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Capacity Reservation and Wholesale Price Contracts under Forecast Sharing: A Behavioral Assessment

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We study a supply chain setup in which a buyer has private end customer demand information that she can share with the supplier. The demand information is relevant to the supplier's capacity decision. We address the question of whether the supplier benefits from installing nonlinear capacity reservation contracts rather than wholesale price contracts. We contribute to the literature by providing the first internally valid comparison of both contracts with human decision makers. We setup an experimental study with four treatments (both contracts as well as different supplier margins). From a supplier's perspective, we observe that the capacity reservation contract significantly outperforms the wholesale price contract; however, the supplier's benefit from using capacity reservation is much higher under low margins than under high margins. Regarding supply chain performance, the positive effect for the supplier exceeds the negative effect for the buyer in the low margin setting, while the two effects neutralize each other in the high margin setting. We identify behavioral factors explaining deviations from the theoretical predictions. In particular, we observe naïve anchoring and trust as strong behavioral drivers common to both contract types. Even though the complexity of the nonlinear contract results in weaker performance than that predicted by theory, our study reveals that suppliers can still benefit from installing them; thus, providing important managerial implications for the choice of the contract type.

Key words: nonlinear contract; wholesale price contract; information sharing; behavioral operations; anchoring; trust & trustworthiness
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1. Introduction

Information is a crucial asset in supply chain management, and many technical challenges hindering efficient information flows have been overcome in our digital era. In this vein, operations management research stresses the importance of truthful information sharing between supply chain partners while acknowledging the risk of deception if incentives are misaligned. Misaligned incentives are, among others, a result of the contract format that governs the business interaction. We contribute to the literature by analyzing the interplay of contract format and information sharing, thereby shedding light on the important question of whether management should offer complex nonlinear contracts or stick to the common mode of wholesale pricing when information is shared.

We consider a capacity reservation game between a supplier (he) and a buyer (she) with an exogenous wholesale price as analyzed by Özer and Wei (2006) as our basic framework. We refer to Cachon and Lariviere (2001), Cohen et al. (2003), Özer and Wei (2006), and Oh and Özer (2013) who, among others, established the practical relevance of incentive conflicts resulting if private demand forecasts are shared. In the stylized game, the buyer who is closer to the end customer possesses private demand information that is relevant for the supplier's capacity decision; that is, the buyer knows whether the demand forecast is high or low. The supplier may offer a nonlinear capacity reservation contract, on top of the exogenous wholesale price, that stipulates reservation fees (fixed payments) to be paid for guaranteeing specific capacity levels. The reservation fees provide monetary incentives to buyers to reveal private information before capacity is set. Such fixed payments are relevant in industries where increasing capacity involves long lead times and high costs, like in the

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bio-pharmaceutical industry (Plambeck and Taylor 2007). The normative benchmark for both contract formats (wholesale price and capacity reservation) is that forecast sharing is ineffective ("cheap talk") and capacity reservation results in higher profits for the supplier and the supply chain than the wholesale price contract.

Yet, behavioral research challenges the normative prediction that nonlinear contracts outperform wholesale price contracts in terms of efficiency. On the one hand, supply chains perform considerably better under wholesale price contracts than theoretically predicted, because shared information is trustworthy and trusted (see Özer et al. 2011). On the other hand, nonlinear contracts perform consistently worse than theoretically predicted (Inderfurth et al. 2013). Three fundamental reasons for the poor performance of nonlinear contracts are that human contract designers set contract parameters suboptimally compared to the normative benchmark (see, Kalkanci et al. 2011, Kalkanci et al. 2014), buyers deviate from profit-maximizing contract choices (see Inderfurth et al. 2013, Johnsen et al. 2019, Kalkanci et al. 2014), and forecast sharing does not fully resolve information asymmetries (Inderfurth et al. 2013, Johnsen et al. 2020). Overall, a sound recommendation for a contract format cannot be made, since none of these studies directly compares wholesale pricing and nonlinear contracting under forecast sharing.

Our first research contribution is providing the first internally valid comparison of forecast sharing under the two contracting modes. We run laboratory experiments with a student subject pool in a 2×2 design varying the contract format (wholesale price vs. capacity reservation contract) and the profit margin (low/high). We show that lower-than-predicted capacity reservation contract performance exceeds higher-than-predicted wholesale price performance when profit margins are low. When profit margins are high, both wholesale price contracts and capacity reservation contracts perform worse-than-predicted, while from a supplier's point of view capacity reservation still outperforms wholesale pricing. In contrast, Kalkanci et al. (2014) find no significant performance differences between the two contract formats when comparing endogenous wholesale price contracts and nonlinear contracts without information sharing.

Our second contribution is demonstrating why information sharing is effective when human decision makers design capacity reservation contracts. We show that suppliers have similar behavioral biases when setting capacities under the two contract formats, namely, anchoring and insufficient adjustment, as well as trust in shared forecasts (contrary to normative prediction, where all shared forecasts are ignored). By conducting capacity reservation treatments in which buyers were forced to share forecasts truthfully, we provide evidence that subjects' anchors can be explained by diversification driven behavior. This "naïve anchoring" covers mean anchoring as a special case, but also provides separate anchors for menus of contracts, like for capacity reservation contracts. We find that despite or because of these behavioral biases, the capacity reservation contract effectively provides incentives to dishonest buyers to choose supply chain aligned capacity reservation levels. In turn, when meeting honest buyers, capacity reservation contracts do not outperform wholesale price contracts.

Our third contribution is showing that suppliers choose capacity reservation contracts over wholesale price contracts when they have the choice between the contract formats. We observe that suppliers tend to offer more capacity reservation levels than theoretically predicted; however, the superior performance results are robust against this bias. Overall, we find evidence that generically promoting capacity reservation contracts in the organization might already be sufficient to capture positive benefits of this contract format, despite behavioral biases human decision makers exhibit.

The remainder of the paper is organized as follows. Section 2 reviews the related literature on nonlinear contracts, wholesale price contracts, and information sharing. The capacity reservation game and the game-theoretic predictions are discussed in section 3. The experimental design and results are presented in section 4. A discussion of the findings and limitations is provided in section 5. Finally, section 6 offers a conclusion.

2. Literature Review

Misaligned incentives are well-known to lead to manipulated forecast sharing (Cohen et al. 2003, Corbett et al. 1999, Terwiesch et al. 2005). Depending on the setup, for example, the timing of forecast sharing (Chu et al. 2017), forecasts may be inflated (when contracts are already negotiated, as with exogenous wholesale prices) or deflated (when information is shared before the contract offer, as with the capacity reservation contract in our case). In the following, we discuss the main mechanisms to resolve the efficiency losses resulting from information asymmetry and misaligned incentives: incentive alignment via nonlinear contracts such that coordination is in the best interest of profit maximizing and rational parties, and behavioral aspects of forecast sharing such as trust and trustworthiness that allow coordination even if incentives are misaligned.

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2.1. Nonlinear Contracts

Nonlinear contracts have been comprehensively discussed with reference to a large variety of economic contexts under both full information and asymmetric information. Prominent examples in the supply chain domain concern pricing decisions (Wang et al. 2009), lot-sizing decisions (Corbett and De Groote 2000), newsvendor decisions (Lau et al. 2007) and capacity planning (Özer and Wei 2006).

Under full information, nonlinear contracts are theoretically effective because they resolve the double marginalization problem (see, e.g., Ho and Zhang 2008, who show the similarity of a two-part tariff and a quantity discount). However, the experimental literature on full information presents a mixed picture of the effectiveness of nonlinear contracts to solve the double marginalization problem. The studies in Lim and Ho (2007) and Ho and Zhang (2008) indicate that nonlinear contracts effectively reduce efficiency losses resulting from double marginalization, while Wu and Chen (2014) present nuanced results where efficiency may improve or worsen, compared to a simple contract. Furthermore, Cui et al. (2020) find, contrary to our results, in laboratory experiments with automated buyers following a probabilistic decision rule that suppliers prefer simple contracts over more complex nonlinear contracts.

Under asymmetric information, nonlinear contracts (also known as screening contracts or a menu of contracts) are theoretically effective because they resolve the double marginalization problem and they allow to tailor contract parameters to private information. While simple contracts, like wholesale price contracts, cannot resolve information asymmetry, nonlinear contracts provide powerful contract mechanisms to do so. As a special form of nonlinear contracts, capacity reservation contracts can align incentives by charging a reservation fee for a certain amount of capacity buildup by the supplier (Özer and Wei 2006).

2.2. Information Asymmetry—Nonlinear Contracts and Information Sharing

Table 1 summarizes previous behavioral research on nonlinear contracting under asymmetric information and positions our contribution. In particular, we discuss the supplier's contract offer, the buyer's contract choice, and the information sharing between buyer and supplier before we outline our contribution to the previous literature.

2.2.1. Contract Offer. One important aspect of nonlinear contracts concerns their design complexities. Kalkanci et al. (2011) and Kalkanci et al. (2014) analyze in laboratory experiments how humans set parameters in quantity discount contracts and find subjects are unable to set quantity breaks effectively. In particular, the actual contract offers do not effectively separate buyer types. To this end, Inderfurth et al. (2013), Sadrieh and Voigt (2017), Johnsen et al. (2019), and Johnsen et al. (2020) focus on the information sharing aspect by introducing a subtle contract design tool that generates optimal contracts based on the subject's beliefs about the private information. The generated contracts ensure the separation of buyer types as long as buyers act rationally and maximize profits. The advantage of this approach is that the results control for contract design complexities faced by human decision makers while focusing on the information sharing aspects. However, since recommendations concerning the contract format might be sensitive toward contract design complexities faced by humans (see Kalkanci et al. 2011, Kalkanci et al. 2014), we complement this research by analyzing how information sharing impacts contract performance when the optimal contract design structure for nonlinear contracts is not enforced.

2.2.2. Contract Choice. Normative theory assumes that buyers make rational and profit-maximizing contract choices. Separation of buyer types then follows

Table 1 Research on Nonlinear Contracting under Asymmetric Information

	Humans design* offered contracts	Humans make contract choice	Information sharing	Contract	Benchmark contract
Johnsen et al. (2019)	–	+	–	Capacity reservation	–
Inderfurth et al. (2013)	–	+	+	Quantity discount	–
Sadrieh and Voigt (2017)	–	+	+	Quantity discount	Two-part tariff
Johnsen et al. (2020)	–	+	+	Quantity discount	–
Kalkanci et al. (2011)	+	–	–	Quantity discount	Wholesale price
Kalkanci et al. (2014)	+	+	–	Quantity discount	Wholesale price
Our study	+	+	+	Capacity reservation	Wholesale price

*Studies marked with (+) refer to setups where humans set the contract parameters. In all studies marked with (–) normatively optimal contracts are generated based on the supplier's a-posteriori belief. The automatically generated contract parameters cannot be adjusted and ensure that they separate rational and profit-maximizing buyers.

from buyers self-selecting the profit-maximizing contract option that was tailored to their type. However, the laboratory studies in Kalkanci et al. (2014), Inderfurth et al. (2013), Sadrieh and Voigt (2017), Johnsen et al. (2019), and Johnsen et al. (2020) show that buyers are concerned with social preferences and suffer from boundedly rational contract choices. Accordingly, even if contract offers follow the normative structure (see section 2.2.1), suppliers and the supply chain performance suffers from non-predicted contract choices.

