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Why are Inventory-Sales Ratios at U.S. Auto Dealerships so High?

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Abstract

Motor vehicle dealerships in the United States tend to hold inventories equivalent to around 65 days' worth of sales, a relatively high level that has been nearly unchanged for 50 years. Despite playing a prominent role in the volatility of U.S. business cycles, very little is known about why the auto industry targets inventory stocks at such a high level. We use a panel of inventory and sales data from 41 vehicle brands over 30 years and the solutions to two well-known inventory planning problems to show that vehicle inventories appear to be related to (1) the size of dealership franchise networks, which tend to be large; (2) product variety, which tends to be high; and (3) the volatility of new vehicle sales, which also tends to be high. We show that differences across brands in these variables explain a good bit of the cross-section dispersion in brand inventory-sales ratios. Offsetting changes in these factors over time also help explain why the industry's overall inventory-sales ratio has been quite flat for many decades. More recently, the net increase observed in the inventory-sales ratio in the past couple of years is in contrast to fit of the model, which might suggest that some of that increase could reverse in the coming years.

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Fluctuations in business inventories are a well-documented source of volatility in aggregate output in the United States, and much of this pattern can be traced to the motor vehicle industry. As shown in figure 1, inventory investment for new motor vehicles can quite easily add or subtract more than half a percentage point to the quarterly growth rate of U.S. gross domestic product (GDP), and it often has much larger effects on changes in GDP around turning points in the business cycle. Indeed, motor vehicle output can single-handedly account for about one quarter of the variance of real quarterly GDP growth in the United States in the post-war period, even though motor vehicle production itself comprises only about 4 percent of GDP.[1]

One characteristic of the motor vehicle industry that likely relates to the volatility of its output is the propensity for sellers to hold high levels of inventories relative to average sales. Indeed, previous studies such as Blanchard (1983), Bresnahan and Ramey (1994), and Hall (2000) have demonstrated an important linkage between the high volatility in motor vehicle production and the industry's high finished goods inventories. Yet despite this connection, very little is known about why the motor vehicle producers and their U.S. dealerships tend to keep inventories so high relative to sales.

Since the 1960s, average inventory holdings at auto dealerships often have exceeded levels consistent with 2 months of average sales—or, as put in the industry vernacular, 65 days supply—and this ratio has changed little, on average, over the past several decades. The inventory-sales ratios observed in the motor vehicle sector are high relative to most other industries in the retail sector. The fact that it has not changed much

[1]The contribution of motor vehicles to the variance of the quarterly changes in real GDP is calculated by comparing the variance of the changes in real GDP with the variance of the changes in real GDP excluding motor vehicles; both measures are published by the Bureau of Economic Analysis (BEA).

in fifty years, we would argue, is also somewhat surprising given both the significant structural changes and technological innovations that have taken place in this industry.

To obtain additional insight into these issues, we examine brand-level data on days supply of vehicles held at auto dealerships, for which heterogeneity over time is more revealing for the industry's aggregate inventory-sales ratio. We find that the noticeable differences in the patterns of days supply among the 41 largest auto brands between 1985 and 2015 can be in large part explained by differences in (1) the size of the dealership network, which affects the volume of sales per dealership; (2) the number of models offered by each brand, which affects the volume of sales per model; and (3) the volatility of sales forecasts. The influence of these variables on inventories is consistent with the implications of two well-known inventory planning problems from the inventories and operations research literatures—the economic order quantity (EOQ) problem and the buffer-stock problem.

Our results suggest that the inventory-sales ratio in the U.S. market for light motor vehicles is high because new vehicle sales in the United States are volatile and are diffused over broad networks of franchised dealerships and across wide varieties of vehicle models. We document that dealership networks have been consolidated considerably over the years, but the inventory efficiency gains that would have resulted were largely offset by a substantial increase in product variety. In addition, we show that the factors in our inventory model can account for most of the dispersion in the inventory-sales ratios observed between brands over the past 30 years. This result contrasts with some of the conventional wisdom in the auto industry, which assumes that the dispersion in days supply across brands largely reflects different inherent levels of supply-chain efficiency.

The paper proceeds as follows: Section I documents the long-run patterns in inventory behavior from the U.S. light motor vehicle market and draws comparisons with other retail industries. In section II we review the traditional inventory planning problems and highlight the theoretical link between sales, dealership networks, product variety, and target inventory levels. Section III illustrates how these measures differ drastically between automakers in ways that are consistent with the observed dispersion in average days supply.

I. U.S. Inventory-Sales Ratios for Light Motor Vehicles

The inventory-sales ratio is often tracked by business and academic economists to forecast production and to gauge efficiency along the supply chain. For the motor vehicle industry, days supply (i.e., the month-end inventory stock divided by the average daily rate of sales) is watched closely, and the automakers often frame their production decisions as reactions to inventory imbalances signaled by undesirable levels of days supply.

Figure 2 shows days supply for U.S. light vehicle inventories from 1965 through 2015. The thin line plots the quarterly movements in days supply, and, to better highlight the long-run behavior, the one-year centered moving average is plotted as the thick line. Month-end inventories and the monthly rate of sales are reported in physical units by the automakers shortly after the end of each month.[2] While days supply has shown essentially no low-frequency trend since the early 1970s, the cyclical fluctuations in days supply have been quite large. During the 2007-2009 recession, for example, inventories swelled to a

[2] Inventories of finished motor vehicles are primarily held at new auto dealerships but also include vehicles in transit, units at assembly plants (called the factory float), and imported vehicles at U.S. ports that have cleared customs. The days supply measure shown in figure 1 includes inventory and sales data for as many market segments as are available at any given time: Data for domestic cars are available over the entire sample, while data for foreign cars begin in 1970. Data for domestic light trucks are available only after 1971, and foreign light truck data begin in 1985. The light truck market segment includes pickup trucks, sport utility vehicles (SUVs), vans, and most cross utility vehicles (CUVs). A vehicle's origin is considered *domestic* if it is produced in North America.

days supply of around 90 when sales collapsed and then moved down below 60 as sales began to recover but production remained low for some time.

Figure 3 shows an alternative measure of the inventory-sales ratio for the motor vehicle industry based on the dollar values of inventories and sales reported in Census surveys along with comparable inventory-sales ratios for other major retail industries. Two patterns are apparent in this chart: First, the inventory-sales ratio for the motor vehicle industry generally has been at the high end of the range of values observed in the retail sector. Second, in contrast to some other industries that exhibit a downward trend over the past decade or so, the inventory-sales ratio for the motor vehicle industry appears not to have any noticeable trend.

The lack of a visible long-run trend in days supply of motor vehicles is somewhat surprising given all of the changes that have occurred in the motor vehicle marketplace over the past few decades. For example, brand market shares have changed considerably, with the market share of vehicles built by the traditional domestic Detroit automakers (Chrysler, Ford and General Motors) falling from almost 75 percent in the early 1980s to about 45 percent in recent years. Such shifts in market shares could affect the industry inventory-sales ratio if automakers follow heterogeneous production and inventory policies. Firm-level data suggests this likely is the case. As shown in table 1, which reports the average days supply and market shares for the 16 largest automakers from 2000 to 2015, the Detroit automakers held inventories between 72 and 75 days of sales, while Toyota and Honda maintained a days supply closer to 40 or 50 days, and the ratio at Nissan averaged about 60 days. For the smaller firms, days supply ranged from 31 at BMW, to

85 at Volkswagen, although most of these firms maintained days supply between 45 and 70 days.[3]

Despite the heterogeneity among the automakers in average inventory patterns, market share churning does not appear to have had much effect on the industry inventory-sales ratio and may have even obscured a slight rising trend. Using an exercise outlined by Irvine (2005) and shown in figure 4, we compare the combined inventory-sales ratio for the six largest automakers (solid line) with a counter-factual version (dashed line) built from the days supply observed at each firm but aggregated with weights fixed at their 2014 averages. The counter-factual constant market share version increases slightly over this period.

Of course, the absence of a downtrend in the inventory-sales ratio does not necessarily imply that inventories in the auto industry have been unaffected by technological change. To the contrary, many examples of innovation in manufacturing have their roots in the automobile industry, such as the *just-in-time* supply chain management techniques introduced in the 1980s and discussed by Kahn, McConnell and Perez-Quiros (2003). In addition, technological improvements could indirectly affect retail inventory behavior by facilitating an increase in product variety—one of the factors we consider below.

[3] This dispersion in days supply across brands does not simply reflect the share of light trucks sold by each firm; this dispersion was also visible within each market segment. For cars, days supply averaged 40 to 50 days at the major Japanese transplants, while the averages for the traditional Detroit Three all exceeded 60 days. For light trucks, the dispersion in average days supply was even more pronounced; the Detroit Three held about 80 days of sales in inventory, and Toyota and Honda held 43 and 30 days of sales, respectively.

II. Optimal Days Supply

Inventories are expensive to hold, and goods-producing firms devote considerable resources to managing their stocks, balancing the cost and benefits of holding inventories. For example, General Motors discussed inventory costs in a series of efficiency initiatives in the 1930s, which were analyzed by Kashyap and Wilcox (1993). For large durable goods such as motor vehicles, the primary cost of holding inventories are the capital, and interest and insurance charges that are tied up in inventory stocks, which are also known as floor plan costs. The losses that might be incurred if sudden inventory liquidations become necessary are a potential cost of carrying inventories.

The primary benefit to holding inventories comes in production smoothing. Because vehicle demand is volatile and sensitive to the seasons, inventories allow automakers to handle peak demand with lower production capacity. Work schedules at the assembly plants are also costly to change, and inventories afford the automakers a means by which to satisfy volatile demand while maintaining a stable workforce and production schedule. Smooth production is more conducive to improvements in technique that eventually lead to increases in productivity.

One of the most popular models used in inventory research, the linear-quadratic (or "production smoothing") model from Holt, Modigliani, Muth and Simon (1960) captures these tradeoffs and prescribes the optimal path of production, conditional on sales.[4] A firm with linear-quadratic cost maximizes profits, shown in equation 1, subject to the constraints in equations 2 through 4.

