Submitted to *Manufacturing & Service Operations Management*
manuscript TO BE SUBMITTED

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

Antonio Moreno
Managerial Economics and Decision Sciences, Kellogg School of Management, Northwestern University, Evanston, IL 60208, a-morenogarcia@kellogg.northwestern.edu

Christian Terwiesch
Operations and Information Management, The Wharton School, University of Pennsylvania, Philadelphia, PA 19104, terwiesch@wharton.upenn.edu

Despite the abundant theoretical literature on production flexibility, price postponement and dynamic pricing, there exists limited empirical evidence on how production flexibility affects pricing decisions. Using a detailed dataset from the U.S. auto industry, we examine the relationship between production flexibility and responsive pricing. Our analysis shows that deploying production flexibility is associated with reductions in observed discounts, as a result of an increased ability to match supply and demand. The reduction in discounts is not explained by changes in costs or list prices after the adoption of flexibility. Under the observed market conditions between 2002 and 2009, flexibility accounts for average savings in discounts of \$200 to \$700 per vehicle sold. This is equivalent to savings of about 10% of the total average discounts provided in the industry. Furthermore, we demonstrate that plant utilization increases after the deployment of flexibility, providing an additional source of benefit from flexibility adoption. To the best of our knowledge, our paper provides the first piece of empirical evidence on how the deployment of production flexibility affects firms' pricing behavior.

Key words: empirical operations management, flexibility, pricing, automotive industry
History: Last edited on November 16, 2012

1. Introduction

Flexibility is typically defined as the ability to adjust and respond to new information (Van Mieghem 2008). Flexibility can take multiple forms. Flexibility can exist with respect to a firm's pricing decisions (pricing flexibility), as has been demonstrated in a large body of literature on dynamic pricing (including yield management and revenue management; see Bitran and Caldentey 2003 for an overview). Flexibility can also exist with respect to a firm's production decisions (production flexibility). Typically, such changes in production take the form of different production quantities (volume flexibility, see Sethi and Sethi 1990) and different product mixes (mix flexibility, see Fine and Freund 1990).

The objective of this paper is to understand the interplay between pricing flexibility and production flexibility. To motivate this choice of research objective, consider the automotive industry and its market dynamics in 2007. Over the first six months of 2007, fuel prices in the US increased by roughly 50% (from $2 per gallon to $3 per gallon), creating a significant (and exogenously triggered) shift in demand towards more fuel efficient vehicles. The responses to this market shift varied substantially across automotive manufacturers. To illustrate this variation, consider two comparable vehicles in the mid-size SUV segment, the Ford Edge and the Honda Pilot. Both vehicles have the same fuel economy (17 mpg in the city and 23 mpg on the highway). Figure 1 shows how Ford and Honda reacted to the shift in demand towards more fuel efficient vehicles, away from SUVs. Figure 1 (left) displays monthly production levels. Production volumes for the Ford Edge remained relatively constant, while production volumes for the Honda Pilot were reduced as gas prices increased. Figure 1 (right) displays the average incentives (money spent by the manufacturers to encourage sales by reducing the cost to the dealer or to the customer) provided by the two manufacturers. We will provide a more detailed definition of incentives at a latter point. For now, observe that the incentives provided by Honda did not change with fuel prices, while incentives for the Ford Edge increased significantly over 2007. In other words, Ford relied on its ability to adjust prices (by providing incentives), while Honda relied on its ability to adjust the number of Honda Pilots that were produced.

One of the essential aspects of production flexibility in the auto industry is given by the number of vehicle types that can be manufactured in a production facility. This is what the operations literature typically calls *mix* flexibility. In our example, Honda was actually able to reduce the production of the Honda Pilot because other types of vehicles were produced in the same facility, which allowed Honda to change the mix towards more fuel efficient vehicles (e.g. Honda Civic) without necessarily hurting plant utilization. Prior literature (e.g., Jordan and Graves 1995) has identified some of the benefits of mix flexibility and has recognized that partial flexibility in the allocation of products to plants can yield most of the benefits of full flexibility. Our definition of flexibility (developed in Section 4) captures this notion of partial mix flexibility and is based on the ability of a plant to manufacture multiple platforms. According to this definition of flexibility, in 2007, the Honda Pilot was produced in *flexible plants*. We therefore consider the Honda Pilot a *flexible model* for that time period. In contrast, the Ford Edge was produced in plants that could only produce this one SUV platform at the time. We thus define it as an *inflexible model* for that time period. The two models in our motivating example also differ in a number of other aspects beyond flexibility and, although the example suggests that mix flexibility may play a role in the explanation of the different reaction to changes in demand, no conclusion about the effect of flexibility can be drawn from the example alone. The rest of this paper explores systematically how companies adjust to changes in demand. In particular, the paper studies the relationship between production flexibility and pricing suggested by the motivating example.

The link between pricing and production flexibility has not been empirically studied in the existing literature. This might be partially explained by the difficulty of obtaining adequate data. In our empirical setting, the U.S. automotive industry, list prices (Manufacturer Suggested Retail Prices, from now on *MSRP*) for new vehicles are relatively easy to find, but manufacturers constantly apply incentives that result in discounts and transaction prices that are significantly below the MSRP. These incentives and thus the actual transaction prices are much harder to obtain. The absence of pricing data has limited prior research to studying sales volume as opposed to analyzing the underlying pricing dynamics.

We have collaborated with *TrueCar.com*, a market research company specialized in new car pricing, and we have gained access to a proprietary data set on prices and incentives in the U.S. auto industry. We have combined this pricing data with other data about the U.S. automotive industry, including sales, production and plant data. Combining these datasets, we are able to model manufacturer's responses to changes in market conditions, be it in the form of price adjustment or in the form of production adjustment. This allows us to empirically analyze the relationship between flexibility and pricing. Our main identification strategy exploits the fact that in our sample the flexibility with which a particular model is produced changes over time.

Our unique dataset, together with our econometric approach, allows us to make the following two main contributions:

First, we show how production flexibility affects discounts. Short run price adjustments in the automotive industry occur mainly through discounts from the MSRP that are implemented using incentives from the manufacturer. We provide evidence that deploying flexibility allows manufacturers to reduce the use of incentives, typically by between $200 and $700 per vehicle. To the best of our knowledge, this is the first piece of empirical evidence supporting the theoretical literature on production flexibility with endogenous pricing (e.g. Van Mieghem and Dada 1999, Chod and Rudi 2005, Goyal and Netessine 2007, Ceryan et al. 2012).

Second, we analyze the effect of flexibility on plant utilization. Jordan and Graves (1995) suggest a positive association between flexibility and capacity utilization when prices are exogenous. The ability to use responsive pricing does not alter this positive association, and we empirically support the claim that the deployment of flexibility is associated with an increase in plant utilization. Our measure of flexibility is built on notions derived from Jordan and Graves's chaining model, emphasizing the benefits of partial mix flexibility. We show that partial mix flexibility increases plant utilization by about 6% in the studied sample.

The rest of the document is organized as follows. Section 2 discusses the underlying theory and related literature and also develops our main hypotheses. Section 3 describes our empirical setting and dataset. Section 4 describes our measures of production flexibility. Section 5 introduces the econometric specification and describes our identification strategy. In Section 6, we present our main results, followed by several robustness checks and alternative explanations in Sections 7 and 8. Finally, Section 9 concludes and points at some areas of current and future research.

2. Theoretical Context and Hypotheses

The literature on flexibility and the literature on dynamic pricing and revenue management provide the theoretical context for our work. Within the literature on flexibility, there exist several studies that have modeled the flexibility and production postponement decisions, to which our work is related. The earlier work in this research stream models the flexibility investment decision under uncertainty in product demand (Fine and Freund 1990). Jordan and Graves (1995) introduced the concept of partial flexibility and demonstrated that partial flexibility can yield most of the benefits of full flexibility. Both of these studies, as well as many others not mentioned here, assume prices to be exogenous. In contrast, the literature on dynamic pricing and revenue management has largely focused on developing models that let firms adjust prices when capacity is exogenous. Gallego and Van Ryzin (1994) is a seminal paper in this line of research; Bitran and Caldentey (2003) and Elmaghraby and Keskinocak (2003) provide comprehensive overviews of this literature. Some of the more recent literature on flexibility and postponement has endogenized the pricing decision in models where firms also choose capacity. For example, Van Mieghem and Dada (1999) study how the timing of decisions with respect to the demand uncertainty, in particular production and price postponement, affects the strategic investment decision of the firm and its value. Other recent papers that analyze flexibility in presence of responsive or dynamic pricing are Chod and Rudi (2005), Goyal and Netessine (2007), and Ceryan et al. (2012). Despite these careful analytical studies of dynamic pricing and production flexibility, the empirical evidence in this area remains scarce, which is one motivation of the present study.

