the empty history.

Stochastic deadlines Suppose that a series of exogenous M ($M < N$) time stochastic deadlines are embedded at periods $n_d^* \in \{1, \cdots, N-1\}$ ($d \in \{1, \cdots, M\}$; d is an order of stochastic deadlines) before the deadline period N. Deadline credibility is captured by a conditional separation risk $\alpha_d \in [0, 1]$ at the end of each stochastic deadline period n_d^*. This implies that if a proposal is rejected in period n_d^*, the negotiation ends with probability α_d and both receive outside options 0, but continues to period $n_d^* + 1$ with probability $1 - \alpha_d$.

I introduce $M > 0$ for generality. The case $M = 1$ is the simplest specification that captures the main insights of the model and is illustrated through simulations (Figures 2, 3, and 4) and tested in the laboratory.

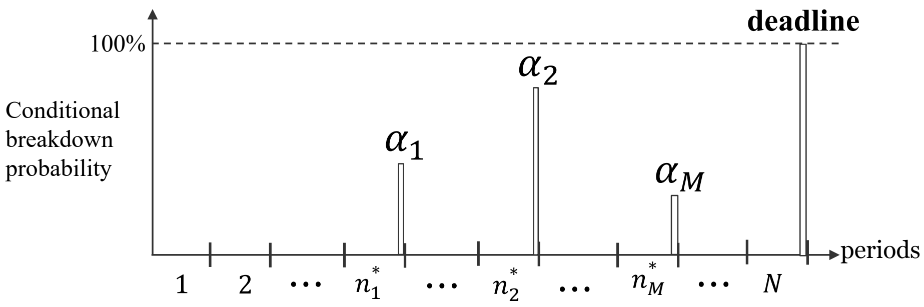

Figure 1: Multiple Stochastic Deadlines under the Deterministic Deadline

2.2 Equilibrium

A complete strategy for the seller $\mathbf{P} = \{p(\{P_s\}_{s=1}^{s=t-1}, N)\}_{t=1}^{t=N}$ determines the prices to offer in each period after each possible price history. In dynamic bargaining games, the types of buyers remaining after any history, including off-equilibrium prices, form a truncated distribution. This is due to the famous skimming property,[22] such that in any equilibrium for any current price P_n and after any history of offered prices $\{P_t\}_{t=1}^{t=n-1}$, there exists a cutoff type $C_n = c(P_n, \{P_s\}_{s=1}^{s=n-1}, N)$ such that the buyer accepts if $v \geq C_n$ and rejects otherwise. Since it is more costly for high types to delay trading than for low types, the buyer's best responses must satisfy the skimming property. Therefore, without loss of generality, buyer's strategy is reduced to a cutoff strategy by $\mathbf{C} = \{c(P_t, \{P_s\}_{s=1}^{s=t-1}, N)\}_{t=1}^{t=N}$.[23]

Let $K_n(\{P_s\}_{s=1}^{s=t-1}, N)$ be the highest remaining type in equilibrium in period n as a function

[22]See, e.g., Muthoo (1999), Lemma 9.3.

[23]Both parties are permitted to use mixed strategies, but in a unique equilibrium, the seller's pricing turns out to be deterministic and the buyer's mixed strategy is rationalizable only when the private value is equal to the cutoff.

of a history of prices and remaining periods (with $K_1(\varnothing, N) = 1$). Directly from the buyer's cutoff strategy, the belief system $\mathbf{K} = \{K_t\}_{t=1}^{t=N} = \{K_t(\{P_s\}_{s=1}^{s=t-1}, N)\}_{t=1}^{t=N}$ is characterized by K_n such that

$$K_1 = 1, \; C_n = K_{n+1} \; (\forall n \in \{1, \cdots, N-1\}), \tag{1}$$

suggesting that the cutoff at period n serves as an upper bound type at period $n+1$. Then, let $[0, K_n(\{P_t\}_{t=1}^{t-1}, N-n))$ be a range of possible types at period n, and both players know K_n at period n as an upper bound of the private value v. Then, using $(\mathbf{P}, \mathbf{C})$ and $\mathbf{K}$, I introduce a perfect Bayesian equilibrium (for theoretical foundations, see Sobel and Takahashi (1983); Fudenberg, Levine and Tirole (1985)).

Definition 1. *A pair of strategies* $(\mathbf{P}, \mathbf{C})$ *and a belief system* $\mathbf{K}$ *constitute a perfect Bayesian equilibrium of the game if their actions maximize their expected payoffs at all information sets and if a belief system is consistent with the Bayes rule whenever possible.*

The model is solved by backward induction from the deterministic deadline. As shown formally in the Appendix, under my distributional assumption, the seller's problem admits a unique price in each period for any upper-bound type K_n induced by $(\mathbf{P}, \mathbf{C})$ and the history. Therefore, the continuation equilibrium is unique and depends on the history only via the state variable K_n and the remaining rounds $N-n$. This conveniently simplifies the notation: the current price and the cutoff are denoted by $P_n = p(K_n, N-n)$, $C_n = c(P_n, K_n, N-n)$, and K_n is given by (1).

Let $V_n(K_n, N)$ be the expected continuation payoff of the seller given K_n with $N-n$ time remaining rounds in period n and strategies $(\mathbf{P}, \mathbf{C})$. For $n < N$, $V_n(K_n, N-n)$ is recursively given by

$$V_n(K_n, N-n) = \underbrace{\left(\frac{F(K_n) - F(C_n)}{F(K_n)}\right)}_{\text{probability of agreement}} p(K_n, N-n) + \underbrace{\frac{F(C_n)}{F(K_n)}}_{\text{probability of rejection}} \eta_n \delta V_{n+1}(K_{n+1}, N-(n+1)), \tag{2}$$

where η_n is a risk adjustment factor attached to a discount factor δ such that $\eta_n = 1 - \alpha_d$ ($n = n_d^*$) and $\eta_n = 1$ ($n \neq n_d^*$). For a terminal deadline $n = N$,

$$V_N(K_N, 0) = \underbrace{\left(\frac{F(K_N) - F(C_N)}{F(K_N)}\right)}_{\text{probability of agreement}} p(K_N, 0) \tag{3}$$

holds. Given the expected path of prices, the buyer's strategy c must satisfy the following as the best response:

$$\text{For } n < N, \qquad \underbrace{C_n - P_n(K_n, N-n)}_{\text{payoff of agreement today}} = \eta_n \delta \underbrace{(C_n - P_{n+1}(K_{n+1}, N-(n+1)))}_{\text{payoff of agreement tomorrow}} \tag{4}$$

$$\text{For } n = N, \qquad \underbrace{C_N - P_N(K_N, 0)}_{\text{payoff of agreement at the hard deadline}} = \underbrace{0}_{\text{outside option}}. \tag{5}$$

Intuitively, (4) implies that a marginal buyer with value $v = C_n$ is indifferent between buying today and tomorrow.[24] Following the proof strategy of Sobel and Takahashi (1983) and Fuchs and Skrzypacz (2013), the action schedules $\{(P_n, C_n)\}$ of the players are periodically determined by a pair of their bargaining powers, captured by sequences $\{(A_n, B_n)\}$ as follows.

Proposition 1. [Unique equilibrium paths and bargaining powers]

The game has a unique perfect Bayesian equilibrium. Given the state variable $\{K_n\}$ at period n, the equilibrium path of $\{(P_n, C_n)\}$ $(n \in \{1, \cdots, N\})$ uniquely exists and is sequentially characterized as

$$P_n = A_n K_n \text{ and } C_n = B_n P_n, \tag{6}$$

where the following difference equations recursively characterize $\{A_n\}$ and $\{B_n\}$:

$$\begin{cases} A_n = ((\sigma+1) - \sigma \eta_n \delta A_{n+1} B_n)^{\frac{-1}{\sigma}} / B_n & (n \in \{1, \cdots, N-1\}) \\ B_n = \{1 - \eta_n \delta (1 - A_{n+1})\}^{-1} & (n \in \{1, \cdots, N-1\}) \\ A_N = (1+\sigma)^{\frac{-1}{\sigma}}, \; B_N = 1. \end{cases} \tag{7}$$

The respective value functions of the seller and the buyer, V_n and W_n, are characterized as follows by $\{A_n\}$:

$$V_n = A_n K_n \mathbb{E}(v), \;\; W_n = (1 - \frac{\sigma+2}{\sigma+1} A_n) K_n \mathbb{E}(v), \tag{8}$$

where $\mathbb{E}(v) = \dfrac{\sigma}{\sigma+1}$ is an ex ante expected private value.

[Proof] See the Appendix.

[24] One can see that the skimming property holds such that a relative benefit of buying today over tomorrow (i.e., a difference of the left and right sides in (4)) is strictly increasing in C_n.

Due to the recursive structure of the model, the seller and buyer choose P_n and cutoffs C_n based solely on the state variable K_n, independent of past actions at equilibrium. Furthermore, the analytical convenience of the functional form $F(v) = v^\sigma$ implies that both P_n and C_n are linear in K_n, with A_n and B_n, which are derived as functions of the primitives $\delta, \sigma, \alpha_d, n_d^*, N$ (see Equations (A.2) and (A.4) in the Appendix for the recursive formulas).

Intuitively, A_n and B_n are the period-n bargaining powers of the seller and buyer, respectively. A higher A_n increases the price, and a higher B_n increases the period-n cutoff. Analogous to prices and cutoffs, the value functions V_n and W_n of the seller and buyer are also linear in the state variable K_n. V_1 and W_1 capture the ex ante surplus of both players, derived from the ex ante maximum gains from trade $\mathbb{E}(v) = \dfrac{\sigma}{\sigma+1}$. How do the two players behave along the equilibrium path?