2.2.3. Information Sharing. In theory, nonlinear contracts provide a powerful mechanism to align incentives in a way that information sharing, that is, communicating the private information via messages that have no pay-off consequences ("cheap talk"), provides little value for the supplier and the supply chain (we discuss the normative benchmarks in detail in the next section). However, behavioral research shows that suppliers using decision support, based on their a-posteriori beliefs, react to shared information (Inderfurth et al. 2013, Johnsen et al. 2020, Sadrieh and Voigt 2017). On average, comparing scenarios with and without information sharing, the supply chain parties benefit from information sharing (Inderfurth et al. 2013, Johnsen et al. 2020). However, the non-profit-maximizing contract choice behavior of buyers (see section 2.2.2) still leads to performances that are significantly below the predicted performances, even though those studies enforce the normatively optimal contract structure (see section 2.2.1).

2.2.4. Contribution to the Previous Literature. The study closest to our research is the one by Kalkanci et al. (2014) who also consider nonlinear contracts designed by human decision makers; however, with the important distinction that they do not allow for information sharing. They analyze a setting with endogenous wholesale prices, stochastic demand, and asymmetric information and compare wholesale price contracts with quantity discount contracts. We complement this research by showing that information sharing can result in superior performance of nonlinear contracts in another planning domain and under a different contract format. It turns out that the combination of behavioral biases (i.e., anchoring and trust) robustly separates honest and dishonest buyers, yet substantial efficiency losses prevail compared to the efficiency level in a full information setting.

Operating under nonlinear contracts leads to performances below the theoretical benchmarks due to a subtle interaction of contract offer, contract choices and information sharing, while under wholesale pricing, supply chain performance consistently increases compared to the standard game-theoretic benchmark. One of the main reasons for the performance increase under wholesale prices seems to be trust based on (anticipated) trustworthiness (Hyndman et al. 2013, Özer et al. 2011, 2014, 2018, Spiliotopoulou et al. 2016). For contracts designed by human decision makers, this state of the art does not allow for a clear recommendation of which contract format to apply when information is shared. We close this gap by comparing these two contract formats under information sharing in controlled laboratory experiments that enable an internally valid comparison in section 4 (and we provide the corresponding game-theoretic benchmarks in section 3). Contrary to Kalkanci et al. (2014), we find that nonlinear contracts outperform simple contracts when information is shared, which supports the conjecture by Haruvy et al. (2020) that a bargaining process with information sharing is likely to improve the performance of nonlinear contracts under asymmetric information.

3. Game-Theoretic Predictions for Information Asymmetry

We describe the general setup in section 3.1 before we discuss the game-theoretic prediction for a wholesale price contract in section 3.2 and for a capacity reservation contract in section 3.3.

3.1. Setup

We employ the setting studied in Özer and Wei (2006) and adapted by Johnsen et al. (2019). We consider a supply chain that consists of a supplier s (principal, male pronouns) who produces a critical component at unit cost c for a buyer b (agent, female pronouns). The buyer pays an exogenous per-unit wholesale price w to her supplier. The sourced component is an integral part of the product that the buyer sells to her end customers at a unit price r. The supplier installs capacity K at unit cost c_k in anticipation of end customer demand. We assume that $r > c + c_k$. The buyer orders realized demand, while the supplier's delivery is constrained by his prior capacity decision. It is common knowledge that the end customer demand $\tilde{D}$ is continuously distributed and given by $\tilde{D} = \mu + \tilde{\xi} + \tilde{\varepsilon}$, where $\tilde{\varepsilon}$ is the market uncertainty, assumed to be a zero-mean random variable with cdf $F_e(\cdot)$ and pdf $f_e(\cdot)$ with possible values on the interval $[\underline{\epsilon}, \overline{\epsilon}]$. The discrete random variable $\tilde{\xi} \in \{\xi_i | i \in \{l, h\}\}$ with support $p(\xi_i)$ captures the buyer's private information. In the following, we denote the buyer with realization ξ_l as the "low type" and the buyer with ξ_h as the "high type." The buyer knows her realization ξ_i, while her supplier only knows the a priori probability distribution $p(\xi_i)$ of the discrete random variable. The supply

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chain optimal capacity decision is given by $K(\xi_i) = K_i^* = \mu + \xi_i + F_e^{-1}\frac{(r-c-c_k)}{(r-c)}$. The buyer may share her private forecast information via a message $S_i \in (S_n, S_l, S_h)$. A message S_i, $i \in \{l, h\}$ corresponds to the demand information ξ_i, while S_n corresponds to "no message."[1] We denote these messages as forecast sharing. The shared forecast may be truthful (i.e., $S_i = \xi_i$) or deceptive ($S_i \neq \xi_i$).

Parameters: The examples in the following subsections and our experiments are based on the parameters from Özer et al. (2011) (adapted for a discrete distribution of demand types). We set the end customer price to $r = 100$, the wholesale price to $w = 75$, and the buyer's per-unit cost to c=0. We consider a high profit margin ($c_k = 15$) and a low profit margin ($c_k = 60$). The market uncertainty $\tilde{\varepsilon}$ follows U [−100, 100]. We further set $\xi_l = 100$ and $\xi_h = 300$. Each type occurs with equal probability, that is, $p(\xi_l) = p(\xi_h) = 0.5$.

3.2. Wholesale Price Contract & Capacity Decision

In the wholesale price scenario, the buyer first observes her private information ξ_i and sends the message S_i. The supplier then sets the capacity K and end customer demand D is realized.

Information sharing: Following the intuition of Theorem 1 in Özer et al. (2011), we note that the buyer's profits are increasing in K. A rational and expected profit-maximizing supplier with full information (i.e., knowing the realization ξ_i) maximizes (1) by choosing $K^{w,*}(\xi_i) = K_i^{w,*} = \mu + \xi_i + F_e^{-1}\frac{(w-c-c_k)}{(r-c)}$. Since $K_i^{w,*}$ increases in ξ_i, the buyer has an incentive to make her supplier believe that the demand forecast is high. In the game-theoretic benchmark, the supplier anticipates this incentive, ignores the shared forecast, and makes a capacity decision that is based on the convoluted random variable $\tilde{G} = \tilde{\xi} + \tilde{\varepsilon}$, that is, $K^w = \mu + G^{-1}\frac{(w-c-c_k)}{(r-c)}$.

Performance: The supply chain performance deteriorates for two reasons: first, the supplier considers his profit margin $(w-c)$ instead of the supply chain profit margin $(r-c)$ which leads to the common double marginalization effect (see Spengler 1950). Second, without credible shared information, the supplier cannot tailor the capacity installment to private information ξ_i. Instead, he bases his capacity decision on the convoluted distribution $\tilde{G} = \tilde{\xi} + \tilde{\varepsilon}$.

Table 2 summarizes the capacity levels and supplier's and buyer's profits in the respective benchmarks. If full information is available, the expected supply chain performance of the wholesale price contract (equilibrium) increases considerably, that is, by more than 116.6% (from 42.9% to 92.9%) in the low margin scenario and by more than 9.0% (from 91.6% to 99.8%) in the high margin scenario, although it is still lower compared to the supply chain optimum.

3.3. Nonlinear Capacity Reservation Contract

Under the capacity reservation contract, denoted with the superscript c, the buyer still pays the exogenously given wholesale price w per unit to her supplier. Additionally, she pays a fixed reservation fee $Z \in (Z_l, Z_h)$ for reserving the capacity $K \in (K_l, K_h)$, and the supplier credibly commits to this capacity reservation level. The supplier's and buyer's expected profits for a given contract (K_j, Z_j) and a given realization ξ_i are

$$\pi_s^c(\xi_i, K_j, Z_j) = (w-c) \cdot E_e[\min(\mu + \xi_i + \tilde{\varepsilon}, K_j)] - c_k \cdot K_j + Z_j \quad (1)$$

$$\pi_b^c(\xi_i, K_j, Z_j) = (r-w) \cdot E_e[\min(\mu + \xi_i + \tilde{\varepsilon}, K_j)] - Z_j \quad (2)$$

and the supplier's optimal menu solves the following optimization problem:

$$\max_{K,Z} E[\pi_s^c(\xi, K, Z)] = \sum_{i=1}^{n} p(\xi_i) \cdot \pi_s^c(\xi_i, K_i, Z_i) \quad (3)$$

$$\pi_b^c(\xi_i, K_i, Z_i) \geq \pi_b^c(\xi_i, K_j, Z_j) \quad \forall i, j \in \{l, h\}; i \neq j \quad (4)$$

$$\pi_b^c(\xi_i, K_i, Z_i) \geq \pi_b^c(\xi_i, K_0, Z_0) \quad \forall i \in \{l, h\}. \quad (5)$$

Table 2 Contract Parameters and Expected Profits for the Wholesale Price Contract

				E(Profit buyer)			E(Profit supplier)			E(Profit SC)	
		ξ_l	ξ_h	ξ_l	ξ_h	$\xi_i \in \{l, h\}$	ξ_l	ξ_h	$\xi_i \in \{l, h\}$	$\xi_i \in \{l, h\}$	Relative
Low margin	Equilibrium (K^w)	80		1600	2000	1800	0	1200	600	2400	42.9%
	Full info. ($K_i^{w,*}$)	40	240	900	5900	3400	300	3300	1800	5200	92.9%
	First best (K_i^*)	80	280	1600	6600	4100	0	3000	1500	5600	100%
High margin	Equilibrium (K^w)	320		2500	7100	4800	2700	16,500	9600	14,400	91.6%
	Full info. ($K_i^{w,*}$)	160	360	2400	7400	4900	4800	16,800	10,800	15,700	99.8%
	First best (K_i^*)	170	370	2444	7444	4944	4781	16,781	10,781	15,725	100%

The optimization problem is fundamentally identical to standard adverse selection models with the exception of the participation constraints (5) that includes the contract option (K_0, $Z_0 = 0$). The supplier has no incentive to allow for higher outside options than necessary, since this shifts profits to the buyer, and sets ($K_0 = 0$, $Z_0 = 0$) ensuring that all buyer types ξ_i will choose one of the contracts (K_i, Z_i), $i \in \{l, h\}$. The incentive constraints (4) ensure that a buyer with realization ξ_i maximizes expected profits by paying the reservation fee Z_i for a capacity installment of K_i. Following fundamental insights from nonlinear contracting, the expected performance of the buyer results from $E(\pi_b^c) = p(\xi_l) \cdot \pi_b^c(\xi_l, K_l, Z_l) + p(\xi_h) \cdot \pi_b^c(\xi_h, K_h, Z_h)$.

