

Online Supplement. Pricing and Production Flexibility: An Empirical Analysis of the U.S. Automotive Industry.

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A. Additional Robustness and Alternative Explanations

A.1. Robustness Analysis

Here we expand on the robustness checks mentioned in Section 5 and describe additional robustness analyses. We discuss the impact of using alternative definitions of flexibility and discounts, and we propose another way to address any remaining endogeneity concerns using an instrumental variable approach.

A.1.1. Alternative Definitions of Flexibility and Discounts

We use the two alternative definitions of flexibility described in Section 4 to show that our results do not critically depend on the measure of flexibility that we use. The first one is the “record” measure of flexibility that keeps the highest value of the flexibility variable observed in the last n months (with $n=6$). Columns 1-4 of Table 1 reproduce the analysis shown in Table 2 of the paper for this alternative measure of flexibility.

The second measure of flexibility is a subjective expert assessment. This is captured by the variable $P_FLEX_HARBOUR_p$, which is a plant-level score between 1 and 4 that denotes the subjective level of flexibility of the plant. This score is measured in years 2004 and 2007. Column 5 of Table 1 reports the results. Note that the magnitude of the effect is not directly comparable to the results shown in Section 5 because the subjective expert assessment is not a binary variable,

Table 1 Robustness Analysis: Plant Level

	(1)	(2)	(3)	(4)	(5)
$P_FLEX_REC_t$	-578.5*** (45.57)	-290.0*** (46.84)	-291.5*** (48.34)	-251.7*** (63.69)	
$P_FLEX_HARBOUR_t$					-656.5*** (136.9)
PLANT EFFS.	No	Yes	Yes	Yes	Yes
TIME CTRLS	Yes	Yes	Yes	Yes	Yes
OTHER CTRLS	No	No	Yes ⁺	Yes ⁺	Yes ⁺
Observations	6,427	6,427	6,168	4,677	1,801
R-squared	0.056	0.668	0.674	0.690	0.704

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

⁺ indicates the following controls: *PRODPLANT, PLANTAGE, UTIL, NPRODS, MODELINV*

The column without plant fixed effects [i.e., (1)] includes a constant.

Columns 4 does not include years 2008 and 2009.

and because the analysis is restricted to the points in time in which the subjective assessment is available. However, the results are also negative and significant, supporting our main hypothesis that more flexibility is associated with lower discounts.

In our model level analysis, we also explore the impact of transformations of our dependent variable—the average discounts offered for a model in a given month. We have chosen to report the main analysis in the text using the dollar level of discounts, as opposed to the logs, because this allows for a more intuitive interpretation of the magnitude of the effect in terms of dollar savings in discounts. However, our main hypothesis is still supported if we use a logarithmic transformation of the discount (Table 2, Column 1) or a relative measure of discounts, such as the percentage discount from the MSRP list price (Table 2, Column 2).

Furthermore, we also conduct transformations of the original flexibility measure at the vehicle model level. Columns 3 and 4 of Table 2 use lagged versions of the flexibility variable, because one could argue that lags in the supply chain and production scheduling process imply that mix flexibility might not affect discounts immediately. Again, we find remarkably similar estimates for the effect of flexibility on discounts.

A.1.2. Instrumental Variable Approach

We also present a complementary analysis using an instrumental variable approach to evaluate the importance of any remaining source of bias in our OLS estimates. A good instrumental variable for the flexibility with which a vehicle model is produced should be correlated with the flexibility variable (relevance condition) and uncorrelated with the error term (exogeneity condition). We use the average flexibility of the rest of models of the same brand as an instrument for the flexibility

Table 2 Robustness Analysis: Model Level

	L(DISC.) (1)	% DISC. (2)	DISC. (3)	DISC. (4)	2SLS DISC. (5)
$FLEX_t$	-0.100*** (0.0371)	-0.00439*** (0.00123)			-670.0*** (186.8)
$FLEX_{t-1}$			-207.5*** (39.83)		
$FLEX_{t-3}$				-186.0*** (39.69)	
MODEL FIXED EFFECTS	Yes	Yes	Yes	Yes	No
SEGMENT-TIME DUMMIES	Yes	Yes	Yes	Yes	No
ADDITIONAL CONTROLS	Yes ⁺	Yes ⁺	Yes ⁺	Yes ⁺	Yes ⁺
Observations	10,411	10,411	10,177	9,831	9,749
R-squared	0.543	0.684	0.747	0.752	0.743

