eCompanion: Why are Minimum Order Quantity Contracts Popular in Practice? A behavioral investigation

1 Extended Theoretical Background for Buyback and Revenue Sharing Contracts

1.1 The Buyback Contract

With the buyback contract, the supplier sells each unit for w_{bb} and buys back the unsold units for b if the retailer cannot sell all the products he bought from the supplier. When terms are appropriately set, the retailer buys more products from the supplier, which increases supply chain efficiency. The expected profits of the retailer and the supplier (Cachon 2003) are given by $\mathbb{E}[\Pi_r(Q_{bb}, w_{bb}, b)] = p\mathbb{E}[\min(D, Q_{bb})] - w_{bb}Q_{bb} + b(Q_{bb} - \mathbb{E}[\min(D, Q_{bb})])$ and $\mathbb{E}[\Pi_s(Q_{bb}, w_{bb}, b)] = (w_{bb} - c)Q_{bb} - b(Q_{bb} - \mathbb{E}[\min(D, Q_{bb})])$. Hence, a supplier facing a retailer with reservation value, v, solves:

$$\max_{(w_{bb}\geq 0, b\geq 0)} \quad (w_{bb} - c)Q^*_{bb} - b(Q^*_{bb} - \mathbb{E}[\min(D, Q^*_{bb})]) \tag{1}$$

$$\text{s.t.} \quad Q^*_{bb} = \arg\max_{Q_{bb}\geq 0} \quad p\mathbb{E}[\min(D, Q_{bb})] - w_{bb}Q_{bb} + b(Q_{bb} - \mathbb{E}[\min(D, Q_{bb})]) \tag{2}$$

$$p\mathbb{E}[\min(D, Q^*_{bb})] - w_{bb}Q^*_{bb} + b(Q^*_{bb} - \mathbb{E}[\min(D, Q^*_{bb})]) \geq v. \tag{3}$$

where (2) gives the optimal quanity decision by a retailer, given the supplier's contract parameter choices and (3) is the retailer's individual rationality constraint. For uniformly distributed demand $D \sim U(x, y)$, the quantity maximizing the retailer's profit (2) can be derived as

$$Q^*_{bb} = x + (y - x)(\frac{p - w_{bb}}{p - b}). \tag{4}$$

Let λ be $v/(\Pi^*_c)$, which is the proportion of the retailer's reservation value to the profit from the centralized supply chain. The optimal solution to the optimization problem (1) can then be expressed as (Katok and Wu 2009):

$$b^* = (1 - \lambda)p, \tag{5}$$

$$w^*_{bb} = b + \lambda c. \tag{6}$$

If we substitute (5) and (6) in (4), we get

$$Q^*_{bb} = Q^*_c. \tag{7}$$

Remember that Q^*_c is the quantity that maximizes the total supply chain expected profit. This means that a supply chain can be coordinated to reach maximum profit (centralized scenario's supply chain profit) with the buyback contract.

1.2 The Revenue-Sharing Contract

With the revenue-sharing contract, the supplier initially sells each unit for w_{rs} but also receives a share of the revenue for each sold unit, r, from the retailer. Not charging the retailer upfront with a high wholesale price but allowing the retailer to share its revenue afterwards encourages the retailer to order more and can provide supply chain coordination. The expected profits of the retailer and the supplier (Cachon 2003) are given by $\mathbb{E}[\Pi_r(Q_{rs}, w_{rs}, r)] = (p-r)\mathbb{E}[\min(D, Q_{rs})] - w_{rs}Q_{rs}$ and $\mathbb{E}[\Pi_s(Q_{rs}, w_{rs}, r)] = (w_{rs} - c)Q_{rs} + r\mathbb{E}[\min(D, Q_{rs})]$ Hence, a supplier facing a retailer with reservation value, v, solves:

$$\max_{(w_{rs}\geq 0, r\geq 0)} \quad (w_{rs} - c)Q^*_{rs} + r\mathbb{E}[\min(D, Q^*_{rs})] \tag{8}$$