Purchase schedule: The buyer's decision is characterized by the cutoff C_n or the minimum value she is willing to accept given the price P_n. Figure 2a shows simulated paths of cutoffs under a parameterized model $(N = 6, M = 1, n_1^* = 3, \delta = 0.98, \sigma = 1)$. The results show that buyers with private values higher than the cutoff curve are willing to trade. The buyer's cutoff curve drops sharply not only at $n = 6$ (the canonical "deadline effect"), but also at $n = 3$ when $\alpha_1 > 0$. The drop at $n_1^* = 3$ may reflect a deadline effect associated with the stochastic deadline. As the stochastic deadline becomes more credible, the magnitude of purchase concessions increases: a buyer with a given private value is more likely to agree at the stochastic deadline.[25]

Price schedule: Given the buyer's concession at the stochastic deadline, one would expect the seller to exploit this by raising the price. Using the same parameterized model, Figure 2b illustrates the simulated price path. Notice that the seller makes a striking price concession at $n = 4$ just after the stochastic deadline. This large sale is novel in my stochastic deadline regime as a direct consequence of the deadline effect at the stochastic deadline discussed above. Since the seller knows that the buyer's cutoff drops at $n_1^* = 3$, he infers that the remaining buyer value at $n = 4$ is significantly lower than $\alpha_1 = 0$ (recall that $K_4 = C_3$ per (1)). Since the buyers of the lower type are screened out by the deadline effects (Figure 2a), the seller responds by lowering the price: the prices of the second half periods (P_4, P_5, P_6) decrease monotonically with higher

[25] In the context of durable goods monopoly under product market of continuum value of buyers, this cutoff drop could be interpreted as a significantly larger distribution of purchases.

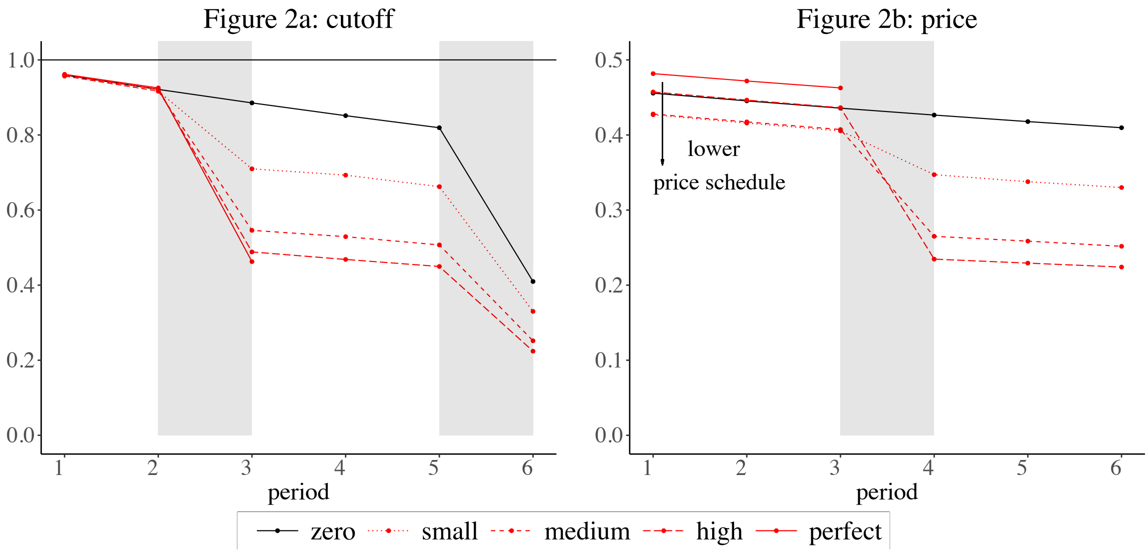

Figure 2: Equilibrium Dynamics across Levels of Deadline Credibility

Note: The model is simulated with an experimental setting ($N = 6$; $M = 1$; $n_1^* = 3$) and baseline parameters ($\delta = 0.98$; $\sigma = 1$). Deadline credibility is zero when $\alpha_1 = 0$, small when $\alpha_1 \in \{0.05, 0.1, 0.2, 0.3\}$, medium when $\alpha_1 \in \{0.4, 0.5, 0.6\}$, large when $\alpha_1 \in \{0.7, 0.8, 0.9\}$, and perfect when $\alpha_1 = 1$. I simulate theoretical average prices within the risk category, weighted by the number of experimental observations of each environment (see Section 3.1 for an experimental setup). The shading shows deadline effects for a buyer at $n \in \{3, 6\}$ (Figure 2a), and a conspicuous sale at $n = 4$ (Figure 2b).

α_1. In other words, the stochastic deadline serves as a signaling device of low private value, once the offer at the stochastic deadline is rejected. Therefore, the forward-looking seller starts with a lower opening price, which shifts the overall price schedule downward. Compared to the case with no stochastic deadline ($\alpha_1 = 0$), Figure 2b shows that the seller discounts the opening price for low and medium deadline credibility. In fact, the simulation shows that for most of the range of imperfectly credible stochastic deadlines ($\alpha_1 \in (0, 0.789]$), the seller's first-half prices (P_1, P_2, P_3) are lower than those in the conventional deadline regime ($\alpha_1 = 0$). However, when a stochastic deadline becomes highly credible, the canonical strategic interaction dominates: the seller raises the price at the stochastic deadline. I formalize this pricing behavior as follows.

Lemma 1. [The seller's opening price] *Suppose the players are sufficiently patient. Then, for every $d \in \{1, \cdots, M\}$, there exists $\widehat{\alpha}_d \in (0,1)$ which uniquely minimizes an opening price P_1 s.t.*

$$\widehat{\alpha}_d = \frac{\delta A^2_{n_d^*+1} - (1-\delta)\{(1+\sigma) - (2+\sigma)A_{n_d^*+1}\}}{\delta(1-A_{n_d^*+1})(1+\sigma - A_{n_d^*+1})}, \tag{9}$$

where $A_{n_d^*}$ is recursively characterized by function of the primitives $A_n \delta, \sigma, \alpha_d, n_d^*$ and N for $d \in \{1, \cdots, M\}$ by (7).

[***Sketch of the Proof***] First, one obtains the first-order condition (F.O.C.) as

$$\frac{dP_1}{d\alpha_d} \underset{\text{Recall } P_1 = A_1}{=} \frac{dA_1}{d\alpha_d} = -\frac{\mathbb{E}(v)}{(\sigma+1)^2} \underbrace{\frac{dA_1}{dA_{n_d^*}}}_{(>0) \text{ See the Appendix}} \frac{dA_{n_d^*}}{d\alpha_d} = 0. \tag{10}$$

The F.O.C. (10) is reduced to $\frac{dA_{n_d^*}}{d\alpha_d} = 0$. By solving for α_d, one obtains the desired $\widehat{\alpha}_d$ in (9). Furthermore, the second order condition (S.O.C.) also holds, so that

$$\frac{d^2P_1}{d\alpha_d^2} = -\frac{\mathbb{E}(v)}{(\sigma+1)^2} \underbrace{\frac{dA_1}{dA_{n_d^*}}}_{\text{independent of } \alpha_d} \frac{d^2A_{n_d^*}}{d\alpha_d^2} < 0. \tag{11}$$

□ (Detailed derivations of the F.O.C. and S.O.C. are provided in the Appendix.)

Because the opening price captures the seller's ex ante bargaining power (recall that $P_1 = A_1$), the theorem suggests that imperfect credibility at each stochastic deadline may suppress monopoly power.[26] As illustrated in Figure 2b, the resulting nonlinearity reflects two forces at work. The first is self-competition under stochastic deadlines. If the seller anticipates that he will have to discount the price when the risk is not realized, he is tempted to lower the price at the outset.[27] However, as the stochastic deadline becomes nearly certain and the game resembles an ultimatum game, conventional strategic interaction dominates, leading to the gradual restoration of exploitative monopoly power. The parameterized model in Figure 2b suggests that pricing is discounted across periods for a substantial range of deadline credibility.

2.3 Efficiency

The key theoretical question is how total trade efficiency responds to the credibility of each stochastic deadline. Total trade efficiency—the primary object of interest—is given by the sum of the value functions at the opening period, $V_1 + W_1$, as defined below.

[26]Importantly, the model assumes that both the number M and the timing n_d of stochastic deadlines are exogenously imposed to isolate the role of deadline credibility. A natural extension would allow these parameters to vary within a more general deadline institution. Such flexibility in deadline design is left for future research.

[27]If players are not patient enough, however, self-competition is dominated by strategic interaction. This is because, as the bargaining becomes more frictional, sellers place less weight on future market outcomes and behave more myopically in exploiting the current market. Consequently, the opening price increases monotonically with the degree of deadline credibility. The finding is consistent with Güth and Ritzberger (1998), who show that the Coase conjecture does not hold when players' patience is low.

Definition 2. [Trade efficiency]

The ex ante trade efficiency U is defined as the sum of the players' ex ante expected payoffs such that $U \equiv V_1 + W_1$.

As a direct consequence of Lemma 1, the main theoretical result of the paper is stated below.

Proposition 2. [Efficiency gain from imperfect deadline credibility]

Suppose that the players are sufficiently patient. Then, for every $d \in \{1, \cdots, M\}$, there exists $\widehat{\alpha}_d \in (0,1)$ (specified by (9)) which uniquely maximizes the efficiency U, as well as the level W_1, and the distributional share W_1/U of the buyers' expected surplus.