A topic in the manufacturing strategy literature that has been empirically studied more extensively is what one might call the opposite of mix flexibility, specialization. Specialization has been shown to improve operational performance in some settings (e.g., Huckman and Zinner 2008, Kc and Terwiesch 2011). Our empirical analysis shows evidence of some positive benefits of producing multiple product lines in one facility and thus speaks to the flexibility vs. specialization debate.

The marketing literature on promotions is also related to our work. This literature has mainly focused on quantifying the effect of promotion on sales (e.g. Gupta 1988) and other related issues (for a comprehensive review, see Neslin 2002). To our knowledge, no paper in this line of work has studied how decisions related to flexibility and utilization affect promotions.

A number of papers in empirical operations management have studied various aspects of the automotive production process, including MacDuffie et al. (1996), Fisher and Ittner (1999), Fisher et al. (1999). Closest to our work, Cachon and Olivares (2010) study the drivers of inventory in the U.S. downstream automotive supply chain. Our paper is concerned with understanding the drivers of observed pricing, rather than the drivers of inventories, but we share their interest in the role of flexibility. Also, Goyal et al. (2006) empirically study the drivers of manufacturing flexibility in the automotive industry. Our paper does not look into what drives flexibility, but into the effects flexibility has on pricing.

A key novelty of our paper is the fact that we consider the manufacturer's pricing. Very few empirical papers have studied the interplay between operational decisions and prices. An exception is Gaur et al. (2005), which investigates the correlation of inventory turnover and gross margin.

In order to motivate our research hypotheses, consider again our example from the introduction. To keep the example simple, assume two types of vehicles, fuel efficient and fuel inefficient, and two types of plants, flexible (can produce both types of vehicle) and inflexible (can only produce one type of vehicles). Following an increase in gas prices, demand for fuel inefficient vehicles decreases. The manufacturer can respond by offering more incentives (higher discounts from the MSRP) for fuel inefficient vehicles or by reducing the production volume of fuel inefficient vehicles. By definition, for a manufacturer with an inflexible plant, a reduction in production volume of the fuel inefficient vehicle implies a reduction in plant utilization. This leads to an increase in the average cost per vehicle in the plant, because the plant's fixed costs are spread over a lower number of units. Higher average costs result, all else being equal, in lower average profits per car. If the manufacturer with the inflexible plant decides to maintain high production volume (and thus high plant utilization), incentives are needed to avoid vehicles accumulating in inventory. In this case, the revenue per vehicle sold decreases, which also results in lower average profits.

A manufacturer with a flexible plant can shift production of the fuel efficient model to the plant that is presently producing the less attractive fuel inefficient vehicle. Depending on the level of correlation between demand for fuel efficient and fuel inefficient vehicles, overall demand for the manufacturer might go down or not go down. However, some pooling benefits exist even at modest levels of positive correlation and so the manufacturer with the flexible plant is less affected by the exogenous demand shock. Note that after adjusting the product mix, the manufacturer with the flexible plant might still decide to reduce plant utilization (at the expense of a higher average cost) or to increase incentives (at the cost of foregoing revenue). The optimal decisions will be a result of manufacturers playing a complex game in which the equilibrium decisions with regards to production volumes and incentives provided will depend on their demand and cost curves and those of their competitors. Rather than estimating the parameters of those curves, we are interested in the equilibrium average relationship between flexibility and incentives under the demand patterns observed during our period of analysis. The exact magnitude of the effect of flexibility will depend on the shape of the cost and demand curves as demonstrated in the recent modeling work by Ceryan et al (2012).

Since flexibility allows manufacturers with a flexible plant to adjust the mix, these manufacturers have an additional tool they can use before engaging in giving costly incentives. We thus establish the following main hypothesis:

Hypothesis 1. *The deployment of flexibility is associated with a reduction of the average incentives*

In addition to confirming that the direction of the effect is the one we hypothesize, we also seek to quantify the magnitude of the impact of flexibility on discounts for the U.S. automotive market during the period covered by our data (2002-2009).

Next, we turn our attention to the relationship between flexibility and plant utilization. Firms can offer incentives to encourage sales. These incentives are hypothesized (Hypothesis 1) to be higher for inflexible plants and thus the relationship between flexibility and utilization depends on the actual cost and demand curves. It is an empirical question whether flexibility is associated with higher or lower plant utilization. In absence of a complete equilibrium model, we follow the Jordan and Graves (1995) argument that flexibility allows firms to change the production mix and thus provides them with an alternative to reducing plant utilization:

Hypothesis 2. *The deployment of flexibility is associated with an increase in plant utilization*

Again, rather than merely validating that the effect goes in the hypothesized direction, we are interested in providing an estimate of the magnitude of the effect of flexibility on plant utilization.

Assuming that flexibility helps to better match supply with demand, the magnitudes of the effects estimated in the validation of Hypotheses 1 and 2 will give an estimate of the benefits that can be obtained by deploying flexibility.

3. Empirical Setting and Data

Our empirical analysis focuses on the U.S. automotive industry, covering the section of the supply chain that spans from the manufacturers to the final consumers. There are three main reasons why we decided to choose the automotive industry as our empirical setting. First, the automotive industry is important on its own. The U.S. automotive industry is responsible for more than 3 million jobs in the U.S. and contributes 5% of the total U.S. GDP (Ramey and Vine 2006). Second, it is an industry where operations and supply chain management play a major role, and companies are known to follow different operational strategies. Third, there is a limited amount of manufacturers in the market and their final product is comparable using a reduced number of attributes. The methodology that we use can be adapted to study the impact of flexibility on prices in other industries and also to study the impact of other operational decisions besides the deployment of flexibility.

In the auto industry, there exist different prices that govern the transactions between manufacturers, dealers and customers. In this paper, we focus on the *manufacturer's pricing decisions*. For every model year, the manufacturer sets the *MSRP*. To respond to changing market conditions, manufacturers offer varying levels of *incentives* to dealers and/or consumers. Incentives include any costly action undertaken by the manufacturer to reduce the net cost of purchasing a vehicle, and they can be targeted to the dealer or to the final customer. These incentives sometimes take the form of loans in favorable conditions or other initiatives of financial nature.

In 2009, auto companies reportedly spent more than $28 billion in incentives. Table 1 shows the average incentives offered by each manufacturer. This includes incentives given by the manufacturers to both dealers and final consumers, and includes the cost of financial incentives (e.g. 0% interest loans). There exist systematic differences in the incentives that firms give. The Big Three are among the companies who offer the highest incentives, and Toyota and Honda are among the companies who offer the lowest incentives. Our analysis shows that changes in flexibility explain part of the observed variation in incentives. Note that our analysis will use firm (and model) level fixed effect to ensure that we truly identify the effect of flexibility as opposed to picking up firm effects.

Our data covers the vehicles marketed in the U.S. in the period of 2002-2009. We have information on the 327 distinct *models* (e.g., Chevrolet Malibu) marketed in the U.S. during the period. Our analysis uses monthly data and we have a total of 18,166 model-month (e.g., Chevrolet Malibu, February 2003) observations. We combine three sources of data: production/sales data, pricing data and vehicle-level data.

Production/sales data. It is obtained from WARDS automotive and includes monthly sales and domestic production (if applicable). Domestic production refers to vehicles produced in the U.S., Mexico or Canada. If a car is imported from outside this region, we label it as not domestic. We have information about the platform on which each of the domestically produced models is based and the segment to which they belong. We observe how domestic production is distributed across different plants, and also across different facilities within the plant (e.g. Fremont 1 and Fremont 2). We have also obtained data on the annual capacity of U.S. plants.