Information sharing: Since the buyer's informational rents (tantamount to her profits) are increasing in $p(\xi_l)$, she has an incentive to make her supplier believe that expected demand is low, contrary to the situation under a wholesale price contract. Intuitively, the participation constraint binds for the low demand type buyer; that is, the supplier sets

$$Z_l = (r - w) \cdot E_e[\min(\mu + \xi_l + \tilde{\varepsilon}, K_l)] \quad (6)$$

to reap all supply chain profits from the low demand type. The side payment Z_l is increasing in the capacity K_l, and a buyer who reserves more capacity K_l makes higher profits that can be extracted via the reservation fee Z_l. The incentive of the high demand type to make the supplier believe that she is a low demand type results from incentive compatibility, requiring that the high demand type earns at least as much when reserving capacity K_h as when reserving capacity K_l. It follows that

$$\pi_b^c(\xi_h, K_h, Z_h) = (r - w) \cdot E_e[\min(\mu + \xi_h + \tilde{\varepsilon}, K_l)] - Z_l \quad (7)$$

and inserting Equation (6) into (7) results in

$$\pi_b^c(\xi_h, K_h, Z_h) = (r - w) \cdot E_e[\min(\mu + \xi_h + \tilde{\varepsilon}, K_l) - E_e[\min(\mu + \xi_l + \tilde{\varepsilon}, K_l)]] \geq 0. \quad (8)$$

A contract that leaves zero profits to the low demand type will leave profits larger than zero to the high demand type (i.e., an informational rent) because the likelihood of using all reserved capacity is higher. Therefore, the supplier lowers capacity levels away from the supply chain optimal level for the low demand type to charge a higher capacity reservation fees from the high demand type. In equilibrium, the supplier realizes the buyers' incentive to make her believe that she is a low demand type and ignores the forecast.

Performance: The reservation fees Z_i provide more leeway to distribute profits. Hence, there is no double marginalization effect under capacity reservation contracts. Furthermore, offering a menu of contracts allows for tailoring of quantities to demand realizations. Nonetheless, we observe efficiency losses due to the supplier's attempts to maximize profits by trading off the informational rents paid to the high demand type and the efficiency losses that lower profits when demand is low. As a result, the low demand type's capacity level is lower than or equal to the supply chain optimum, that is, with ($K_i^{*,c}$, $Z_i^{*,c}$) denoting the optimal contract parameters given ξ_i, it follows that $K_l^{*,c} \leq K_l^*$ while the high type is offered the supply chain optimal capacity level, that is, $K_h^{*,c} = K_h^*$.[2]

The contract parameters and expected profits of buyers and suppliers by realization ξ_i are summarized in Table 3. Furthermore, Table 3 summarizes the expected buyer, supplier, and supply chain performance if the buyer chooses the expected profit-maximizing contract option (bold boxes). Compared to capacity reservation contracts and full information, that is, the first best solution (see Table 2), the supply chain performance reaches more than 99% efficiency in both the low margin setting and the high margin setting. Compared to the wholesale price contract, the capacity reservation contract reduces the consequences of information asymmetries effectively. If full information was available, the performance increases would be lower for the capacity reservation contract (less than 1%) than for the wholesale price contract (see above).

4. Comparison of Wholesale Price and Capacity Reservation Contracts

According to game theory, the wholesale price contract profits more from information than the capacity reservation contract (while still performing worse). However, the game-theoretic prediction for both contracts is that shared information is not truthful. More precisely, depending on the contract format information is either inflated or deflated, that is, forecast sharing does not reduce information asymmetries at all. Thus, according to the normative prediction, the capacity reservation contract, which reduces information asymmetries by separating buyers, performs better than the wholesale price contract.

However, behavioral studies (see section 2) demonstrate that people are rarely able to design separating contracts, thus information asymmetries are not resolved if human decision makers come into play. While the influence of information sharing on the performance of self-designed capacity reservation contracts has not previously been explored, behavioral

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Table 3 Contract Parameters and Expected Profits for the Capacity Reservation Contract

		E(Profit buyer)			E(Profit supplier)			E(Profit SC)	
		ξ_l	ξ_h	$\xi_i \in \{l, h\}$	ξ_l	ξ_h	$\xi_i \in \{l, h\}$	$\xi_i \in \{l, h\}$	Relative
Low margin	$(K_l^{*,c}, Z_l^{*,c}) = (64, 1344)$	**0**	256	128	**1536**	2304	5440	5568	99.4%
	$(K_h^{*,c}, Z_h^{*,c}) = (280, 6344)$	−3844	**256**		−2956	**9344**			
High margin	$(K_l^{*,c}, Z_l^{*,c}) = (136, 2244)$	**0**	1156	578	**6936**	10,404	15,003	15,581	99.1%
	$(K_h^{*,c}, Z_h^{*,c}) = (370, 6288)$	−3788	**1156**		8238	**23,069**			

Notes: Bold fields indicate the profit maximizing contract choice given the realization ξ_i.

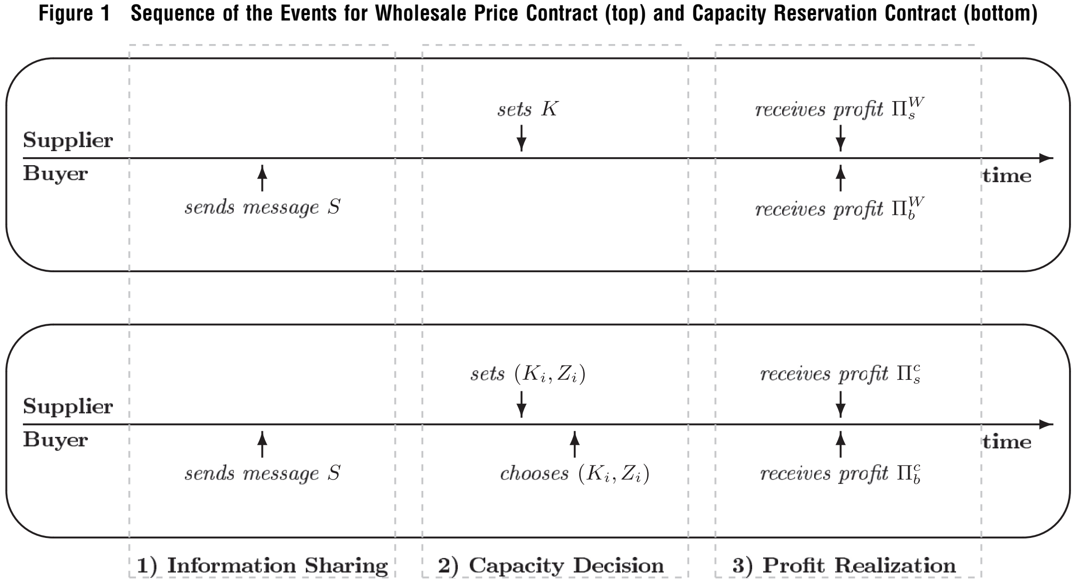
studies show that human decision makers share partially truthful information under the wholesale price contract (as well as under optimal separating capacity reservation contracts), and this information sharing results in contracts that perform better than predicted by game theory.

Overall, for human decision makers it remains questionable whether nonlinear contracts should be considered to resolve information asymmetries since simple contracts perform better than nonlinear contracts without information sharing, and simple contracts are further improved through forecast sharing which partially reduces information asymmetries. However, whether information can be shared (which appears to be the norm not the exception in practice) is independent of the contract format, and the answer to this question depends on whether information sharing is similarly effective for both contracts, whether humans take this shared information into account in a similar way in both contracts, and whether similar behavioral drivers influence human decisions in both contracts. We omit the presentation of behavioral hypotheses on performance because the state of the art is inconclusive, and explore whether suppliers can benefit from capacity reservation contracts. We setup controlled laboratory experiments which we explain in the next subsection before we discuss the three experimental studies that we conducted.

4.1. Design and Protocol of the Experimental Studies

We manipulate the contract types (wholesale price contract and capacity reservation) and consider two cost levels (low margin and high margin) employing a 2×2 design. The sequence of the events for the wholesale price contract and the capacity reservation contract consisted of three phases presented in Figure 1. In the first phase (*Information Sharing*), the buyer observes the demand state and sends a message (low forecast, no message, high forecast). After each buyer has made her decision, the second phase starts (*Capacity Decision*), where the supplier observes the message and determines the capacity for the wholesale price contract or the capacities and fixed fees for the capacity reservation contract. The capacity reservation contract consists of the outside option with a zero side payment (*Outside Option Contract*), which is equivalent to the wholesale price contract, and two freely adjustable contracts, one intended for a low

Figure 1 Sequence of the Events for Wholesale Price Contract (top) and Capacity Reservation Contract (bottom)



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demand (*Contract Low*) and one intended for a high demand (*Contract High*). In the experiment, we refer to these contract options as contracts no. 1, no. 2, and no. 3 to avoid framing effects, and subjects are informed that the quantities and reservation fees must not be higher for a lower contract number, which ensures an identical contract order for all subjects. Then, the buyer decides which contract she wants to choose for the capacity reservation contract. In the last phase (*Profit Realization*), all subjects observe the demand and their profit.

All sessions were conducted at the University of Hamburg's laboratory for experimental research in economics. Subjects were randomly placed into a cohort (matching groups) of six participants and assigned to roles (buyer or supplier) at the beginning of each treatment. Roles remained fixed for the duration of each session. Upon entering the laboratory, subjects were asked to read instructions that were identical for both margin treatments and both roles and only slightly differed for both contract treatments (see Online Appendix). Subjects could ask questions, which were answered privately. Afterward, the subject had to pass a quiz taking approximately 15 minutes to ensure that they understood the instructions correctly. The experiment was programmed and conducted with the software z-Tree (Fischbacher 2007). During the experiment, communication between subjects other than sharing forecasts via the software was prohibited, and none was observed. There was no time pressure, and the experiment started with three training periods to ensure that subjects understood the task well. Afterward, 30 payout-relevant periods with random matching (within the cohort) followed, thereby mimicking a one-shot game. Upon completion of the session, each subject was privately paid his or her total earnings in cash.