$$\text{s.t.} \quad Q^*_{rs} = \arg\max_{Q_{rs}\geq 0} \quad (p - r)\mathbb{E}[\min(D, Q_{rs})] - w_{rs}Q_{rs} \tag{9}$$

$$(p - r)\mathbb{E}[\min(D, Q^*_{rs})] - w_{rs}Q^*_{rs} \geq v. \tag{10}$$

For uniformly distributed demand $D\sim U(x, y)$, the quantity maximizing the retailer's profit (9) can be derived as

$$Q^*_{rs} = x + (y - x)(\frac{p - w_{rs} - r}{p - r}). \tag{11}$$

Let λ be $v/(\Pi^*_c)$, which is the proportion of the retailer's reservation value to the profit from the centralized supply chain. The optimal solution to the optimization problem (8) can then be expressed as (Katok and Wu 2009):

$$r^* = (1 - \lambda)p, \tag{12}$$

$$w^*_{rs} = \lambda c. \tag{13}$$

If we substitute equations (12) and (13) in (11), we get

$$Q^*_{rs} = Q^*_c. \tag{14}$$

Therefore, reaching maximum efficiency in a supply chain is also possible with the revenue-sharing contract given the right parameters.

2 Summary Statistics

Table 1: Supplier Game: Theoretical versus Experimental Outcomes

Stat	**Theory**	**Base**		**Hedge**		**CL**		**W**	
				Minimum Order Quantity Contract					
Q	75	67.82	(11.36)	–	–	68.19	(9.95)	74.03	(6.27)
$\mathbb{E}[\Pi_c]$	337.5	324.55	(15.51)	–	–	326.13	(17.96)	333.90	(12.40)
$\mathbb{E}[\Pi_s]$	292.5	274.85	(17.78)	–	–	277.02	(21.22)	288.21	(12.67)
w	6.9	7.17	(0.58)	–	–	7.15	(0.43)	6.93	(0.30)
$Q_{\min}$	75	67.69	(11.43)	–	–	67.61	(11.99)	74.03	(6.27)
				Buyback Contract					
Q	75	46.66	(14.54)	58.48	(15.00)	48.85	(10.74)	68.54	(10.74)
$\mathbb{E}[\Pi_c]$	337.5	273.99	(33.41)	298.48	(28.14)	284.73	(27.92)	325.18	(8.91)
$\mathbb{E}[\Pi_s]$	292.5	201.93	(30.05)	230.19	(29.91)	203.20	(27.50)	244.02	(32.69)
w	10.8	8.85	(0.83)	9.5	(0.72)	8.68	(0.87)	9.40	(1.20)
b	10.4	4.56	(2.66)	6.96	(2.31)	4.76	(1.97)	7.76	(2.43)
				Revenue Sharing Contract					
Q	75	45.66	(9.26)	53.73	(10.63)	–	–	–	–
$\mathbb{E}[\Pi_c]$	337.5	279.29	(29.26)	297.98	(25.37)	–	–	–	–
$\mathbb{E}[\Pi_s]$	292.5	203.21	(36.53)	235.01	(28.51)	–	–	–	–
w	0.4	4.18	(1.62)	2.78	(1.59)	–	–	–	–
r	10.4	4.54	(2.24)	6.73	(2.20)	–	–	–	–

