ELSEVIER

Japan and the World Economy 11 (1999) 57–93

Japan and the WORLD ECONOMY

# The impact of shocks to exchange rates and oil prices on U.S. sales of American and Japanese automakers

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Manuscript received February 1997; Final version received April 1998

**Abstract**

Since 1973, floating exchange rates and significant oil-price changes have coincided with dramatic market-share gains (losses) by Japanese (American) automakers in the U.S. market. This paper analyzes and empirically estimates the extent to which exchange rate and oil price changes have contributed to this market shift. We first develop a dynamic Cournot model of long-run profit-maximizing firms that operate in a macroeconomy characterized by shocks to income, exchanges rates, oil prices, and firm-specific demands and supplies. Using the solutions for quantities sold from this model, we then construct a structural vector autoregression (VAR) to estimate and identify a reduced-form VAR. The empirical results indicate that a strong yen increases quantities sold by American automakers and decreases quantities sold by Japanese automakers; this exchange-rate effect accounts for approximately four percent of the variance of changes in monthly-sales quantity for automakers. Oil-price increases reduce the quantity of automobiles sold by American automakers, but, contrary to the common belief, have little effect on Japanese automakers; this oil-price effect accounts for 6.5 percent of the variance of changes in monthly-sales quantities for American automakers. Over the two decades we analyze, however, the real value of the dollar has almost steadily declined against the yen, and the real price of oil has ended up unchanged, so these variables cannot explain the decline (rise) of American (Japanese) automakers. Clearly, automobile sales are exposed to exchange rate, oil price, and income risk; between 10 and 20 percent of the changes in monthly-sales quantities can be explained by the macroeconomic variables that we analyze. However, we conclude that firm-specific policies probably account for the bulk of gains and losses actually experienced by the automakers. © 1999 Elsevier Science B.V.

*Keywords:* U.S. automobile industry; Foreign exchange exposure; Structural VAR

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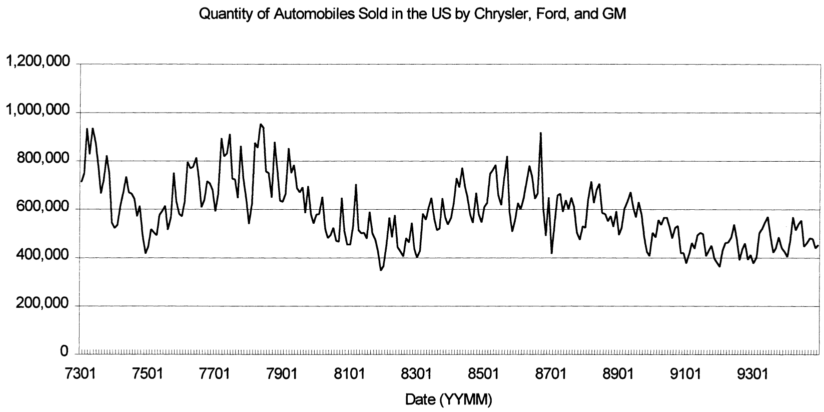
PII: S0922-1425(98)00041-3

## 1. Introduction

Research on financial-risk management and competitive strategy, which focuses on the influence of macroeconomic variables and competitor characteristics on a firm's position within an industry, has progressed considerably over the past several years. The macroeconomic variables and competitor characteristics are often referred to as 'environmental variables'. There is also a widespread belief that firm strategy and risk management is particularly important internationally (see, e.g. Porter, 1986; Smith et al., 1990). One implication of this research is that managers should continuously monitor environmental variables and be prepared to adapt to changes in order to maximize firm value. An industry that has received substantial attention in this regard is the global automobile industry, particularly with respect to American and Japanese producers competing for sales in the U.S. market. There are frequent references by both, academics and practitioners to the importance and effects of the dollar/yen exchange rate and the price of oil on sales quantities and prices of automobiles. In addition, since the characteristics of Japanese and American manufactured automobiles differ, we also anticipate that changes in the general income level affect the sales of these automobiles differentially. However, there has not yet been a careful investigation on the effects of these macroeconomic variables on industry structure. This paper, therefore, carefully examines the impact of exchange rates, oil prices, and income on the U.S. sales of American and Japanese automakers.