Pricing data. We have obtained incentive data from TrueCar. TrueCar is a market information company that provides prospective car buyers with real transaction price data of new cars (www.truecar.com). TrueCar obtains data directly from car dealers, respected dealer management system (DMS) providers, and well-known data aggregators within the automotive space. We have collaborated with TrueCar and we have obtained access to some of their historical data. In this paper we focus on the incentives given by manufacturers. As are sales and production data, incentive data is available at the model-month level and indicate the average amount spent by the manufacturer for each vehicle sold in that month. The measure includes incentives given to the dealers and to the final consumers, and it also includes incentives of financial nature (e.g., credit in favorable conditions), which are converted to their equivalent monetary values. Not all the incentives are necessarily passed-through to the consumer (see Busse et al. 2006), yet incentives always represent an additional cost to the manufacturer.

Vehicle level data. Our model also uses data on vehicle attributes, which we also obtain from WARDS Automotive. We include some vehicles attributes as control variable in our analysis. For example, fuel economy is an important attribute because it will determine how sensitive a model is to changes in gas prices that will cause shocks in demand to which the manufacturer will adjust. We also use vehicle attributes to identify possible major changes in design that might explain changes in prices of a given model. The vehicle attributes are specific to the *trim* level (e.g. Chevrolet Malibu LS 4dr Sedan) and model year. This poses some integration challenges, because our sales, inventory and incentive data is available at the model level (e.g., Chevrolet Malibu), and we do not observe the breakdown of sales for the different trims of a model (or for different model years that might be sold simultaneously). Our solution is to match every model with the median of the attributes across the different trims in which a model is available. We also run some robustness checks using the minimum and the maximum of the attributes instead of the median.

Table 2 includes a description of the main variables used in our analysis and their summary statistics.

4. Measures of Flexibility

Our objective is not to identify the specific contribution of each of the types of flexibility identified in the previous literature, but to define a simple measure that embodies the most important dimensions of flexibility at the strategic level in the auto industry. We refer the reader to the review by Sethi and Sethi (1990) that identifies over 50 ways to operationalize flexibility.

Our primary measure of flexibility is an objective measure based on the *demonstrated* ability of a plant to produce multiple products in the same facility. This is what has been called *mix flexibility* or product flexibility in some taxonomies (for example, see Parker and Wirth 1999). Mix flexibility has been used in prior academic studies and is also used by analysts following the automotive industry. For example, the Prudential Report, a third party evaluation of the financial outlook of the various U.S. car manufacturers, uses the number of nameplates manufactured in a production line as the criteria to define a plant as flexible; lines producing more than one nameplate are considered flexible, while lines producing a single nameplate are considered inflexible.

We use a binary variable to code flexibility. We define a production facility p as flexible ($P\_FLEX_{pt} = 1$) if it produces more than one platform in month t. We choose the number of platforms as opposed to the number of products for our measure of mix flexibility because the number of platforms is more related to the necessary technological and managerial complexity in the plant (two "different" products can just be branded versions of the same vehicle), but our qualitative results still hold if we take a product-based measure. As an example, Figure 2 shows the allocation of platforms to plants for Nissan and Ford in the end of 2010. According to our measure, the four plants that Nissan has in North America were flexible in the end of 2010, while only five out of the thirteen North American plants that manufacture Ford vehicles were flexible. The figure is just a snapshot, as flexibility has evolved over time. With substantial investments, an inflexible plant can become flexible. In some cases, a flexible plant can become inflexible. This can happen, for example, when one of the models manufactured in the plant is discontinued and leaves the plant with a single allocated platform.

Since our sales and incentive data are at the model-month level, we assign a flexibility score to every model on a monthly basis. We use a binary score: a model i is given a high flexibility score in a given month t ($FLEX_{it}$=1) if it has at least some production in a domestic (North American) flexible facility. Previous research has shown that partial flexibility can go a long way in achieving the benefits of full flexibility (Jordan and Graves 1995). This insight has been extended to multi-stage supply chains (Graves and Tomlin 2003), queuing settings (Bassamboo et al. 2008), and newsvendor settings (Bassamboo et al. 2010). Model flexibility changes over time, since a model can *(a)* be shifted from a flexible to an inflexible plant, *(b)* be shifted from an inflexible to a flexible plant, or *(c)* remain at a plant which changes its flexibility level because of changes in other models. This variation in model flexibility over time is essential for our identification strategy, as we discuss in Section 5.

We consider fully imported models not flexible. Transportation adds a lead time of at least 4 to 6 weeks to the production time, meaning that firms have a limited ability to quickly adjust production to match changes in demand. The inability to adjust to demand because of poor mix flexibility and because of long lead times can have different effects. In order to make sure that our decision to code fully imported models as inflexible does not drive the results, we perform additional analyses excluding the fully imported models. Our results do not change qualitatively.

Using our definition of flexibility, we can perform a simple comparison between the incentives given for models manufactured with flexibility and for models manufactured without flexibility. The average incentive for models that are produced with flexibility was $2,691 in 2007, while the average incentive for models that are produced without flexibility was \$3,411 in the same year. Not all the difference between the two groups (\$720) comes necessarily from differences in flexibility. It could be, for example, that Japanese firms are more flexible and that Japanese firms also provide systematically lower discounts for reasons different from flexibility. A more refined econometric analysis to evaluate the effects of flexibility is needed, and it is developed in Section 5.

The flexibility measure described above is based on the demonstrated ability to produce a mix, but a plant could have this flexibility and choose not to use it. Moreover, a plant can produce multiple products but have each product allocated to an independent production line without mix flexibility. To strengthen our measure of flexibility, we also created flexibility scores of the plants based on the subjective assessment of an industry expert. We obtained the assessment of the flexibility of all the North American plants in two points in time from Mr. Ron Harbour, widely acknowledged as a leading expert in understanding the U.S. automotive industry. He has visited every single automotive plant in North America and has been the producer of the Harbour Reports (now published through Oliver Wyman, see https://www.theharbourreport.com), which is the authoritative information source for automotive plant productivity. We compared his subjective assessment that he kindly provided to us with our measure and found them to largely be consistent. We also performed our empirical analysis using his evaluation as the flexibility measure and found the results to be similar. To allow future research to replicate our results and build on our work, the main analysis of this paper is based on the objective flexibility measure that we previously defined, but we also report the results with the subjective measure to show that the effects that we are finding are not an artifact of our measure of flexibility.

5. Econometric Specification and Identification

Automotive manufacturers play a complex game in which the equilibrium decisions with regards to flexibility deployment, production and pricing will depend on their demand and cost curves and those of their competitors. One potential approach to analyze their decisions would be to fully characterize the problem that firms are solving and to structurally estimate the model primitives. However, the lack of cost data and the number of interdependent decisions that firms are making limit the appeal of such an approach. Our approach is instead to focus on the equilibrium average relationship between flexibility and incentives and plant utilization under the demand patterns observed during our period of analysis.

We start by modeling the impact of flexibility on discounts (incentives) at the *model level*. We use a family of reduced form specifications that model discounts as:

$$DISCOUNT_{it} = \mu_i + \beta_1 FLEX_{it} + CONTROLS_{it} + \gamma_{s(i)t} + \epsilon_{it} \tag{1}$$

where i is the model, t is the month and $s(i)t$ is the segment to which model i belongs. All specifications include $FLEX_{it}$, the demonstrated flexibility measure described in Section 4; μ_i, a model fixed effect; $\gamma_{s(i)t}$, a variable that controls for segment-time interactions; and u_{it}, the error term. The set of additional controls includes the variables $DISC\_COMP_{it}$, MPD_{it}, AGE_{it}, $INTRO_{it}$, $PHASE\_OUT_{it}$ and $DESIGN\_CHNG_{it}$ (these and the rest of the main variables of our analysis are described in Table 2).

Hypothesis 1 (the deployment of flexibility is associated with a reduction of the average incentives) holds if $\beta_1 < 0$, with β_1 giving the magnitude of the impact of flexibility on discounts. Model fixed effects capture the contribution to discounts of any model characteristics that do not change over time (for example, being a model produced by a Japanese firm, being a Ford, being a Toyota Corolla or being an SUV are features that do not change over time). The identification of the coefficients, including that of flexibility, is enabled by temporal variations of the level of discounts for a given model. Since some models change from flexibility to inflexibility or vice versa, it is possible to identify the effect of flexibility.