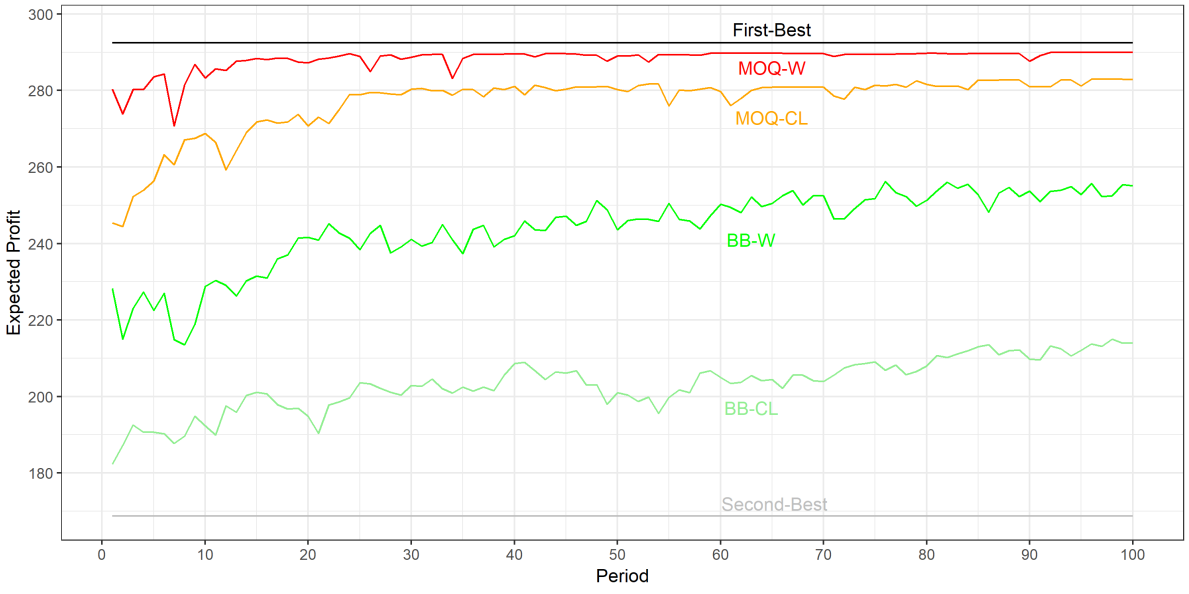
Note: Average values reported for experimental outcomes. For profit, this corresponds to average expected profit.

Standard deviations reported in parentheses.

3 Supplier Performance Graphs

Figure E1: Average Expected Supplier Profits in Base and Hedge Treatments

Figure E2: Average Expected Supplier Profits in CL and W treatments



4 Discussion of Hypothesis 2 for the Revenue-Sharing Contract

For brevity, we had only discussed Hypothesis 2 for the buyback contract in the main body of the paper. Here, we repeat the discussion for the revenue sharing contract.

The performance gap between the MOQ and RS contracts was $\overline{\mathbb{E}[\Pi_s]}_{\text{MOQ}} - \overline{\mathbb{E}[\Pi_s]}_{\text{RS}} = 82.47$ (Table 2 H1). With the results from the RS-Hedge treatment we can calculate $\overline{\mathbb{E}[\Pi_s]}_{\text{RSHedge}} - \overline{\mathbb{E}[\Pi_s]}_{\text{RS}} = 29.96$ and $\overline{\mathbb{E}[\Pi_s]}_{\text{MOQ}} - \overline{\mathbb{E}[\Pi_s]}_{\text{RSHedge}} = 52.52$ (Table 2 H2). This suggests that, of the total supplier profit performance gap of 82.47 between the MOQ and RS treatments, 29.96 can be attributed to risk but 52.52 cannot.

5 Supply Chain Performance Analysis

Here, we state and test hypotheses analogous to Hypotheses 1–3 of the paper from a supply chain performance – rather than a supplier performance – perspective. We use Q as a unifying metric to analyze supply chain performance because total supply chain profits depend only on Q for all coordinating contracts (cf. Katok and Wu 2009). For completeness, we also test these hypotheses with expected supply chain profit. We expect to arrive at similar conclusions with the supply chain performance hypotheses here and the supplier performance hypotheses in the paper since maximizing supplier profit requires optimizing both the supply chain profit and the supplier's of that profit. The hypothesis test results can be found in Table E1.