During the last two decades, the U.S. automobile market saw major shifts in the market share held by various automakers. The dominance of American automakers has been seriously threatened by Japanese automakers, while the significance of European automakers has all but disappeared. From 1973 to 1994, the three largest Japanese automakers (Honda, Nissan, and Toyota) have increased their sales of automobiles threefold, from a monthly average of less than 50 000 to about 150 000 vehicles (see Fig. 1). In contrast, over the same period, the three largest U.S. automakers (Chrysler, Ford, and GM) experienced declining sales levels, from a monthly average of more than 700 000 to about 500 000 vehicles. The shift in market shares over this period coincides with two important changes in the macroeconomic environment: large fluctuations in exchange rates and significant changes in the price of oil. A natural question that arises is whether these macroeconomic fluctuations significantly affect automaker market shares in the U.S. We establish, empirically, the extent to which the fluctuations in key macroeconomic variables have affected the sales of American and Japanese automakers in the U.S. market.

We focus on the automobile industry for three reasons. First, American automakers represent the largest employer in the U.S. manufacturing sector. In addition, they also operate in a worldwide market. Thus, their sheer size warrants a better understanding of how macroeconomics and international competition affect the fortunes of these companies. Second, it is widely conjectured that exchange rates and oil prices have been important determinants of the competitive strength of American and Japanese automakers. While many studies have analyzed the impact of exchange rates on prices of imported automobiles ('pass-through'), we are aware of no study that has analyzed the impact of exchange rates (or oil prices) on quantity – and, by extension, on market share. Third, the auto industry is generally characterized by a well-defined, though heterogeneous, product and oligopolistic competition with the same major players. Thus, unlike other industries,



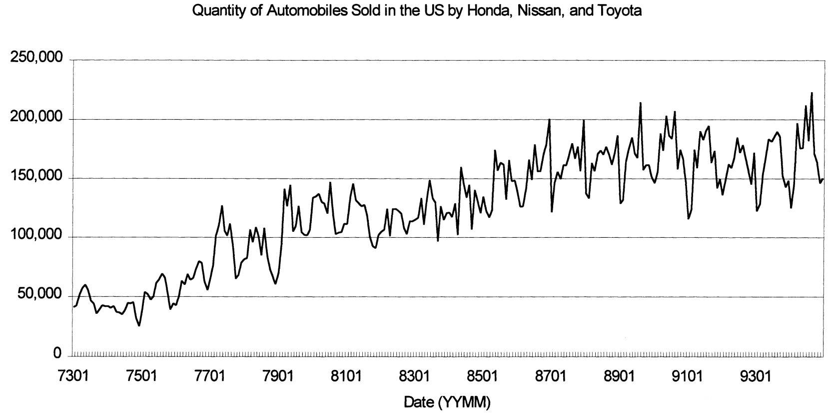




Fig. 1. Quantity of automobiles sold in the U.S., 1973–1994, by major U.S. (Chrysler, Ford, and GM) and Japanese (Honda, Nissan, Toyota) automakers according to Ward's Automotive Yearbook.

where competition and products have changed over time, the auto industry presents a unique opportunity for analyzing the impact of the macroeconomic environment on international competition.

We begin our analysis by building a dynamic model of imperfect competition in the U.S. automobile market. Firms maximize intertemporal profits by choosing a sequence of sales quantities subject to demand and cost conditions. The firms face linear demand curves, where quantity demanded is a function of price, income, product substitutability, and the price of oil. These firms face constant or increasing marginal costs and adjustment costs associated with changing quantity from one period to the next. Oil prices also affect production costs, and exchange rates affect costs by altering the dollar price of imported inputs (or imported vehicles in the case of Japanese manufacturers). The solution to this model can be expressed as an autoregressive moving average process, and when combined with autoregressive processes for the exogenous macroeconomic variables, a structural model of the entire system is specified. We express this structural model as a vector autoregression (VAR) and empirically identify it from an estimated reduced-form VAR. This econometric technique focuses on unanticipated changes – or 'shocks' – to the macroeconomy and identifies how such shocks affect the quantity of automobiles sold by firms over time (depicted in impulse response functions). In addition, we assess the importance of the shocks by examining the forecast error variance decomposition from the VAR.