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

⁺ indicates the following controls: *DISC_COMP*, *INTRO*, *PHASE_OUT*, *AGE*, *MPD*, *MSRP*, *DESIGN_CHNG*, *USED_INDEX*.

of a model. This instrument satisfies the relevance condition because there exists correlation in the adoption of flexibility for different plants of the same firm. On the other hand, we do not expect the discounts of a model to be affected by the flexibility of the other models of the firm, after including all our controls.

Column 5 of Table 2 shows the estimates when we use the average flexibility of the rest of the models of the same brand as an instrument for flexibility of each vehicle model and estimate the econometric model using 2SLS. The estimates show that the coefficient of flexibility is even more negative when using the instrumental variable estimation, and therefore our Hypothesis H1 is still supported. This column suggests an effect of -670 USD of mix flexibility on discounts, even more negative than the one obtained using the OLS estimates. It is well known that instrumental variables can result in a substantial small sample bias, and we should be cautious about taking the 2SLS estimates at face value. However, they are useful at indicating the likely direction of any potential remaining bias, and we can consider our OLS results as a lower bound on the effect of flexibility.

The modeling literature can actually offer some additional guidance in interpreting our findings and in understanding the likely direction of potential bias in our OLS estimates. Demand uncertainty has been identified as one of the key drivers for adopting flexibility (e.g., Fine and Freund

1990). Given that price adjustments in the auto industry are asymmetric (discounts from the list price are offered when demand is low but price premiums over the list price are never charged), a more uncertain demand is likely to result in higher average discounts — because as the variance of the demand distribution increases, the size of the price adjustments downwards (if realized demand is low) or upwards (if realized demand is high) is expected to increase. Because the upward price increases are capped by the list price, we expect the average effect to result in higher discounts. If adopting mix flexibility is correlated with expected uncertainty, our flexibility variable is likely to pick up part of the contribution of uncertainty to discounts, which is expected to be positive. This suggests that a potential correlation between the flexibility variable and the omitted uncertainty is positive and the OLS coefficient of flexibility is likely to be biased upwards. This is consistent with the results that we find with our instrumental variable specification.

A.2. Alternative Explanations

Having established support for our central hypothesis, our preferred interpretation of the results is that mix flexibility allows companies to better match between supply and demand, decreasing supply-demand mismatches that result in discounts. However, there could be alternative explanations to the observed findings. We examine whether changes in the evolution of list prices, inventories, or production costs could explain our findings.

A.2.1. Evolution of list prices

While our analysis focused on short-run pricing behavior given by discounts, this behavior has to be examined in the context of the totality of the pricing decisions made by the firm, and in particular with the annual setting of MSRP (on average, incentives are bigger for vehicles with higher MSRP – the correlation between incentives and MSRP is 0.28). Even if flexibility reduces discounts, the effect of flexibility on final transaction prices and on manufacturer revenue per car is ambiguous. In other words, are savings in discounts really savings? If the savings in discounts that we attribute to flexibility coincide in time with reductions in the list prices that can also be attributed to flexibility, then it could well be that the net effect of flexibility on prices is zero or negative (i.e., vehicles might be sold at a cheaper price after flexibility is deployed). This would go against our explanation that the reduction of discounts comes from a better ability to match supply with demand following the deployment of flexibility. In order to test how flexibility affects list prices, we propose the following specification:

$$MSRP_{it} = \mu_i + \beta_1 FLEX_{it} + CONTROLS_{it} + \gamma_{st} + u_{it} \quad (1)$$

where μ_i are model fixed effects, $FLEX_{it}$ is the flexibility with which vehicle model i is produced in time t , γ_{st} are segment-time dummies and $CONTROLS_{it}$ includes additional control variables, such as *DISC_COMP*, *INTRO*, *PHASE_OUT*, *AGE*, and *DESIGN_CHNG*.