Hypothesis $\mathbf{1_{SC}}$ (Theoretical equivalence of MOQ, BB and RS contracts). *Average order quantities* $\overline{Q}_{\text{MOQ}}$, $\overline{Q}_{\text{BB}}$, *and* $\overline{Q}_{\text{RS}}$; *and the average expected supply chain profit values* $\overline{\mathbb{E}[\Pi_c]}_{\text{MOQ}}$, $\overline{\mathbb{E}[\Pi_c]}_{\text{BB}}$, and $\overline{\mathbb{E}[\Pi_c]}_{\text{RS}}$ *will be the same in the MOQ, BB, and RS games.*

Hypothesis $\mathbf{2_{SC}}$ (Effect of risk on supply chain performance). *Average order quantities and supply chain profits for the BB and RS contracts,* $\overline{Q}_{\text{BB}}, \overline{Q}_{\text{RS}}, \overline{\mathbb{E}[\Pi_c]}_{\text{BB}}$, *and* $\overline{\mathbb{E}[\Pi_c]}_{\text{RS}}$, *will be higher in the Hedge versions of the BB and RS games where demand risk is eliminated. However, the average order quantity and supply chain profits for the MOQ contract,* $\overline{Q}_{\text{MOQ}}$, *and* $\overline{\mathbb{E}[\Pi_c]}_{\text{MOQ}}$ *will be higher still.*

Hypothesis $\mathbf{3c_{SC}}$ (Effect of cognitive load on supply chain performance: within contracts). *The lower cognitive load experienced by subjects in the MOQ-W treatment when compared to the MOQ-CL treatment will be accompanied by higher order quantity and supply chain profit. Likewise, the lower cognitive load experienced by subjects in the BB-W treatment when compared to the BB-CL treatment will be accompanied by higher order quantity and supply chain profit.*

Table E1: Supply Chain Performance: Supplier Game Hypotheses with Median Differences

	Hypothesis	ΔQ	**Hypothesis**	$\Delta E[\Pi_c]$
	$\overline{Q}_{BB} - \overline{Q}_{RS} = 0$	-3.27	$\overline{\mathbb{E}[\Pi_c]}_{BB} - \overline{\mathbb{E}[\Pi_c]}_{RS} = 0$	-8.83
H1sc	$\overline{Q}_{MOQ} - \overline{Q}_{BB} = 0$	28.81^{***}	$\overline{\mathbb{E}[\Pi_c]}_{MOQ} - \overline{\mathbb{E}[\Pi_c]}_{BB} = 0$	62.84^{***}
	$\overline{Q}_{MOQ} - \overline{Q}_{RS} = 0$	25.54^{***}	$\overline{\mathbb{E}[\Pi_c]}_{MOQ} - \overline{\mathbb{E}[\Pi_c]}_{RS} = 0$	54.01^{***}
	$\overline{Q}_{BBHedge} - \overline{Q}_{BB} = 0$	19.06^{***}	$\overline{\mathbb{E}[\Pi_c]}_{BBHedge} - \overline{\mathbb{E}[\Pi_c]}_{BB} = 0$	37.31^{**}
H2sc	$\overline{Q}_{MOQ} - \overline{Q}_{BBHedge} = 0$	9.75^{**}	$\overline{\mathbb{E}[\Pi_c]}_{MOQ} - \overline{\mathbb{E}[\Pi_c]}_{BBHedge} = 0$	25.53^{***}
	$\overline{Q}_{RSHedge} - \overline{Q}_{RS} = 0$	7.39^{***}	$\overline{\mathbb{E}[\Pi_c]}_{RSHedge} - \overline{\mathbb{E}[\Pi_c]}_{RS} = 0$	22.17^{**}
	$\overline{Q}_{MOQ} - \overline{Q}_{RSHedge} = 0$	18.15^{***}	$\overline{\mathbb{E}[\Pi_c]}_{MOQ} - \overline{\mathbb{E}[\Pi_c]}_{RSHedge} = 0$	31.84^{***}
H3csc	$\overline{Q}_{BB-W} - \overline{Q}_{BB-CL} = 0$	18.11^{***}	$\overline{\mathbb{E}[\Pi_c]}_{BB-W} - \overline{\mathbb{E}[\Pi_c]}_{BB-CL} = 0$	33.00^{***}
	$\overline{Q}_{MOQ-W} - \overline{Q}_{MOQ-CL} = 0$	2.72^{***}	$\overline{\mathbb{E}[\Pi_c]}_{MOQ-W} - \overline{\mathbb{E}[\Pi_c]}_{MOQ-CL} = 0$	3.07^{***}