[4] Sales are often taken as exogenous to this shorter-run cost minimization production scheduling problem, even though sales need not be exogenous to the firm's longer-run overall profit maximization problem. (See Ramey and West (1999), footnote number 14 (p. 888).

(1) $\max_{Y_t} \lim_{t \to \infty} \sum_{j=0}^{T} \beta^j \left(P_{t+j} S_{t+j} - C_{t+j}\right)$

(2) $C_t = \frac{1}{2}[\alpha_0(\Delta Y_t)^2 + \alpha_1 Y_t^2 + \alpha_2(I_{t-1} - I_t^*)^2]$

(3) $I_t^* = \alpha_3 S_t$

(4) $Y_t = S_t + I_t - I_{t-1}$

S_t is sales in period *t*, $P_t S_t$ is revenue, Y_t is production, I_t is the stock of inventories at the end of period *t*, and I_t^* is the desired size of the inventory stock.[5]

The cost function in equation 2 reflects the two broad motives for holding inventories discussed above. Marginal costs of production are rising as long as $\alpha_1 > 0$, and changes in the rate of production between periods *t - 1* and *t* lead to rising marginal cost of changing production when $\alpha_0 > 0$. Under these conditions, firms reduce cost by using inventories to smooth production.[6] The term $\alpha_2(I_{t-1} - I_t^*)^2$ embodies revenue-related motives for holding inventories, which Holt et al described as stock-out avoidance. Cost rises when inventories deviate from the target level I_t^*, which depends on the forecast for sales when $\alpha_3 > 0$.[7]

The steady state solution to equations (1) through (4), assuming exogenous sales, calls for a level of inventory equal to $I_t^* - (\alpha_1/\alpha_2) \cdot (1-\beta)/\beta$, which is the target level of inventories minus an adjustment for inter-temporal discounting. When the discount rate between adjacent periods is small, as it likely is in monthly data, then β is close to one and

[5] The cost function C_t shown here is abbreviated for notational simplicity. Linear terms and trends are excluded, and some authors have included cost shocks to help match key stylized facts in the data. (See Ramey and West (1999) for a discussion of how this cost function reasonably approximates the dynamics of more complicated cost structures.)

[6] Blanchard (1983) found that adjustment costs were more influential in motor vehicle production than were rising marginal costs.

[7] More generally, $\alpha_2(I_{t-1} - I_t^*)^2$ could be considered the second order term of a quadratic approximation to any arbitrary inventory holding cost function, and the "target" may include interest rates and other observable economic variables . This leads to a potential cost channel for monetary policy.

inventories in the steady state solution are just equal to I_t^*.[8] The inventory-sales ratio in steady state, accordingly, is simply α_3.

What governs the parameter α_3? This parameter marks the level of inventory that, conditional on sales, enables a firm to achieve the optimal balance between (1) the physical costs of carrying inventories, which increase in the level of inventories, (2) the costs of ordering new batches of product, which increase when orders are placed more often, and (3) the opportunity costs of stocking out, which decrease when inventories are larger. As we summarize below, the solutions to two well-known problems in operations research—the optimal batch-size and the buffer-stock problems—explicitly address these tradeoffs.[9] These problems also shed light on why some automakers, conditional on their product lineups and their networks of dealerships, might target a days supply that is considerably higher than what other automakers target.

A. Inventories and Optimal Batch Size

Assume that dealers order vehicles in batches of size Q and that there is no demand uncertainty for the time being. If sales arrive at the rate $\bar{S} > 0$ per period, then a dealership places $\bar{S}/Q$ orders each period and the average size of the inventory stock is $Q/2$, as shown in the upper panel of figure 5.

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[8] The adjustment due to time discounting occurs because the first-order condition equates the marginal cost of producing one additional unit today and holding it in inventory with the discounted savings from producing one less unit *next* period. Holt et al (1960) posit that planning horizons are usually short enough to set $\beta = 1$. If the discount rate is time-varying, however, this serves as a channel through which monetary policy can affect inventories.

[9] Some authors argue that inventories affect revenues in ways that are not adequately captured by these concerns alone. For example, Kahn (1987, 1992) and Bils and Kahn (2000) derive the target inventory level from non-negativity constraints on inventories, markups over marginal cost and forecast uncertainty; these factors help justify the relatively high level of inventory-sales ratios maintained in industries such as motor vehicles. Additionally, Ramey (1989) and Humphreys, Maccini and Schuh (2000) model an explicit demand for inventories as a function of relative prices, and shifts in these demand schedules are the source of the output fluctuations that result.

The optimal batch size Q^* solves the dealers' optimization problem shown in equation 5, where c_F is the fixed cost of placing an order (or a setup cost), and c_I is the cost of storing one vehicle in inventory for one period.

(5) $$\min_Q C = c_F \cdot \left(\frac{\bar{S}}{Q}\right) + c_I \cdot \left(\frac{Q}{2}\right)$$

Equation 5 is a standard economic order quantity problem, and its solution is the well-known square root rule shown in equation 6.

(6) $$Q^* = \sqrt{\frac{2c_F}{c_I} \cdot \bar{S}}$$

The number of units held in inventory, on average, equals $Q^*/2 = \sqrt{(c_F/(2c_I)) \cdot \bar{S}}$. For a given pace of sales, a firm with lower setup costs, which proxy for the administrative costs of managing inventories, places smaller but more frequent orders, as shown in the lower panel of figure 5.

B. Buffer-Stock Problem

When sales are stochastic and orders are placed in advance of sales, the supply of goods available for sale in the current period may be insufficient to satisfy potential demand. As noted by Blanchard (1983), Kahn (1987, 1992), and Bils and Kahn (2000), auto dealerships incur a backlog cost—or often lose potential sales entirely—when they sell vehicles not currently in stock. Therefore, protecting the revenue stream against stockouts requires a buffer stock of inventories.

The decision rule for buffer inventories, originally formulated by Bonini (1958), weighs the expected cost of carrying inventories from one period to the next against the expected cost of stocking out. Let potential sales in each period be given by S_t, a random variable with mean $\overline{S_t}$ and variance σ_S^2.[10] The actual end-of-period inventory stock net of any backlog, I_t, is related to expected end-of-period inventories $\overline{I_t}$ as shown in equation 7.

(7) $I_t = \overline{I_t} - (S_t - \overline{S_t})$

The firm is left with unsold inventory at the end of period *t* if S_t is less than $\overline{I_t} + \overline{S_t}$; a stockout occurs if S_t exceeds $\overline{I_t} + \overline{S_t}$.

The firm minimizes the sum of expected carry-over and stockout costs, as shown in equation 8, where c_I is the cost of carrying one unit of inventory into the next period, c_d is the opportunity cost to the dealer per unit lost in the event of a stockout, and $f(S)$ is the probability distribution for sales.

(8) $\min_{\overline{I_t}} \left[c_I \int_0^{\overline{I_t}+\overline{S_t}} (\overline{I_t} + \overline{S_t} - S_t) f(S) dS + c_d \int_{\overline{I_t}+\overline{S_t}}^{\infty} (S_t - \overline{S_t} - \overline{I_t}) f(S) dS \right]$

The solution to the minimization problem in equation 8 is the level of buffer-stock inventories $\overline{I_t^*}$ that satisfies equation 9, where $F(X)$ is the cumulative density function.

(9) $1 - F\left(\overline{I_t^*} + \overline{S_t}\right) = \frac{c_I}{c_I + c_d}$

The solution to the buffer-stock problem states that inventories should be set so that the probability of a stockout equals the ratio $c_I/(c_I + c_d)$. If sales have a normal distribution, the optimal buffer stock is given by equation 10, where $N^{-1}(x)$ is the inverse of the normal cumulative distribution function:[11]

(10) $\overline{I_t^*} = -\sigma \cdot N^{-1}\left(\frac{c_I}{c_I + c_d}\right)$

The optimal buffer stock is higher when the variance of sales is higher and when the cost of stocking out is high relative to the cost of carrying excess inventories.

[10] $\overline{S_t}$ might vary over time due to trends in sales or to seasonal fluctuations.
[11] $N(t) = \int_{-\infty}^{t} (2\pi)^{-1/2} \cdot e^{-x^2/2} dx$

C. Implications for optimal inventory stocks

The optimal level of inventories, given sales, is determined by the optimal batch size and the buffer stock, as shown in equation 11, where ν is the variance of sales normalized by the mean of sales.[12]

$$(11)\quad I_t^* = \overline{I_t^*} + \frac{Q^*}{2} = \left[-\nu \cdot N^{-1}\left(\frac{c_I}{c_I + c_d}\right) + \sqrt{\frac{c_F}{2c_I}}\right]\sqrt{\bar{S}}$$

I_t^* is an increasing function in the square root of steady-state pace of sales, and the slope is determined by (1) the cost of holding inventory, (2) the cost of stocking out, and (3) the volatility of the forecast error for sales. In the Holt et al. (1960) linear-quadratic inventory model, this square root relationship between target inventories and expected sales is approximated as linear on the assumption that the model is used to prescribe production responses to sales fluctuations that are reasonably close to the steady-state pace of sales. While this assumption is plausible when evaluating short-term fluctuations in sales, it is less reasonable when comparing inventory levels between two periods or two firms with quite different volumes of sales.

The solutions to the batch-size and buffer-stock problems imply that the optimal inventory stock grows in proportion to the square root of sales, and so the optimal inventory-sales ratio is lower if the average pace of sales is higher. In addition, a higher inventory-sales ratio is preferred when the variance of the forecast errors of sales is higher and when the fixed costs of placing orders are higher.

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[12] This solution assumes that the inventory and back order positions at the end of each period are representative of the average positions during the month. This assumption was also made by Holt et al. (1960).