Empirical estimation of the model utilizes monthly data for the period from January 1973 through December 1994. Results from the identified reduced-form vector autoregression suggest that the macroeconomic variables under examination affect sales quantities as predicted by the model. With regard to exchange rates, yen appreciation has historically reduced the sales quantity of Japanese automakers and increased the sales quantity of American automakers, yielding market-share gains for the American automakers. With regard to oil prices, increased oil prices have indeed led to declines in sales by American automakers, yielding gains in the market share controlled by the Japanese. Finally, with regard to income, higher income has led to sales gains by all firms, but particularly for American firms, leading to increased market share for the American automakers. In sum, the macroeconomic variables are moderately important in the overall determination of market share. They are more important for the American automakers, accounting for nearly 20 percent of the changes in monthly sales, than for the Japanese automakers, for whom they account for a little more than 10 percent. For automakers in both countries, however, other variables and firm-specific policies appear to account for the bulk of the changes in market share.

The remainder of the paper is organized as follows. In Section 2, we provide further background and review related academic literature. In Section 3, we develop our model of imperfect competition in the U.S. automobile market with a particular emphasis on the effects of exchange rates and oil prices. We discuss the data and methods used to estimate our model in Section 4, and report empirical results in Section 5. Closing remarks are made in Section 6.

## 2. Background and previous literature

### *2.1. Exchange rates*

In August 1994, as the yen/dollar exchange rate hovered around 100, the *Wall Street Journal* reported that Toyota was increasing prices on vehicles sold in North America "to reflect the yen's sharp rise against the dollar."[1] The article concluded "[t]hough the Big Three American auto makers have also raised prices on some vehicles in advance of the 1995 model year, a significant jump in Toyota's prices would likely hurt its standing in the U.S. market." Furthermore, some have estimated that, as a rough rule of thumb, "every ¥1 rise in the value of the yen against the U.S. dollar cuts profits by ¥10 billion at Toyota."[2] Such accounts of price increases and reductions in profitability attributed to exchange-rate

[1] *The Wall Street Journal*, 8/26/94, p. A3.
[2] *Tokyo Business*, November, 1993, p. 44.

movements are plentiful in the financial press. By extension, American automobile producers may have increased their profits due to a yen appreciation.[3] These quotations reflect two areas that academic research has focused on:

1. The extent to which the domestic prices of imported vehicles reflect the 'pass-through' of changes in exchange rates; and
2. The relation between exchange rates and firm value.

We consider each of these areas of inquiry in turn.

Several papers have studied the extent to which import prices reflect the 'pass-through' of changes in exchange rates. Pass-through is defined as the elasticity of the local currency price of a foreign-produced good with respect to a change in the exchange rate between the local currency and the currency of the exporter. Krugman (1987), Dornbusch (1987), Feenstra (1989), Froot and Klemperer (1989), and Knetter (1994) all model the relation of exchange rates and import prices in an imperfectly competitive market. Gagnon and Knetter (1995) focus exclusively on the automobile industry. Dixit (1988) and Berry et al. (1995) use variations of these models to analyze the social welfare impacts of voluntary export restraints by Japanese automakers. Feenstra et al. (1996) extend these models to predict that pass-through should increase with market share.