4.2. Results (Study 1)

In total, 234 subjects participated in Study 1, resulting in 54 to 60 subjects and 9 to 10 cohorts per treatment. The experiment took on average approximately 75 minutes, and the average performance-dependent compensation was approximately 16 euros. In the following, we provide and compare the results of both contracts for the three experimental phases (*Information Sharing*, *Capacity Decision*, and *Profit Realization*).

4.2.1. Information Sharing. Table 4 shows the share of each message type (low forecast, no message, high forecast) by profit margin for both contracts and both margin treatments. In the wholesale price setting, a rational and profit-maximizing buyer would inflate the forecast (see section 3). In both treatments, buyers report a forecast in more than 90% of all cases, whereby a high forecast was shared more often than a low forecast. There are only a few cases without forecast sharing, and almost all of them (97%) correspond to a low demand state. Almost all low forecasts were truthful, while only approximately two-thirds of high forecasts were truthful. Overall, we do not observe major differences between the margin settings.

Table 4 Share of Message Types and Share of Truthful Forecasts for a Given Type in Brackets

	Wholesale price contract		Capacity reservation contract	
	Low margin	High margin	Low margin	High margin
Low forecast	28% (99%)	22% (100%)	40% (90%)	41% (92%)
No message	7%	8%	17%	17%
High forecast	65% (70%)	70% (66%)	43% (81%)	42% (88%)

In the capacity reservation setting, a rational and profit-maximizing buyer would deflate the forecast (see section 3). However, grasping the incentive to deflate requires, among others, expertise in nonlinear contracts. To this end, we observe neither consistent inflation nor consistent deflation of forecasts. Forty percent of the messages are low forecasts and 43% are high forecasts, while most but not all of the shared forecasts are truthful (approximately 88%). There is no forecast sharing in 17% of all cases, and if no forecast is shared, demand is low in 58% and high in 42% of all cases. We observe no major difference between both margin settings.

For both contracts, information sharing results in better yet not fully informed suppliers. Using the average truthfulness of the shared low and high forecasts of all buyers within each cohort as the statistical unit of analysis, we observe that forecasts are (mildly significant) more truthful for the capacity reservation contract than for the wholesale price contract for both the low margin (Mann–Whitney U, $p=0.06$) and the high margin (Mann–Whitney U, $p<0.05$). Thus, information sharing works well if the supplier installs a capacity reservation contract. Untruthful messages tend to be evenly distributed between inflation and deflation while, for the wholesale price contract, inflation is predominant.

4.2.2. Capacity Decision. For both contracts, the suppliers adjust the capacities based on the information provided as illustrated in Figure 2, which shows the box plots of the contract capacities (average capacity provided within each cohort). For the wholesale price contract and the capacity reservation contract (i.e., *Outside Option Contract*, *Contract Low*, and *Contract High*) suppliers react significantly to the information provided by the buyers (each Wilcoxon signed-rank test, $p<0.05$). However, in contrast to the other contracts, the capacity of the *Outside Option Contract*

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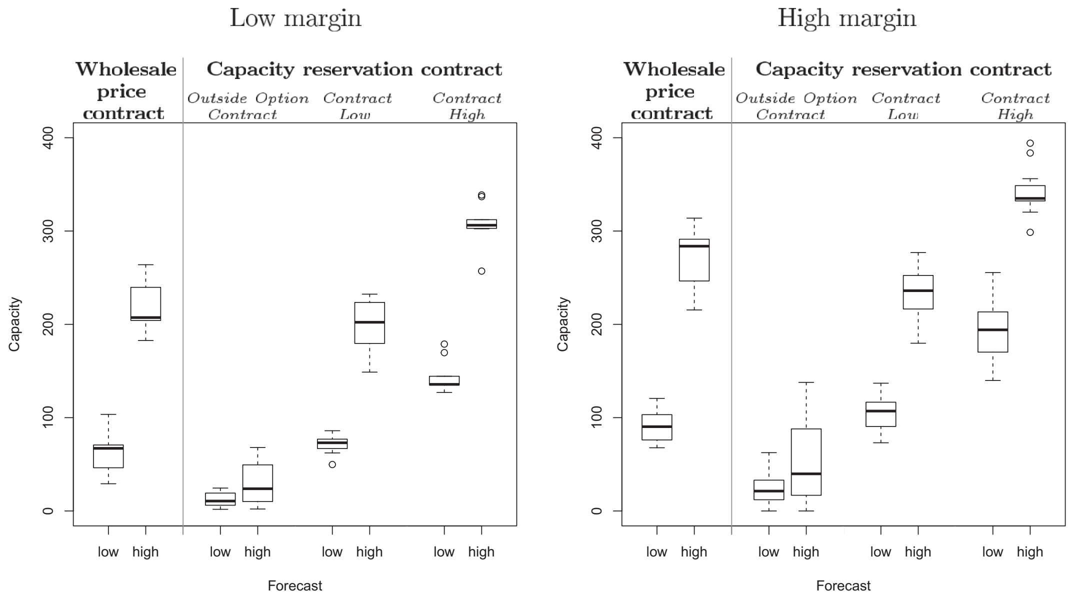
Figure 2 Average Capacities for Wholesale Price and Capacity Reservation Contract for High and Low Forecast



only increases slightly, and we observe that suppliers set a rather small but positive quantity in approximately half of all interactions while they set the quantity to the game-theoretic prediction of zero otherwise (resulting in an average capacity of 20 (39) for the low (high) margin case).[3]

According to the game-theoretic prediction, the capacity of *Contract Low* is intended for a low demand and the capacity of *Contract High* is intended for a high demand. For both margin treatments, given a high demand, *Contract High* was selected significantly more often than both *Contract Low* and the *Outside Option Contract* (each Wilcoxon signed-rank test, $p < 0.05$). In turn, given a low demand, *Contract High* was selected (mildly) significantly less often than both *Contract Low* (each Wilcoxon signed-rank test, $p < 0.05$) and the *Outside Option Contract* (low margin, Wilcoxon signed-rank test, $p < 0.05$; high margin, Wilcoxon signed-rank test, $p = 0.06$). However, Figure 2 illustrates that the capacities of the capacity reservation contracts do not allow for an efficient separation of forecast sharing buyers, because the capacity reservation levels are not properly distributed over the low and high demand ranges. Given a low forecast, less than 14% of all capacity reservation contracts contained a quantity intended for a high demand state, that is, above 200. In turn, given a high forecast, less than 25% of all capacity reservation contracts (without the *Outside Option Contract*) contained a quantity intended for a low demand state, that is, below 200.

Nevertheless, the observed capacity reservation offers separate dishonest buyers from honest buyers effectively. Provided that the forecast is low while the demand is high, the *Contract High* is mostly chosen (87%). In turn, provided the forecast is high while demand is low, the *Outside Option Contract* is chosen most often (65%) while *Contract High* is never chosen (0%). This observation can be explained as follows: given a high demand and a dishonest buyer, *Contract Low* and *Contract High* offer less capacity than the high demand type requires, thus she goes for *Contract High*. In turn, given a low demand and a dishonest buyer, *Contract Low* and *Contract High* offer more capacity than the low demand type requires, thus she goes for *Contract Low* (or the *Outside Option Contract*).[4]

4.2.3. Profit Realization. Thus far, we observed that the information shared is partially truthful (even more for the capacity reservation contract), and capacity decisions strongly react to the information. As a consequence, capacity reservation contracts do not optimally separate forecast sharing buyers. However, they still separate buyers, in particular untruthful buyers. Next, we compare realized profits for both contracts.

We compare the equilibrium performance of rational and expected profit-maximizing suppliers and buyers for capacity reservation contracts (Cr*) and wholesale price contracts (Wh*) to the corresponding observed performance levels (Wh and Cr). The performance by contract type, margin setting, and supply chain parties are displayed in Figure 3. Using the average performance of all suppliers (all buyers) within each cohort as the statistical unit of analysis validates that suppliers (buyers) earn significantly more (less) with the capacity reservation contracts for each margin case (each Mann–Whitney U,

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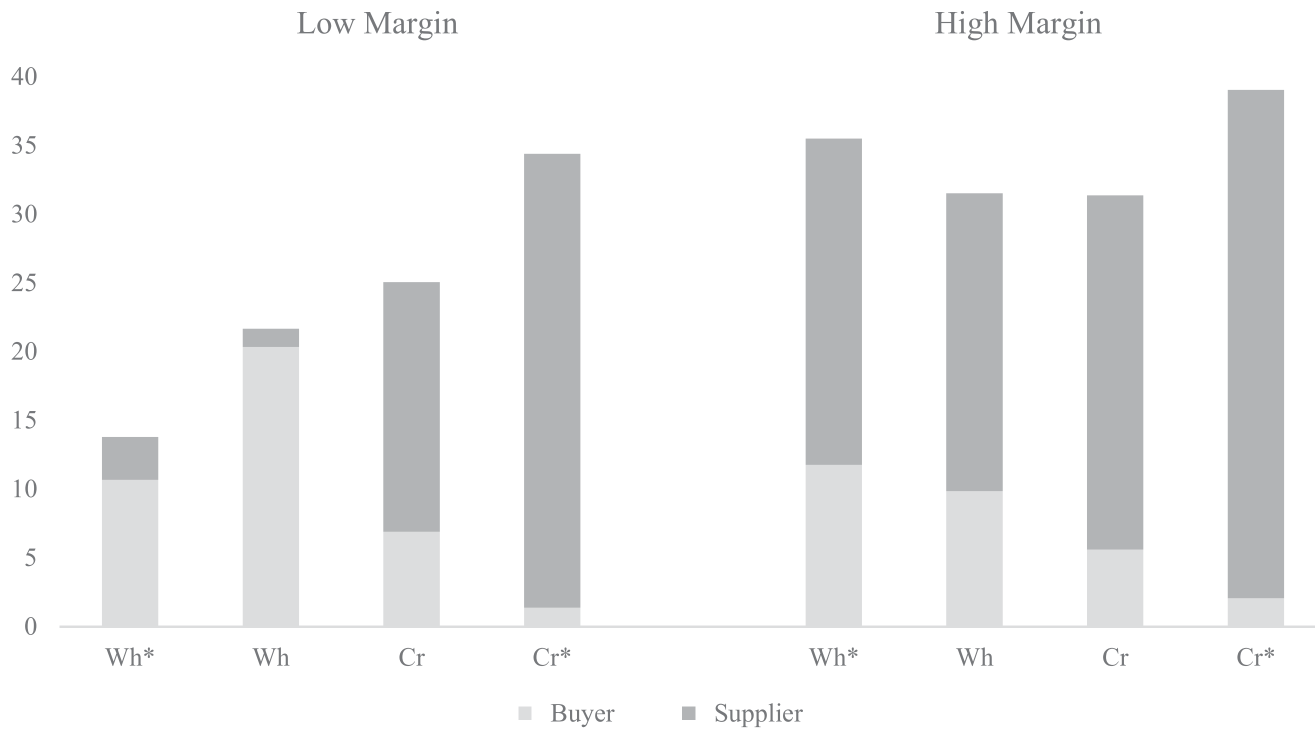
Figure 3 Suppliers' and Buyers' Performance Over All Periods (in euros)



