

# Web Appendix to: “Profit Implications of Judgmental Adjustments to Forecast Inputs: Evidence from a Large-Scale Field Experiment”

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## Web Appendix 1 (WA1)

### Summary Statistics Overall, Product Life Cycle, Supplier Size, and High/Low-Margin

	Overall	High Gross Margin <sup>†</sup> (top 50%)	Low Gross Margin (bottom 50%)	Growth	Established	Large Suppliers	Small Suppliers
Unique SKUS	17,476	8,742	8,734	521	16,955	8,903	8,573
Number of Suppliers	96	89	89	49	95	17	79
Number of Merchants	24	24	23	18	24	20	20
Avg. Stores Added	5.22	10.07	.37	6.68	5.17	6.23	4.17
Avg. Stores Removed	20.78	32.66	8.91	11.26	21.07	26.69	14.67
Avg. Units Sold ( $\bar{x}$ -score)	.0000	.2243	-.2245	.1385	-.0045	.0089	-.0097
Avg. Unit Margin ( $\bar{x}$ -score)	.0000	-.0043	.0046	.2928	-.0088	.0698	-.0722
Avg. Total Margin ( $\bar{x}$ -score)	.0000	.3294	-.3298	.0039	-.0001	.1102	-.1151
Avg. Inventory ( $\bar{x}$ -score)	.0000	-.0209	.0194	-.0959	-.0022	-.0853	.0871

Note: † Gross Margin is unit sales times unit margin from the year prior to the experimental intervention.

## Web Appendix 2 (WA2)

### Testing for Covariate Balance

Variable	Automation	Augmentation	t-stat of Difference
Margin Percent (z-score)	-.018	.003	1.05
Markup Percent (z-score)	-.034	.006	1.92
Prior Inventory Levels (z-score)	-.002	.005	0.65
Supplier Size (Natural Log of Supplier Sales)	13.27	13.24	1.11
Growth (% of SKUs)	3.32%	2.93%	1.08

Note: \* $p < .10$ ; \*\*  $p < .05$ ; \*\*\* $p < .01$

Web Appendix 3 (WA3)

Robustness Tests

Impact to Profits Dependent Variable: $PRFT_{ijklm}$	Low Inventory Holding Cost		High Inventory Holding Cost		Winsorised (Mid 98%)		Ignoring SKUs Affecting Few Stores		Ignoring SKUs with No Sales		Ignoring Profits from Leftover Inventory		Ignoring SKUs with Complementarities	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
$TRMT_i$ (Automation)	-0.4741***	.0227	-0.5017***	.0228	-0.0659***	.0024	-0.0705***	.0042	-0.1550***	.0242	-0.1092***	.0042	-0.0849***	.0411
Fixed Effects†	Yes		Yes		Yes		Yes		Yes		Yes		Yes	
Sample Size	454,252		454,252		445,270		373,032		45,775		454,252		450,261	
R-Sq	9.09%		9.09%		11.09%		5.49%		38.45%		4.11%		5.67%	

Note: † Store, Location, and Supplier\*Buyer fixed effects; Supplier\*Buyer includes all observed combinations of supplier-buyer pairs; \* $p < .10$ ; \*\*  $p < .05$ ; \*\*\*  $p < .01$

## Web Appendix 4 (WA4)

### Decomposition of Manager Adjustment Impact to Forecast Accuracy

In this section, we demonstrate how merchant overrides resolve noise present in the algorithm's forecast. We form a simple model to inspect. Suppose that the algorithm has a noisy forecast relative to the true demand (Garber and Klepper 1980) so that its error from true demand  $\varepsilon = x - x^*$  has some bias  $\mu_\varepsilon$  and variance from noise  $\sigma_\varepsilon^2$ . Suppose that the manager makes an update to the algorithm's forecast according to  $\bar{x} = x + \eta$  where  $\eta$  has mean  $\mu_\eta$  and variance  $\sigma_\eta^2$ . We consider  $\mu_\eta$  as additional bias (if  $\mu_\eta$  has the same sign of  $\mu_\varepsilon$ ) or bias correction (if  $\mu_\eta$  has the opposite sign of  $\mu_\varepsilon$ ) resulting from the manager's update. We can re-write the variance in the manager's forecast from demand as

$$\text{var}[\bar{x} - x^*] = \text{var}[\varepsilon + \eta] = \sigma_\varepsilon^2 + \sigma_\eta^2 + 2\text{cov}[\varepsilon, \eta] \quad (1)$$