III. Sales Volumes, Dealership Networks and Product Variety

New light vehicle sales in the United States take place almost exclusively through networks of franchise dealerships. Therefore, the optimal level of inventories is primarily determined by the costs and benefits of delivering and holding inventory at dealerships.[13] As shown above, the steady-state inventory-sales relationship, motivated by the batch-size and the buffer-stock problems, depends partly on the average expected volume of sales. When viewed on a per-dealership basis, the data reveal that some brands in the United States sell a high volume of vehicles at a modest number of dealerships, while other brands maintain wide dealer networks and sell far fewer vehicles per dealership. In addition, the variety of models sold and the variance of sales also varies significantly across brands and over time.

A. Dealership Networks

The population of new car and light truck dealerships in the United States, shown in figure 6, stood at 18,000 on January 1st, 2015, according to the dealership census published by *Automotive News*. A dealership is defined as a physical location (a "rooftop") where cars and light trucks are sold. Dealerships sign franchise agreements with a particular brand of vehicles. Brands are channels through which automakers market and sell vehicles. Some automakers operate multiple brands. For example, General Motors sells its vehicles in the U.S. through four brands: Chevrolet, Buick, Cadillac, and GMC. Dealerships can carry more than one brand franchise and sometimes sell brands from more than one automaker (although this is the norm). About 55 percent of dealerships open in

[13] The *dynamics* of inventories—but not the steady-state *level* of inventories—also depend on other elements in the cost function, such as the slope of marginal production costs, and the structure of the market between a manufacturer and its franchised dealers. (See Blanchard (1983) for an inventory-relevant discussion of the manufacturer-dealer market in the U.S. auto industry.)

2015 sell domestic brands from the Detroit automakers, while 45 percent sell exclusively foreign brands.[14]

The dealership population edged up by 125 outlets between 2014 and 2015, a net change that included a loss of 32 Detroit Three dealerships and a gain of 157 foreign-brand dealerships. But more generally, the population of dealerships has been declining for the past several decades, bottoming out in 2011 and increasing only slightly since then. All told, the population of dealerships in 2015 is less than 40 percent of its size in 1949, when it peaked at about 49,000 establishments.

The drop in the U.S. dealership population partly reflected a good bit of industry consolidation during the early post-War years, when a number of domestic auto producers exited the market.[15] Demographic changes after World War II, including urbanization and the growth of suburbs, also favored larger dealerships over neighborhood and small-town dealerships. Competition intensified in later decades as the new auto market matured, a move that has transformed the business of selling cars from one of relatively small boutique dealerships into one of larger and better-capitalized dealerships.

The consolidation of dealerships was led by the Detroit automakers, as shown by the shrinking blue area in figure 6. More recently, Detroit brand dealerships declined notably in 2011, when these firms closed some of their brands, and General Motors and Chrysler terminated some of their franchise agreements while in bankruptcy. Meanwhile, the number of dealerships exclusively selling import brands, represented by the red area in

[14] Some dealerships that sell domestic brands also sell foreign brands. The terms "foreign" and "domestic" in this context refer to the home country of the automaker and not to the location of production. Many foreign brands produce vehicles in the U.S. Fiat is not counted as a domestic brand of Chrysler, although dealerships that sell Chrysler and Fiat vehicles are counted in the population of domestic brand outlets.

[15] The domestic brands that exited the market during the 1950s include Nash, Hudson, Studebaker, Willys-Overland, Kaiser-Frazer, Crosley, DeSoto and Edsel.

the chart, has grown steadily ever since *Automotive News* began tracking these establishments in 1957.

Dealership consolidation has led to a secular rise in sales per outlet over the years. As shown in figure 7, the average dealership sold almost 950 new vehicles during the 2015 model year, or about 3 vehicles per selling day. Sales per dealership in 2015 were about twice as high in the 1980s and three times higher than in the 1960s. The increase for domestic brands (as shown by the thin line) was somewhat less than for the industry overall.[16]

The variance in sales per retail outlet across the different auto brands can be quite wide. Figure 8 shows average annual sales per franchise between 2000 and 2015 for the major vehicle brands. At this level of detail we divide sales by the number of franchises that carry each brand rather than by the population of dealerships.[17] For the Japanese brands Toyota, Honda and Lexus, sales per outlet during this period were well above 1,000 units per year. The domestic brand with the highest annual sales per franchise was the Ford division (Ford), with 671 units, followed by Chevrolet (GM) with 586 units. Sales at the other domestic brands ranged from 482 at Saturn (GM), to a bit under 100 units per year at Lincoln (Ford).[18] Because the Detroit automakers tend to own more brands than

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[16] Sales of import-brand vehicles per import-only dealership have increased from 303 units per year in 1967 to 1,113 units per year in 2014. The rate would be a bit lower (but increase more over time) if the unknown (but small and shrinking) population of dealerships that sell both foreign and domestic brand vehicles were included in the dealership population. We do know that about 2,300 of these dealerships existed in 2005, and *Automotive News* reported that this business model was declining in favor of brand-exclusive outlets. For the same reason, total sales per dealership for domestic-brand dealerships would be slightly higher and rise a little more slowly than the thin line in figure 7.

[17] *Automotive News* reports the population of franchises for all brands, but firm-level dealership tallies are available only for the Detroit Three firms.

[18] GM discontinued the Saturn brand in 2010. The Oldsmobile brand at General Motors and Plymouth brand at Chrysler were also discontinued during this period. Their sales per franchise averaged less than 100 units per year during the years they were open.

their competitors and may be more likely to house more than one franchise at each dealership, we also calculated sales per dealership for these firms and included the results in figure 8. As shown by the light-colored bars, sales per dealership averaged 572 units per year at Chrysler, 609 units per year at GM, and 661 units per year at Ford. Among the smaller brands, sales per franchise vary widely.

Sales per franchise moved up for most (though not all) brands between 1980 and 2015, though the increases were quite uneven. For example, sales per franchise more than doubled for Honda, Toyota and Ford outlets, while sales per franchise at Chevrolet and Nissan increased much more modestly. For brands such as Buick, Hyundai and Mitsubishi, sales per franchise has declined on net.[19]

B. Product Variety

Product variety affects target inventory-sales ratios through at least two channels: First, as noted by Bils and Kahn (2000), if a good is available in an assortment of various sizes, colors and models, then a larger inventory with a wider offering of products is more likely to match consumers' preferences. In the linear-quadratic inventory planning model, where product variety is not explicitly included, the effect of product variety on optimal inventories is embedded in the parameter α_3, which determines the steady-state inventory-sales ratio. Second, if product variety is greater, then sales per product-type are likely lower. From an operational standpoint, product variety divides the firm's production-planning problem into several smaller (though not necessarily independent)

[19] For Hyundai, this statement pertains to sales per dealership between 1986, when the brand begun selling in the U.S., and 2014.

model-level problems and therefore affects the optimal inventory-sales ratio through the effect it has on the model-level batch-size and buffer-stock solutions.

One way to measure product variety in the auto industry is to count the number of different vehicle models each brand sells simultaneously. While model counts do not capture all dimensions of product variety, this is the level of product differentiation at which dealerships most likely plan their inventories.[20] This is true, in part, because nameplates on vehicles are not mutable after they arrive at the dealership, despite the fact that some models are built on common chassis at assembly plants using flexible production technology. Dealerships may also try to stock each model in a variety of available trims, such as engine size, body type, color, and other options, but it is often not possibly to accommodate all of these dimensions of the product space.

As shown in figure 9, automakers sold 293 different vehicle model lines in the U.S. in the 2015 model year. Product variety has risen about 75 percent since the 1980 model year, when 163 models were offered. The number of models sold by the Detroit brands—shown as the bottom area in Figure 9—increased by 37 models, on net, from 1980 to 2006, when their product variety peaked, and then fell by 48 by 2015. The major Japanese automakers—shown in the middle area—expanded their product variety by more than fourfold between 1980 and 2015 (adding 63 models), and the other firms more than doubled their variety (adding 78 models).

[20] Some dimensions to product variety that are not well captured by counting models. For example, product differentiation exists even within models—this is often called the *trim level*. Differentiation at the trim level covers product attributes such as engine size, power train, and major options packages. Paint color and other cosmetic choices add even more dimensions to product variety, and, as emphasized by Corrado, Dunn, and Otoo (2006), dealerships often hold and sell multiple model years of the same newly-produced vehicle at the same time.

The average auto brand offered about seven different models per year between 2000 and 2015. However, as shown in figure 10, the dispersion in product variety across brands is quite wide. Chevrolet and Toyota offered around 18 models each, while the specialty brands of major automakers and the smaller import brands tended to offer far fewer models.

IV. The Empirical Relationship between Inventories, Sales, Franchise Networks, and Product Variety across Brands and Time

The considerable heterogeneity in franchise networks and product variety documented above implies that sales per model per franchise can be quite different across brands and over time. In this section we show that a good bit of the heterogeneity observed over time in the brand-level inventory-sales relationships is consistent with these differences.

To measure the historical relationship between brand target inventory levels and the determinants discussed above, we estimate the regression in equation 12.

$$(12) \quad \Delta \ln(I_{i,t}) = C + \beta_1 \Delta \ln(Sales_{i,t-1}) + \beta_2 \Delta \ln(Fran_{i,t}) + \beta_3 \Delta \ln(Models_{i,t}) + \beta_4 \Delta \sigma_{i,t-1}^{Sales} + \beta_5 \Delta ImpShr_{i,t-1} + \delta_t + \varepsilon_{i,t}$$

Equation 12 is a reduced-form log-linear version of the target inventory-sales relationship derived in equation 11. It posits that the average level of inventories for brand *i* during model year *t* is a function of its sales, the volatility of its sales, the size of its retail network, the number of models it offers, and the share of its sales comprised of imported vehicles.