[*Proof*] Using (8), it can be seen that the efficiency U and the level of buyers' expected surplus W_1 are strictly decreasing in the opening price P_1 such that

$$U \equiv V_1 + W_1 = (1 - \frac{P_1}{\sigma + 1})\mathbb{E}(v) \tag{12}$$

and

$$W_1 = (1 - \frac{\sigma + 2}{\sigma + 1} P_1)\mathbb{E}(v). \tag{13}$$

The buyer's share of expected surplus is $W_1/U = \frac{(\sigma+1)-(\sigma+2)P_1}{(\sigma+1)-P_1}$. W_1/U is also strictly decreasing in P_1, since

$$\frac{d(W_1/U)}{dP_1} = -(\sigma+1)^2 < 0 \tag{14}$$

holds. The desired results follow directly from the proof of Lemma 1. □

The theorem states that, given the specific stochastic deadline at n_d^*, imperfect deadline credibility α_d maximizes overall trade efficiency and the ex ante buyer surplus share. This implies that the non-zero threat of separation may *enhance* trade efficiency by suppressing monopoly power compared to the conventional deadline regime ($\alpha_d = 0$). In Figure 3, a parameterized model shows that overall efficiency is maximized at an interior credibility $\widehat{\alpha_1} = 0.28$, suggesting that efficiency is improved in most of the credibility range ($\alpha_1 \in (0, 0.789]$) compared to the case with no stochastic deadline ($\alpha_1 = 0$). In the parameterized case ($N = 6, M = 1$, $\sigma = 1$, $\delta = 0.98$), imposing a stochastic deadline with optimal credibility, $\widehat{\alpha_1}$, enhances efficiency by 2.5% relative to the deterministic deadline game ($\alpha_1 = 0$).

Note that in this class of non-cooperative games under asymmetric information, trade efficiency is inversely related to the seller's power (as confirmed by equation (12)). Therefore, this inverted-U efficiency reflects the minimized seller power, as represented by the behavior of the opening price, as shown in Lemma 1. Analogously, Proposition 2 shows that an efficiency maximizer $\widehat{\alpha}_d$ also maximizes the ex ante buyer surplus (W_1) and the buyer's surplus share (W_1/U). This is because both the level and the share of buyer surplus are decreasing functions of the opening price (P_1), which captures ex ante monopoly power (A_1) (see (13) and (14)). This insight echoes the mathematically equivalent durable-goods monopolist model, in which total efficiency is positively related to consumer surplus and negatively related to monopoly power.

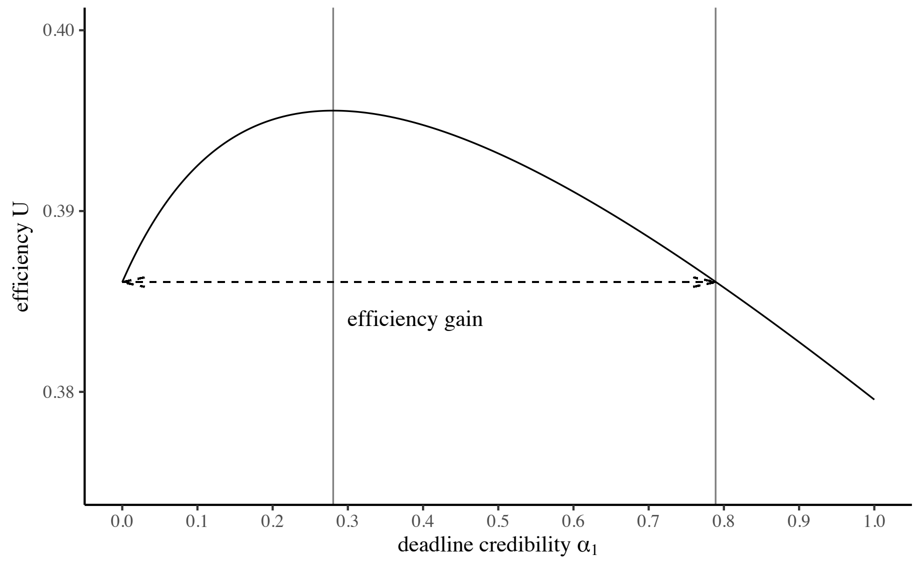

Figure 3: Deadline Credibility and Trade Efficiency

Note: The efficiency $U \equiv V_1 + W_1$ is calculated based on (12). A model was simulated based on the analytical formula with a baseline parameter of experiments $N = 6$, $M = 1$, $\sigma = 1$, $\delta = 0.98$, and a single stochastic deadline is set to $n_1^* = 3$. The vertical line is the optimal deadline credibility $\widehat{\alpha_1} = 0.28$ and the upper bound of imperfect credibility to increase the efficiency $\alpha_1 = 0.789$.

The theoretical results revisit the conventional wisdom in the literature on durable-goods monopolists regarding the link between a time horizon specified by a deadline and market efficiency. In line with the Coase conjecture (Coase (1972)), the monopolist loses the bulk of his bargaining power under an unbounded horizon without a binding deadline. In my model, this corresponds to the extreme case in which, as the horizon becomes infinite $(N \to \infty)$, U converges to the maximum fraction of the total gains from trade $\mathbb{E}(v)$.[28] At the other extreme

[28]Under $\delta = 0.98, \sigma = 1$, and $N \to \infty$, the efficiency U increases to 0.469, which is closest to the total potential

of a one-period ultimatum game ($N = 1$), the monopolist gains the most bargaining power and minimizes efficiency. Note that if a buyer's value is uniformly distributed ($\sigma = 1$), then, perhaps surprisingly high, exactly half of the buyers cannot trade, since the price and the cutoff are both $1/2$. My model shows that in a multi-stage game ($1 < N < \infty$), a seemingly *shorter* time horizon with imperfect credibility $\alpha_d \in (0,1)$ at the $d \in \{1, \cdots, M\}$th stochastic deadline partially restores trade efficiency by facilitate mutual concessions.

2.4 Efficiency Loss

The previous section shows that imposing a well-designed intermediate stochastic deadline before a terminal deadline may improve trade efficiency. Nevertheless, the outcome remains below the Pareto optimum. This section complements the efficiency analysis by examining how the sources of efficiency loss—potential separation and frictional delay—vary with deadline credibility. Operationally, I formally define the pair of efficiency losses as follows.

Definition 3. [Ex ante probability of separation and delay to agreement]

The ex ante probability of separation for a buyer is defined by

$$\underbrace{\alpha_d C_{n_1^*}}_{\text{first threat period } (d=1)} + \underbrace{\sum_{d=2}^{M}\left(\left(\prod_{d'=2}^{M}(1-\alpha_{d'-1})\right)\alpha_d C_{n_d^*}\right)}_{\text{following threat periods } (d\geq 2)} + \underbrace{\prod_{d=1}^{M}(1-\alpha_d)C_N}_{\text{terminal period}}. \tag{15}$$

The ex ante delay to agreement is defined by

$$\sum_{n=1}^{N} n\left(\prod_{l=1}^{n}\eta_l\right)\underbrace{(K_n - C_n)}_{\text{proportion of buyers of agreement at } n}, \tag{16}$$

where C_n and K_n are functions of the bargaining primitives, as characterized in (6) and (7), respectively.

Based on Definition 3, the sensitivity of these two sources of inefficiency to deadline credibility is simulated and illustrated in Figure 4. The parameterized model shows that the ex ante separation probability exhibits a nonlinear sensitivity. Consistent with the nonlinear sensitivity of trade efficiency to α_1, as shown in Proposition 2, an appropriately designed deadline

gains from trade $\mathbb{E}(v) = 0.5$. The monopoly power A_1 decreases to the lowest value of 0.124, in contrast to the static ultimatum maximum of 0.5 (see Figure A.1 for the simulation as $N \to \infty$).

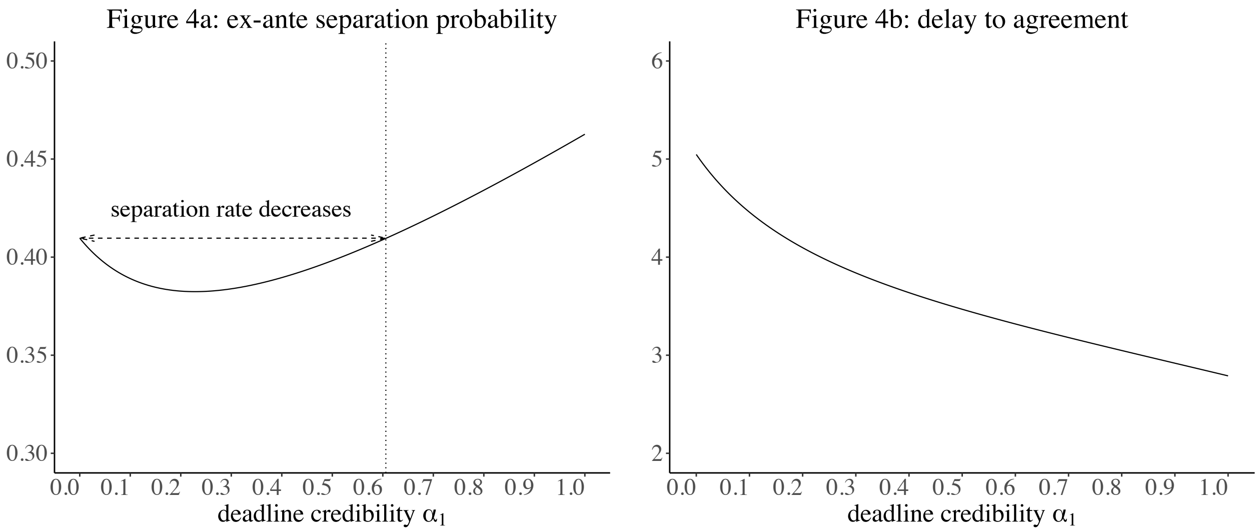

Figure 4: Ex ante Probability of Separation and Delay to Agreement

Note: (15) and (16) are simulated with $N = 6, M = 1, \sigma = 1, \delta \in \{0.7, 0.98\}$, and a single stochastic deadline is set to $n_1^* = 3$. When $M = 1$, (15) is reduced to $C_{n_1^*}\alpha_1 + (1-\alpha_1)C_N$.

credibility induces agreements that help avoid separations. Intriguingly, for most of the range $\alpha_1 \in (0, 0.606]$, the probability of separation is lower than under the conventional deadline regime $(\alpha_1 = 0)$. However, when the stochastic deadline becomes highly credible, separation goes beyond its role as a catalyst.[29]

Another proxy to capture bargaining frictions is the expected duration to reach an agreement, as shown in Figure 4b. Since delays are only defined in samples in which agreements are reached, the ex ante bargaining duration until agreement is expected to decrease in α_1 regardless of discount factors, contributing to another efficiency gain from the stochastic deadline. The response of these proxies is also tested in laboratory experiments, as presented in the following section.[30]

3 Laboratory Experiments

In the previous section, my model provides a theoretical possibility: embedding a stochastic deadline at an earlier intermediate point may restore trade efficiency in bargaining under a credible deadline. To provide proof of concept for the proposed mechanism, I conducted a

[29] If players are not sufficiently patient, however, the probability of separation monotonically increases with deadline credibility, consistent with Proposition 2, because the breakdown risk no longer serves as an effective catalyst for agreement.