Inspecting (1), we can see that the manager's update introduces additional variance  $\sigma_\eta^2$  to the variance of the algorithm's forecast  $\sigma_\varepsilon^2$ . Since  $\varepsilon$  is noise to the machine,  $\text{cov}[\varepsilon, \eta]$  represents how valuable the manager's adjustment from  $\eta$  is on reducing noise from the machine's forecast from  $\varepsilon$ . The benefits from managerial intervention can only reduce variance in the machine's forecast if  $\text{cov}[\varepsilon, \eta] < -\frac{1}{2} \sigma_\eta^2$ . This can be rewritten as  $\rho_{\varepsilon, \eta} < -\frac{1}{2} \sigma_\eta / \sigma_\varepsilon$  when convenient to interpret the condition based on correlation. In our discussion we will use the covariance formulation as it reduces the number of variables required when calculating to make the determination.

We interpret our condition as whether private information enters the manager's adjustment to improve noise in the algorithm's forecast. Assuming bias correction is small or  $\mu_\eta \approx 0$ , private information  $\eta$  only improves forecast accuracy when  $\eta$  is negatively related with the error  $\varepsilon$  of the machine *and* outweighs the additional noise  $\sigma_\eta^2$  introduced from reviewing the forecast (by a factor of  $\frac{1}{2}$  when using the covariance relation).

We make the following observations based on the MSE decomposition. First, managers can improve forecast accuracy by reducing bias or by reducing noise in machine forecasts. Thus, an improvement in forecast accuracy cannot be completely attributed to managers' capacity to resolve noise through private information, as managers may simply be applying bias reduction to machine forecasts based on historical performance. Second, manager review introduces noise into the forecast and only when private information is valuable beyond a threshold will augmentation result in improved forecast accuracy. In other words, even when managers possess private information they may reduce forecast accuracy.

Examining our empirical context in the table below, we see that the magnitude of bias adjustment of 0.32 is small relative to the variance added from review ( $\sigma_\eta^2 = 2,361.16$ ) and the benefits added from review ( $\text{cov}[\varepsilon, \eta] = -2,064.82$ ). Our condition is met that  $\text{cov}[\varepsilon, \eta] < -\frac{1}{2} \sigma_\eta^2$ , where manager intervention reduces the noise from the forecast algorithm by a total of  $\sigma_\varepsilon^2 + 2\text{cov}[\varepsilon, \eta] = 2,361.16 - 2 * 2,064.82 = -1,768.48$ . This can be confirmed by examining the noise reduction from manager adjustment in the Variance column of Table 2.

### Decomposition of Manager Adjustment Impact to Forecast Accuracy

<b>Manager Adjustment</b>	<b>Bias Adjustment</b> $\mu_\eta$	<b>Added Variance from Review</b> $\sigma_\eta^2$	<b>Benefit from Review</b> $\text{cov}[\varepsilon, \eta]$
	.32	2,361.16	-2,064.82

### Web Appendix 5 (WA5)

#### Including Interactions on Treatment and Moderator Indicator Variables

Impact to Profits Dependent Variable: $PRFT_{ijklm}$	Coeff <sup>††</sup>	S.E.
$TRMT_i$ (Automation)	-.0168*	.0093
$TRMT_i * MRGN_i$	-.0258***	.0093
$TRMT_i * GRWTH_i$	-.4633***	.0353
$TRMT_i * SUPPSIZE_i$	-.0477***	.0072
Fixed Effects <sup>†</sup>	Life Cycle, Margin, Store, Location, and Supplier*Buyer <sup>†</sup>	
Sample Size	454,252	
R-Squared	5.51%	

Note: † Supplier\*Buyer includes all observed combinations of supplier-buyer pairs; †† Main effect of Product Life Cycle (Growth vs. Established), Gross Margin (High vs. Low), and Supplier Size (Large vs. Small) are absorbed by the fixed effects; \* $p < .10$ ; \*\* $p < .05$ ; \*\*\* $p < .01$

Web Appendix 6 (WA6)