$p < 0.05$)—suppliers profit from the capacity reservation contract.5 In the high margin setting, the supplier's profit increase is approximately the same as the profit loss of the buyer, which is in line with the non-significant effect on supply chain performance (Mann–Whitney U, $p = 0.557$). In the low margin scenario, however, the buyer's profit decreases by less than the supplier's profit increases, resulting in a significant supply chain performance increase (Mann–Whitney U, $p < 0.05$).[6]

Table 5 displays the supply chain performance for the two contract formats when forecasts are shared truthfully/untruthfully. For example, the average supply chain performance per period is –64 cents (2 cents) if a low demand buyer sends an untruthful forecast under the wholesale price contract (capacity reservation contract). We observe that the performances of the contract formats are almost the same, regardless of the profit margin, when information is shared truthfully. There seems to be no need to have two tailored capacity levels if the demand type is "known." Considering the untruthful forecasts, we observe that the wholesale price contract performs poorly for the low margin and well for the high margin, an asymmetry that can be explained by trust in inflated forecasts in combination with a mean anchor effect. The latter results in too high capacities for low margins and too low capacities for high margins, while trust in inflated (i.e., untruthful) forecasts results in increased capacities. In combination, both effects tend to "neutralize" each other in the high margin while they "exacerbate" in the low margin. For the capacity reservation contract, we do not observe that buyers systematically inflate (or deflate) forecasts, and furthermore it effectively, but not optimally, separates untruthful buyers (see previous subsection). As a result, it performs quite well for untruthful forecasts, and, in combination with side payments that shift profits from the buyer to the supplier, we find that from a supplier's perspective capacity reservation contracts perform better than wholesale price contracts, particularly when forecasts are deceptive.

Table 5 Supply Chain Performance Per Period (in cents) if Forecast was Shared (number of observations in brackets)

		Low margin		High margin	
	Contract	Low demand	High demand	Low demand	High demand
Untruthful forecast	Wholesale price	–64 (157)	70 (2)	47 (214)	– (0)
	Capacity reservation	2 (65)	101 (31)	37 (51)	113 (32)
Truthful forecast	Wholesale price	16 (224)	171 (373)	41 (198)	175 (420)
	Capacity reservation	17 (291)	180 (284)	40 (371)	185 (365)

4.3. Behavioral Model Describing the Capacity Decision

We identify trust and anchoring effects as potential drivers of biased wholesale price capacities, and we

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observe biased capacities, driven by trust, which do not allow for an optimal buyer separation for the capacity reservation contract. In the following, we elaborate on behavioral aspects influencing the capacity decision of both contracts. We claim that, besides trust, diversification based anchoring and insufficient adjustment, which we refer to as *naïve anchoring*, is the main driver of contracts with non-optimal capacities. We first discuss *naïve anchoring* in subsection 4.3.1 before we examine its interaction with trust in subsection 4.3.2.

4.3.1. Diversification Based Anchoring and Insufficient Adjustment. Anchoring and insufficient adjustment behavior is well-known to be a strong driver of human behavior in general (Furnham and Boo 2011) as well as in closely related operations management settings where subjects determine supply before facing stochastic demand (Becker-Peth and Thonemann 2018). We assume, in line with closely related studies on single contract decision, that subjects employ one anchor per contract (e.g., two anchors if two contacts are offered). Most experiments on anchoring study the role of exogenous anchors (Furnham and Boo 2011) while little is known about how subjects set anchors endogenously. In our setup, where subjects determine supply before facing demand, there are several ways to set anchors (Schweitzer and Cachon 2000), for example, based on the maximum, the minimum, or the mean demand. Assuming the number of anchors corresponds to the number of contracts, subjects might set anchors that diversify between the potential options they have. The diversification heuristic, which covers similar behavioral concepts like the diversification bias, the 1/n heuristic, or variety seeking (see Thaler 1999), provides indications of how these anchors might be set. We know from related studies that if many options are available, subjects tend to choose only a few (Huberman and Jiang 2006),[7] an observation that Benartzi and Thaler (2007) interpret as evidence consistent with naïve diversification as subjects have to simplify in situations with many options, for example, by choosing one option from each category. In this context, Hedesström et al. (2004) observe that subjects select a subset of options that all belong to different categories (yet avoiding very low or high risks), which they interpret as a tendency to select as diverse as possible while avoiding extremes.

Translating these findings to contract settings, subjects might favor diversified contracts and offer a variety of quantities. In this line, we expect that subjects set anchors by varying evenly along the range of possible quantities, that is, between the lowest demand $\underline{d}$ and the highest demand $\bar{d}$. We propose the following generic approach to model $n = 1 \ldots N$ evenly distributed naïve anchors as $A(n) = \frac{n}{N+1} \cdot \left(\bar{d} - \underline{d}\right) + \underline{d}$. For simplicity, we introduce $\bar{\underline{d}} = \bar{d} - \underline{d}$. For each anchor n, we model the capacity based on anchoring and insufficiently adjustment (by $\pm\Lambda$) as follows:

$$\tilde{K}(n) = \frac{n}{N+1} \cdot \bar{\underline{d}} + \underline{d} \pm \Lambda \qquad \forall n \tag{9}$$

where the adjustment is positive for the high margin and negative for the low margin.

The wholesale price contract is a special case with a single anchor ($n = N = 1$) which results in a mean anchor according to Formula 9. Decision makers are known to apply and adjust this mean anchor toward the optimal decision $K^{w,*}$, resulting in decisions between the mean and the optimal capacity in these kinds of settings. We model the adjustment process with the weighting factor $\lambda \in [0; 1]$, resulting in a capacity of

$$\tilde{K} = \frac{1}{2} \cdot \bar{\underline{d}} + \underline{d} + \lambda \cdot \left(K^{w,*} - \left(\frac{1}{2} \cdot \bar{\underline{d}} + \underline{d}\right)\right) \tag{10}$$

where $\Lambda = \lambda \cdot \left(K^{w,*} - \left(\frac{1}{2} \cdot \bar{\underline{d}} + \underline{d}\right)\right)$. This is a reformulation of the well-known mean anchor model which is very well established for the settings where supply is determined before facing stochastic demand, like the wholesale price contract (see e.g., Becker-Peth and Thonemann 2018).

In our experimental setup the demand should be in the interval [0, 200] when suppliers believe demand to be low, resulting in an anchor of $A_{\xi_l} = 100 = \mu_{\xi_l}$, and if they believe demand to be high, the demand should be in the interval [200, 400], with an anchor of $A_{\xi_h} = 300 = \mu_{\xi_h}$.

The capacity reservation contract has several contract options and the *naïve anchoring* model is capable to suggest several anchors. In our setup we assume suppliers focus on the freely adjustable contract options *Contract Low* and *Contract High* as they seem to understand the intention of the outside option (overall, for the outside option the deviations from zero are rather small, and suppliers set the quantity to the rational prediction of zero in approximately half of all interactions). Thus, we assume that suppliers employ two anchors ($N = 2$), one for the capacity level of *Contract Low* and one for the capacity level of *Contract High*, by splitting the demand range into three equal parts analogous to the wholesale price contract with a single anchor, splitting the demand range into two equal parts. Formally, given the demand interval $[\underline{d}, \bar{d}]$, we obtain one anchor for *Contract Low* ($n = 1$) and one anchor for *Contract High* ($n = 2$) by $\frac{n}{N+1} \cdot \bar{\underline{d}} + \underline{d}$. Thus, when the supplier believes the demand to be low (high), he considers the anchors 67 (267) for *Contract Low* and 133 (333) for *Contract High*.

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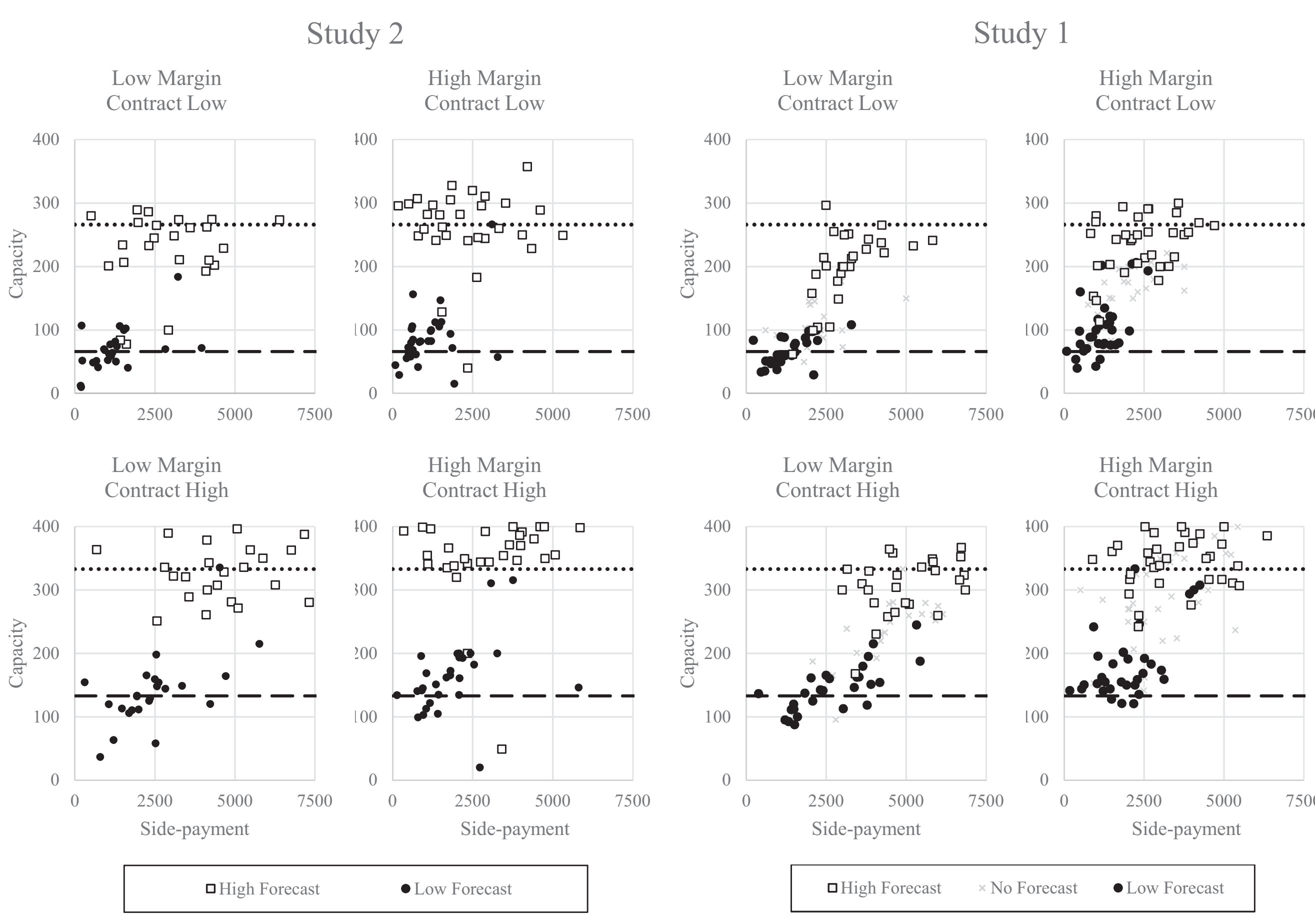
In order to verify the *naïve anchoring* model for the capacity reservation contract while isolating confounding factors arising from trust and trustworthiness, we setup an experimental study similar to Study 1 with the only difference that messages were always truthful (the instructions are provided in the Online Appendix). We followed the same design (but enforced truthful messages) and protocol as described in subsection 4.1. We excluded subjects that participated in Study 1, and in total 108 subjects participated, resulting in 48 to 60 subjects and 8 to 10 cohorts per treatment. Their average performance-dependent compensation was approximately 18 euros.