The data used to estimate equation 12 cover 41 vehicle brands sold in the United States between the 1986 and 2015 model years. $I_{i,t}$ is the average month-end inventory stock for brand *i* in model year *t*, and $Sales_{i,t-1}$ is the average monthly pace of sales in the preceding model year, which we use to proxy expectation of sales in the current model year.[21] $Fran_{i,t}$ is the number of retail outlets brand *i* has on January 1st of model year *t*, and $Models_{i,t}$ is the count of different vehicle models offered by brand *i* with sales of at least 1,200 units in model year *t* (or at least 100 per month).[22] The variable $\sigma_{i,t}^{Sales}$ is the standard deviation of the residuals from a simple first-order autoregressive sales forecasting model for brand *i* in model year *t*, and $Impshr_{i,t}$ is the share of U.S. sales sourced by imported vehicles.[23] Finally, δ_t captures time fixed effects, and $\varepsilon_{i,t}$ is the error term for brand *i* in model year *t*.

The parameters in equation 12 are estimated with OLS using fixed weights based on each brand's average market share over the 1986 – 2015 sample period. Equation 12 is estimated in first differences to ensure that the error terms were stationary. For brands that entered or exited the market during the sample period, we exclude from the estimation the first or last year of data, as inventories at these times are more likely quite far from target levels.

The time fixed effects capture unobserved factors that vary over time but are the same for all brands, such as interest rates, cost shocks to the auto industry, and changes in overall vehicle sales. We tried but did not ultimately include brand fixed effects in the

[21] The model year begins in October of the preceding calendar year and ends in following September.

[22] Using the 1,200 threshold trims from the data vehicle models that are sold at volumes likely too low to be stocked by very many dealerships or noticeably affect brand inventory patterns. These trimmed models were often models that had been discontinued at the end of the preceding model.

[23] Vehicles produced in Canada and Mexico are classified as domestic. To estimate the standard deviation of sales forecast errors, we regress monthly log sales for brand *i* on a time trend, one lag of its own log sales, and one lag of aggregate log sales. We calculate the 3-year rolling standard deviation of the residuals from this regression after trimming the top and bottom 10th percentiles of the observations from the sample to reduce the influence of isolated spikes in sales.

specification of equation 12, as these terms were not jointly statistically different from zero.[24]

The parameter estimates are shown in table 2. Columns 1 through 6 show parameter estimates as right-hand side variables are consecutively added to the regression. (In columns 2 and 3 franchise and model counts are added separately to the equation.) The parameter estimates suggest that the relationship between target inventories and sales, which in this model is the log-linear expression in equation 13, is increasing in the level of sales, the number of models a brand offers, the number of franchises it supplies, and the expected volatility of its sales.

(13) $IS_{i,t} = \ln(I_{i,t}) - \hat{\beta}_1 \cdot \ln(Sales_{i,t-1})$

The coefficients on the count of franchises, the number of models, and the volatility of sales are significantly different from zero with greater than 95 percent confidence, and the estimates are not very sensitive to the presence of other variables in the model. The effect on inventories of sourcing vehicles from abroad was not precisely estimated, but the point estimate suggests that a higher import share raises target inventories.

The parameter estimates are qualitatively consistent with the solutions to the batch-size and buffer-stock inventory problems presented earlier: A higher concentration of sales among models and dealerships generally leads to lower inventories, while brands with more volatile sales shocks hold higher inventories, all else equal.

Next, we examine more closely the quantitative implications of the parameter estimates. The economic order quantity inventory model, if applied to sales on a per

[24] The differences between brands in the inventory-sales relationship modeled in equation 12 appear to be relatively constant over time, possibly reflecting differences in management style and stock-out costs. In log differences, these brand fixed level effects are indistinguishable from zero.

franchise per model basis, dictates that β_2 should equal β_3, β_1 should equal $1-\beta_2$ and also $1-\beta_3$. One of these restrictions is satisfied by the point estimates: A Wald test does not reject the equality of β_1 and $1-\beta_2$ at the 5 percent level. Wald tests do reject the equality of β_2 with β_3, and of β_1 with $1-\beta_3$, however.[25] These rejections suggest that the aspects of product variety relevant for inventory planning are not perfectly measured by counting models. It is also possible that inventory decisions are not made strictly independently for each model and each franchise.

Nonetheless, variation across brands and over time in the sales volumes, franchise networks, product variety, and the other explanatory variables appears to explain a good bit of the dispersion in the brand-level inventories-sales relationships, $IS_{i,t}$. To quantify how much of the cross-section variation in these relationships is accounted for by the explanatory variables in equation 12, we calculate the cross-section variance of the inventory-sales relationships, as shown in equation 14, which is taken from a similar exercise in Bresnahan and Ramey (1993).

$$(14) \quad V_t^{IS} = \sum_i \frac{I_{i,t}}{I_t^{Agg}} \left(IS_{i,t} - IS_t^{Ave} \right)^2$$

$I_{i,t}$ is the inventory stock in period t for brand i, I_t^{Agg} is the aggregate inventory stock, $IS_{i,t}$ is the inventory-sales relationship defined in equation 13, and IS_t^{Ave} is the industry average inventory-sales relationship in year t, which is plotted as the solid line in figure 11.

Using the definition of variance in equation 14, the red dashed lines in figure 11 outline the area around the industry average that includes the middle 95 percent of brand inventory-sales relationships in each model year. The width between these lines—labeled

[25] The F statistic on the test of $\beta_1 = 1 - \beta_2$ is $F(1,910) = 1.17$ with a significance of 28 percent. The F statistic on the test of $\beta_2 = \beta_3$ is $F(1,910) = 4.16$ with a significance of 4 percent. The F statistic on the test of $\beta_1 = 1 - \beta_3$ is $F(1,910) = 4.88$ with a significance of 3 percent.

in the figure as the unconditional dispersion—is quite large, consistent with the wide dispersion in average days supply across brands shown in table 1. On the log point scale used to define the inventory-sales relationship in the model, the bands around the aggregate inventory-sales relationship within which fall 95 percent of the brand-level relationships are ±1.1, on average, between the 1985 and 2015 model years. This dispersion is high relative to the aggregate inventory-sales relationship observed during this period of about 3.5.

A large share of the dispersion in the brand inventory-sales relationships appears to be accounted for by the variation observed in the explanatory variables included in equation 12. To see this, the grey shaded region in figure 11 marks the area that includes the middle 95 percent of brand inventory-sales relationships that would have prevailed—according to the model—if sales, franchise populations, model counts, and other explanatory variables for each brand had been equal to the industry averages in each period. These bands—labeled in the figure as the conditional dispersion—are ±0.5 on the log scale of figure 11, about half as large as the unconditional dispersion.

Stated in terms of the total variance explained, the conditional variance of the inventory-sales relationships is 25 percent as large as the unconditional variance, suggesting that the explanatory variables account for about 75 percent of the cross-section dispersion of brand inventory-sales relationships.[26]

The model can only partly explain the relatively flat inventory sales ratio that has prevailed over the past 25 years, however. Between 1986 and 2005, the fitted model is

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[26] Variance explained derived as $1-\frac{\sum_{i,t}\left(I_{i,t}/I_t^{Agg}\right)\left(IS_{i,t}-\widehat{IS_{i,t}}\right)^2}{\sum_{i,i}\left(I_{i,t}/I_t^{Agg}\right)\left(IS_{i,t}-IS_t^{Ave}\right)^2}=1-\frac{2.54}{10.05}=0.75$, where $\widehat{IS_{i,t}}$ are the fitted inventory-sales relationships implied by the estimates from equation 12 and the deviation of each brand's explanatory variables from the industry averages in each period.

relatively in line with the flat inventory-sales ratio actually observed. The effects on target inventories of the 40 percent increase in product variety observed over this period roughly offset the effects of the 13 percent decline in dealer franchises. The results since 2005, however, are more puzzling, as dealer franchises fell almost 40 percent and the count of models sold edged up only one percent. These changes, together with a modest decline in the standard deviation of light vehicle sales and a nearly unchanged share of vehicles imported, yield a days supply target that would have declined by more than 10 days.

Although the fit of the model is likely not sufficiently good nor its variables sufficiently exogenous to conclude that target inventories have declined quite this much, it seems plausible that the dealership consolidation campaigns that took place after the 2007-09 recession could have reduced target inventory-sales ratios somewhat. In 2010 and 2011, when many of these structural changes were taking place, the inventory-sales ratio for new vehicles averaged 57 days, a level noticeably below its previous long-run average. The inventory-sales ratio has slowly risen in the past couple of years, however, and averaged 63 days in 2015. The analysis in this paper suggests that some of that increase may reverse in the coming years.

V. Conclusions

Using a panel of disaggregated brand-level inventory and sales data from the U.S. auto industry, we showed that the inventory-sales ratio for light vehicles is related to the population of active retail franchises, the number of different models being offered, and the volatility of final sales. These factors are consistent with the implications of classic buffer-stock and economic order quantity problems used in inventory management. High levels of product variety and a rather large network of franchise auto dealerships are likely two reasons why inventories in the auto industry are quite high relative to sales.

We showed that product variety and franchise dealer networks have varied considerably over time and across brands and that taking these factors into account can account for about three quarters of the cross section dispersion in brand-level inventory-sales relationships between the 1986 and 2015 model years. Offsetting changes in these factors also help explain why the auto industry's overall inventory-sales ratio has been quite flat for many decades, despite the innovations that have occurred in production and supply chain technologies. The model does not explain why the inventory-sales ratio has risen, on net, during the past couple of years, despite the consolidation in retail franchises that took place around the 2007-09 recession. It is possible that some of that increase may reverse in the coming years.

Work Cited

Bils, Mark and James A. Kahn. "What Inventory Behavior Tells us about Business Cycles." *American Economic Review*, 90(3), June 2000, pp. 458—481.

Blanchard, Olivier J. "The Production and Inventory Behavior of the American Automobile Industry." *The Journal of Political Economy*. 91(3), June 1983, pp. 365—400.

Bonini, Charles P. "Decision Rules for Buffer Inventories." *Management Science*, 4(4), July 1958, pp. 457—471.

Bresnahan, Timothy F. and Valerie A. Ramey. "Segment Shifts and Capacity Utilization in the U.S. Automobile Industry." *American Economic Review*, May 1993, pp. 213—218.