The first column of Table 3 shows the impact of flexibility on MSRP, according to specification 1. We can reject the hypothesis that list prices are reduced after flexibility is deployed. In fact, flexibility has a positive, statistically significant association with list prices, which allows us to conclude that the net effect of flexibility on prices is positive. In other words, the savings in discounts afforded by flexibility really are savings.

Table 3 Alternative Explanations: List Prices, Inventories and Sales

	MSRP	DISC.	2SLS DISC.	SALES	SALES	SALES	SALES
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$FLEX_t$	363.7*** (52.74)	-199.3*** (39.93)	-159.7*** (77.21)	713.2*** (132.9)	679.6*** (132.3)	724.6*** (132.0)	489.8** (115.4)
$INVENTORY_t$		-2.633*** (0.287)	40.46*** (6.400)				
$DISCOUNT_t$						0.242*** (0.0296)	0.331*** (0.0262)
$PRODUCTION_t$							0.282*** (0.0143)
MODEL FIXED EFF.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SEGMENT-TIME DUM.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ADDITIONAL CONT.	Yes [#]	Yes ⁺	Yes ⁺	No	Yes ⁺	Yes ⁺	Yes ⁺
Observations	10,415	10,411	10,411	10,535	10,415	10,415	10,415
R-squared	0.979	0.745	0.006	0.877	0.878	0.878	0.901

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

[#] indicates the following controls: *DISC_COMP*, *INTRO*, *PHASE_OUT*, *AGE*, *DESIGN_CHNG*, *USED_INDEX*, *MPD*

⁺ indicates the controls in [#] plus the additional following controls: *MSRP*

A.2.2. The Role of Inventory

We argue that flexibility has a direct effect on discounts. An alternative explanation is that flexibility does not directly affect discounts; rather, it affects inventories which, in turn, affect discounts. It could be that flexibility affects the level of finished goods inventories (i.e., with models manufactured in inflexible plants having higher inventories), and that vehicles with higher inventories are more likely to offer discounts. Actually, Cachon and Olivares (2010) find an association between flexibility and finished goods inventory. In order to test whether inventory is the channel through which flexibility affects demand, we modify our specification 2 in the paper to include an additional control variable, $INVENTORY_{it}$, which contains the days of supply of model i in month t :

$$DISCOUNT_{it} = \mu_i + \beta_1 FLEX_{it} + \beta_2 INVENTORY_{it} + CONTROLS_{it} + \gamma_{s(i)t} + u_{it} \quad (2)$$

Column 2 of Table 3 includes inventory and other additional controls. We observe that the value of the coefficient of flexibility does not change substantially after controlling for inventory: The direct effect of flexibility on discounts is an average reduction of 199.30 USD per vehicle. Note that inventory is highly endogenous in the discount equations. A high level of inventory can be held in anticipation of a positive future demand shock or as a consequence of a negative contemporaneous demand shock. In Column 2 of Table 3 we observe a negative coefficient of inventory, which would suggest that high levels of inventory are associated to lower discounts. In order to address the endogeneity of inventory and to obtain estimates with a clearer causal interpretation, we use instrumental variables. Cachon and Olivares (2010) report an association between the number of dealers and the amount of finished goods inventory, and between the number of variants of a model and the amount of finished goods inventories. Therefore, both the number of dealers and the number of variants of a model satisfy the relevance condition to be used as instrumental variables. Furthermore, we can argue that they also satisfy the exogeneity condition in the discount equation, because dealer structure and the number of variants of a model are decided long before the determinants of discounts are realized. Column 3 of Table 3 reports the estimates of specification 2 using 2SLS, with the number of dealers that are able to sell model i and the number of variants of model i as instrumental variables for the inventory level. We observe that, again, the effect of flexibility on discounts remains negative and significant. However, now we find a positive impact of inventory on discounts. An additional day of supply is associated with an increase of 40.46 USD in average discounts.

In summary, while inventory does indeed affect discounts, the effect of flexibility on discounts is not an indirect effect through inventories.