Figure 4 plots the demand state dependent *naïve anchors* (dashed lines) and subject level averages for *Contract Low* and *Contract High* for both margin treatments (Study 2 is provided on the left and Study 1 is provided as comparison on the right). We observe that most subject level averages are close to the corresponding anchors and, depending on the margin, subjects seem to adjust upward or downward. Except for a few outliers, subjects' capacity decisions appear consistent and are in line with our proposed naïve anchoring and adjustment model. For a high forecast (white squares) most subjects set capacities above 200 while for a low forecast (black circles) most of them set capacities below 200.

Building on the diversification heuristic, we propose a naïve anchoring and insufficient adjustment model which extends previous anchoring approaches to multiple contracts and includes mean anchoring as a special case. This approach describes well suppliers' capacity decisions for both the wholesale price contract (where *naïve anchoring* corresponds to mean anchoring) and the capacity reservation contract with full information.[8]

4.3.2. Naïve Anchoring and Insufficient Adjustment Combined with Trust. As discussed in subsection 4.2, shared forecasts are partially truthful (trustworthy) and contract capacities react to the messages demonstrating that suppliers partially trust them. In order to model the contract capacities, again focusing on the freely adjustable contract options *Contract Low* and *Contract High*, we capture the influence of the message as follows: the supplier assumes that a message $S_i \in (S_l, S_n, S_h)$ corresponds to state ξ_l in

Figure 4 Average Contract Parameter Per Subject Depending on the Message Type



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$\beta_{l|S_i} \in [0;1]$ percent of cases and to state ξ_h in $\beta_{h|S_i} \in [0;1]$ percent of cases. The supplier weights the capacity choice (according to formula 9 or 10, respectively) with the probabilities $\beta_{l|S_i} = (1-\beta_{h|S_i})$ and $\beta_{h|S_i}$, resulting in

$$\tilde{K}(S_i) = (1-\beta_{h|S_i}) \cdot \tilde{K}(\xi_l) + \beta_{h|S_i} \cdot \tilde{K}(\xi_h) \qquad \forall S_i. \qquad (11)$$

Note that a fully trusting (mistrusting) supplier sets $\beta_{l|S_l} = \beta_{h|S_h} = 100\%$ ($\beta_{l|S_l} = \beta_{h|S_h} = 0\%$), while a supplier that neither trusts nor mistrusts ignores any shared forecasts and sets $\beta_{l|S_i} = \beta_{h|S_i} = 50\%$. Comparing Study 1 with Study 2 (see Figure 4), we observe that capacities for a low forecast in Study 1 (where messages might be wrong) tend to be higher and capacities for a high forecast tend to be lower than in Study 2 (where messages are always truthful) suggesting that suppliers only partially trust the shared forecast.

Next, we present a parsimonious behavioral model where anchoring and trust are estimated from the observed data, first for the wholesale price and then for the capacity reservation contract.

Given the parametrization in our experiments, $\underline{d} = 200$ for both high and low demand, and we replace in Equation (10) $K^{w,*} - \left(\frac{1}{2} \cdot \bar{\underline{d}} + \underline{d}\right)$ by ± 60 (positive for the high margin and negative for the low margin). Inserting Equation (10) into Equation (11) with $\Lambda = \lambda \cdot 60$, results in

$$\tilde{K}(S_i) = \frac{1}{2} \cdot \bar{\underline{d}} \pm \Lambda + \beta_{h|S_i} \cdot \Delta \qquad \forall S_i, \qquad (12)$$

where $\Delta = 200$ (note that Δ represents the difference between the low and high demand state). Capacity decisions are nested in subjects; thus, we employ a linear mixed-effects model and account for the variation between participants as random effects for subjects (both intercept and period (slope) to cover the difference related to repeated decisions), which reflect any variability in their decisions. The model according to Equation (12) is fitted based on all observations (high and low margin)[9] using restricted maximum likelihood estimation. We use the lme4 package (Bates et al. 2015) for the R statistical computing language (R Core Team 2017). We present the results for the unbounded model and the bounded model with $\beta_{h|S_l}$ and $\beta_{h|S_n}$ fixed to zero, as both values become slightly negative for the unbounded model while $\beta_{h|S_i} \in [0;1]$, in Table 6.

For both models, the random effects at the individual level can be confirmed, and both models yield similar results; that is, for the bounded model (unbounded model), with $\lambda = \Lambda/60$ we receive a mean anchor of $1-\lambda = 63\%$ ($1-\lambda = 61\%$) and trust in the high forecast of $\beta_{h|S_h} = 83\%$ ($\beta_{h|S_h} = 73\%$). Mean anchor weights between 50% and 70% are common in related studies (see Becker-Peth and Thonemann 2018), and interestingly, the fitted trust level is similar to the observed trustworthiness level for the high forecast of 68% (see Table 4).

For capacity reservation contract, inserting Equation (9) in Equation (11) provides the contract block and forecast dependent capacity

$$\tilde{K}(S_i, n) = \frac{n}{2+1} \cdot \bar{\underline{d}} \pm \Lambda + \beta_{h|S_i} \cdot \Delta \quad \forall S_i,\ n = 1, 2. \qquad (13)$$

Again, we employ a linear mixed-effects model with all observations (high and low margin) and account for the variation between participants as random effects. The random effects at the individual level can be confirmed, as summarized in Table 6. We observe a margin setting adjustment of ± 19.8, which is quite similar to the margin setting adjustment in the wholesale price setting of ± 22.2. Furthermore, according to the fitted model, we observe 86% trust in high forecasts and 87% trust in low forecasts. Interestingly, this matches the observed trustworthiness of the buyers' shared forecasts, which is 88%. Note that if no shared forecast provides no information about the demand state, $\beta_{l|S_n} = \beta_{h|S_n} = 50\%$, and in this vein, we observe $\beta_{l|S_n} = 46\%$, resulting in the counterpart of $\beta_{h|S_n} = 54\%$.

Figure 5 plots the predicted capacities according to our model and the observed capacities for both contracts and both margin treatments. There is one marker per message (indicating the capacity) for the wholesale price contract while there are two markers per message for the capacity reservation contract where the lower marks *Contract Low* and the higher marks *Contract High*. While a perfect fit would result in predictions lying on the bisecting line, we observe a good fit, with actual capacities being slightly lower than the predicted ones for the wholesale price

Table 6 Results of Linear Mixed-Effects Model

	Fixed effects				Standard deviation of random effects		
	Λ	$\beta_{h\|S_h}$	$\beta_{h\|S_n}$	$\beta_{h\|S_l}$	Intercept	Period	Residual
Wh (unbounded)	23.11***	0.73***	−0.06	−0.12***	38.96	0.86	51.39
Wh (bounded)	22.27***	0.83***	–	–	42.93	0.83	51.52
Cr (unbounded)	19.80***	0.86***	0.46***	0.13***	36.78	0.89	54.21

*$p<0.1$, **$p<0.05$, ***$p<0.01$.

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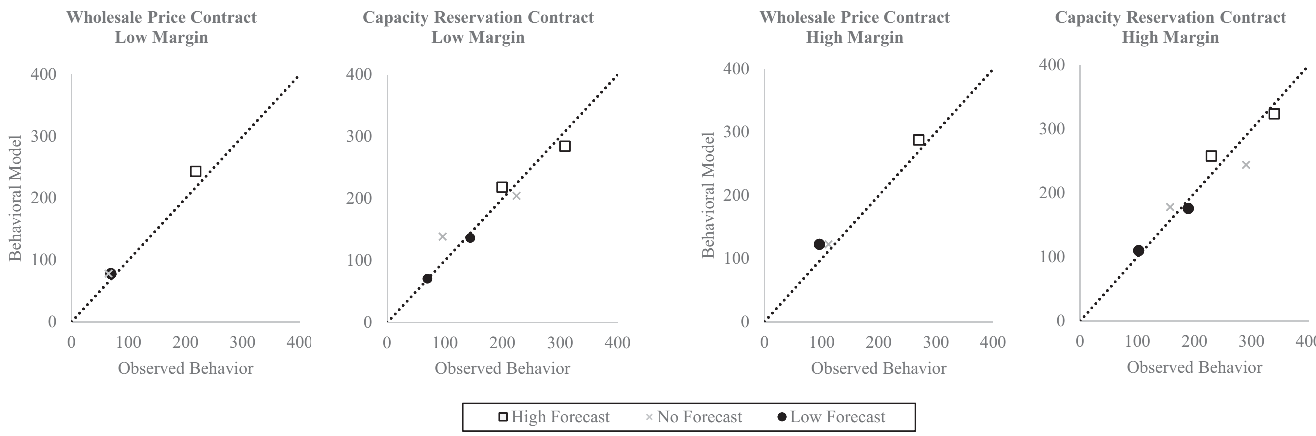
Figure 5 Comparison of Predicted and Actual Quantities in Dependence of the Forecast



contract while capacities for "contract block low" tend to be too low and too high for "contract block high," for the capacity reservation contract (which could be accounted for by block-wise specific estimates at the risk of overfitting). Overall, trust combined with *naïve anchoring* can explain well the capacities offered to the buyer in both contracts.