Corrado, Carol, Dunn, Wendy and Maria Otoo. "Incentives and prices for motor vehicles: What has been happening in recent years?" *Board of Governors of the Federal Reserve System (U.S.), Finance and Economics Discussion Series*, 2006, 2006-9.

Hall, George. "Non-convex Costs and Capital Utilization: A Study of Production Scheduling at Automobile Assembly Plants." *Journal of Monetary Economics*, June 2000, pp. 681—716.

Holt, Charles C., Modigliani, Franco, Muth, John F., and Simon, Herbert A. *Planning Production, Inventories and Workforce.* Englewood Cliffs: Prentice-Hall, 1960.

Irvine, Owen F. "Trend Breaks in U.S. Inventory to Sales Ratios." *International Journal of Production Economics*, 93-94, 2005, pp. 13—23.

Kahn, James A. "Inventories and the Volatility of Production." *American Economic Review*, 77(4), September 1987, pp. 667—679.

Kahn, James A. "Why is Production More Volatile than Sales? Theory and Evidence on the Stockout-Avoidance Motive for Inventory-Holding." *Quarterly Journal of Economics*, 107(2), May 1992, pp. 481—510.

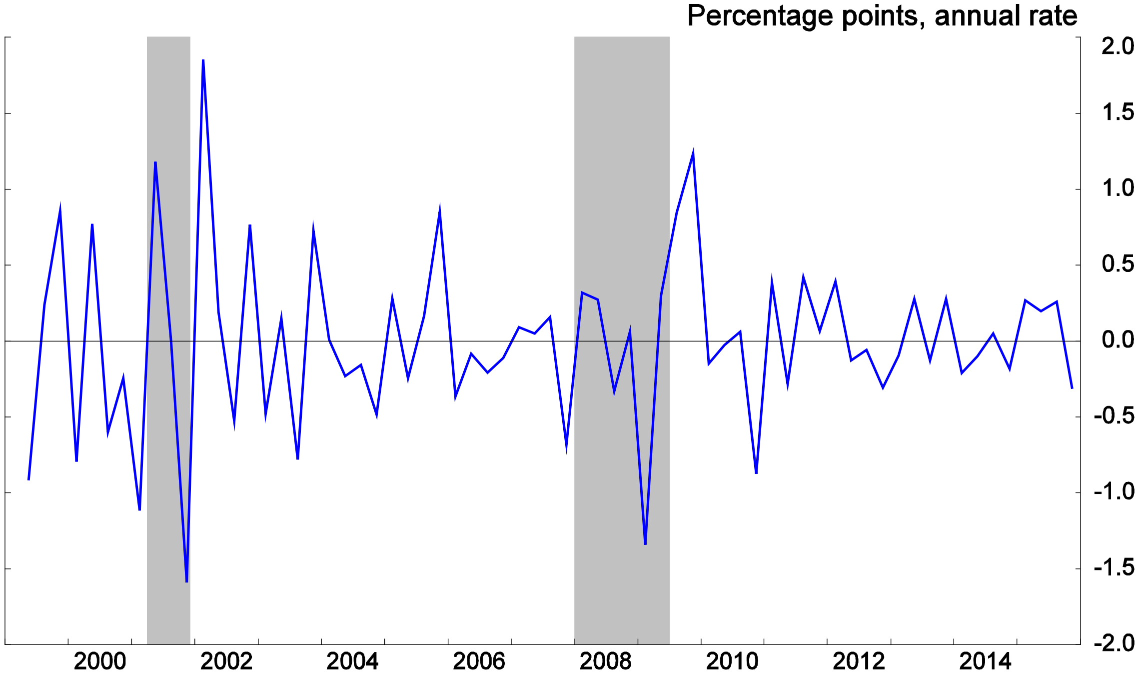
Kahn, James A. and Margaret M. McConnell and Gabriel Perez-Quiros. "On the Causes of the Increased Stability of the U.S. Economy." *Federal Reserve Bank of New York Economic Policy Review*, May 2003, pp. 183—202.

Kashyap, Anil K. and David W. Wilcox. "Production and Inventory Control at General Motors Corporation During the 1920s and 1930s." *American Economic Review*, 83(3), June 1993, pp. 383—401.

Ramey, Valerie A. and Kenneth D. West. "Inventories." in *Handbook of Macroeconomics*. eds. John D. Taylor and Michael Woodford, Elsevier Science Press, 1999.

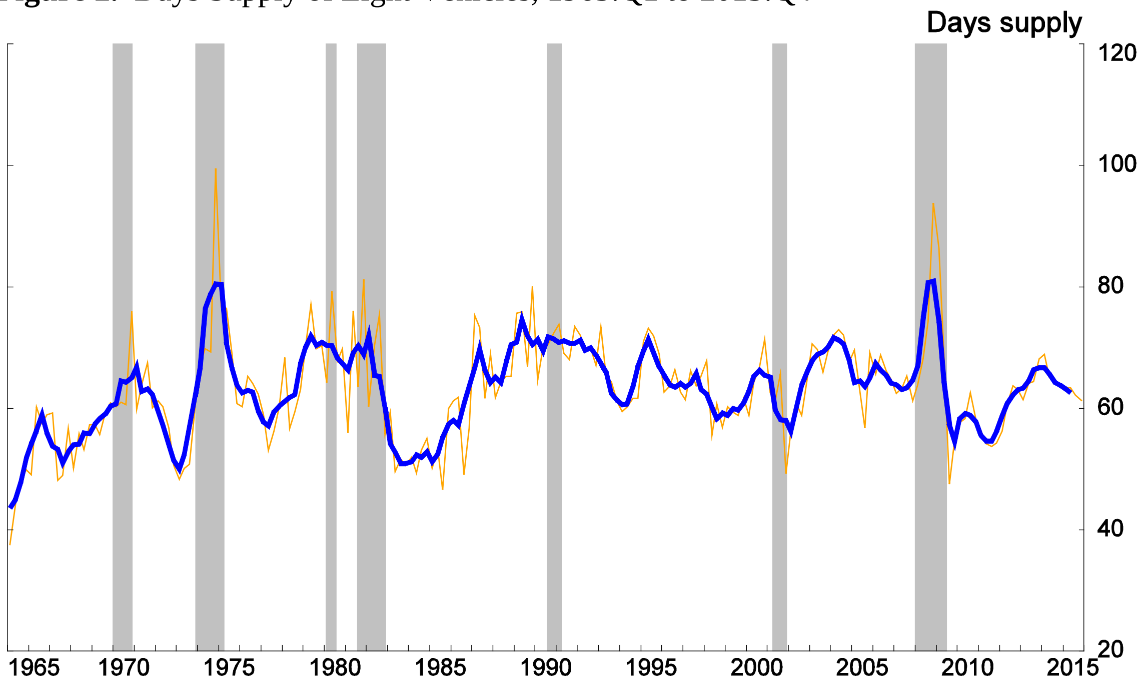
Figures and Tables

Figure 1. Contributions of Motor Vehicle Inventory Investment to Real U.S. GDP Growth, 1999:Q2 to 2015:Q4



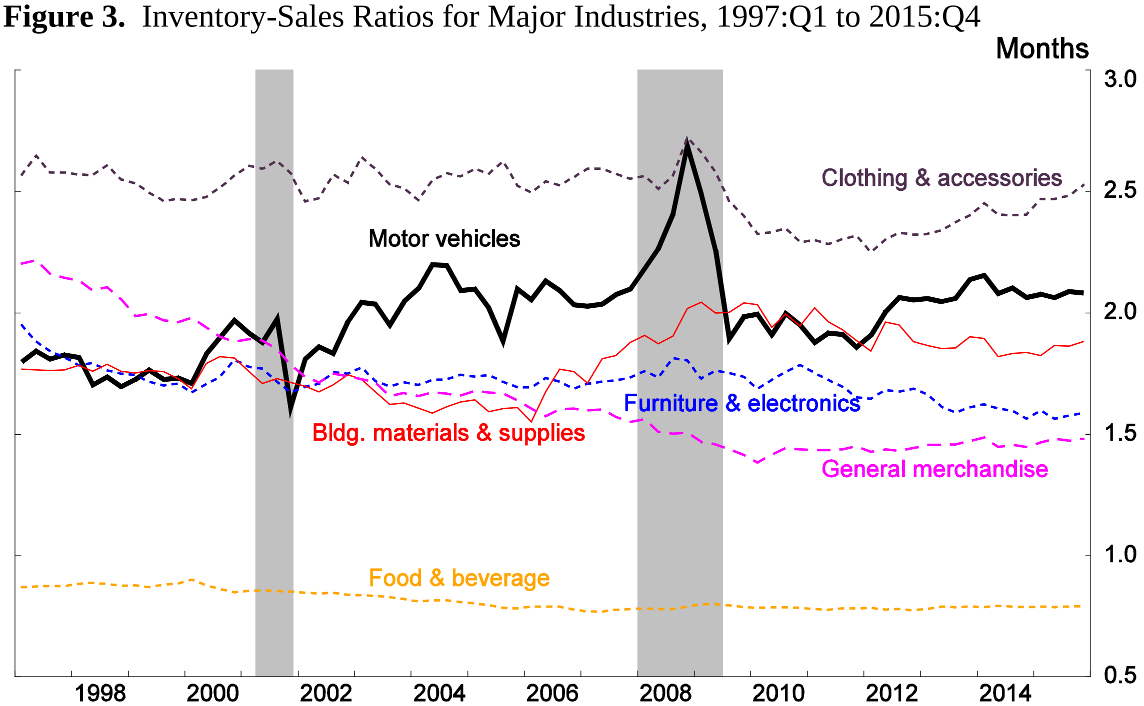
Notes. Shaded areas denote NBER recession. Source: Authors' calculation based on data from the Bureau of Economic Analysis.