As an example of the variation that helps to identify the coefficient of flexibility, Figure 3 shows the evolution of incentives for two similar vehicles, the GMC Envoy and the Nissan Pathfinder. Both vehicles were manufactured in inflexible plants until September 2004. The evolution of the average incentive is similar for both vehicles before that. In September 2004, the Nissan Pathfinder started to be produced in the flexible Smyrna Plant, making the model flexible according to our definition. After that, the average incentive for the Nissan Pathfinder dropped considerably, compared with the average incentive given for the GMC Envoy. Our econometric analysis does a more rigorous job by controlling for additional variables that may play a role before and after the deployment of flexibility. For example, in the period shown in Figure 3 there were also changes in MSRP for the Nissan Pathfinder, and therefore not all the difference in observed incentives comes from flexibility.

Using flexible technology to produce a model is clearly an endogenous decision, since firms choose which models to produce with flexible technology and when. This decision might be based on factors that also affect the discount policy for the vehicle, and the specification shown above could result in biased estimates if the use of flexibility is correlated with any unobserved variable captured by the error term. Model fixed effects reduce the extent of the problem, because they account for any potentially ignored cross-sectional variable that might affect discounts and might be correlated with the adoption of flexibility. Adding fixed effects deals with omitted variables that are constant over time for a given model. The potential endogeneity concern is further attenuated if we control for additional variables that can change over time. In particular, some of our specifications control for the vehicle list price (MSRP), which is adjusted yearly. Unobserved changes in the demand conditions expected by the firm for a year, which can be potentially correlated with the adoption of flexibility, can be accounted for by observed changes in the list price. Also, all our specifications include segment-time dummies. They account for any temporal shocks that affect all models of a given segment. This includes any temporal trends in discounts at the segment level as well as any global industry trends. In Section 7 we describe an additional robustness check using instrumental variables that allows us to determine the extent to which any remaining endogeneity might be affecting our estimates.

In order to assess the impact of flexibility on utilization, we perform the analysis at the *plant level*. We use the following specification:

$$UTIL_{pt} = \mu_p + \alpha_1 P\_FLEX_{pt} + CONTROLS_{pt} + \gamma_t + u_{pt} \tag{2}$$

where $UTIL_{pt}$ is the plant utilization of plant p in month t, P_FLEX_{pt} is the plant flexibility and $CONTROLS_{pt}$ include any plant level controls, such as the average production volume of the models in plant p in month t ($AVGPROD_{pt}$) or the total inventory of the models produced in plant p in month t ($INVENTORY_{pt}$). The model includes plant fixed effects μ_p and time effects γ_t. Again, the identification of the effect of flexibility comes from temporal variations in plant flexibility. Hypothesis H2 (the deployment of flexibility is associated with an increase in plant utilization) holds if $\alpha_1 > 0$, with α_1 giving the magnitude of the impact of flexibility on discounts.

6. Results

6.1. Flexibility and Discounts

We begin by estimating the models characterizing model level discounts (Equation 1). Table 3 shows the estimates obtained using OLS. In all six columns, the dependent variables is $DISCOUNTS_{it}$. The first three columns focus on vehicles with some domestic production (that is, excluding fully imported vehicles), while Columns 4, 5 and 6 show the estimates using all the vehicles marketed in the U.S., including those that are fully imported.

Columns 1 and 4 show the estimates including the flexibility and the competitor discounts variables and segment-time interactions, but without any other controls and without including fixed effects. In both groups the flexibility coefficient is negative and significant, suggesting that flexibility is associated with lower discounts. However, in these cases endogeneity is a serious concern - flexible vehicles might have other characteristics that result in the observed lower discount activity. Columns 2 and 5 incorporate model fixed effects, which account for persistent unobserved variables at the model level. The effect of flexibility is still negative and significant when we add the model fixed effects (-202.4 for the models with domestic production and -300.5 for all the models). Columns 3 and 6 incorporate additional controls for some variables that change over time. The flexibility estimate remains almost constant across these models, which suggests that flexibility adoption is not correlated with those observed variables. Columns 3 and 6 are our preferred specifications in Table 3, as they include all controls. We observe an estimated effect of flexibility on discounts of -215.5 for vehicles with domestic production and -293.8 for all vehicles. These coefficients can be interpreted as the average dollar savings in discounts that are obtained by switching a model from an inflexible facility to a flexible one. Standard errors are robust and clustered by model.

Overall, the results of Table 3 show strong support for Hypothesis 1: the deployment of flexibility is indeed associated with a reduction of the average discounts. The magnitude of the effect is both statistically and economically significant. Deploying flexibility saves an amount in the order of 10% of the average discount. In Section 7 we perform an extensive number of robustness checks that further validate this result.

6.2. Flexibility and Utilization

Turning our attention to the effect of flexibility on utilization, Table 4 shows the estimates of the family of specifications given by Equation 2, which are at the *plant level*. In all the models, the dependent variables is $UTIL_{pt}$ and the unit of observation is a plant-month. This analysis only includes North American plants because we do not have plant level data for the rest of the plants. All the specifications include monthly dummies. The basic analysis is presented in Columns 1-3, with Columns 4-7 providing additional robustness checks.

Columns 1-3 use the mix flexibility variable P_FLEX_{pt} described in Section 4. The difference between columns 1, 2 and 3 is in the controls that are included. Column 1 does not include plant fixed effects and therefore is potentially affected by substantial endogeneity. It is only reported as a baseline. The estimate for the effect of P_FLEX_{pt} is 0.151, which can be interpreted as attributing a 15.1% increase in plant utilization to the effect of mix flexibility. Column 2 adds plant fixed effects, which control for some of the endogeneity. This results in an estimate of 10.7% for the effect of plant mix flexibility. Column 3 adds some additional control variables ($AVGPROD_{pt}$ and $INVENTORY_{pt}$) and the estimates of the effect of P_FLEX_{pt} barely change (9%), which suggests that the additional control variables are not highly correlated with P_FLEX_{pt}.

Overall, the results of Columns 1-3 show support for Hypothesis H2: the deployment of flexibility is associated with an increase in plant utilization. The effect is economically and statistically significant.

The rest of the Columns 4-7 provide additional robustness checks that further validate the finding that deploying plant mix flexibility has a positive impact on flexibility.

Columns 4 and 5 use a modified version of our plant mix flexibility variable based on the highest flexibility that a plant has had in the past. Since our flexibility measure captures the demonstrated flexibility rather than the potential flexibility, there exists a potential endogeneity problem. A plant that is able to produce multiple platforms might only do so when demand for them is high. We also expect high utilization when demand for the products manufactured in a plant is high. Therefore, the effect attributed to flexibility might be actually related to unobserved demand shocks. For our modified version of plant flexibility, named $P\_FLEX\_RECORD_{pt}$, we assume that a plant that has ever produced more than two platforms at the same time in the past remains flexible, even if the firm might decide not to use that flexibility. When we use this variable instead of the original measure of flexibility, we observe that the estimated effect of flexibility on utilization is attenuated, suggesting that the 9% effect obtained with our original measure might be upwards biased. Column 4 uses the modified version of plant mix flexibility and plant fixed effects, but no additional controls, and finds an effect of 6.3%. Column 5 adds the same additional controls used in Column 3, obtaining an effect of 6.6%, suggesting that there was no substantial omitted variable bias when those controls were not used. We have run additional robustness analyses using variations of this measure, such as setting the flexibility variable to 1 if the plant has demonstrated mix flexibility in the last n months, even if the plant is not producing multiple platforms in a given month. The results found using these variations for several values of n (e.g., n=*3*, n=*6*) are consistent with the results that we present here.

Finally, Columns 6 and 7 use yet another measure of plant flexibility, based on the subjective assessment of an expert, as described in Section 4. We obtained the expert's assessment of the flexibility potential of the technology available in each plant in two points in time, 2004 and 2007. Columns 6 and 7 show that the effect of this flexibility measure, named $P\_FLEX\_HARBOUR_{pt}$, on plant utilization, is also positive and significant. In both columns we have plant fixed effects and Column 7 includes additional control variables. Note that the magnitude of the estimates is not directly comparable to the estimates of the effect of flexibility shown in Columns 1-5, because $P\_FLEX\_HARBOUR_{pt}$ is not a binary variable, but a score between 1 and 4. Also, note that the sample is smaller because we only have this measure for two years.