Note: $'p < 0.1$,$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

6 Game Screenshots

Figure E3: Supplier Game

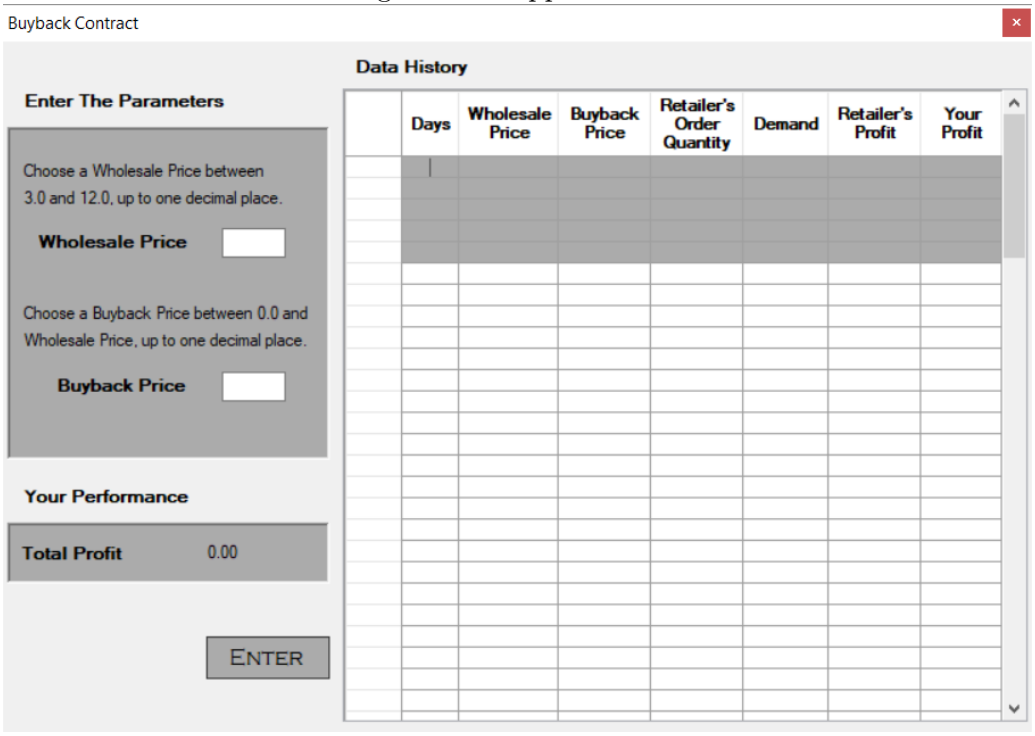


Figure E4: Supplier Game: Hedge Treatments

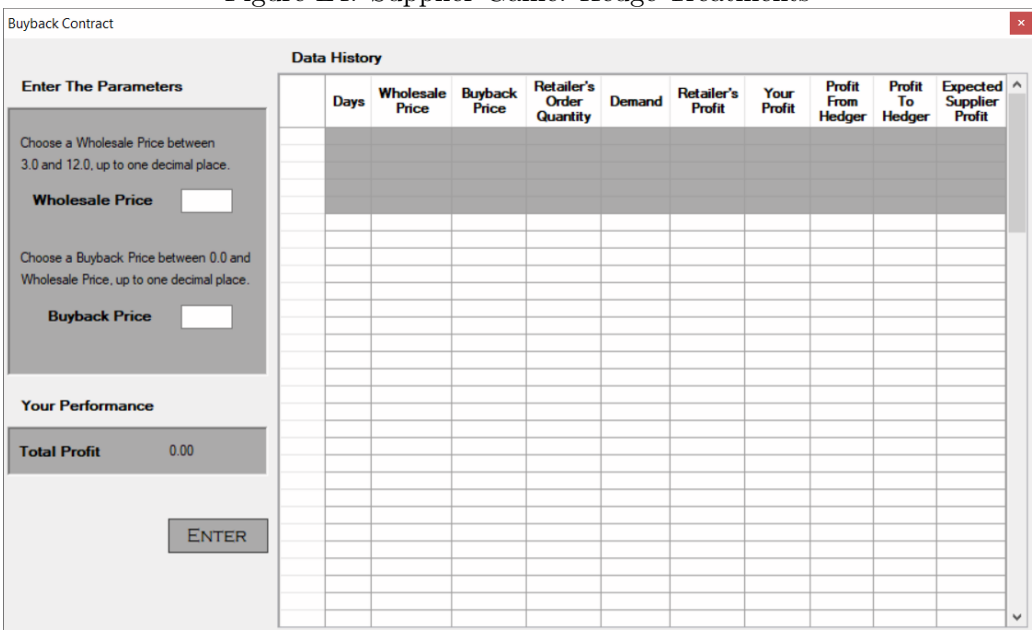