Breakout of MSE Differences Reported in Table 3

Measure	Motivation				Opportunity				Ability			
	High Margin	Low Margin	High Minus Low	t-stat of Diff	Growth Products	Established Products	Growth Minus Established	t-stat of Diff	Large Suppliers	Small Suppliers	Large Minus Small	t-stat of Diff
<b>Automation MSE</b>	2.5500 (.2555)	2.1842 (.2875)	.3657 (.3847)	.95	5.9756 (1.6347)	2.2562 (.1917)	3.7194 (1.6459)	2.26**	1.6380 (.1492)	3.1246 (.3601)	-1.4866 (.3898)	3.81***
<b>Augmentation MSE</b>	1.8119 (.1779)	2.6876 (.3227)	-.8757 (.3685)	2.38**	2.3507 (0.4697)	2.2467 (.1894)	.1040 (.5065)	.21	1.4850 (.1072)	3.0445 (.3588)	-1.5595 (.3744)	4.16***
<b>(-) MSE Difference -(Automation - Augmentation)</b>	-.7381 (.3114)	.5033 (.4322)	-1.2414 (.5327)	2.33**	-3.6249 (1.7008)	-.0095 (.2695)	3.6154 (1.7220)	2.10**	-.1530 (.1837)	-.0802 (.5083)	.0728 (.5405)	.13
<b>t-stat of Diff</b>	2.37**	1.16			2.13**	.04			.83	.16		

Note: When considering heterogeneity of MSE, SKU-level forecasts are transformed by dividing by number of stores under review to avoid a scaling issue when comparing across subsamples; standard errors in the parentheses; \* $p < .10$ ; \*\* $p < .05$ ; \*\*\* $p < .01$

### Web Appendix 7 (WA7)

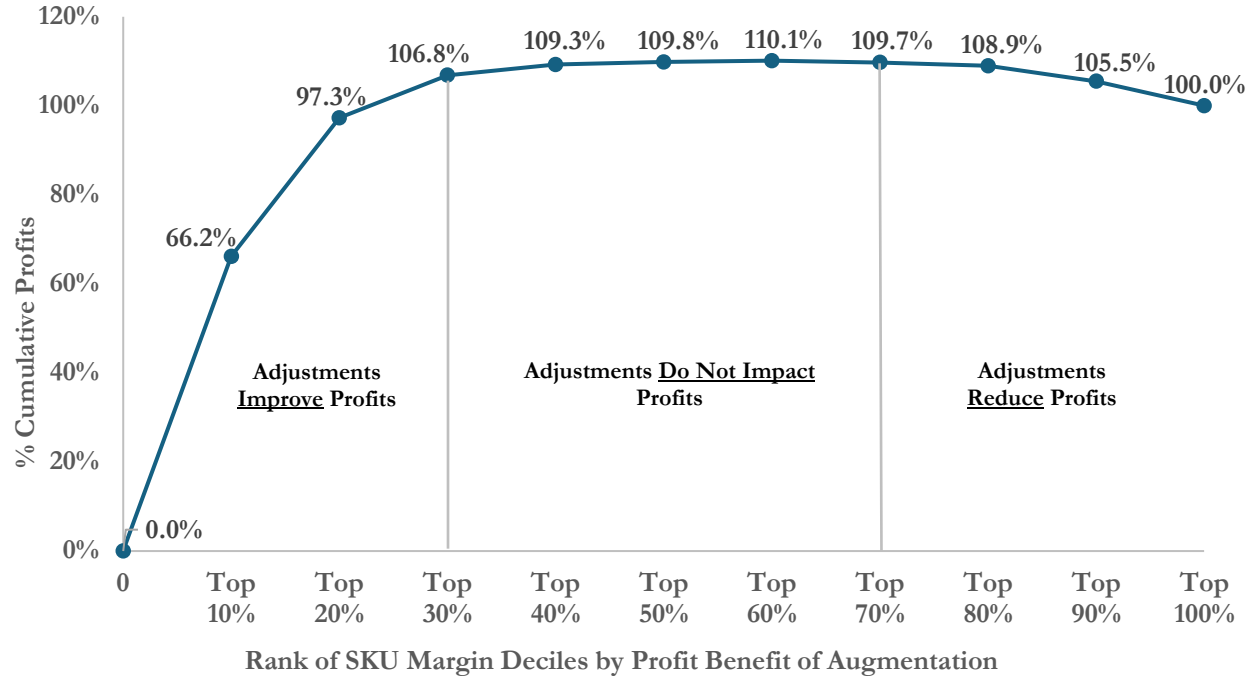
#### Decile of SKU based on Gross Margin – Ranked from Lowest to Highest