In all cases, the results support our hypothesis H2: the deployment of flexibility is associated with a reduction of the average incentives. Our preferred estimate for the magnitude of the effect is the one obtained in Columns 3 and 4, around 6%. If an average plant has the capacity to produce around 15,000 vehicles per month, increasing average utilization by 6% is roughly equivalent to producing a total of 900 more vehicles per month on average. If the fixed costs of operating the plant do not increase, adopting flexibility results in lower fixed costs per vehicle sold and more efficient capital investments.

7. Robustness Analysis

We now show that the results described in the previous section, which provide support for our two hypotheses, are robust. We focus mainly on the impact of flexibility on discounts (some robustness analysis on the relation between flexibility and utilization have been described in Section 6). We discuss the impact of using alternative definitions of flexibility and discounts, and address any remaining endogeneity concerns.

Alternative Definitions of Flexibility and Discounts

The unit of observation for the analysis of the impact of flexibility on discounts shown in Section 6 is model-month. Since we have data at the plant level as well, we replicate our results at this level of aggregation, to validate that our results are not driven by the definition of flexibility at the model level. In order to do that, we compute the production weighted incentive given at every plant. The econometric specification is the following:

$$DISCOUNT_{pt} = \mu_p + \beta_1 P\_FLEX_{pt} + CONTROLS_{pt} + \gamma_t + u_{pt} \tag{3}$$

where $DISCOUNT_{pt}$ is the production weighted average incentive, $FLEX_{pt}$ is the plant flexibility measure, $CONTROLS_{pt}$ include any additional plant level controls, μ_p is a fixed effect, γ_t is a set of time dummies and u_{pt} is the error term. Based on this specification, we can use either the objective measure of demonstrated mix flexibility (P_FLEX_p) other transformations of this variable, or the subjective flexibility measure provided by the expert ($P\_FLEX\_HARBOUR_p$).

Table 5 shows the results of the discount regressions at the plant level. Columns 1 and 2 show the effect of the original measure of demonstrated mix flexibility on plant level average incentives. Column 1 does not include plant fixed effects and is included just for reference purposes. Column 2 does include plant fixed effects, and it shows an impact of flexibility on average discounts of -232.2 USD, largely consistent with the results found at the model level.

As discussed above, one of the potential shortcomings of our demonstrated flexibility measure is the fact that it is based on what the plants choose to product, rather than what the plants can produce. For example, we have noticed that in some (infrequent) cases a flexible plant produces only one model during a short period of time. In order to address this, we have redefined our mix flexibility measure as the maximum historical mix flexibility for the plant ($P\_FLEX\_RECORD_{pt}$). Columns 3 and 4 of Table 5 use this measure and the estimates are remarkably similar, suggesting that this potential limitation is not affecting the results. We have also used the maximum flexibility observed over at the plant the last n months (with $n = 3$ and $n = 6$), and the results remain consistent.

Another potential shortcoming of our measure is that we do not have production data at the line level but at the plant level. However, having multiple platforms produced in independent lines of the same plant is not much different from having independent plants, and our measure based on the demonstrated ability to produce multiple platforms in the same plant might be overestimating the actual flexibility potential in some cases. The subjective expert assessment of flexibility that we introduced in Section 4 addresses this potential issue. Columns 5 and 6 use the subjective assessment of flexibility, $P\_FLEX\_HARBOUR_p$, and the estimates of the impact of flexibility on discounts are again negative and significant. Note that the magnitude of the effect is not directly comparable to the results shown in Section 6 because the flexibility variable is not binary, and the analysis is restricted to the points in time where the subjective assessment is available.

Besides the analysis using alternative definitions of flexibility at the plant level, we also conduct transformations of the original flexibility measure at the model level. From now on, we focus on models that have at least some domestic production, so that we can put our results in perspective with our plant level analysis, for which only North American plants are available.

Columns 1 and 2 of Table 6 use lagged versions of the flexibility variable, since one could argue that the flexibility might not affect discounts immediately. Again, we find remarkably similar estimates for the effect of flexibility on discounts.

We also explore the impact of transformations of our dependent variable, the average discounts given for a model in a month. We have chosen to report the main analysis using the level of discounts, as opposed to the logs, because this allows for a more intuitive interpretation of the magnitude of the effect as dollar savings in discounts. However, our hypothesis is still supported if we use a logarithmic transformation (Table 6, Column 3) or a relative measure of discounts, such as the percentage discount from the list price (Table 6, Column 4).

Endogeneity Concern: Instrumental Variable Approach

Despite our extensive set of controls and the use of model fixed effects, the OLS specification estimated in Table 3 can still suffer from an endogenous vehicle-to-flexibility assignment as described in Section 5. In order to evaluate the importance of any remaining source of flexibility endogeneity, we use instrumental variables (IV). A good instrumental variable for the flexibility with which a 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 make as an instrument for the flexibility 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.

Columns 5 and 6 of Table 6 show the estimates when we use the average flexibility of the rest of the models of the same make as an instrument for flexibility and then estimate the 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. Our preferred specification is the one in Column 6, which includes all the control variables, besides the model fixed effects and the segment-time dummies. This column suggests an effect of -699 USD of mix flexibility on discounts. The rest of coefficients of the control variables remain largely unchanged.

As we have shown, both the OLS and the 2SLS results show support for H1. In other words, the adoption of flexibility is clearly associated with a reduction of discounts. Note that the point estimates that quantify the average effect of flexibility on discounts change significantly in the IV model, compared to the OLS estimates. We might wonder whether we can take at face value the magnitude of the flexibility coefficient in the 2SLS estimation. While the Durbin-Wu-Hausman test allows us to reject the hypothesis that the flexibility is exogenous (e.g. p=0.00215 for the specification shown in Column 6), we have to acknowledge that our instrument might have problems related to the violation of the two conditions, instrument exogeneity and relevance. The IV model assumes that the discounts given for a model are not affected by the flexibility of the other plants. This instrument exogeneity condition is not testable in our case, because we only have one instrument. We are thus in the just-identified case. If the relevance condition is satisfied only weakly, it is well known that instrumental variables can have a substantial small sample bias (for example, see Angrist and Pischke 2008). The instrument is correlated with the endogenous variable and the first stage for Column 6 has an adjusted R-squared of 0.753, but the Partial R-squared is 0.06, which seems somewhat low, suggesting that we should be cautious because we might have a weak instrument. Another potential problem could be that the instrument might affect a particular subpopulation more significantly, and it also might be picking up additional effects, such us portfolio effects that might or might not be related to flexibility.

Altogether, these potential problems with the instruments suggest that we should not take the 2SLS estimates at face value. But this does not mean that they are useless. The results of the instrumental variable estimation suggest that our OLS estimation, if biased, is probably biased upwards, and that the effect of flexibility on discounts is stronger than the effect estimated by OLS. Thus, we can consider our OLS results as a lower bound on the effect of flexibility.

Actually, the modeling literature can offer some guidance in interpreting our findings and in understanding in what direction our OLS estimates are likely to be biased. Demand uncertainty has been identified as one of the key drivers of flexibility adoption (Fine and Freund 1990, Swaminathan and Lee 2003). We can argue what the likely direction of the bias would be if flexibility is endogenously adopted as a response to increased expected uncertainty for the demand of one model. 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 will probably result in higher average discounts. To see that, note that 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. Since the upward price increases are capped by the list price, we expect the average effect to result in higher discounts. If the flexibility adoption 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. Therefore the OLS coefficient of flexibility would be biased upwards. This is consistent with the results that we find with our instrumental variable specification.

We have also used variations of the instrument (for example, excluding models that are manufactured in the same plant as the model of interest in the calculation of the average flexibility) without substantial changes in the results.

In summary, our results indicate that, under the observed market conditions between 2002 and 2009, flexibility accounts for average savings in discounts of between \$200 and \$700 per vehicle.

8. Alternative Explanations

Having established support for our hypotheses, our preferred interpretation of the results is that flexibility allows to better match supply with demand, and therefore it allows to decrease supply-demand mismatches that result in discounts (H1) and to achieve a better utilization of resources (H2). There are alternative explanations to the obtained results, which we discuss here. The alternative explanations that we examine are related to the evolution of list prices, the role of inventories, and the increase of production costs after the deployment of flexibility.