[30] The analysis of delays to agreement is presented in Table B.3 of the Supplementary Material.

simple laboratory experiment, building on previous experiments on multi-period durable goods trades (Rapoport, Erev and Zwick (1995); Reynolds (2000); Cason and Reynolds (2005)).

3.1 Setup

The experiments were conducted at the Missouri Social Science Experimental Laboratory (MISSEL) from April to October 2016. The lab is designed exclusively for computer experiments in social science. Each desk was partitioned for privacy, and each participant was identified by an ID number. The experimental program was written in z-Tree, a C++-based software package from the University of Zurich (Fischbacher (2007)). All game actions and results were recorded on a central host computer.

A total of 62 subjects participated in the experiments over four days. Each day before the experiments, the subjects practiced unrecorded games as sellers and buyers that would not affect their scores. Operationally, the subjects were divided into two groups, with each taking turns as a seller or a buyer. To exclude reputation formation or potential coordination with the same opponent, subjects were randomly matched with a different subject across groups in every game. Only individual payoffs earned during the day were converted into monetary compensation using a linear exchange rate: 30 points equaled 1 U.S. dollar. Each day lasted approximately two hours, and subjects received an average of \$29.6 per day.

Subjects played a simplified model with one stochastic deadline $(M = 1, n_1^* = 3)$ out of six periods $(N = 6)$. An environment for each game was characterized by its unique set of three bargaining primitives $\{\alpha_1, \sigma, \delta\}$. To identify the effect of deadline credibility, I let the credibility α_1 vary from $\alpha_1 \in \{0.1m, 0.05\}$, $(m \in \{0, 1, \cdots, 10\})$ within each session of a given $(\sigma, \delta) \in \{(1, 0.98), (2, 0.98), (1, 0.7)\}$.[31] Seven to eight sessions with different bargaining primitives (σ, δ) were conducted each day, and each subject participated in multiple sessions as either a seller or a buyer (see Table B.1 in the Supplementary Material for the assignment of players across bargaining environments). Table 1A tabulates the 1,161 bargaining observations across various environments.

Before each bargaining, both parties were informed of their role (seller or buyer) and the environment. A private value for a buyer was drawn from the shape parameter $\sigma \in \{1, 2\}$, generating a uniformly distributed or an upward skewed distribution of the private value.[32] The

[31] $\alpha_1 = 0.05$ is to examine the effect of a small positive credibility, guided by a simulation in Figure 3.
[32] Both players were informed of σ through the pie chart illustrating the probability distribution across intervals

price history was displayed at the beginning of each period at $n \geq 2$ to ensure participants' perfect memory. To make their decisions as consistent as possible, subjects were encouraged to record all their actions and results on paper after completing each bargaining.

3.2 Descriptive Summary

Table 1B summarizes descriptive statistics on prices, agreements, and bargaining outcomes.[33] In line with the model, most prices decline over the periods; there is little commitment to a single price or price increases. Out of 2,407 pairwise prices (i.e., P_n and P_{n+1} $(n = 1, \cdots, 5)$), 2,050 (85.2%) are discounted, 270 (11.2%) are maintained, and 87 (3.6%) are increased. Moreover, as predicted by the simulation in Figure 2a, increases in deadline credibility disproportionately raise the agreement rate at the stochastic deadline $(n = 3)$ rather than at the deterministic deadline $(n = 6)$ (see Table B.3 in the Supplementary Material for a formal test).

In contrast to the model's predictions, however, three systematic departures are worth noting. First, opening prices under no stochastic deadline $(\alpha_1 = 0)$ (mean 63.7) are higher than the model prediction (mean 44.3), consistent with Rapoport, Erev and Zwick (1995) and Reynolds (2000), and in some cases even exceed the theoretical ultimatum price (mean 52.2), as documented in Rapoport, Erev and Zwick (1995).

Second, despite higher opening prices P_1, the first-period agreement rate (23.6%) is, on average, substantially higher than predicted by the model (14.5%), suggesting that some buyers concede immediately. The simulation predicts a first-period agreement rate of about 12–15% across credibility levels, while it consistently around or above 20% in the experiment.

Third, the average share of a buyer's surplus among bargainings that reach agreement is 34.8%—systematically lower than 50% across all credibility levels, indicating a persistent seller advantage.[34] This share is even lower than the model's corresponding ex ante surplus share for buyers (44.4%), consistent with buyers' apparent early concessions in the opening period. Taken together, these behavioral departures from the theoretical benchmarks are formally tested and discussed in Section 4.

of the buyer's private value v.

[33]The simulated value (opening price, agreement rate, and buyer's share of surplus) is calculated according to formulas (6)–(8), weighted by samples from each environment in the experiment.

[34]Table 1B documents an alternative proxy, a buyer surplus share including separations: the share of the sum of all buyer surpluses in the sum of the efficiencies of all bargainings. This proxy records a similar level of 35.7%, which is again lower than its simulation counterpart of 44.8%.

Table 1: Descriptive Statistics

Table 1A: Bargainings across environments

sessions		σ = 1, δ = 0.98	σ = 2, δ = 0.98	σ = 1, δ = 0.7	total
credibility level	zero	35	27	27	89
	small	159	110	136	405
	medium	115	80	85	280
	high	115	81	100	296
	perfect	39	27	25	91
sum		463	325	373	1,161

Table 1B: Descriptive statistics

sellers' actions		price						
		n = 1	n = 2	n = 3	n = 4	n = 5	n = 6	average
credibility level	zero	67.1	61.7	53.5	48.2	44.4	32.5	54.2
	small	64.5	56.9	47.8	42.3	36.7	28.4	51.0
	medium	61.9	53.8	41.7	39.0	35.6	28.7	51.3
	high	60.6	53.1	38.9	32.1	30.4	23.5	51.0
	perfect	59.4	53.9	36.0	-	-	-	52.2
average		62.7	55.4	44.0	42.2	37.7	28.9	51.5

buyers' actions		agreement rate						
		n = 1	n = 2	n = 3	n = 4	n = 5	n = 6	total
credibility level	zero	21.3%	2.3%	13.5%	5.6%	14.6%	21.3%	78.6%
	small	19.8%	9.6%	14.3%	8.4%	9.4%	14.8%	76.3%
	medium	24.3%	15.7%	23.9%	6.4%	3.9%	3.2%	77.5%
	high	24.3%	12.8%	29.7%	0.7%	1.0%	1.7%	70.2%
	perfect	38.5%	9.9%	33.0%	-	-	-	81.4%
average		23.6%	11.4%	22.0%	5.1%	5.6%	8.0%	75.7%

outcomes		delay to agreement	separation	efficiency	buyer's surplus: level, separations excluded	buyer's surplus: level, separations included	buyer's surplus: share, separations excluded	buyer's surplus: share, separations included
credibility level	zero	3.69	21.3%	43.0	19.9	15.2	33.9%	35.4%
	small	3.29	23.7%	42.8	20.2	15.2	34.6%	35.5%
	medium	2.48	22.5%	46.4	20.1	15.2	32.8%	32.9%
	high	2.24	29.7%	43.6	23.2	16.0	34.9%	36.6%
	perfect	1.93	18.7%	56.2	29.5	23.7	41.7%	42.2%
average		2.76	24.4%	44.9	21.6	16.1	34.8%	35.7%

Note: Deadline credibility is zero when $\alpha_1 = 0$, small when $\alpha_1 \in \{0.05, 0.1, 0.2, 0.3\}$, medium when $\alpha_1 \in \{0.4, 0.5, 0.6\}$, large when $\alpha_1 \in \{0.7, 0.8, 0.9\}$, and perfect when $\alpha_1 = 1$. "–" indicates a value not available by design ($\alpha_1 = 1$). Delay to agreement is defined within bargainings that reach agreement. Separations consist of cases at both $n = 3$ and $n = 6$. Efficiency is the sum of both players' payoffs. Buyer's surplus share (excluding separations) is an averaged share of a buyer's surplus within bargainings that reach agreement. Buyer surplus share (separations included) is the share of the sum of all buyer surpluses in the sum of trade efficiencies, including separations.