Figure 2. Days Supply of Light Vehicles, 1965:Q1 to 2015:Q4



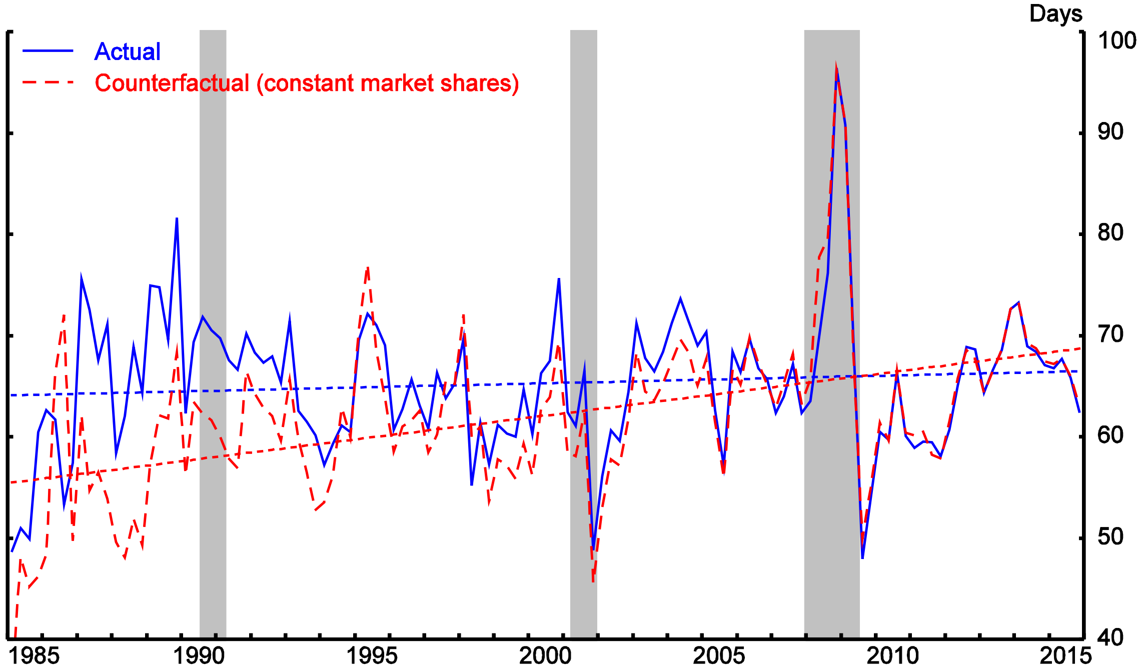
Note. Thick line is a centered 4-quarter moving average of the thin line. Days supply is calculated as the stock of vehicles in dealer inventories at the end of the quarter divided by the average pace of sales during the quarter multiplied by 307, the average number of selling days in a calendar year. Data are seasonally adjusted. Shaded areas denote NBER recession.

Figure 3. Inventory-Sales Ratios for Major Industries, 1997:Q1 to 2015:Q4



Note. Shaded areas denote NBER recession. Source: U.S. Census Bureau.

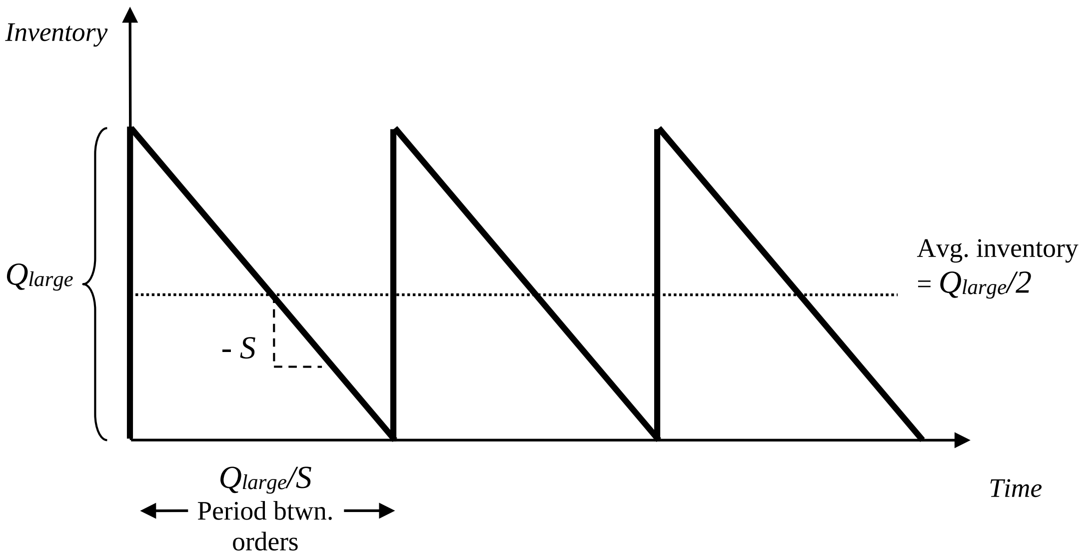
Figure 4. Days Supply at the Big Six Automakers, Actual and Counterfactual (Fixed Market Share), 1985:Q1 – 2015:Q4



Note. Counterfactual days supply is constructed by aggregating actual days supply observed by vehicle type (cars and light trucks) and firm using fixed 2014 average market shares for each Big Six firm. The Big Six include Chrysler, Ford, GM, Toyota, Honda and Nissan. The dotted lines represent the linear time-trend of each measure of days' supply. Shaded areas denote NBER recession. Source: Authors' calucations based on data from Ward's Automotive Group. *Ward's Communication*. Ward's AutoInfoBank. http://wardsauto.com/miscellaneous/wards-autoinfobank.

Figure 5. Batch Size and Average Inventories from the Economic Order Quantity Problem

Panel A: Example with Large Batches (Q_{large})



Panel B: Example with Small Batches (Q_{small})

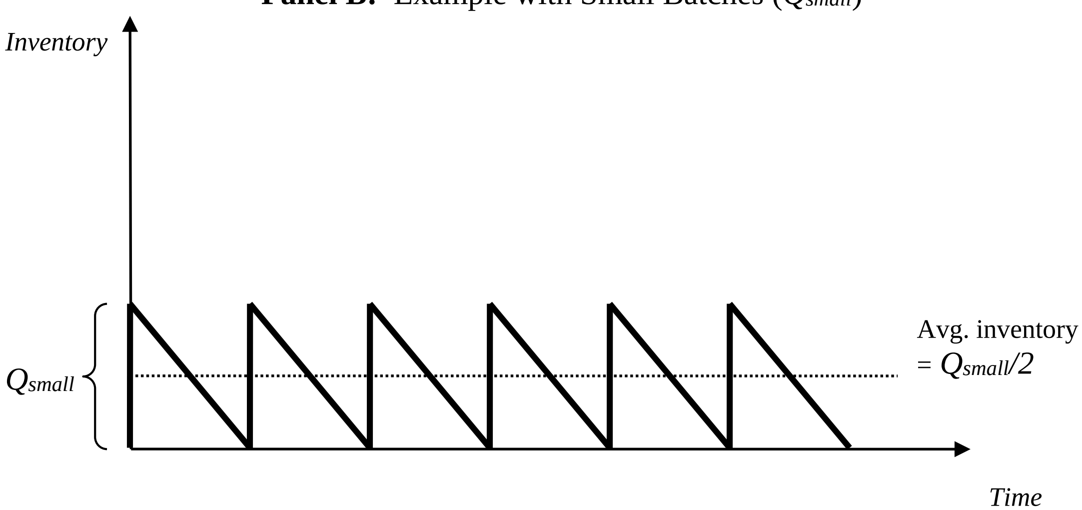
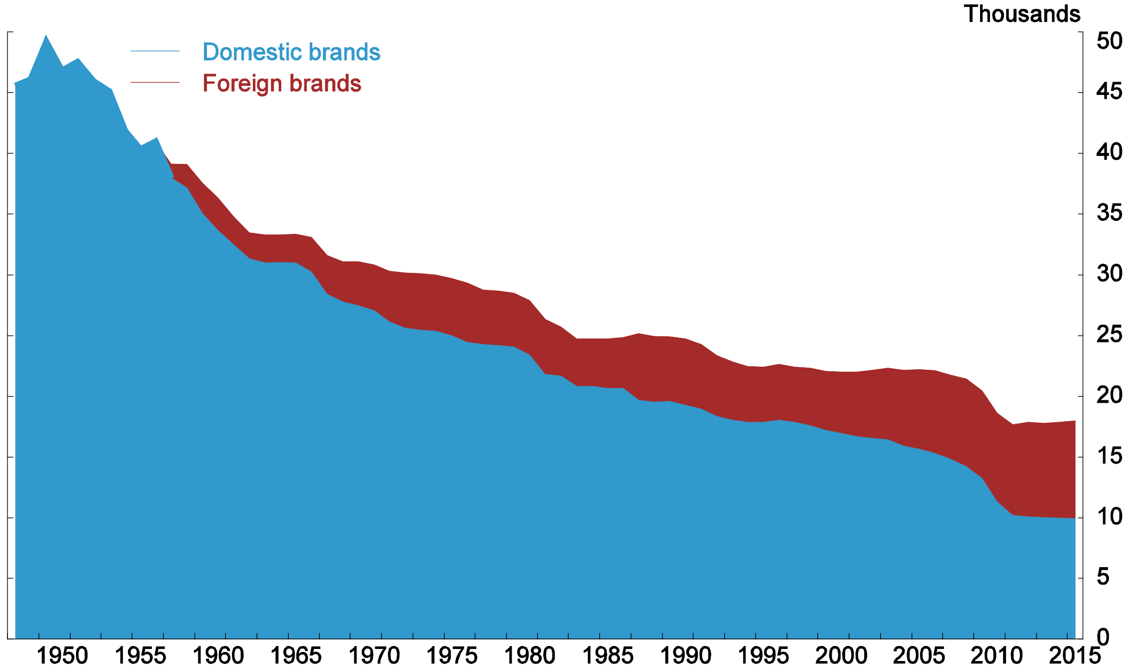
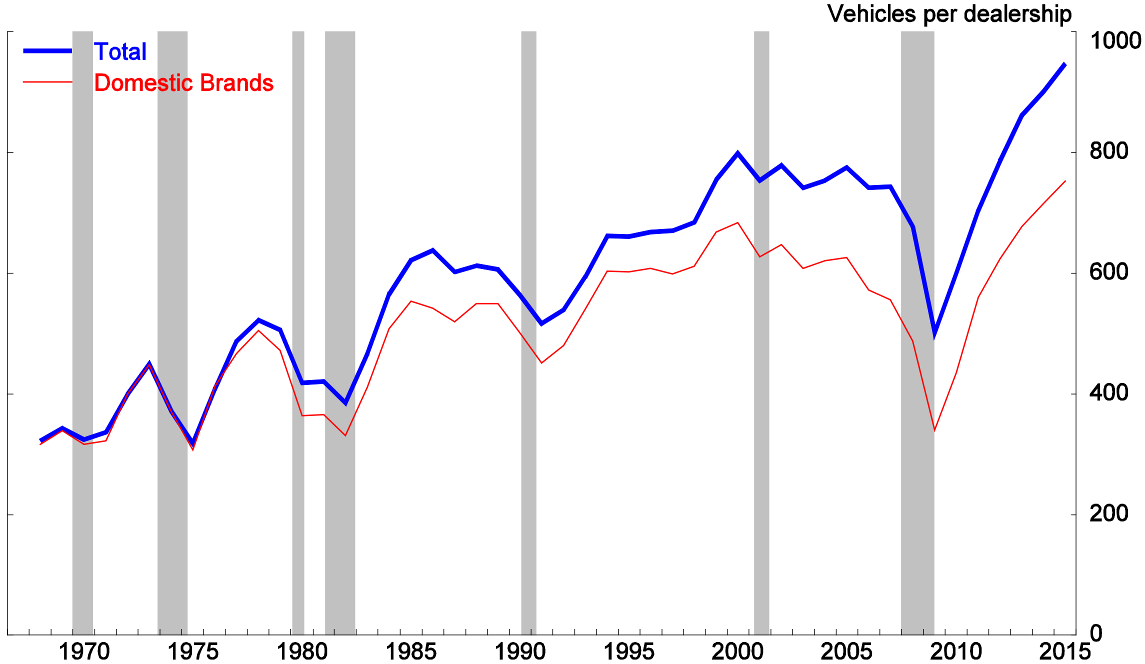