Figure E5: Supplier Game: W Treatments

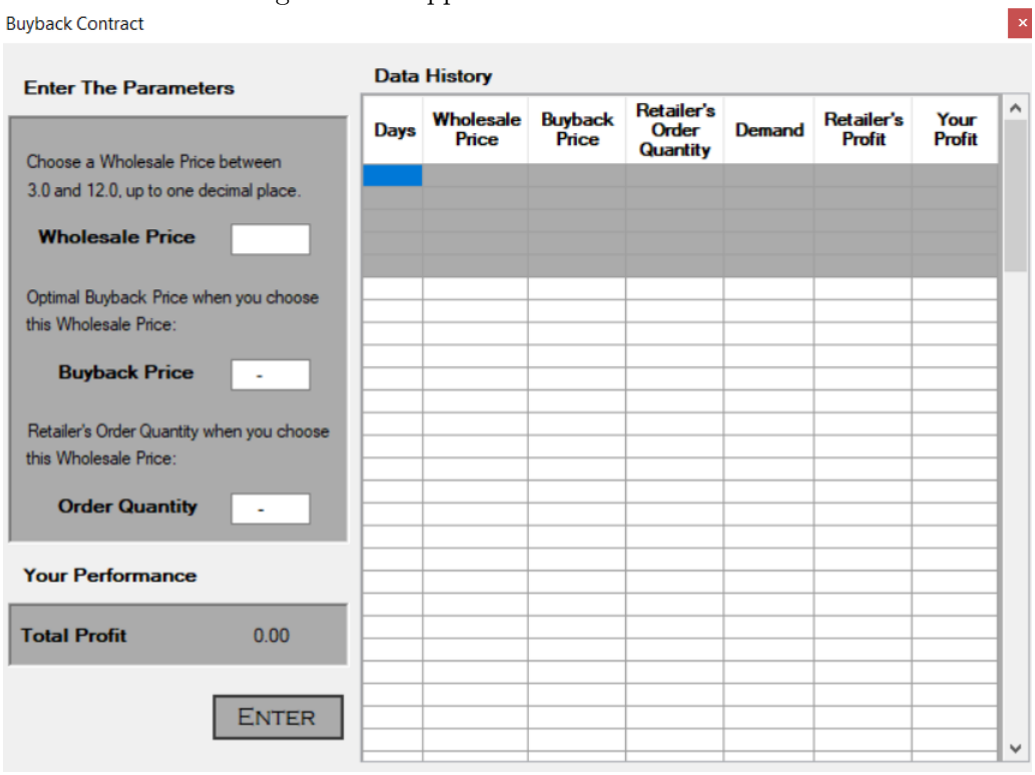


Figure E6: Choose Your Contract Game

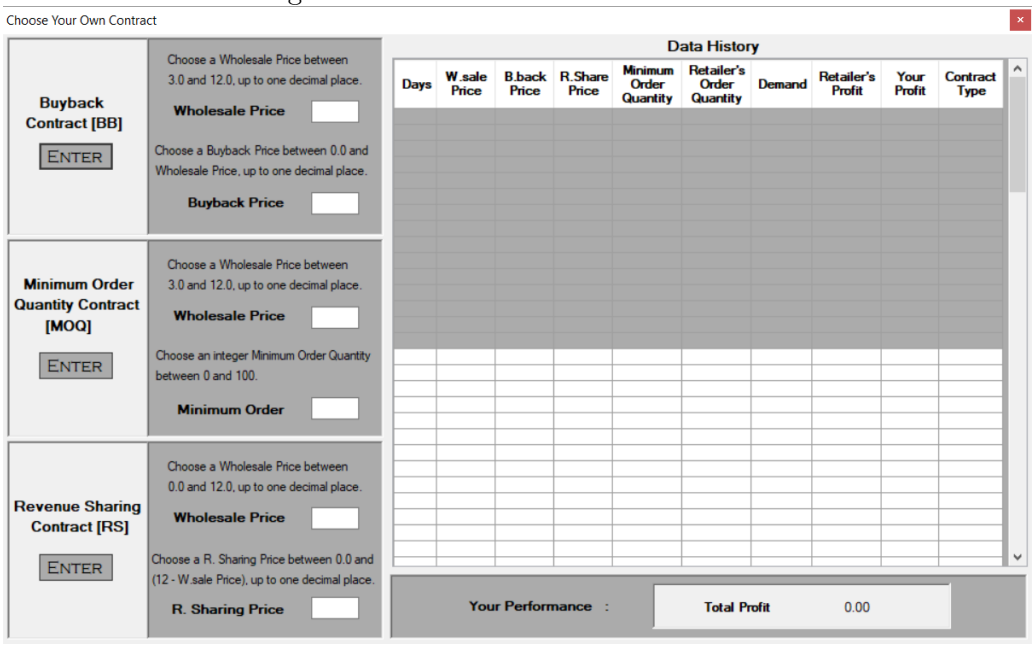


Figure E7: Risk Aversion Survey