Empirical studies have usually found that pass-through is small. In general, foreign companies have not responded to a weakening dollar; rather, they have maintained dollar prices on exports to the U.S. (see, e.g. Krugman, 1987; Froot and Klemperer, 1989; Hooper and Mann, 1989; Okuro, 1989; Marston, 1990; Knetter, 1994; Rangan and Lawrence, 1993). The automobile industry, particularly during the 1980s, is also characterized as one industry in which the dramatic swings in the dollar did not translate into dramatic swings in the price of foreign automobiles. Goldberg (1995), using household data from the Consumer Expenditure Survey from 1983–87, estimates that "the pass-through coefficient for Japanese cars is small (between 15 and 30 percent)." While these price changes are characterized as small, it remains an empirical question whether changes in exchange rates (and the small price changes that result) have a significant impact on the quantity of automobiles sold and, thus, an impact on the relative market share of American and Japanese automakers. In fact, a small price change is consistent with either a small change in quantity (when supply is relatively inelastic) or with a large change in quantity (when demand is relatively elastic). Goldberg (1995) finds that the quantity effect is more important than the price effect, underscoring the importance of quantity studies.

Unlike prior work in this area, our analysis focuses directly on quantity data for two reasons. First, the quality of the data is superior. With the exception of Goldberg (1995), who uses the transaction price of new car purchases, most empirical work has used unit-value series as price proxies. These series have well-known limitations as price proxies, particularly for manufactured goods (Lipsey et al., 1991). In contrast, the quantities of automobiles sold in the U.S. by the major automakers are readily available on a monthly basis. Second, an analysis of the impact of exchange-rate changes on quantity has direct implications for market share gains and losses by both American and Japanese auto-

[3]For an interesting case study, see Millman (1990).

makers.[4] Thus, unlike previous work that has focused on exchange-rate pass-through of Japanese imports in the American automobile market, we consider the impact of shocks to the yen/dollar exchange rate on American automakers as well as their Japanese counterparts.

Our work also complements the empirical work in financial economics on the relation between exchange rates and firm value, usually referred to as foreign-exchange exposure and risk. Financial economists have generally been puzzled by the lack of relation between changes in firm value (as measured by changes in the market value of equity) and exchange rates. Jorion (1990), Amihud (1994), and Bartov and Bodnar (1994) document that the contemporaneous relation between equity returns and changes in dollar exchange rates has been insignificantly different from zero for large American exporters. Amihud (1994) finds some evidence of lagged effects, and is generally puzzled. Bartov and Bodnar (1994) argue that market response to exchange-rate shocks is delayed because of the complexity of the relation between firm value and exchange rates. The vector autoregressive (VAR) econometric technique that we use to study the quantities of automobiles sold exploits these findings by estimating regressions of sales quantity onto lagged values of all variables in the system, including exchange rates. Though we do not explicitly analyze firm value, our research measures the degree to which, and the speed at which, the quantity of a firm's sales in the American automobile market is exposed to exchange-rate changes. It is reasonable to conjecture that, if exchange rates affect the sales of American and Japanese automakers, profits and firm value are also likely affected.

### 2.2. *Oil prices*

The popular financial press often cites the increase in oil prices as the catalyst for 'opening up' the American automobile market to Japanese automakers. The following quote is typical of such conjecture:

> A complete history of Detroit's impotent response to Japan would stretch back nearly 20 years. Beginning with the gasoline crisis of 1973, Japan opened up a substantial market in the U.S. for its fuel-efficient, trouble-free cars. A second gasoline shortage in 1979–1980 added momentum, and by 1982 the Japanese had 20 percent of the U.S. car market. (*Fortune*, *November 16*, *1992*, *p. 56*.)

Dolan and Goodman (1989) and Kwoka (1993) provide further discussion on this issue. While there has been considerable research on the effect of exchange rates on international competition, and the auto industry in particular, we are aware of no systematic analysis of the impact of oil-price shocks on the relative competitiveness of American and Japanese automakers. This research undertakes such an analysis.