Figure 6. U.S. Population of New Car and Light Truck Dealerships, 1947 to 2015



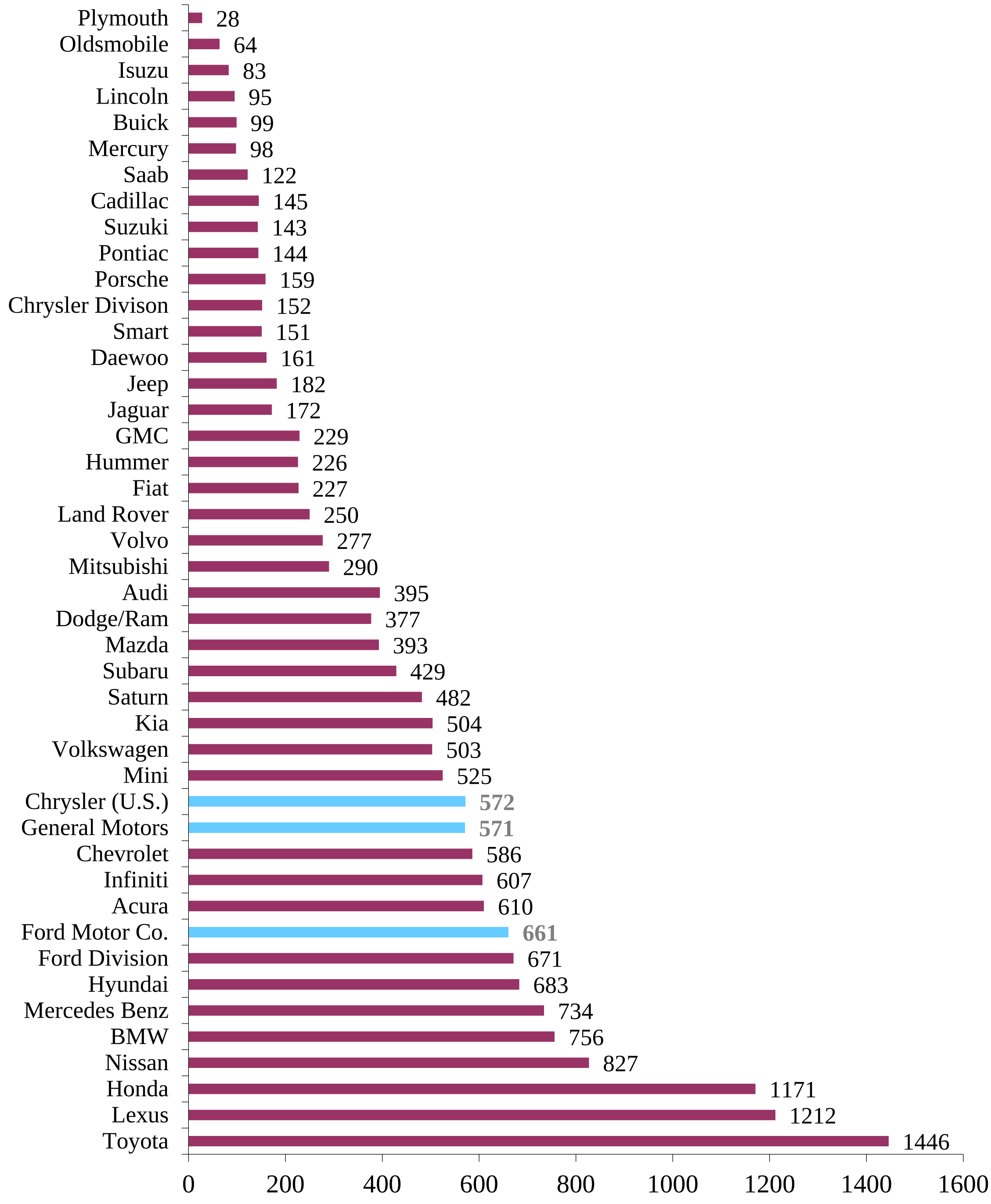
Note. Dealership population is measured on January 1st. Data on import-brand dealerships begin in 1957. Domestic brand figures include dealerships that sold domestic and foreign brand vehicles. Data prior to 1996 exclude truck-only dealerships; about 300 truck-only dealerships existed in 1996. Source: Crain Communications. *Automotive News*. Automotive News Data Center.

Figure 7. Annual New Car and Light Truck Sales per Dealership, Model Years 1968 to 2015



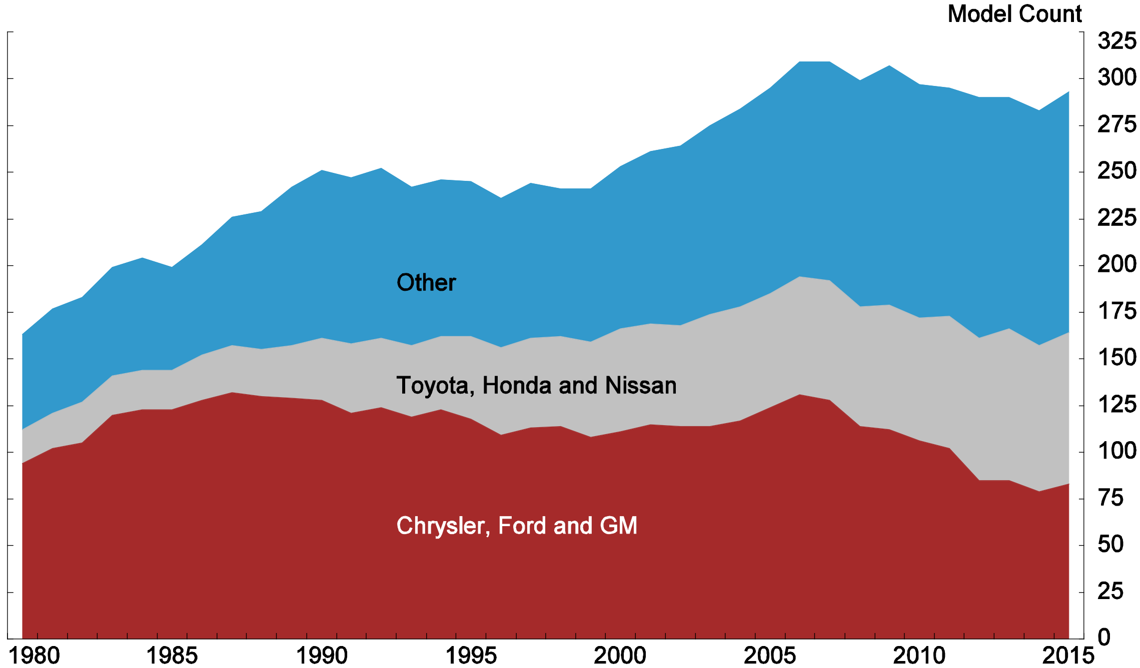
Note. Light vehicle sales divided by the number of dealerships that exist on January 1st of each year. Domestic brands (thin line) include American Motors, Chrysler, Ford, General Motors and Studebaker. Figures reflect a small discontinuity in the dealership population in 1996, when the scope was expanded to include about 300 truck-only dealerships (250 domestic-brand and 50 import-brand), adding a bit more than 1 percent to the total population. Shaded areas denote NBER recession.