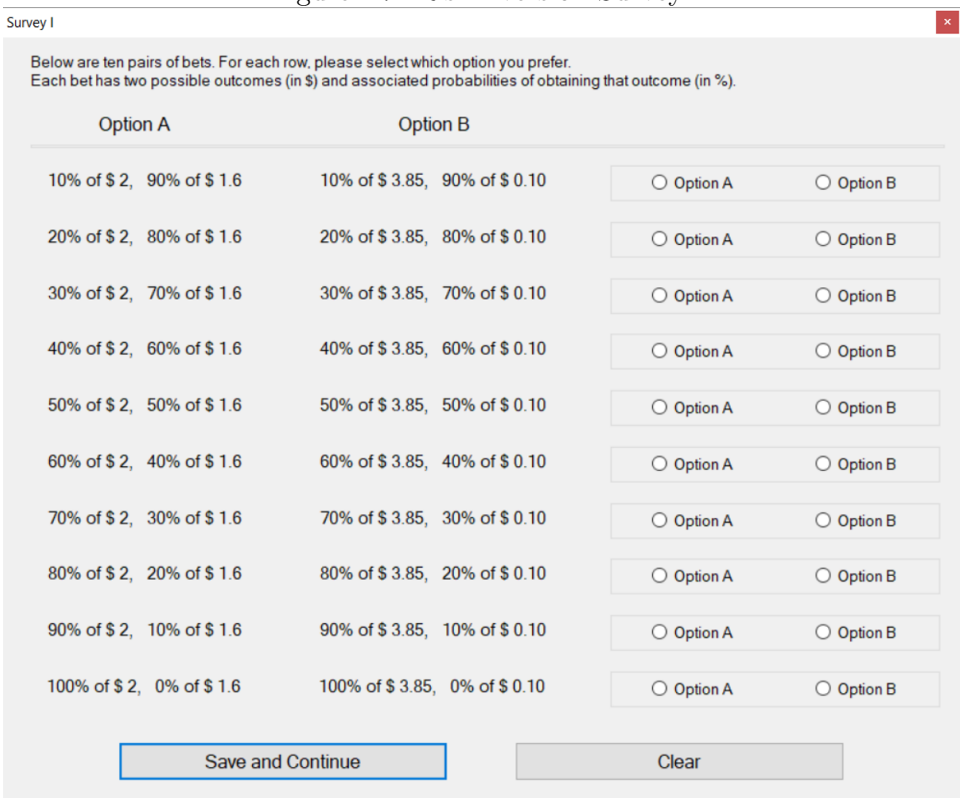
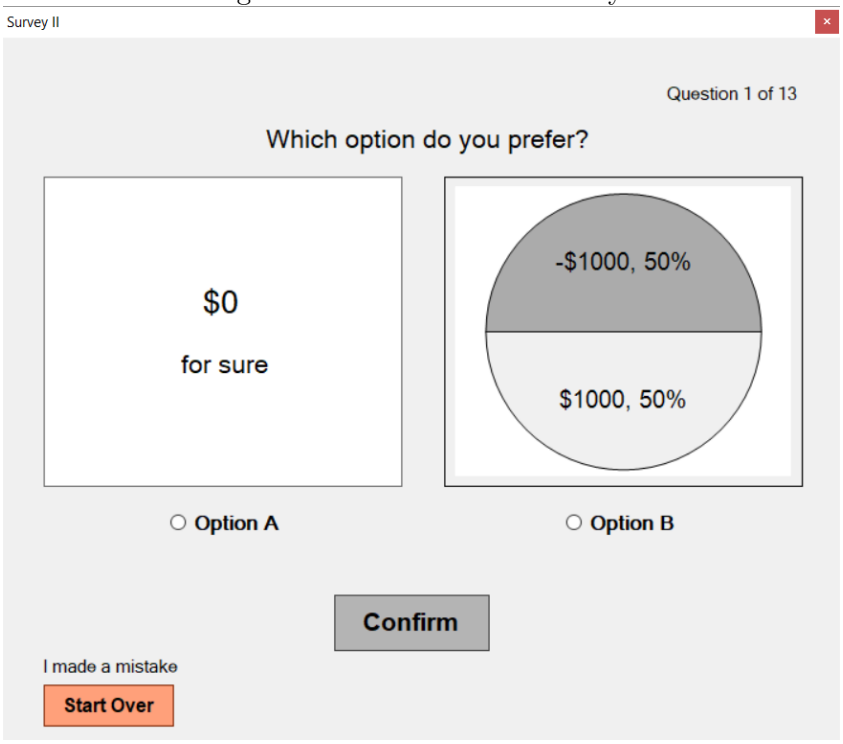


Figure E8: Loss Aversion Survey



References

Cachon, G. P. 2003. Supply chain coordination with contracts. eds. A. G. de Kok, S. C. Graves, ed., *Handbooks in Operations Research and Management Science: Supply Chain Management*, vol. 10. Elsevier B.V., Amsterdam, 229–340.

Katok, E., D. Y. Wu. 2009. Contracting in supply chains: A laboratory investigation. *Management Science* **55**(12) 1953–1968.