<b>Deciles Based on Gross Margin</b>	<b>0-10%</b>	<b>10-20%</b>	<b>20-30%</b>	<b>30-40%</b>	<b>40-50%</b>	<b>50-60%</b>	<b>60-70%</b>	<b>70-80%</b>	<b>80-90%</b>	<b>90-100%</b>
Profit Difference from Treatment† (Automation - Augmentation)	-.0042 (.0032)	.0057* (.0031)	.0258** (.0118)	.0411*** (.0143)	.0031 (.0211)	-.0022 (.0069)	-.0182 (.0145)	-.0714** (.0267)	-.2328*** (.0466)	-.4951*** (.1475)
Number SKUs	1,746	1,747	1,748	1,749	1,748	1,748	1,747	1,748	1,749	1,746
% Contribution to Gross Margin	.18%	.36%	.68%	1.49%	1.32%	1.18%	3.65%	8.49%	20.97%	61.68%

Note: † profits transformed to z-scores for analysis; Standard errors in the parentheses; \* $p < .10$ ; \*\* $p < .05$ ; \*\*\* $p < .01$

Web Appendix 8 (WA8)

Whale Curve for Cumulative Benefits of Augmentation by SKUs



Note: Determination of regions of profit improvement is based on statistical significance of the profit impact of augmentation in the decile (see table below). The profit benefits depicted in the chart are applied across all SKUs in the decile, extrapolating the benefits of human intervention to all SKUs.

Inputs to Whale Curve – WA7 Ranked by Profit Benefits of Augmentation

	Rank of SKU Margin Deciles by Profit Benefit of Augmentation									
	Top 10%	Top 20%	Top 30%	Top 40%	Top 50%	Top 60%	Top 70%	Top 80%	Top 90%	Top 100%
Profit Difference from Treatment† (Automation - Augmentation)	-.4951*** (.1475)	-.2328*** (.0466)	-.0714** (.0267)	-.0182 (.0145)	-.0042 (.0032)	-.0022 (.0069)	.0031 (.0211)	.0057* (.0031)	.0258** (.0118)	.0411*** (.0143)
Cumulative Profit Impact	-4951	-7279	-7993	-8175	-8217	-8239	-8208	-8151	-7893	-7482
% Cumulative Profit Impact	66.2%	97.3%	106.8%	109.3%	109.8%	110.1%	109.7%	108.9%	105.5%	100.0%

Note: † profits transformed to z-scores for analysis; Standard errors in the parentheses; \* $p < .10$ ; \*\* $p < .05$ ; \*\*\* $p < .01$

Web Appendix 9 (WA9)

Established Products and Large Suppliers Split by High/Low-Margin

Measure	Established Products			Large Suppliers		
	High Margin	Low Margin	t-stat of Diff	High Margin	Low Margin	t-stat of Diff
Profit Difference from Treatment (Automation - Augmentation) <sup>†</sup>	-.1183*** (.0366)	.0076 (.0064)	3.41***	-.2817*** (.0710)	.0157 (.0231)	3.98***
(-) MSE Difference from Treatment -(Automation - Augmentation) <sup>‡</sup>	-.5487* (.3064)	.5259 (.4426)	2.00**	-.7430* (.4537)	.0624 (.1882)	1.65*
% of SKUs with an Override	81.58% (.42%)	79.14% (.44%)	4.02***	72.93% (.63%)	72.08% (.72%)	.90
Avg. % Degree of Change of Override	16.67% (.63%)	12.92% (.58%)	4.38***	13.87% (.75%)	11.82% (.90%)	1.74*

Note: <sup>†</sup>Based on Z-scores at SKU level; <sup>‡</sup>When considering heterogeneity of MSE, SKU-level forecasts are transformed by dividing by number of stores under review to avoid a scaling issue when comparing across subsamples; standard errors in the parentheses; \* $p < .10$ ; \*\* $p < .05$ ; \*\*\* $p < .01$

## WEB APPENDIX REFERENCES

Garber, S, Klepper S. 1980. Extending the Classical Normal Errors-in-Variables Model. *Econometrica*. 48(6):1541-1546.