A.2.3. Cost explanation

An alternative explanation of the observed pricing behavior is based on a cost story. It could be that the marginal costs of production in flexible plants are higher than the marginal costs of production in inflexible plants. If this were the case, lower discounts could arise merely from the fact that marginal costs of production are higher with flexibility, with part of this cost increase being passed to the customer. If customers were facing higher prices for the same vehicles, we would expect that, all else being equal, sales would decrease. However, observe that sales do not decrease after flexibility is deployed. Columns 4-7 of Table 3 include several specifications of the following form:

$$SALES_{it} = \mu_i + \beta_1 FLEX_{it} + CONTROLS_{it} + \gamma_{st} + u_{it} \quad (3)$$

where μ_i are model fixed effects, $FLEX_{it}$ is the flexibility with which model i is produced in time t , γ_{st} are segment-time dummies, and $CONTROLS_{it}$ denotes additional control variables that vary across the four particular specifications.

We have conducted several tests on whether flexibility is associated with a sales decrease, but this hypothesis can always be rejected (see Table 3, columns 4-7). It would be difficult to explain why customers would be willing to buy more and at higher prices if this was purely a cost story. The observed pattern is more consistent with a superior ability to match supply and demand after the deployment of flexibility. Actually, the effect of flexibility on sales is positive and significant. This finding that flexibility increases sales is consistent with some of the principles described in Jordan and Graves (1995), which associate flexibility with a reduction of expected lost sales.

Therefore, our explanation that the effects on discounts and utilization come from a superior ability to match supply with demand after the deployment of flexibility seems the most plausible one. If anything, sales and list prices also increase, which means that our estimates of the benefits of flexibility through savings in discounts and increase in utilization are only a lower bound of the total benefits obtained from flexibility.

A.3. Additional Results

Due to space limitations, we have not reported in main body of the text the results of the estimation of Equation 3 in the paper, which predicts the probability of treatment as a function of observable covariates. For completeness, we reproduce the results here in Table 4.

Table 4 Estimation of the probability of treatment

VARIABLES	(1)	S.E.	(2)	S.E.
	logit FLEX		probit FLEX	
<i>WBASE_IN</i>	-0.0505***	(0.00658)	-0.0268***	(0.00436)
<i>LENGTH_IN</i>	0.0562***	(0.00507)	0.0304***	(0.00345)
<i>WIDTH_IN</i>	0.0504***	(0.00871)	0.0336***	(0.00555)
<i>HEIGHT_IN</i>	-0.0178***	(0.00666)	-0.0132***	(0.00407)
<i>WEIGHT_IN</i>	0.000382***	(8.82e-05)	0.000266***	(5.32e-05)
<i>ENG_CC</i>	-0.000567***	(5.02e-05)	-0.000346***	(3.06e-05)
<i>HP</i>	0.00551***	(0.000757)	0.00322***	(0.000464)
<i>MPGCTY</i>	0.155***	(0.0199)	0.0901***	(0.0123)
<i>MPGHWY</i>	-0.0445***	(0.0165)	-0.0223**	(0.0102)
Constant	-10.42***	(0.787)	-6.277***	(0.477)
<i>TIME EFFECTS</i>	Year, Month		Year, Month	
Observations	11,252		11,252	

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

We also report the quasi-experimental analysis of Section 5.3, but conducted at the plant level, in Table 5. The variables that we use for the matching are year, month, the total plant production, the age of the plant, the utilization, the number of products manufactured in the plant, and the average inventory of the models produced in the plant.

Table 5 Quasi-experimental Analysis: Plant Level

Technique	Comments	(1) Mean effect All sample
Propensity score matching	NN=1	-183.9*** (67.29)
Nearest neighbor	NN=1	-403.5*** (54.07)
Nearest neighbor	NN=1, bias adjusted	-462.5*** (55.13)
Nearest neighbor	NN=1, exact	-392.5*** (54.41)
Nearest neighbor	NN=1, bias adjusted, exact	-371.8*** (54.39)
IPW		-280.6*** (78.27)
RA		-449.6*** (52.37)
IPWRA		-493.5*** (50.90)

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

References

- Cachon, G.P., M. Olivares. 2010. Drivers of finished-goods inventory in the us automobile industry. *Management Science* **56**(1) 202.
- Fine, C.H., R.M. Freund. 1990. Optimal investment in product-flexible manufacturing capacity. *Management Science* 449–466.
- Jordan, W.C., S.C. Graves. 1995. Principles on the benefits of manufacturing process flexibility. *Management Science* 577–594.