3.3 Testing the Efficiency Benefit

Using the laboratory data and guided by theoretical insights from the model, I empirically assess testable predictions about three effects of an imperfectly credible deadline. Given my random assignment of deadline credibility, I estimate the effect of deadline credibility on bargaining outcomes (e.g., prices, efficiencies, and payoffs) with ordinary least square (OLS) regressions that control for bargaining primitives (δ, σ). Although the separation risk is random by design, each bargaining sample is not independent. To address serial correlation, individual player fixed effects for sellers and buyers are included separately. In addition, to isolate learning effects from bargaining experience, I control for the order of games and session fixed effects within each day. To account for potential intratemporal correlation, standard errors are clustered at the session-by-day level. These econometric safeguards are maintained throughout the analysis.

Discounted offers: As a key mechanism for restoring trade efficiency, the model predicts that non-zero credibility of the stochastic deadline may induce price discounts. Lemma 1 shows that opening prices can fall under some imperfect credibility. Figure 2b shows a case under the base parameter ($\delta = 0.98, \sigma = 1$) where prices in the first half of the horizon ($n \in \{1,2,3\}$) decrease for most imperfect credibility ($\alpha_1 \in (0, 0.789]$) relative to the conventional deadline regime ($\alpha_1 = 0$). Moreover, reflecting the expansion of deadline effects with deadline credibility, prices in the second half of the horizon ($n \in \{4,5,6\}$) monotonically decrease, because a remaining buyer after the stochastic deadline is more likely to have a lower private value than under $\alpha_1 = 0$ (see Figure 2b). Guided by this general pricing behavior, I test whether a stochastic deadline system induces sellers to make price concessions, as stated below.

Effect 1 [Discounted offers] *In contrast to the conventional deadline regime, a stochastic deadline reduces a price (Lemma 1).*

Table 2 reports the estimated sensitivity of a periodic price to deadline credibility. Columns (1)–(3) show significantly negative sensitivity of pricing at $n \in \{1,2,3\}$. ($-0.076, -0.076, -0.174$; all $p < 0.1\%$) Note that this decrease is most pronounced in the stochastic deadline period ($n = 3$), which is reminiscent of ultimatum game experiments (see Section 4 for further discussion). After the stochastic deadline, the price schedule declines monotonically with deadline credibility at period $n \in \{4,5\}$ (-0.153, $p < 0.1\%$ in (4) and -0.095, $p < 5\%$ in (5)), consistent with the model. At $n = 6$, the point estimate is negative but not statistically significant in (6) (-0.059, $p = 27.1\%$), plausibly due to the limited number of remaining buyers.

Efficiency and distribution: If higher deadline credibility suppresses prices (Effect 1), does it also enhance trade efficiency? Which party benefits from the stochastic deadline? Based on Proposition 2, this subsection tests the sensitivity of efficiency and buyer surplus to deadline

Table 2: Deadline Credibility and Price Schedules

	price level (normalized to unity) (OLS)					
	n = 1	n = 2	n = 3	n = 4	n = 5	n = 6
	(1)	(2)	(3)	(4)	(5)	(6)
deadline credibility α_1	-0.076 ****	-0.076 ****	-0.174 ****	-0.153 ****	-0.095 **	-0.059
	(0.013)	(0.015)	(0.017)	(0.040)	(0.044)	(0.053)
value σ	0.067 ****	0.069 ****	0.083 ****	0.073 **	0.100 **	0.102 ***
	(0.015)	(0.014)	(0.016)	(0.033)	-(0.042)	(0.039)
patience δ	0.163 ***	0.212 ****	0.169 ***	0.261 ****	0.199 *	0.153 *
	(0.050)	(0.051)	(0.053)	(0.063)	(0.105)	(0.090)
fixed effects of sellers and buyers	Yes	Yes	Yes	Yes	Yes	Yes
bargaining experience	Yes	Yes	Yes	Yes	Yes	Yes
observations	1161	887	755	316	257	192

Note: Bargaining experience controls for within-day order of games and session fixed effects. Parentheses contain standard errors, clustered by day-by-session. ****, ***, **, and * indicate $p < 0.1\%$, $p < 1\%$, $p < 5\%$, and $p < 10\%$, respectively.

credibility.

Effect 2 [Restored trade efficiency] *In contrast to the conventional deadline regime, a stochastic deadline improves trade efficiency (Proposition 2).*

Effect 3 [Advantage for the responder] *In contrast to the conventional deadline regime, a stochastic deadline yields a higher level and a larger distributional share of the buyer's surplus (Proposition 2).*

To test Effect 2, column (1) of Table 3 regresses efficiency U (or the sum of players' realized payoffs) and finds that the coefficient on credibility α_1 is significantly positive (0.057, $p <$ 10%). This result indicates that, on average, higher deadline credibility *enhances* efficiency. Specifically, imposing a stochastic deadline with a 10 *p.p.* larger termination hazard increases efficiency by 0.57 *p.p.* The effect is substantially greater than the model's prediction: a 0.18 *p.p.* average benefit predicted for all stochastic deadline cases ($\alpha_1 > 0$) relative to the deterministic deadline ($\alpha_1 = 0$).[35]

The result suggests that an expected downside of a stochastic deadline—separation costs—does not increase to the extent that overall trade efficiency is harmed. Guided by this inference,

[35]The simulated benefits relative to deterministic deadline cases ($\alpha_1 = 0$) are averaged across bargaining environments ($\alpha_1 > 0$), with each environment weighted by its number of observations.

I examine whether higher deadline credibility induces separations relative to the case without a stochastic deadline. In column (2), I estimate the effect of higher deadline credibility on a binary outcome of separation using a logit model. Perhaps surprisingly, higher credibility does not significantly increase the separation probability (0.286, $p = 20.7\%$). While the positive point estimate suggests that higher credibility may raise the separation probability, the effect is not large enough to materially harm efficiency.[36]

Table 3: Deadline Credibility and Bargaining Outcomes

	dependent variables					
			buyer's surplus			
	efficiency (0–1)	separation probability (0–1)	level (0–1)		share (0–1)	
			separations excluded	separations included	separations excluded	separations included
	OLS	logit	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)
deadline credibility α_1	0.057 *	0.286	0.064 ****	0.035 **	0.031	0.040 *
	(0.032)	(0.227)	(0.018)	(0.017)	(0.020)	(0.014)
preference σ	0.376 ****	-1.34 ****	0.200 ****	0.103 ***	-0.015	0.005
	(0.067)	(0.240)	(0.050)	(0.036)	(0.072)	(0.017)
patience δ	0.217 ****	0.511	0.037 **	0.076 ****	0.001	-0.100
	(0.017)	(0.778)	(0.016)	(0.012)	(0.020)	(0.065)
fixed effects of sellers and buyers	Yes	Yes	Yes	Yes	Yes	-
bargaining experience	Yes	Yes	Yes	Yes	Yes	-
observations	1,161	1,120	861	1,161	861	138

Note: All outcomes are normalized to unity. In (2), 41 samples are dropped after including fixed effects. In (5), the buyer's surplus share (separations excluded) is an average share of the buyer's surplus within bargainings that reach agreement. In (6), the buyer surplus share (separations included) is the ratio of total buyer surpluses to total trade efficiency, including separations. The unit of observation is a day-by-environment, and the specification includes day fixed effects. Bargaining experience controls for within-day order of games and session fixed effects. Parentheses contain standard errors, clustered by day-by-session in (1)–(5) and by day in (6). ****, ***, **, and * indicate $p < 0.1\%$, $p < 1\%$, $p < 5\%$, and $p < 10\%$, respectively.

I then examine whether higher deadline credibility contributes to buyers' surplus. In columns (3)–(6), I examine the sensitivity of the level and share of buyer surplus, reported with and without separations, respectively.[37] Since the model relates overall trade efficiency to these measures (see Proposition 2), we should expect columns (3)–(6) to display similar patterns—which is indeed the case. Columns (3)–(6) suggest that a 10 $p.p.$ increase in deadline credibility significantly increases the expected buyer surplus by 0.64 $p.p.$ (level, $p < 0.1\%$), 0.35 $p.p.$ (level, $p < 5\%$), 0.31 $p.p.$ (share, $p = 12\%$), and 0.40 $p.p.$(share, $p < 10\%$), respectively. Positive es-

[36] A weakly significant positive estimate is consistent with the simulation in Figure 4a.

[37] Since a distribution share of separated pairs cannot be computed, (6) adopts the environment-by-day level as the unit of analysis and includes day fixed effects.

timates of these α_1 terms indicate that a stochastic deadline can also serve as a countermeasure to monopoly power.

Overall, Tables 2 and 3 suggest more direct and robust evidence of the effectiveness (Effects 2–4) of the stochastic deadline than predicted by the benchmark model: higher deadline credibility reduces the seller's price, improves trade efficiency without strongly inducing separations, and strengthens buyers' bargaining power.[38] This result suggests that a stochastic deadline is an affordable catalyst, albeit not a costless empty threat. In the following, I elaborate on the interpretation of these stronger experimental effects.

4 Discussion

As shown in Section 3, the experiments demonstrate more robust effects of the stochastic deadline than the model predicts. Higher credibility of the stochastic deadline suppresses offered prices, strengthens the buyer's bargaining power, and improves efficiency without a noticeable increase in separations. I next examine the sources of these deviations from the model to discuss how the results can be interpreted.