4.4. Endogenous Contract Choice (Study 3)

Our previous results reveal that from a suppliers perspective capacity reservation contracts perform better than wholesale price contracts (driven by an effective separation of untruthful buyer and side payments that shift profits to the supplier) which leads to the follow-up questions whether suppliers recognize that they benefit from capacity reservation contracts, that is, do they offer capacity reservation contracts if they can choose the contract type endogenously, and if so, do they offer an appropriate number of capacity levels?

In order to address this question, we setup an experimental study similar to Study 1 with the difference that the contract choice is endogenous. Suppliers offer a wholesale price contract, that is, a capacity without side payment which corresponds to the *Outside Option Contract*, but they are free to offer up to three additional contracts with varying capacity levels and reservation fees. If they do not offer additional contracts, the treatment corresponds to the wholesale price treatment, and if they offer two additional contracts the treatment corresponds to the capacity reservation treatment. The capacity reservation treatment in Study 1 contains the optimal setup of two freely adjustable contracts, that is, one per demand state, and we are interested in revealing if suppliers tend to offer more or less than these two.[10]

We followed the same design and protocol as described in subsection 4.1 (the instructions are provided in the Online Appendix). We excluded subjects that participated in Study 1 or Study 2, and in total 102 subjects participated, resulting in 48 to 54 subjects and 8 to 9 cohorts per treatment.[11] The average performance-dependent compensation was approximately 17 euros.

We observe that suppliers almost always offer additional capacity reservation contracts, that is, suppliers offer at least one additional contract in 99% of all cases for the low margin and 100% for the high margin, and they offer at least two additional contracts in 91% of all cases for the low margin and 98% for the high margin. While offering two additional contracts allows to optimally separate buyers (see section 3), we observe, that subjects tend to offer more contracts, that is, they offer three additional contracts (the maximum amount in our setup) in 46% of all cases for the low margin and 65% for the high margin.

Comparing the average performance of all suppliers (buyers) within each cohort as the statistical unit of analysis with Study 1 validates that suppliers (buyers) earn significantly more (less) with the "endogenous" capacity reservation contract than with the wholesale price contract for each margin case (each Mann–Whitney U, $p < 0.05$), while we do not observe significant differences compared to the "forced" capacity reservation contract from Study 1 (each Mann–Whitney U, $p > 0.49$). Furthermore, the performance of the capacity reservation contract is robust to the observed tendency that people offer more contracts than game theory predicts (see Appendix B).

Suppliers seem to understand that they benefit from capacity reservation contracts, that is, they offer such contracts when this is an endogenous decision; however, they tend to offer more contracts than normatively predicted.

5. Discussion

Our main contribution is showing that suppliers can benefit considerably from offering rather complex

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capacity reservation contracts despite and because of several behavioral phenomena. We next discuss our results in light of our model and experimental design assumptions.

Parametrization of the experimental study: We observe that the suppliers' and the supply chains' benefits of using capacity reservation are proportional to the game-theoretic predictions. If the theoretical benefits are large, as in our low margin setting, the observed performances are significantly and economically relevant. In turn, if the theoretical benefits are relatively low, as in our high margin setting, the benefit for the supplier (supply chain) is still significantly higher (not significant) but the effect size is rather small. The extent to which capacity reservation contracts theoretically outperform wholesale price contracts is based on two components, a "screening component" and a "double marginalization component." The lower the information asymmetry, the lower the value of the screening component (since capacities are based on almost full information anyway), and, the lower the performance loss through double marginalization, the lower the value of the double marginalization component (since capacities are based on almost the supply chain optimum anyway).

We have chosen the parametrization employed by Özer et al. (2011) to allow for a comparison of both studies. We believe that our two profit margins appropriately reflect critical factors such as anchoring and adjustment, as in related newsvendor experiments (Becker-Peth and Thonemann 2018). With this parameterization, we show theoretically and observe in the experiments that under wholesale pricing, the supplier receives a lower supply chain profit share than his buyer, while this relation is reversed under capacity reservation contracts.

In addition to the margin parameters, the choice of the demand distribution information asymmetry is an essential driver of the result, and we consider a stylized setting with two distinct information states. Intuitively, the lower the asymmetry, the lower the potential benefit of both forecast sharing and capacity reservation. To this end, it is important to note that we consider two demand types (low and high), while Özer et al. (2011) consider a continuous distribution. At an aggregated level, they observe anchoring, as we do; that is, the capacity levels lie in-between the theoretically optimal capacity levels and the mean demand. However, a visual inspection of their figures does not indicate that buyers' low forecasts are more trustworthy than their high forecasts, while we observe that low forecasts are almost always truthful, while high forecasts are less truthful. This difference is likely driven by the discretization of types; that is, low types do not have the option to inflate by an arbitrary amount. Furthermore, in our experimental design the actual demand type is revealed ex-post. Even though a buyer interacts with another supplier in the next period, they might not want to be identified as liars. Accordingly, our design has a somewhat optimistic view of buyers' trustworthiness. However, if this is the case, then our observed wholesale price performance is optimistic as well. Thus, with a lower trustworthiness for both contract settings, the main insight that capacity reservation increases supplier profits should hold (or be even more pronounced).

Power structure: We assume, in line with previous research on trust and trustworthiness under wholesale pricing (Özer et al. 2011), that buyers order realized demand. As such, even if the buyer is offered an unfavorable contract, she cannot reciprocate by ordering nothing or less to thus reduce her supplier's profits. Her only way to reciprocate unfavorable offers is by choosing the *Outside Option Contract* with a zero side payment. In turn, buyers (such as newsvendors) in Kalkanci et al. (2014) could order nothing and thereby leave a supplier with unfavorable contract offers with zero profits. Thus, one driver of the different results is likely to be that buyers have a different leeway to retaliate against unfavorable contract offers. As an alternative experimental design, one might consider exogenous payoffs in case of a contract rejection (e.g., both parties receive zero payoffs if a capacity reservation offer is rejected), thereby controlling for other power structures in the supply chain. To this end, we believe that it is an important component of the specific context (capacity reservation game) that subjects agreed in advance on a wholesale price interaction (and are apparently willing to trade under these contract terms), and this is reflected in our experimental design.

While we observe that suppliers tend to set the capacity reservation fees too low, we would expect the fees to be even lower with stronger buyers (who retaliate or are able to retaliate by ordering less), which could diminish the supplier's benefits from offering capacity reservation contracts. On the other hand, we believe it to be less likely that capacity levels react to the power structure since it seems reasonable that profit allocations are controlled via the reservation fee and thus do not impact the capacity level. Hence, the supply chain enhancing effects of capacity reservation contracts in low profit margin settings would sustain, underscoring our recommendation to consider this contract format in these scenarios.

Buyers contract choices: We do not provide a detailed behavioral explanation of the contract choices under capacity reservation. Previous research clearly shows that buyers' contract choices are motivated by fairness preferences and plagued by bounded rationality (Kalkanci et al. 2014). Johnsen

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et al. (2019) show that, from the suppliers' perspective, this adverse contract choice behavior can be mitigated by increasing profit differences between contract alternatives. We find indications for fairness preferences and bounded rationality in our data as well (e.g., buyers choose the outside option contract to reduce inequity in payoffs), and we see, as in former studies, that this contract choice behavior can reduce the effectiveness of capacity reservation. However, buyers' non-optimal contract choices have no significant effect on suppliers' performance (see Appendix A).

Behavioral Model: Our behavioral model is based on a cognitive heuristic (anchoring and insufficient adjustment) that factors in trust in shared forecasts. Another prominent, utility-based, approach is modeling preferences (e.g., fairness preferences, lying aversion, etc.), and consider bounded rationality in a logit choice framework (see, e.g., Kalkanci et al. 2011). We believe that both approaches have their merits but acknowledge that our study is not designed to provide support for or against one of these modeling approaches (see Kremer et al. 2010 for a discussion of logit choice models and context specific anchoring heuristics in the newsvendor context).

6. Conclusion

We address the question whether firms should offer rather complex nonlinear contracts or stick to the common mode of wholesale price contracts when information can be shared among the supply chain parties. While normative theory suggests that nonlinear contracts outperform simple wholesale price contracts, behavioral research gives rise to the suspicion that this might not hold if human decision-makers design contracts, share and process information, and make contract choices that are not profit maximizing. We analyze this question in laboratory experiments based on a well-established stylized supply chain setting with asymmetric forecast information and provide evidence that, when, and why capacity reservation contracts (as a specific form of nonlinear contracts) are a beneficial contract format if information can be shared.

Contrary to previous research on information sharing under nonlinear contracts, our experimental study is the first to consider contract design complexities, that is, the contracts are self-designed by human decision makers (without optimization based decision support that enforces separating contract offers). We observe that the supplier's and supply chain's benefits from using capacity reservation are proportional to what is predicted theoretically. In the low margin treatment, we observe a substantial and significant benefit from using capacity reservation for both the supplier and the supply chain. While the supplier's benefit remains significant, the supply chain's benefit vanishes, for the high margin treatment. These results complement and put into perspective previous behavioral research on nonlinear contract design without information sharing that finds no benefits from nonlinear contracts (Kalkanci et al. 2014). We find that capacity reservation contracts plus information sharing can be beneficial for suppliers, because (or despite) several behavioral phenomena that result in an effective separation of dishonest buyers. To this end, we present a novel behavioral model based on naïve anchoring and insufficient adjustment and show that *naïve anchoring*, as well as trust and trustworthiness, provide one plausible explanation for the observed behavior. Under both contract formats (wholesale price and capacity reservation), *naïve anchoring* is an important driver of non-optimal capacities, and trust and trustworthiness turn out to reduce information asymmetry.

Suppliers that can choose between offering several capacity reservation levels or sticking to the wholesale price contract realize that capacity reservation contracts are beneficial. We observe that capacity reservation is extensively used, and while suppliers tend to offer more capacity reservation levels than game theory predicts, we find that the superior performance is robust against this bias. Overall, we find evidence that generically promoting capacity reservation contracts in the organization is sufficient to capture the positive benefits of this contract format, despite the behavioral biases human decision makers exhibit.

Although we observe capacity reservation contracts to be beneficial for suppliers, we identify biases that are subject to performance losses. Further research might shed light on the question if behavioral interventions reduce anchoring when setting capacity levels or lead to a more theory-aligned utilization of reservation fees that effectively separates buyer types. Another interesting avenue for further research is to study different combinations of baseline contracts and nonlinear contracts with and without information sharing, which is beyond the scope of this study. Several other contract types such as revenue sharing, buyback, or option contracts (Becker-Peth et al. 2013, Cachon and Lariviere 2005, Davis and Leider 2018) might serve as a benchmark for capacity reservation contracts, and as an alternative for the capacity reservation contract one might also consider advance purchase commitments that also allow suppliers to gather private information of the buyer before setting capacity (see Özer and Wei 2006). Finally, we assume that wholesale prices are exogenous, and one might consider whether wholesale prices perform better or worse in our scenario when negotiated endogenously (e.g., before, after, or when receiving the forecast).