Evolution of list prices

While our analysis has focused on short run pricing behavior given by discounts, this behavior has to be examined in the context of the rest of pricing decisions that the firm makes, and in particular with the setting of MSRP. 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, it could well be that the net effect of flexibility on prices is 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 after the deployment of flexibility. In order to test how flexibility affects list prices, we propose the following specification:

$$MSRP_{it} = \mu_i + \beta_1 FLEX_{it} + CONTROLS_{it} + \gamma_{st} + u_{it} \tag{4}$$

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 $CONTROLS_{it}$ includes $DISC\_COMP$, $INTRO$, $PHASE\_OUT$, AGE, and $DESIGN\_CHNG$.

The first column of Table 7 able shows the impact of flexibility on MSRP, according to specification 4. We can reject the hypothesis that list prices are reduced after flexibility is deployed, which allows us to conclude that the net effect of flexibility on prices is positive. In other words, the savings in discounts are really savings. Actually, flexibility has a positive, statistically significant association with list prices.

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, but it only does so through inventories. It could be that flexibility affects the level of finished goods inventories (i.e., with inflexible models 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 1 to include an additional control variable, $INVENTORY_{it}$, which contains the days of supply of model i in month t:

$$DISCOUNT_{it} = \mu_i + \beta_1 FLEX_{it} + \beta_2 INVENTORY_{it} + CONTROLS_{it} + \gamma_{s(i)t} + \epsilon_{it} \quad (5)$$

Column 2 of Table 7 includes inventory and other additional controls. We observe that the value of the coefficient of flexibility almost does not change when controlling for inventory: the direct effect of flexibility on discounts is an average reduction of 214.10 per vehicle. Note that inventory is highly endogenous in the discount equations. A high level of inventory can be held in anticipation of the firm to a future positive demand shock or as a consequence of a negative contemporaneous demand shock. In Column 2 of Table 7 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, since dealer structure and the number of variants of a model are decided way before the determinants of discounts are realized. Column 3 of Table 7 reports the estimates of specification 5 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 stable around -200 (-241.80). However, now we find a positive impact of inventory on discounts. An additional day of supply is associated with an increase of 38.56 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.

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 this were the case, and customers were facing higher prices for the same vehicles, we would expect that, all the rest being equal, sales would decrease. However, observe that sales do not decrease after flexibility is deployed. Columns 4-7 of Table 7 include several specifications of the following form:

$$SALES_{it} = \mu_i + \beta_1 FLEX_{it} + CONTROLS_{it} + \gamma_{st} + u_{it} \tag{6}$$

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 be rejected (see Table 7, 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 an 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 loss 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.

9. Conclusion and Discussion

We have illustrated some of the benefits of deploying production mix flexibility. We have shown that the deployment of production flexibility is associated with savings in average discounts of between $200 and $700 per vehicle during our period of analysis, 2002-2009. We have also shown that flexibility is associated with higher plant utilization, around 6% higher on average. All the rest being equal, achieving higher utilization allows firms to reduce the fixed cost per vehicle, and therefore to increase average profits. Besides the benefits from flexibility in terms of discount avoidance and increased utilization, our analysis suggests that flexibility is associated with higher overall prices and higher sales. All these benefits come from the increased ability to match supply with demand enabled by mix flexibility.

To see the managerial importance of flexibility and the results presented in this paper, consider the following, back-on-the-envelope calculation. Ford sells about 150K vehicles per month. If, through flexibility, Ford could reduce its average discounts by the most conservative amount we estimated ($200), our model suggests incremental profits of 150K*$200=30M$ per month. This calculation does not consider how the competitive equilibrium will change as more plants are becoming flexible, but gives a sense of the order of magnitude of the potential gains, purely from discount avoidance. This does not include the benefits of higher plant utilizations and potentially increased sales (see our results of Tables 4 and 7). Of course, when evaluating the deployment of flexibility, firms have to also examine the associated costs. The costs of flexibility depend highly on the current plant and product portfolio of the firm. For newly built plants, the costs of a flexible plant and the costs of an inflexible plant are nowadays very similar. But the capital investment of a new plant is huge, and firms typically update and retool existing plants. The cost of doing that depends on the plant technology and the models that are going to be manufactured. It is therefore difficult to give a universal measure for the costs of flexibility. As a reference point, consider Ford's plans to retool its Wayne (MI) plant, which is estimated to require a $550 million investment. Rather than illustrating a cost benefit analysis for each manufacturer, we have presented our estimates of the average benefit of flexibility based on discount savings and increase utilization. Firms can combine our results and methodology with their detailed information about their cost structure and current capital equipment in order to evaluate the convenience of investing in flexibility.

As far as the implication for the academic community is concerned, we believe that the analysis that we present in this paper complements the modeling literature on flexibility and opens up several opportunities for future research. Our results give a sense of the magnitude of some phenomena that have been discussed in theoretical papers (e.g. Jordan and Graves 1995 discuss the effect of flexibility on average utilization and expected loss sales, and we quantify those benefits in the U.S. automotive industry in 2002-2009, plus we describe an additional benefit coming from discount avoidance). In the present work we have focused on the effects of mix flexibility in the automotive industry, but future research could look at the effects of other types of flexibility (e.g., volume flexibility) or the effects of flexibility in other industries (e.g., fashion, services, electric power industry).

More generally, future research can estimate the impact of other operational variables, including product variety, fuel efficiency or the timing of new product launches, on pricing behavior. Empirical models of pricing could be particularly fruitful in studying the interplay between pricing and inventory decisions. This area has been the subject of several modeling papers but there is little empirical research complementing the theoretical results.

Acknowledgments

We thank helpful comments from Robert Bray, Gerard Cachon, Santiago Gallino, Lorin Hitt, Jun Li, John Paul McDuffie, Serguei Netessine, Marcelo Olivares, the participants in the 2010 Workshop on Empirical Operations Management, and seminars at Northwestern University, Cornell University, Harvard University, Tilburg University and University of Cambridge. We thank Steve Fader (Mile One), Ron Harbour (Oliver Wyman), Glenn Mercer (International Motor Vehicle Program), Keith Robertson (Toyota), Mike Swinson and Mikhail Semeniuk (TrueCar), Deby Domby (Automotive News) and Lisa Williamson (Wards Automotive) for sharing their industry expertise in interviews with the authors and for their help with data interpretation.

References

Angrist, J.D., J.S. Pischke. 2008. *Mostly harmless econometrics: An empiricist's companion*. Princeton University Press.

Bassamboo, A., R.S. Randhawa, J.A. Van Mieghem. 2008. A little flexibility is all you need: Optimality of tailored chaining and pairing. *Preprint* .

Bassamboo, A., R.S. Randhawa, J.A. Van Mieghem. 2010. Optimal flexibility configurations in newsvendor networks: Going beyond chaining and pairing. *Management Science* **56**(8) 1285.

Bitran, G., R. Caldentey. 2003. Commissioned paper: An overview of pricing models for revenue management. *Manufacturing & Service Operations Management* **5**(3) 203–229.

Busse, M., J. Silva-Risso, F. Zettelmeyer. 2006. 1,000 cash back: The pass-through of auto manufacturer promotions. *The American Economic Review* **96**(4) 1253–1270.

Cachon, G.P., M. Olivares. 2010. Drivers of finished-goods inventory in the us automobile industry. *Management Science* **56**(1) 202.

Ceryan, O., O. Sahin, I. Duenyas. 2012. Dynamic pricing of substitutable products in the presence of capacity flexibility .

Chod, J., N. Rudi. 2005. Resource flexibility with responsive pricing. *Operations Research* 532–548.

Elmaghraby, W., P. Keskinocak. 2003. Dynamic pricing in the presence of inventory considerations: Research overview, current practices, and future directions. *Management Science* 1287–1309.

Fine, C.H., R.M. Freund. 1990. Optimal investment in product-flexible manufacturing capacity. *Management Science* 449–466.

Fisher, M., K. Ramdas, K. Ulrich. 1999. Component sharing in the management of product variety: A study of automotive braking systems. *Management Science* 297–315.

Fisher, M.L., C.D. Ittner. 1999. The impact of product variety on automobile assembly operations: Empirical evidence and simulation analysis. *Management Science* 771–786.

Gallego, G., G. Van Ryzin. 1994. Optimal dynamic pricing of inventories with stochastic demand over finite horizons. *Management science* 999–1020.