Figure 8. Average Annual Sales per Franchise by Brand, Model Years 2000 to 2015



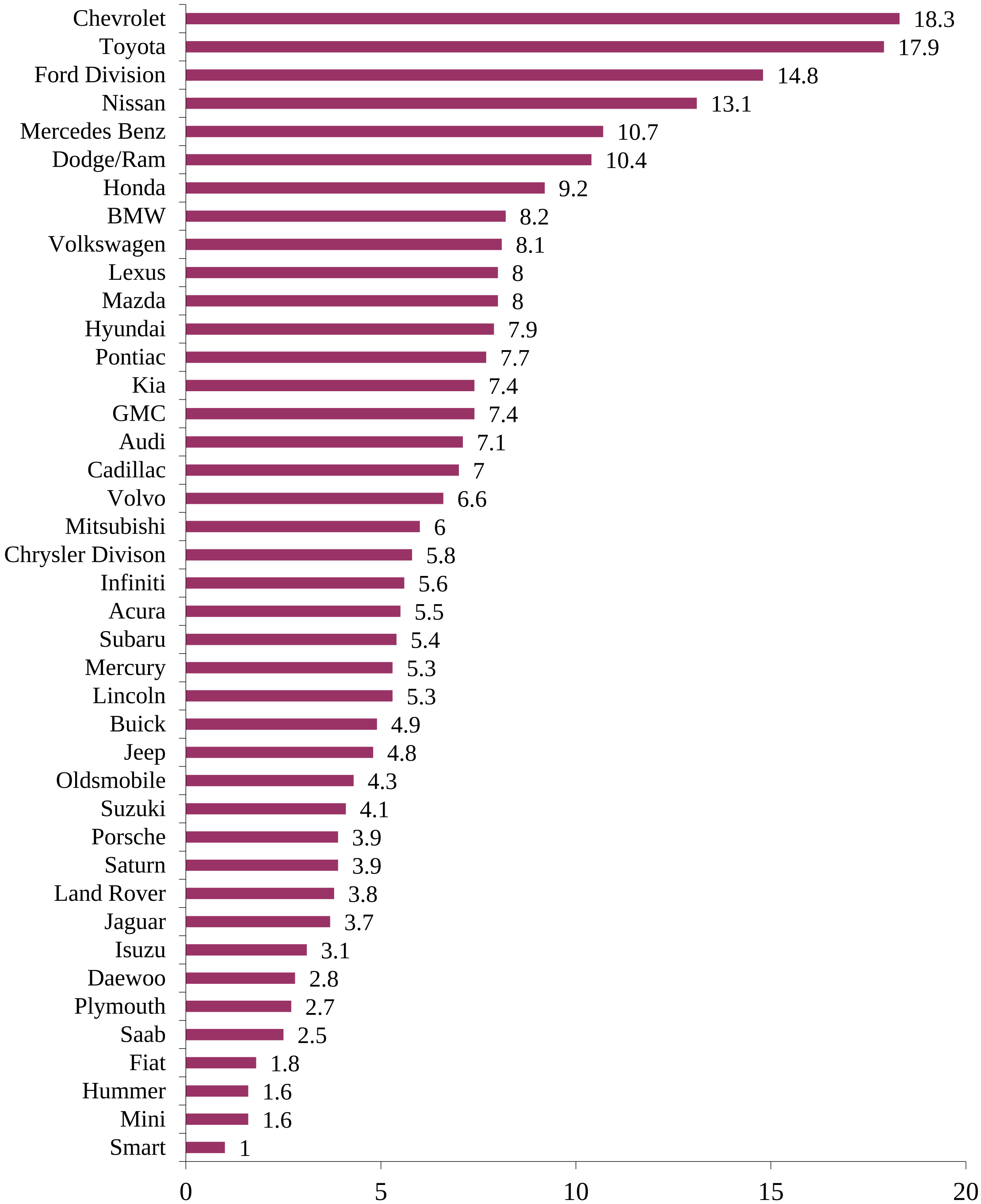
Note. Sales per franchise are annual sales divided by the number of franchises reported by each brand on January 1st of each year. For brands that open or closed during this period, the average is calculated for years during which brand exists. For the Detroit Three firms, which are more likely than other firms to host multiple franchises within a dealership, the light blue bars show sales per dealership for comparison.

Figure 9. Count of Models Sold, Model Years 1980 to 2015



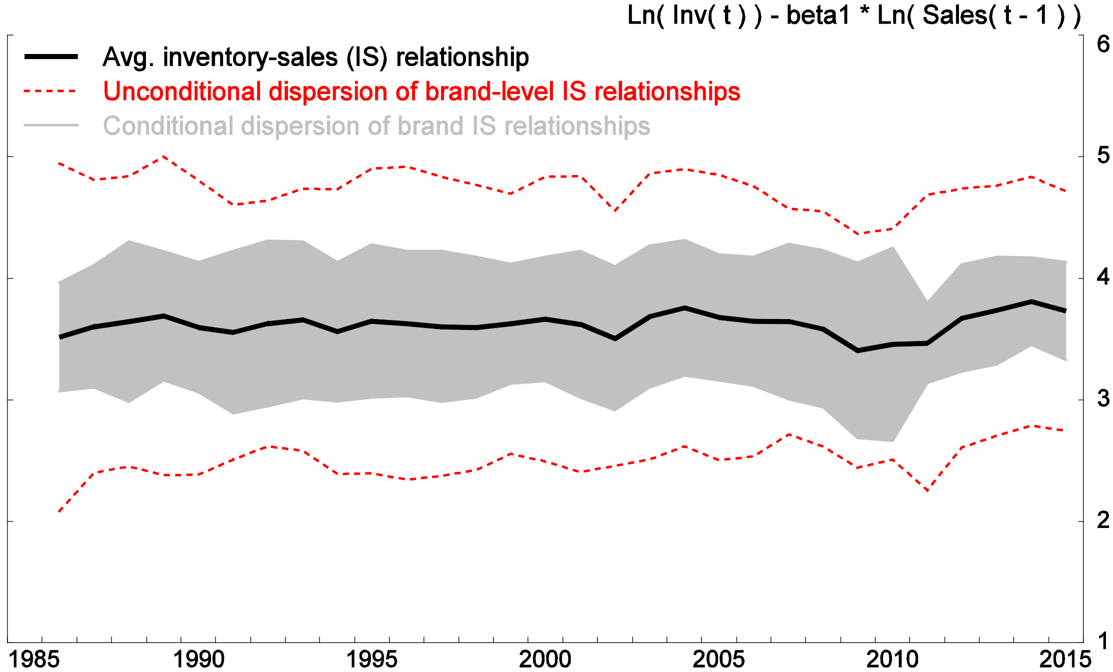
Note. Count of unique vehicle models sold during each model year (October through September).
Source: Ward's Automotive Group. *Ward's Communication*. Ward's AutoInfoBank.
http://wardsauto.com/miscellaneous/wards-autoinfobank.

Figure 10. Average Number of Models Offered by Brand, Model Years 2000 to 2015



Note: Average for each brand calculated over model years in which the brand sold vehicles in the U.S. Counts of unique models sold by brand. Excludes models with fewer than 1,200 sales per model year.
Source: Authors' calculations based on data from Ward's Automotive Group. *Ward's Communication*. Ward's AutoInfoBank. http://wardsauto.com/miscellaneous/wards-autoinfobank.

Figure 11. Unconditional and Conditional Dispersion of Inventory-Sales Relationships across Brands, Model Years 1986 to 2015



Note. The log inventory-sales (IS) relationship is defined in equation 13. The area between the red dotted lines shows +/- 2 standard deviations of the cross section dispersion of the IS relationships across brands in each year. The shaded grey area shows +/- 2 standard deviations of the cross section dispersion of the errors in the IS relationships across brands in each year, conditional on the levels observed for the independent variables in equation 12.

Table 1. Average Days Supply and Market Shares by Firm, 2000 to 2015

Firm	Days Supply	Market Share
GM	75	23
Ford	72	17
Chrysler	73	9
Toyota	45	13
Honda	51	9
Nissan	63	6
Hyundai	51	3
Kia	52	2
Volkswagen	83	2
BMW	31	2
Mazda	72	2
Subaru	44	2
Mercedes	49	2
Mitsubishi	72	1
Audi	50	1
Volvo	67	1
Suzuki	81	<1
Other	72	4
Total	**64**	**100**

Note: Average month-end inventories divided by the average monthly pace of sales (in physical units), multiplied by 25.6, the average number of selling days per month. GM, Ford, and Chrysler figures include only their domestic brands. BMW figures include Mini. Mercedes figures include Smart. Source: Authors' calculations based on data from Ward's Automotive Group. *Ward's Communication*. Ward's AutoInfoBank. http://wardsauto.com/miscellaneous/wards-autoinfobank.

Table 2. Regression Coefficient Estimates

$$\Delta \log I_{i,t} = C + \beta_1 \Delta \log(Sales_{i,t-1}) + \beta_2 \Delta \log(Fran_{i,t}) + \beta_3 \Delta \log(Models_{i,t}) + \beta_4 \Delta \sigma_{i,t-1}^{Sales} + \beta_5 \cdot \Delta ImpShr_{i,t-1} + \delta_t + \varepsilon_{i,t}$$

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
β_1 (Sales)	0.66*** (0.09)	0.59*** (0.09)	0.63*** (0.08)	0.57*** (0.09)	0.60*** (0.09)	0.60*** (0.09)
β_2 (Franchises)		0.63*** (0.21)		0.59*** (0.20)	0.58*** (0.19)	0.60*** (0.19)
β_3 (Model count)			0.19*** (0.04)	0.18*** (0.04)	0.18*** (0.04)	0.18** (0.04)
β_4 (Sales volatility)					1.40** (0.61)	1.43** (0.60)
β_5 (Import share)						0.12 (0.19)
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.39	0.40	0.41	0.42	0.42	0.42
Observations	944	944	944	944	944	944

Note: Estimated on annual data from 1986 to 2015 model years. All right-hand side variables are expressed as the log change except for the import share and sales volatility, which are expressed as changes. Sales, sales volatility, and the import share are from the preceding year, while franchises and model counts are from the current year. Robust standard errors are in parentheses.
***99 percent confidence **95 percent confidence *90 percent confidence