To identify the deviations from the model, I first categorize sellers' pricing and buyers' decisions using the following criteria. A periodic price in a given environment is classified as *reasonable* if it lies within $\pm 20\%$ of the theoretical price, and as *demanding* (or *cooperative*) if it exceeds (or falls below) the theoretical benchmark by more than 20%. The buyer's acceptance or rejection in period n is *reasonable* if she follows a cutoff rule—accepting if $v \geq C_n$ and rejecting if $v < C_n$—where C_n is the cutoff computed for each environment (see Section 2.2). By contrast, accepting when $v < C_n$ is classified as *cooperative*, and rejecting when $v \geq C_n$ is classified as *demanding*.[39]

Table 4A documents the benchmark distribution of pricing attitudes under the conventional deadline regime ($\alpha_1 = 0$). Most prices (59%)—especially opening prices (74%)—are categorized as demanding, as in Reynolds (2000), and in some cases even exceed the static monopoly benchmark, consistent with Rapoport, Erev and Zwick (1995). By contrast, relatively few pric-

[38] Given the nonlinear implications of the model, where the costs and benefits of the stochastic deadline are comparable, I formally test for nonlinearity using a quadratic specification. However, the qualitative implications remain largely unchanged relative to the simpler linear model. The results are available upon request.

[39] Acceptance in the final period cannot be classified as cooperative by design, because accepting with $v < C_6$ yields a negative payoff, given that $C_6 = P_6$.

Table 4: Baseline Assessment of Behavioral Attitudes under a Credible Deadline ($\alpha_1 = 0$)

	Seller's pricing						
	period						total
	n = 1	n = 2	n = 3	n = 4	n = 5	n = 6	
	Table 4A: distribution of pricing ($\alpha_1 = 0$)						
reasonable	25%	16%	28%	43%	47%	21%	29%
demanding	74%	79%	62%	41%	41%	37%	59%
cooperative	1.1%	5.7%	10%	16%	12%	42%	12%
sample	89	70	68	56	51	38	372

	Buyer's decision						
	period						total
	n = 1	n = 2	n = 3	n = 4	n = 5	n = 6	
	Table 4B: distribution of decisions ($\alpha_1 = 0$)						
reasonable (accept)	1.1%	0.0%	5.9%	1.8%	7.8%	50%	7.8%
reasonable (reject)	79%	97%	82%	86%	63%	47%	79%
cooperative (accept)	20%	2.9%	12%	7.1%	18%	-	11%
demanding (reject)	0.0%	0.0%	0.0%	5.4%	12%	2.6%	2.7%
sample	89	70	68	56	51	38	372

Note: For definitions of behavioral attitudes (sellers: reasonable, demanding, cooperative; buyers: reasonable (accept), reasonable (reject), cooperative (accept), demanding (reject)), see the main text. "–" indicates a value unavailable by design (see footnote 39). NA denotes an unavailable estimate due to a lack of variation under fixed effects.

ing decisions—12%—are cooperative. However, the proportion of cooperative pricing gradually increases over time, from 1% in period $n = 1$ to 12% in period $n = 5$, and peaks at 42% in the final period ($n = 6$). This last-minute discounting appears to be novel in the context of multi-period trading experiments with one-sided incomplete information,[40] yet it is reminiscent of ultimatum games (discussed below). On the buyer side, a much larger proportion of decisions are cooperative (11%) than demanding (2.7%). This marked asymmetry in attitudes between sellers and buyers plausibly contributes to the lower buyer surplus share in the experiment than in the model (35.7% in the experiment versus 44.8% in the model, including separations).

Following the evaluation criteria, I analyze the sensitivity of pricing and acceptance behavior to deadline credibility, relative to the conventional deadline regime ($\alpha_1 = 0$) (see Table B.4 in the Supplementary Material). Consistent with Table 2, pricing becomes less demanding, more reasonable, and increasingly cooperative in periods $n \in \{1,2,3\}$, with the most

[40] Previous studies—Reynolds (2000) in a six-period setting and Rapoport, Erev and Zwick (1995) in an infinite-horizon environment—document a puzzling *increase* in prices near the end. They interpret this pattern in terms of fairness considerations, but in the opposite direction from my explanation: sellers become less willing to discount after repeated rejections.

pronounced changes occurring at the stochastic deadline period ($n = 3$). Plausibly, lower prices induce buyers to replace reasonable rejections with reasonable acceptances in periods $n \in \{1,2,3\}$, while reducing cooperative acceptances. Since the change in buyers' attitudes is closely aligned with sellers' price discounting, my overall assessment is that higher deadline credibility corrects sellers' systematic biases toward demanding prices—especially in opening prices (Effect 1)—and facilitates reasonable agreements by buyers, thereby improving trade efficiency (Effect 2) and strengthening buyers' bargaining power (Effect 3).

Still, an important question remains: why do more sellers become cooperative during the stochastic deadline period ($n = 3$) relative to earlier periods ($n \in \{1,2\}$) as deadline credibility increases, as documented in Table 2? In the following, I discuss four behavioral mechanisms relevant in this context: fairness, bounded rationality, ill-updated belief, and risk aversion.

Fairness: The stochastic deadline is reminiscent of canonical ultimatum games embedded in earlier periods $n \in \{1,2,3\}$. In ultimatum games, standard rationality predicts that even extremely selfish offers should be accepted by responders. However, hundreds of experiments show a well-known behavioral regularity: an average proposer offers between 30% and 50% of the money, and more than half of the opponents reject the proposal with a share below 20% (Camerer (2003)).[41] The literature emphasizes proposers' fairness concerns as a central explanation (e.g., Fehr and Schmidt (1999); Bolton and Ockenfels (2000)). Observing the similarity in the protocol not only at the final deadline ($n = 6$) but also at the intermediate deadline ($n = 3$), one can interpret sellers' systematic discounting before the deadline threat as a manifestation of fairness, as the probability of continuation approaches zero.[42]

Consistently, in the final period ($n = 6$) of the baseline deadline regime ($\alpha_1 = 0$), similarly high cooperative pricing (42%) is observed, even though static ultimatum behavior would be optimal at that stage. However, as the stochastic deadline becomes credible, the same behavioral force in ultimatum games is activated earlier, in the intermediate period ($n = 3$). The effect of deadline-induced fairness appears to be greater in the stochastic deadline regime because the separation risk affects many more remaining pairs in $n = 3$ than in $n = 6$: in the experiments,

[41] Alternatively, the experimental literature refers to fairness as inequality aversion, equity, or reciprocity. In this paper, I use the term fairness throughout.

[42] To rationalize the failure of the Coase conjecture in the laboratory, Fanning (2022) builds a behavioral model with a preference for fairness along the lines of Fehr and Schmidt (1999) and proposes disadvantageous pricing (i.e., monopolists prefer not to offer unfavorable competitive prices) as an explanation. In contrast, my use of fairness has the opposite meaning for sellers (i.e., monopolists do not prefer to set prices that are too demanding).

65% of all games (755 pairs) remain in $n = 3$, whereas only 16% (192 pairs) reach $n = 6$ due to earlier agreements and separations. Faced with a stochastic deadline, this behavioral tendency leads sellers to concede rather than strategically exploit the buyer's concession.

Bounded rationality: Given the similarity to ultimatum games, a fairness-based explanation is appealing. However, fairness concerns may be mitigated under asymmetric information: a higher price may be unfair to lower-type buyers but fair to higher-type buyers, and rejection in this setting does not necessarily reflect an aversion to inequality (Güth, Ockenfels and Ritzberger (1995)).[43] In addition, when the roles of seller and buyer alternate, social norms of fairness may be diluted. If subjects rotate through the advantaged seller position, they would feel less guilt in exercising this privilege.

Beyond fairness, another compelling explanation is a form of bounded rationality, following Selten (1978), who argued that multi-period environments hinder fully rational decision-making. In the six-period experiment, subjects' ability to correctly infer opponents' best responses through backward induction appears limited. Consistently, most participants spend very little time on each decision—about 5 to 10 seconds, especially in later games within each day. Because computing a perfect Bayesian equilibrium path under a stochastic deadline would plausibly require substantially more time, subjects instead appear to rely on heuristic rules of thumb. Their attention is directed primarily toward intuitive perceptions of separation losses. As a result, sellers fail to exploit the stochastic deadline strategically, suggesting that greater deadline credibility monotonically reduces their bargaining power.

Ill-updated beliefs: The previous two biases limit monopoly power. Alternatively, sellers may fail to update their Bayesian beliefs, as reflected in $K_{n_1^*}$ (see "Homemade Priors" by Camerer and Weigelt (1988)).[44] The experimental protocol imposes common initial beliefs about private values across subjects, but beliefs may be substantially revised downward for various reasons in the stochastic deadline period. Although I cannot definitively rule out the possibility that $K_{n_1^*}$ is substantially low, I consider this explanation unlikely to be the primary driver of price concessions. Suppose that $K_{n_1^*}$ were substantially low to account for the observed

[43] Comparing dictator and ultimatum games, Forsythe et al. (1994) show that fairness alone cannot account for discounted offers in ultimatum games.

[44] To formally trace this reasoning, recall that the sellers' pricing is formulated as $P_n = A_n K_n$, where A_n is a period-specific monopoly power and K_n is (the sellers' inference of) the upper bound of their opponents' types. Therefore, lower $P_{n_1^*}$ results from either lower bargaining power $A_{n_1^*}$ or lower $K_{n_1^*}$.

price drop. Because beliefs are driven by previous cutoffs (i.e., $K_{n_1^*} = C_{n_1^*-1}$), this would imply that, as α_1 increases, a correspondingly larger fraction of negotiations in $n \in \{1,2\}$ should reach agreement. This implication is inconsistent with the observed distribution of agreements; the increase in agreements in the pre-stochastic deadline period $n \in \{1,2\}$ with deadline credibility is much smaller than the increase in agreements in the stochastic deadline period $(n = 3)$.[45] Moreover, there is no particular reason to expect beliefs K_n to drop sharply at $n = 3$ rather than at $n = 4$.[46]

Risk aversion: The model assumes that both parties are risk neutral; subjects' risk preferences are neither measured nor controlled in the experiment. Since typical pricing is classified as demanding, pricing is generally consistent with risk-seeking behavior among sellers. Since buyers' decisions are more cooperative than demanding, this buying behavior is consistent with risk-aversion among buyers. If the same person could be potentially both risk-seeking as a seller and risk-averse as a buyer in different roles, individual risk preferences may explain the results. To partially mitigate this concern, recall that the estimation allows the inclusion of individual fixed effects as seller or buyer, so that all the sensitivity to deadline credibility is interpreted as within-person by role, divorced from idiosyncratic components of individual decision making. However, these time-invariant behavioral fixed effects cannot explain the seller's changing attitude within the game: from demanding prices in the opening periods to cooperative prices at the stochastic deadline.