## 3. A duopoly model of the U.S. automobile market

We develop a Cournot duopoly model of the U.S. automobile market to focus on the macroeconomic factors that are likely to influence market share. Although the market is

[4] This is an insight shared by the Assistant Tresurer of Chrysler, see Millman (1990), p. 77.

characterized by competition among many firms, we develop a duopoly model to illustrate imperfect competition between American and Japanese producers.[5] In the Cournot model, producers choose a quantity of output to be sold (rather than a price). We believe this is consistent with how automakers behave, since they must design, produce, and ship the autos well before they are sold to the consumer. The Cournot model has also been applied to the automobile industry by Dixit (1988), for similar reasons. Although automakers set ‘sticker’ prices, actual transaction prices need not be at these levels. In fact, the available supply of new cars seems to determine the transaction price. The Cournot specification allows us to readily determine equilibrium quantities and to focus on market shares, which is advantageous since high-quality quantity data are easily available but price data are not.[6]

In this model, we focus on the environmental factors that affect the cost of production and demand in the auto industry. We explicitly account for the impact of exchange rates and oil prices on production costs and the impact of income and oil prices on the demand for automobiles. The solution to a linear-quadratic optimization model of firm behavior is expressed as an autoregressive moving average (ARMA) process. When combined with autoregressive processes for the exogenous variables, a structural model of the entire system is specified. We then empirically estimate this time-series model for quantities of automobiles sold, allowing us to avoid estimating a more complex system of demand and supply equations. Section 3.1 presents the general framework of the model, Section 3.2 examines the comparative statics of the long-run equilibrium, and Section 3.3 expresses the model as a structural vector autoregression.

### 3.1. Model framework

Assume that there are two incumbent firms, $i$ and $j$, which we later identify as American and Japanese automakers, respectively. Note that we are not explaining market entry; the firms already compete in the market. Each firm maximizes, at time 0, the present value of profits in the (U.S.) market by choosing a sequence of quantities. For firm $i$, this choice is characterized as:

$$\max_{\{Q_{it}\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \pi_{it}, \tag{1}$$

where

$$\pi_{it} = p_{it} Q_{it} - C_{it} \tag{2}$$

[5]When there are more firms competing in a Cournot fashion, the equilibrium quantity for each firm is smaller. For example, if there are six identical Cournot oligopolists rather than two, each would produce M/7 units instead of M/3, where M is determined by market demand and cost conditions. The total supply by all automakers will be higher as the number of oligopolists increases. For example, with six, the total would be 6M/7, whereas with two, it would be 2M/3. Thus, the total units in a six firm oligopoly market would be about 19 percent higher than in a duopoly market.

[6]If automakers are assumed to engage in price competition, a Bertrand model would be more appropriate. With Bertrand competition, the equilibrium prices are lower and the quantities are higher. However, the comparative statics have the same signs, although the magnitudes are different.

and $Q_{it}$ is the quantity sold by firm $i$ in period $t$, $p_{it}$ the price per unit for firm $i$ in period $t$, $C_{it}$ the total cost to produce $Q_{it}$, and $\pi_{it}$ the profits from sales in the U.S. market for firm $i$ in period $t$. $\beta_t$ is a discount factor and $E_0(\cdot)$ represents expectations at period 0. Note that there is no inventory in this model; quantities produced and sold are identical. (For a discussion of production and inventories in the auto industry, see Kashyap and Wilcox, 1993.)

Each firm faces a linear inverse demand curve in which price is a function of income, quantities of automobiles sold, and the price of oil:

$$p_{it} = a_i Y_t - b_{ii} Q_{it} - b_{ij} Q_{jt} - c_i O_t + \varepsilon^d_{it}, \quad (3)$$

where $Y_t$ is the aggregate income in period $t$, $O_t$ the price of oil in period $t$, $\varepsilon^d_{it}$ the firm-specific demand shocks, and $a_i$>0, $b_{ii}$>0, $b_{ij}$>0, $c_i$>0.

The parameters $a_i$ and $c_i$ measure the sensitivity of price to changes in income and oil prices, respectively. The parameter $b_{ii}$ measures the relation between price and quantity for firm $i$ (where own-price elasticity for firm $i$ is equal to $-p_{it}/(b_{ii}Q_{it})$). The parameter $b_{ij}$ measures the substitutability of products produced by firm $i$ and $j$. We include oil prices in the demand curve because we expect increases in oil prices would reduce the demand for automobiles ($c_i$>0), by increasing the operating costs of owning a vehicle.