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However, the analysis is considerably more complex because the incentives to inflate, deflate, or truthfully report forecasts change depending on the timing of forecast sharing and the actual cost parametrization (see Chu et al. 2017 for analytical benchmarks).

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Appendix: A

Side Payments and Profit-Maximizing Contract Choices

While the side payment of the *Outside Option Contract* is fixed to zero, the side payments of the other two contracts are set by the supplier. Figure A1 displays all side payment–quantity combinations from the three contracts (with darker color indicating overlapping dots). The squares show the optimal side payment–quantity combinations of the optimal capacity reservation contract (i.e., for all three contracts), the three triangles highlight the observed average side payment–quantity combinations and the dashed black line shows our linear fit, as described below.

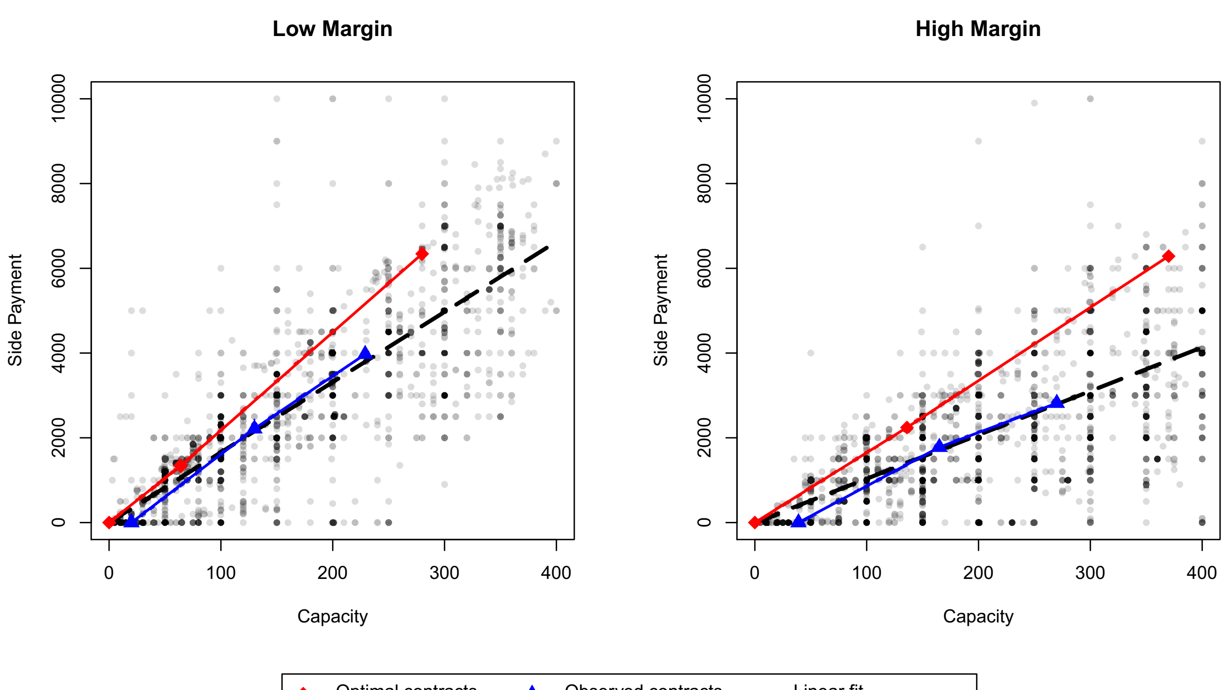
Table A1 Results of Linear Mixed-Effects Model for Side Payments

	Fixed effects		Standard deviation of random effects		
	Payment per quantity	Standard error	Intercept	Period	Residual
Low margin	16.57***	0.17	775.06	24.78	931.59
High margin	10.33***	0.14	601.70	24.65	898.63

*p<0.05, **p<0.01, ***p<0.001.

Although the optimal capacity reservation contract is nonlinear, that is, $0 < Z_l/K_l < Z_h/K_h$, a linear approximation through the origin describes the relationship between side payment and quantity well since the nonlinearity is only nuanced (see Figure A1). Running a linear mixed model to fit the side payment per quantity ratio with random effects for subjects, we reveal that the side payments increase more per quantity for the low margin than for the high margin case (see Table A1), which is in line with the optimal capacity reservation contract; however, they are lower than optimal (an explanation for this behavior is that it reduces inequity in the interaction, and we refer to Johnsen et al. (2019) for an extensive discussion). Note that running the model with an intercept has very little effect on the slope, while the intercept is not significantly different from zero for both margins. Thus, the relationship between side

Figure A1 Relation of Side Payments and Capacity [Color figure can be viewed at wileyonlinelibrary.com]



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payment and quantity is well described by a constant ratio.

Besides shifting profits between the supply chain parties, the main purpose of side payments is to separate the buyer types via self-selection. We find, in line with Kalkanci et al. (2011) and Kalkanci et al. (2014), that suppliers are hardly able to offer contracts that optimally separate profit-maximizing buyers. However, even theoretically optimal contracts that separate profit-maximizing buyer types typically do not result in perfect separation empirically, since buyers may choose non-optimal contracts due to fairness preferences or boundedly rational behavior; see Inderfurth et al. (2013), Johnsen et al. (2019). We replicate this observation and find that 69% of all selected contracts are expected profit maximizing, while 23% are the second best choice and 8% the worst choice. From the buyers' perspective, non-optimal choices (of non-optimal contracts) decrease their performance. However, we do not observe a consistent effect of non-optimal choices on supply chain performance; that is, we observe a 2.5% increase and 4.0% decrease in the low and high margin settings, respectively.

Appendix: B

Performance of the Capacity Reservation Contract in Study 3

For both margin treatments, we run a linear mixed model for the supplier profit (in cents per period) with the four categories: no, one, two, or three capacity reservation contracts offered. We employ a maximum likelihood estimator that allows us to take into account individual differences over time as random effects. As shown in Table B1, offering two or three capacity reservation contracts results in highly significant positive profits for both margins. Offering fewer results in a lower performance, which is non-significantly different from zero if no capacity reservation contract is offered (which only occurs for low margin). These findings demonstrate that the performance of the capacity reservation contract is robust to the observed tendency that people offer more contracts than game theory predicts, as the performance is even higher for three than for two than for one contract.

Notes

[1]From an external validity perspective, the "no information sharing" option almost always exists. From a behavioral perspective, lying (i.e., sending a deceptive message) might cause disutility (lying aversion). If subjects were forced to signal either low or high demand, we take the opportunity to abstain from information sharing without suffering from lying aversion. Furthermore, sending uninformative messages in such a scenario would require to send messages that are uncorrelated with the demand state (in the extreme case; always sending the same message). By our design choice, we control for related confounding factors.

[2]Intuitively, the contract for the high type has no consequences for the informational rents of other types. As such, there is no "informational rent—efficiency" trade-off, and setting the supply chain efficient capacity level is optimal.

[3]The positive quantities might be due to suppliers that aim to secure some minimal expected profits even if the buyer chooses the *Outside Option Contract*.

[4]Note that this reasoning does not hold for strongly nonlinear side-payments; however, we observe that the relationship between side payment and quantity is well described by a linear approximation, that is, the ratio side payment per quantity is almost constant (see Appendix A).

[5]For the capacity reservation contract supply chain profits are shifted between the supply chain parties by the side payments, and side payments lower than optimal (see Appendix A) explain why the supplier's share of the supply chain profit is lower than game theory predicts (as illustrated in Figure 3). Still, side payments shift profits from the buyer to the supplier, which drives higher supplier performance compared to the wholesale price contract.

[6]As discussed in subsection 4.2.1 for the capacity reservation contract we observe neither a consistent inflation nor a consistent deflation if "no message" was shared. Thus, assuming that a supplier does not interpret "no message" in a distinct way, these situations correspond to a setting without information sharing. Using the average performance of all suppliers within each cohort, the suppliers' performance with shared information is better than without, that is, the difference is strongly significant for the low margin (Wilcoxon signed-rank test, $p < 0.05$) and mildly significant for

Table B1 Linear Mixed-Effects Model of Supplier's Performance (in cents) if Zero, One, Two, or Three Capacity Reservation Contracts are Offered in a Period

	Fixed effects				Standard deviation of random effects		
	Wh & no Cr	Wh & one Cr	Wh & two Cr	Wh & three Cr	Intercept	Period	Residual
Low margin	19.27	41.02***	51.32***	68.30***	24.46	1.62	72.58
	(33.13)	(10.67)	(4.68)	(4.73)			
High margin	–	58.78**	79.20***	88.10***	15.87	0.96	68.92
	–	(21.07)	(4.45)	(3.22)			

*$p<0.1$, **$p<0.05$, ***$p<0.01$.

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the high margin (Wilcoxon signed-rank test, $p = 0.11$). Furthermore, the low margin suppliers perform significantly better in the capacity reservation treatment without shared information than in the wholesale price treatment with the possibility to share information (Mann–Whitney U, $p < 0.05$), a difference that vanishes for the high margin treatment (Mann–Whitney U, $p = 0.40$). These findings indicate that the capacity reservation contract might already be valuable without information sharing, but becomes even more valuable with information sharing.

[7]Once the investment options are selected, subjects divide assets evenly among them, which is referred to as the conditional 1/n rule (Huberman and Jiang 2006).

[8]Our approach might also explain quantity decisions in other contracts, like quantity discount contracts as studied for example, by Kalkanci et al. (2011) who observe that suppliers set a single price break quantity of 102, where our approach suggests one anchor of 100, and they set the two price break quantities of 81 and 129 where our approach suggests the two anchors 70 and 130, respectively (similar results are obtained in a related study by Kalkanci et al. 2014).

[9]A recent meta-analysis by Zhang and Siemsen (2019) reveals that the mean anchor effect is not consistently stronger in high-margin or low-margin conditions.

[10]The revelation principle states that two contracts in the menu of contracts suffice to implement the second-best outcome. We note that more than two contracts might also be optimal in a normative sense, if two contract offers have identical parameters (i.e., one contract is a copy of another) or if a contract option is off the equilibrium path.

[11]We had to exclude one cohort from the following analysis since a subject left the experiment early due to physical issues.

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Supporting Information

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

Appendix. Instructions Study 1.

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