Therefore, I view the seller's price discounting before the stochastic deadline as consistent with a discontinuous manifestation of the seller's risk aversion in the face of separation risk. Put differently, risk aversion is activated at the "time bomb" as the possibility of the next period approaches zero. This also complements my earlier explanation that fairness is salient at the stochastic deadline, suggesting that a deadline has a unique capacity to induce behavioral biases. I conclude that fairness, bounded rationality, and changing risk attitudes are intertwined in the face of a stochastic deadline, but their identification remains challenging.

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[45] See Table 1 for the change in agreement rate as α_1 increases. Rigorously, the multinomial logit sensitivity of agreement with credibility is 0.57, 0.63, and 1.03 for $n \in \{1,2,3\}$, respectively (see Table B.3 in the Supplementary Material).

[46] Recall that updating the belief about an opponent's value induces a striking drop in price from $n = 3$ to $n = 4$. The remaining buyers in period $n = 4$ who reject the offer despite the separation risk faced in period $n = 3$ credibly signal that their valuations are low.

5 Concluding Remarks

Many instances of real-world negotiations drag on until deadlines are reached, often generating costly breakdowns. Must all deadlines be perfectly credible? Motivated by the disproportionate clustering of eleventh-hour agreements around deadlines, I propose redesigning conventional deadline structures by embedding an earlier stochastic deadline to restore ex ante trade efficiency.

By enriching a seller–buyer bargaining model with a non-fatal stochastic deadline at an intermediate period, I demonstrate theoretically that imperfectly credible stochastic deadlines can improve ex ante trade efficiency. Using a laboratory experiment, I provide proof of concept for this mechanism. The results suggest effects that are even stronger than predicted by the model, possibly because earlier agreements are facilitated by sellers' price discounting in the face of the stochastic deadline. This paper thus offers a new perspective for market designers seeking to enhance trade efficiency.

Appendix

The Appendix contains the proofs of the main theoretical results. For detailed experimental settings, auxiliary analyses, and instructions, see the Supplementary Material.

A Proofs

For generality, I allow the model to incorporate $M < N$ stochastic deadlines at period n_d (where d is the order of stochastic deadlines, with $d \in \{1, 2, \cdots, M\}$). As written in the paper, a simple model with $M = 1$ is sufficient to capture the model's insights.

A.1 Proof of Proposition 1 [Equilibrium paths and bargaining powers]

[*Proof*] The proof largely follows a backward induction technique by Sobel and Takahashi (1983) and Fuchs and Skrzypacz (2013). The last period N is an ultimatum game. When

$v > P_N$, the buyer accepts by setting $C_N = P_N$. Then, define

$$X_N \equiv \frac{P_N}{C_N} = 1.$$

The seller's problem at period $n = N$ is

$$V_N = \max_{P_N} \underbrace{\frac{F(K_N) - F(C_N)}{F(K_N)}}_{\text{prob. of agreement}} P_N.$$

Recall that the state variable K_n is the upper-bound private value of the buyer who is still negotiating with the monopolist at period n, and $K_{n+1} = C_n$ $(\forall\, n \leq N-1)$ holds. Recall that the cumulative distribution function of private value v is $F(v) = v^{\sigma}$. The first-order condition yields

$$P_N = A_N K_N, \text{ where } A_N = (\sigma+1)^{-\frac{1}{\sigma}}.$$

Thereby, the seller's value function is

$$V_N = \frac{\sigma}{\sigma+1} P_N.$$

Next, at all periods $n \in \{1, \cdots, N-1\}$, the buyer's cutoff C_n must satisfy

$$\underbrace{C_n - P_n}_{\text{payoff of agreement today}} = \eta_n \delta \underbrace{(C_n - P_{n+1})}_{\text{payoff of agreement tomorrow}}, \tag{A.1}$$

where a risk-adjustment factor η_n is given by

$$\eta_n = \begin{cases} 1 - \alpha_d & (n = n_d^*) \\ 1 & (n \neq n_d^*) \end{cases} \quad (\forall\, d \in \{1, \cdots, M\}).$$

Plugging $P_{n+1} = A_{n+1} K_{n+1} = A_n C_n$ into (A.1), I obtain the cutoff

$$C_n = B_n P_n,$$

where a buyer's bargaining power B_n is inversely characterized by

$$X_n \equiv (B_n)^{-1} = 1 - \eta_n \delta (1 - A_{n+1}). \tag{A.2}$$

For notational convenience, I use X_n instead of B_n in the Appendix. Given the buyer's cutoff strategy characterized by $\{C_n\}$, the seller's problem at period n is

$$V_n = \max_{P_n} \underbrace{\frac{F(K_n) - F(C_n)}{F(K_n)}}_{\text{prob. of agreement}} P_n + \underbrace{\frac{F(C_n)}{F(K_n)}}_{\text{prob. of rejection}} \eta_n \delta V_{n+1}. \tag{A.3}$$

Plugging the inductive hypothesis of $V_{n+1} = \frac{\sigma}{\sigma+1} A_{n+1} C_n$ and $C_n = \frac{P_n}{X_n}$ into (A.3), the first-order condition of (A.3) yields $P_n = A_n K_n$, where

$$A_n = (\frac{X_n}{(\sigma+1)X_n - \eta_n \delta \sigma A_{n+1}})^{\frac{1}{\sigma}} X_n = ((\sigma+1) - \sigma \eta_n \delta A_{n+1} B_n)^{\frac{-1}{\sigma}} / B_n. \tag{A.4}$$

Thereby, the value function for the monopolist is $V_n = \frac{\sigma}{\sigma+1} P_n$.

Analogously, I derive the buyer's value function W_n by backward induction. Consider $\alpha_d \in (0,1)$ ($\forall\, d \in \{1, \cdots, M\}$). In the last period N, the buyer's value function is

$$\begin{aligned} W_N &= \underbrace{\frac{F(K_n) - F(C_n)}{F(K_n)}}_{\text{prob. of agreement}} (\underbrace{\int_{C_N}^{K_N} \frac{f(v)v}{F(K_N) - F(C_N)} dv}_{\text{expected payoff on agreement}} - P_N) \\ &= \underbrace{\{\frac{\sigma}{\sigma+1}(1 - A_N^{\sigma+1}) - (1 - A_N^{\sigma}) A_N\}}_{=E_N} K_N \quad (C_N = P_N = A_N K_N). \end{aligned}$$

Then, define

$$E_N \equiv \frac{W_N}{K_N} = \frac{\sigma}{\sigma+1}\{1 - \frac{\sigma+2}{\sigma+1} A_N\}.$$

At any period, $n \in \{1, \cdots, N-1\}$, an inductive assumption $W_{n+1} = E_{n+1} K_{n+1}$ is imposed such that

$$E_{n+1} \equiv \frac{W_{n+1}}{K_{n+1}} = \frac{\sigma}{\sigma+1}(1 - \frac{\sigma+2}{\sigma+1} A_{n+1}). \tag{A.5}$$

The buyer's problem is given by

$$W_n = \underbrace{\frac{F(K_n) - F(C_n)}{F(K_n)}}_{\text{prob. of agreement}} (\underbrace{\int_{C_n}^{K_n} \frac{f(v)v}{F(K_n) - F(C_n)} dv}_{\text{expected payoff on agreement}} - P_n) + \underbrace{\frac{F(C_n)}{F(K_n)}}_{\text{prob. of rejection}} \eta_n \delta W_{n+1}. \tag{A.6}$$

Plugging $P_n = A_n K_n$, $C_n = \frac{A_n K_n}{X_n}$, and (A.5) into (A.6), one gets

$$W_n = \underbrace{\{\frac{\sigma}{\sigma+1}((\frac{A_n}{X_n})^{\sigma-1} - (\frac{A_n}{X_n})^{\sigma+1}) - (1-(\frac{A_n}{X_n})^{\sigma})A_n + (\frac{A_n}{X_n})^{\sigma+1}\eta_n \delta E_{n+1}\}}_{=E_n} K_n.$$

$\{E_n\}$ is recursively characterized and rearranging it yields

$$\begin{aligned}
E_n &= \frac{\sigma}{\sigma+1}\{1-(\frac{A_n}{X_n})^{\sigma+1}\} - \{1-(\frac{A_n}{X_n})^{\sigma}\}A_n + (\frac{A_n}{X_n})^{\sigma+1}\eta_n \delta E_{n+1} \\
&= \frac{\sigma}{\sigma+1} - A_n + (\frac{A_n}{X_n})^{\sigma+1}\{\frac{1-\eta_n\delta}{\sigma+1} + \frac{\eta_n \delta A_{n+1}}{(\sigma+1)^2}\} \text{ (Insert (A.5))} \\
&= \frac{\sigma}{\sigma+1}(1-\frac{\sigma+2}{\sigma+1}A_n) \text{ (Insert (A.2))}.
\end{aligned}$$

Therefore, by induction,

$$E_n = \frac{\sigma}{\sigma+1}(1-\frac{\sigma+2}{\sigma+1}A_n) \tag{A.7}$$

holds. □

Sensitivity of bargaining powers regarding the time horizon

Figure A.1 shows the simulation of ex ante bargaining powers A_1 for the seller and B_1 for the buyer when periods N increases. One can see that A_1 (or B_1) is monotonically decreasing (or increasing, respectively) at a diminishing rate.