Gaur, V., M.L. Fisher, A. Raman. 2005. An econometric analysis of inventory turnover performance in retail services. *Management Science* 181–194.

Goyal, M., S. Netessine. 2007. Strategic technology choice and capacity investment under demand uncertainty. *Management Science* **53**(2) 192.

Goyal, M., S. Netessine, T. Randall. 2006. Deployment of manufacturing flexibility: An empirical analysis of the north american automotive industry. *Manufacturing & science operations management conference (INFORMS), MSOM*.

Graves, S.C., B.T. Tomlin. 2003. Process flexibility in supply chains. *Management Science* 907–919.

Gupta, S. 1988. Impact of sales promotions on when, what, and how much to buy. *Journal of Marketing Research* 342–355.

Huckman, R.S., D.E. Zinner. 2008. Does focus improve operational performance? lessons from the management of clinical trials. *Strategic Management Journal* **29**(2) 173–193.

Jordan, W.C., S.C. Graves. 1995. Principles on the benefits of manufacturing process flexibility. *Management Science* 577–594.

Kc, D.S., C. Terwiesch. 2011. The effects of focus on performance: Evidence from california hospitals. *Management Science* **57**(11) 1897.

MacDuffie, J.P., K. Sethuraman, M.L. Fisher. 1996. Product variety and manufacturing performance: evidence from the international automotive assembly plant study. *Management Science* 350–369.

Neslin, S.A. 2002. Sales promotion. *Handbook of marketing* 310–38.

Parker, R.P., A. Wirth. 1999. Manufacturing flexibility: measures and relationships. *European journal of operational research* **118**(3) 429–449.

Ramey, V.A., D. J. Vine. 2006. Declining volatility in the us automobile industry. *American Economic Review* **96**(5) 1876–89.

Sethi, A.K., S.P. Sethi. 1990. Flexibility in manufacturing: a survey. *International journal of flexible manufacturing systems* **2**(4) 289–328.

Van Mieghem, J.A. 2008. *Operations Strategy: Principles and Practice*. Dinesystems.

Van Mieghem, J.A., M. Dada. 1999. Price versus production postponement: Capacity and competition. *Management Science* 1631–1649.

10. Tables and Figures

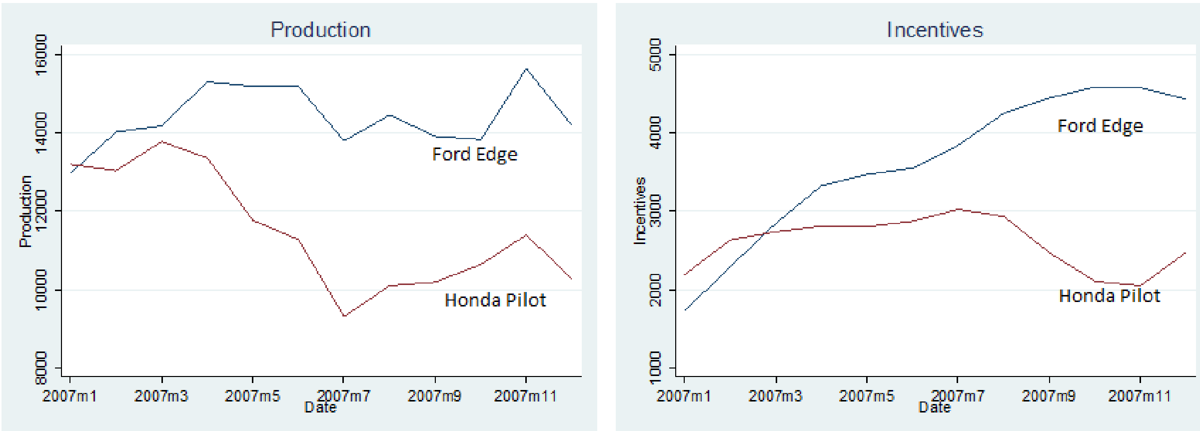

Figure 1 Production (left) and incentive (right) data for Ford Edge vs Honda Pilot

Table 1 Average Trade Incentives (2003-2009)

Company	Mean (USD)	Mean (as % of MSRP)
Porsche	809	1.10%
Honda	1,024	4.00%
Toyota	1,083	4.30%
Daimler	2,469	4.80%
BMW	2,691	5.80%
Subaru	1,470	5.80%
Volkswagen	2,041	7.30%
Nissan	2,170	8.30%
Mazda	2,040	8.60%
Hyundai Group	2,252	11.00%
Mitsubishi	2,776	12.00%
Chrysler	3,682	13.00%
Ford	3,585	13.00%
General Motors	3,587	13.00%

Table 2 Variables and Summary Statistics

Variable	Description	Mean	St.Dev.	N
$DISCOUNT_{it}$	Average incentive given for model i in month t.	2823	2080	18166
$FLEX_{it}$	Binary variable that indicates if model i is flexible in month t, according to the measure described in Section 4.	0.25	0.42	17167
$DISC\_COMP_{it}$	For every model, we compute the average incentive per car given by the competitors in models of the same segment and luxury level.	2698	956	18162
$MSRP_{it}$	Median list price of the model i, constant during the model year.	32795	13500	18166
MPD_{it}	Miles per dollar. The evolution of gas prices changes the attractiveness of some models and incentives might respond to that. We define $MPD_{it} = MPG_i/gasprice_t$.	9.42	3.41	18046
AGE_{it}	Number of years since the model was first introduced.	3.14	2.21	18166
$INTRO_{it}$	Dummy variable that is 1 in the model year when the model is introduced.	0.08	0.27	18166
$PHASE\_OUT_{it}$	Dummy variable that is 1 for observations that correspond to the last year in which a model is produced and for observations after production for the model has stopped.	0.03	0.16	18166
$DESIGN\_CHNG_{it}$	Dummy variable that is 1 when there has been a change in vehicle characteristics that might relate to changes in design with respect to the previous model year.	0.34	0.47	18166
P_FLEX_{pt}	Binary variable that indicates if plant p is flexible in month t, according to the measure described in Section 4.	0.26	0.44	7705
$P\_FLEX\_RECORD_{pt}$	Binary variable with the maximum value of P_FLEX_{pt} observed for plant p in the last n months (we report results with $n = 6$).	0.29	0.45	7705
$P\_FLEX\_HARBOUR_{pt}$	Score (between 1 and 4) that denotes the level of flexibility of a plant p in period t, obtained from the editor of the Harbour Report for two points in time (2004 and 2007).	2.03	0.91	1951
$UTIL_{pt}$	Average utilization of plant p in month t. It is calculated as the total production of the plant divided over $1/12_{th}$ of the annual capacity.	0.78	0.88	7719
$INVENTORY_{it}$	Days of supply for model i in month t. When used for a plant p, it denotes the total amount of finished units of the models manufactured in the plant.	89.67	53.94	18166
$PRODUCTION_{it}$	Amount of units of model i produced in month t.	5760	10853	18166

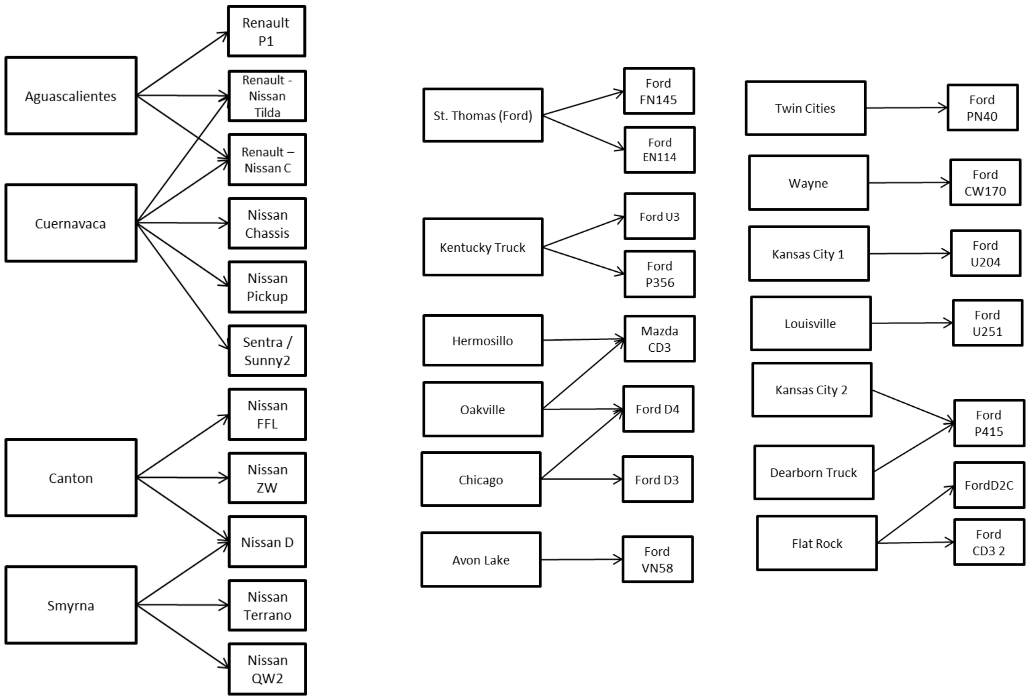

Figure 2 **Allocation of platforms to North American plants at Nissan (left) and Ford (right)**