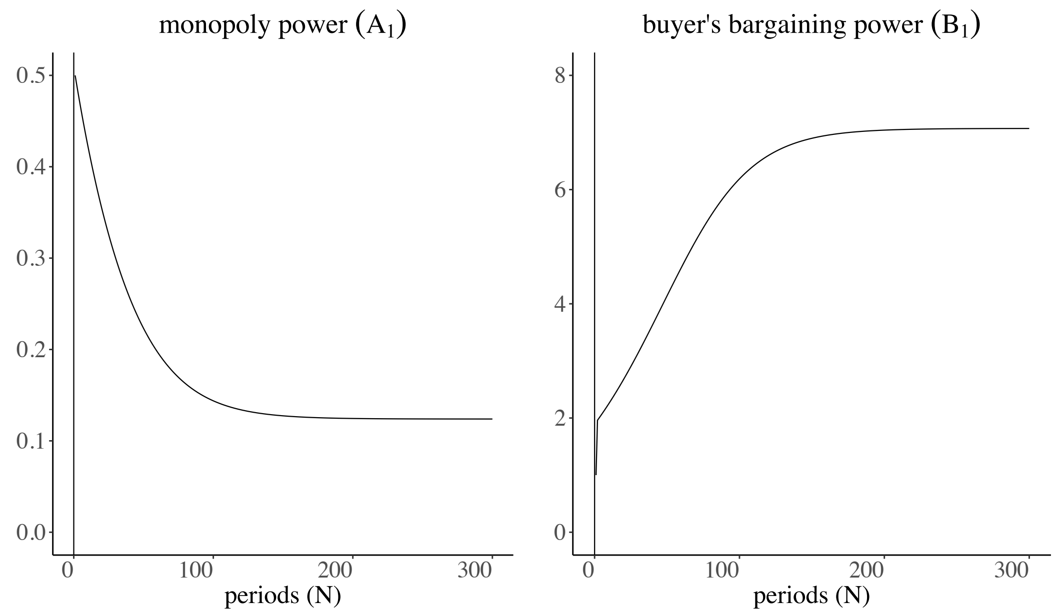

Figure A.1: Simulation: Bargaining Power by Bargaining Horizon

Note: Simulated with $\sigma = 1, \delta = 0.98$ and no stochastic deadlines.

A.2 Proof of Lemma 1 [Seller's opening price]

[*Proof*] A proof consists of Steps 1–4. Recall the first-order condition (F.O.C.) in the main text,

$$\frac{dP_1}{d\alpha_d} = \frac{dA_1}{d\alpha_d} = \underbrace{\frac{dA_1}{dA_{n_d^*}}}_{(>0)\text{ Step 1}} \underbrace{\frac{dA_{n_d^*}}{d\alpha_d}}_{\text{Step 2}} = 0. \tag{A.8}$$

Consider the final stochastic deadline $d = M$. First, I show this F.O.C. in Steps 1–2.

[Step 1] derive A_1 as an increasing function of $A_{n_d^*}$

I show that initial bargaining power increases with bargaining power in the stochastic deadline period n_d^*. Differentiating A_1 with $A_{n_d^*}$, one gets

$$\frac{dA_1}{dA_{n_d^*}} = \prod_{e=1}^{n_d^*} \frac{dA_{e-1}}{dA_e} = \frac{dA_1}{dA_2}\frac{dA_2}{dA_3}\cdots\frac{dA_{n_d^*-1}}{dA_{n_d^*}}$$

and

$$\frac{dA_e}{dA_{e+1}} = \delta\left(\frac{1-(1-A_{e+1})\delta}{\sigma+1-\delta(\sigma+1-A_{e+1})}\right)^{\frac{1}{\sigma}} \frac{\sigma+2-\delta(\sigma+2-A_{e+1})}{\sigma+1-\delta(\sigma+1-A_{e+1})} > 0.$$

Therefore, $\dfrac{dA_1}{dA_{n_d^*}} > 0$ holds.

[Step 2] differentiate $A_{n_d^*}$ with deadline credibility α_d

I decompose $\dfrac{dA_{n_d^*}}{d\alpha_d}$ using $X_{n_d^*}$ (Recall (A.2) for a definition of $X_n \equiv (B_n)^{-1}$) as follows:

$$\underbrace{\frac{dA_{n_d^*}(X_{n^*},\alpha_d)}{d\alpha_d}}_{\text{change in the seller's bargaining power}} = \underbrace{\overbrace{\frac{dA_{n_d^*}}{dX_{n_d^*}}}^{\text{seller's response}(>0)} \overbrace{\frac{dX_{n_d^*}}{d\alpha_d}}^{\text{buyer's response }(>0)}}_{\text{strategic interaction}} + \underbrace{\overbrace{\frac{\partial A_{n_d^*}}{\partial \alpha_d}}^{\text{seller's response }(<0)}}_{\text{self-competition}} \tag{A.9}$$

Using algebra, each component is computed as

$$\begin{cases} \dfrac{dA_{n_d^*}}{dX_{n_d^*}} &= (1+\sigma)(1-(1-\alpha_d)\delta)\dfrac{X_{n_d^*}^{\frac{1}{\sigma}}}{\{1+\sigma-(1-\alpha_d)\delta(1+\sigma-A_{n_d^*+1})\}^{\frac{1+\sigma}{\sigma}}} \\ \\ \dfrac{dX_{n_d^*}}{d\alpha_d} &= (1-A_{n_d^*+1})\delta \\ \\ \dfrac{\partial A_{n_d^*}}{\partial \alpha_d} &= -A_{n_d^*+1}X_{n_d^*}\delta\dfrac{X_{n_d^*}^{\frac{1}{\sigma}}}{\{1+\sigma-(1-\alpha_d)\delta(1+\sigma-A_{n_d^*+1})\}^{\frac{1+\sigma}{\sigma}}} \end{cases}$$

Plugging these equations into (A.9), and using algebra, the F.O.C. is reduced to

$$\frac{dA_{n_d^*}}{d\alpha_d} = \delta\underbrace{\Big((\sigma+1)(1-(1-\alpha_d)\delta)-(1-\alpha_d)A_{n_d^*+1}^2\delta - A_{n_d^*+1}(\sigma+2)(1-(1-\alpha_d)\delta)\Big)}_{\equiv f(\alpha_d)}$$
$$\times g(N,\sigma,\delta,\alpha_d) = 0,$$

where $g(N,\sigma,\delta,\alpha_d)$ is a function of bargaining primitives such that

$$g(N,\sigma,\delta,\alpha_d) = \underbrace{\Big(1-(1-\alpha_d)\delta(1-A_{n_d^*+1})\Big)^{\frac{1}{\sigma}}}_{>0}\underbrace{\Big(1+\delta-(1-\alpha_d)\delta(1+\sigma-A_{n_d^*+1})\Big)^{\frac{-(\sigma+1)}{\sigma}}}_{>0}.$$

Solving for $f(\alpha_d)=0$ yields $\widehat{\alpha}_d$, as given in equation (9) of Lemma 1:

$$\widehat{\alpha}_d = \frac{\delta A_{n_d^*+1}^2-(1-\delta)\{(1+\sigma)-(2+\sigma)A_{n_d^*+1}\}}{\delta(1-A_{n_d^*+1})(1+\sigma-A_{n_d^*+1})}.$$

[Step 3] Parameter conditions for an interior minimizer

Then, I show that $\widehat{\alpha}_d \in (0,1)$. $\widehat{\alpha}_d > 0$ requires a sufficiently large discount factor, $\delta > \overline{\delta}$, where the threshold discount factor $\overline{\delta}$ is given by

$$\overline{\delta} = \frac{(1+\sigma)-(2+\sigma)A_{n_d^*+1}}{(1+\sigma-A_{n_d^*+1})(1-A_{n_d^*+1})}. \tag{A.10}$$

Suppose $\widehat{\alpha}_d \geq 1$. Then, by algebra, $A_{n_d^*+1} \geq \dfrac{1+\sigma}{2+\sigma}$ must hold. Accordingly, because $A_{n_d^*+1} < A_N = (1+\sigma)^{-\frac{1}{\sigma}} < \dfrac{1+\sigma}{2+\sigma}$ $(\forall \sigma > 0)$ holds, this is a contradiction. Therefore, $\widehat{\alpha}_d < 1$.

[Step 4] Second-order condition (S.O.C.)

To show that $\widehat{\alpha}_d$ is a global minimizer, I derive a S.O.C. Note that

$$\frac{d^2 P_1}{d\alpha_d^2} = -\frac{\mathbb{E}(v)}{(\sigma+1)^2} \underbrace{\frac{dA_1}{dA_{n_d^*}}}_{\text{independent of } \alpha_d} \frac{df(\alpha_d)}{d\alpha_d}$$

holds. Because $\dfrac{df(\alpha_d)}{d\alpha_d} = \delta(1-A_{n_d^*+1})(1+\sigma-A_{n_d^*+1}) > 0$ holds, the S.O.C. also holds as $\dfrac{d^2 P_1}{d\alpha_d^2} < 0$. Combining Steps 1–4, the optimal deadline credibility $\widehat{\alpha}_d$ at the last stochastic Mth ($d = M$) deadline is recursively specified by $A_{n_d^*+1}$. For other earlier stochastic deadlines $\widehat{\alpha}_d$ ($d \in \{1, \cdots, M-1\}$), repeating the argument backward from $d = M-1$ to $d = 1$ specifies each optimal deadline credibility $\widehat{\alpha}_d$. □

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