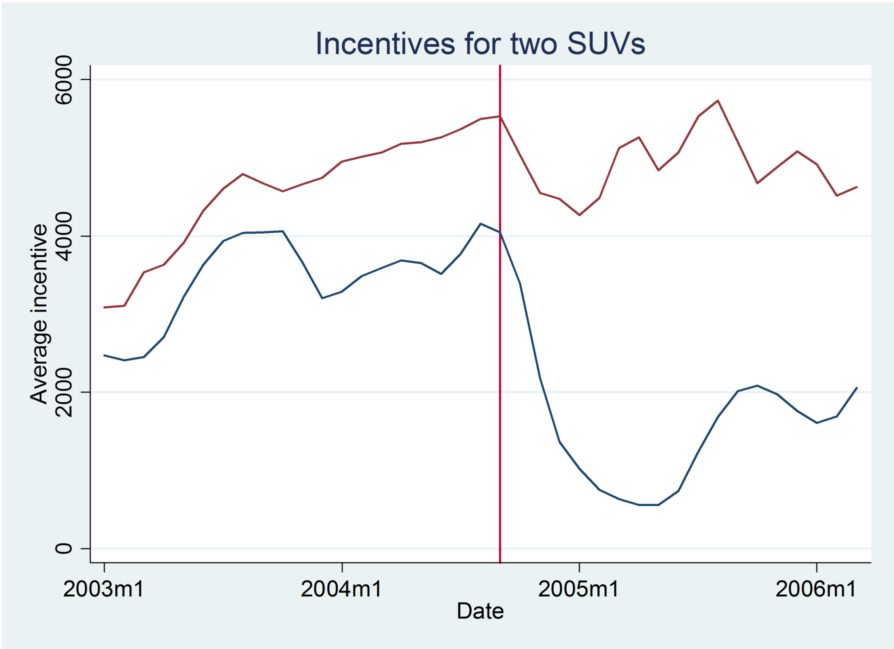

Figure 3 **Average incentive for GMC Envoy (up) and Nissan Pathfinder (down)**

Table 3 Flexibility and Incentives: Model Level Analysis

	Domestic			All Vehicles		
	(1)	(2)	(3)	(4)	(5)	(6)
$FLEX_t$	-676.9***	-202.4***	-215.5***	-196.5***	-300.5***	-293.8***
	(37.80)	(43.90)	(42.69)	(34.07)	(43.52)	(42.51)
$DISC\_COMP_t$	0.161***	0.368***	0.238***	0.154***	0.388***	0.267***
	(0.0436)	(0.0357)	(0.0341)	(0.0320)	(0.0300)	(0.0305)
MODEL FIXED EFFECTS	No	Yes	Yes	No	Yes	Yes
SEGMENT-TIME DUMMIES	Yes	Yes	Yes	Yes	Yes	Yes
ADDITIONAL CONTROLS	No	No	Yes$^+$	No	No	Yes$^+$
Observations	10,043	10,043	9,929	17,166	17,166	17,052
R-squared	0.169	0.721	0.747	0.133	0.690	0.707

Robust standard errors in parentheses. $***p < 0.01, **p < 0.05, *p < 0.1$
$^+$ indicates the following controls: $INTRO, PHASE\_OUT, AGE, MPD, MSRP, DESIGN\_CHNG$
The columns without model fixed effects [i.e., (1) and (4)] include a constant

Table 4 Flexibility and Plant Utilization

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
P_FLEX_t	0.151***	0.107***	0.0901***				
	(0.00814)	(0.0117)	(0.00908)				
$P\_FLEX\_RECORD_t$				0.0632***	0.0663***		
				(0.0117)	(0.00906)		
$P\_FLEX\_HARBOUR_t$						0.369***	0.272***
						(0.0193)	(0.0334)
PLANT FIXED EFFECTS	No	Yes	Yes	Yes	Yes	Yes	Yes
TIME CONTROLS	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ADDITIONAL CONTROLS	No	No	Yes$^+$	No	Yes$^+$	No	Yes$^+$
Observations	7,459	7,459	6,710	7,459	6,710	2,054	1,847
R-squared	0.197	0.530	0.696	0.195	0.694	0.640	0.729

Robust standard errors in parentheses. $***p < 0.01, **p < 0.05, *p < 0.1$
The column without plant fixed effects [i.e., (1)] includes a constant
$^+$ indicates the following controls: $AVGPROD, INVENTORY$

Table 5 Flexibility and Incentives: Plant Level Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
P_FLEX_t	-612.7***	-232.3***				
	(44.77)	(48.99)				
$P\_FLEX\_RECORD_t$			-629.1***	-226.3***		
			(44.17)	(47.61)		
$P\_FLEX\_HARBOUR_t$					-742.8***	-656.5***
					(33.35)	(136.9)
PLANT FIXED EFFECTS	No	Yes	No	Yes	No	Yes
TIME CONTROLS	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,427	6,427	6,427	6,427	1,801	1,801
R-squared	0.059	0.667	0.062	0.667	0.156	0.704

Robust standard errors in parentheses. $***p < 0.01, **p < 0.05, *p < 0.1$
The columns without plant fixed effects [i.e., (1), (3), (5)] include a constant

Table 6 Robustness Analysis

	DISC. (1)	DISC. (2)	L(DISC.) (3)	% DISC. (4)	2SLS DISC. (5)	2SLS DISC. (6)
$FLEX_t$			-0.0956**	-0.00450***	-576.9***	-699.0***
			(0.0414)	(0.00131)	(187.7)	(177.7)
$FLEX_{t-1}$	-214.6***					
	(42.26)					
$FLEX_{t-3}$		-225.3***				
		(41.76)				
MODEL FIXED EFFECTS	Yes	Yes	Yes	Yes	Yes	Yes
SEGMENT-TIME DUMMIES	Yes	Yes	Yes	Yes	Yes	Yes
ADDITIONAL CONTROLS	Yes^+	Yes^+	Yes^+	Yes^+	No	Yes^+
Observations	9,779	9,533	9,929	9,929	10,034	9,923
R-squared	0.750	0.757	0.557	0.687	0.719	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, $MSRP$, $DESIGN\_CHNG$

Table 7 Alternative Explanations: List Prices, Inventories and Sales

	MSRP (1)	DISC. (2)	2SLS DISC. (3)	SALES (4)	SALES (5)	SALES (6)	SALES (7)
$FLEX_t$	274.9***	-214.1***	-241.8***	495.1***	468.3***	509.7***	282.7**
	(56.78)	(42.67)	(70.55)	(136.9)	(135.6)	(135.1)	(114.5)
$INVENTORY_t$		-2.016***	38.56***				
		(0.309)	(5.839)				
$DISCOUNT_t$						0.215***	0.305***
						(0.0312)	(0.0278)
$PRODUCTION_t$							0.267***
							(0.0147)
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	10,044	9,929	9,929	10,044	9,930	9,930	9,930
R-squared	0.979	0.748	0.758	0.886	0.888	0.888	0.907

Robust standard errors in parentheses. $***p < 0.01, **p < 0.05, *p < 0.1$
$^{\#}$ indicates the following controls: $DISC\_COMP$, $INTRO$, $PHASE\_OUT$, AGE, $DESIGN\_CHNG$
$^{+}$ indicates the controls in $^{\#}$ plus the additional following controls: $MSRP$, MPD