Total costs (in dollars) for firm $i$ in period $t$ are a function of the quantity produced, the exchange rate, oil prices, and the quantity produced in the previous period:

$$C_{it} = d_i Q^2_{it} + f_i e_t Q_{it} + g_i O_t Q_{it} + h_i (Q_{it} - Q_{i,t-1})^2 + \varepsilon^s_{it} Q_{it}, \quad (4)$$

where $e_t$ is the dollar/yen exchange rate, $\varepsilon^s_{it}$ the firm-specific supply shocks, and $d_i, f_i$, $g_i$ and $h_i$ are assumed nonnegative.

The parameter $d_i$ measures the extent to which marginal costs increase with output. This embraces the cost of labor, raw materials, and other domestic inputs. The parameter $h_i$ measures the costs associated with adjusting output and sales from period $t-1$ to $t$. We include the exchange rate in the cost function to account for the dollar cost of inputs imported from Japan, particularly for the Japanese automakers. We include the oil price to capture utility costs in the production process. The cost function is written such that each of the parameters is assumed nonnegative. For example, total dollar-denominated costs are assumed to increase with an increase in the dollar/yen exchange rate ($f_i$>0), due to higher costs of imported inputs from Japan, and with an increase in oil prices ($g_i$>0).

An important feature of the cost function is that firms face adjustment costs from changing the quantity produced and sold from period $t-1$ to period $t$. Consider a period in which a firm wishes to increase the quantity sold. Adjustment costs would include the costs of overtime wages, hiring additional (perhaps temporary) workers, adding a shift at existing plants, and adding (if necessary) additional plant capacity. Alternatively, when a firm wishes to decrease the quantity sold, adjustment costs would include the costs of downsizing, laying off workers, and idling plants and equipment. In their study of pass-through, Gagnon and Knetter (1995) also use quadratic adjustment costs for changing the volume of exports from Japan. Over a sufficiently long horizon these adjustment costs are close to zero. However, from one month to the next, it is likely that auto manufacturers face significant adjustment costs when they try to alter the production process. This feature of the model is what produces temporal dynamics. It is designed to explain why there may be very little contemporaneous, yet an important long-term effect of a shock.

There are no fixed costs in Eq. (4), so we are not modeling the decision of whether to produce. Sunk costs have already been incurred, and there are no additional investment decisions. Furthermore, there is no exit or shutdown decision. Instead, we are modeling the decision of how much to produce, assuming that the firm is an ongoing operation. Although entry and exit decision would be interesting extensions of the model, they are beyond the scope of this paper.

Although we do not incorporate them in the model, there may be additional dynamics resulting from gradual adjustment on the demand side if consumers exhibit brand loyalty and are slow to switch their purchases across companies. Additional analyses, which are not presented here in the interest of parsimony, reveal that these short-run demand-side dynamics do not substantively alter the long-run comparative statics or the econometric estimation of the model.

The second firm, $j$, faces the same optimization problem (Eq. (1)), a similar demand curve (Eq. (3)), and a similar cost curve (Eq. (4)). The Euler equations for these two firms can be written together as:

$$E_0\left\{\begin{bmatrix}\Gamma_i & b_{ij}\\ b_{ji} & \Gamma_j\end{bmatrix}\begin{bmatrix}Q_{it}\\ Q_{jt}\end{bmatrix}\right\}=\begin{bmatrix}a_i\\ a_j\end{bmatrix}Y_t-\begin{bmatrix}f_i\\ f_j\end{bmatrix}e_t-\begin{bmatrix}c_i+g_i\\ c_j+g_j\end{bmatrix}O_t+\begin{bmatrix}v_{it}\\ v_{jt}\end{bmatrix} \tag{5}$$

for $t \geq 0$, where

$$\Gamma_i = 2[-h_i L + (b_{ii} + d_i + h_i + \beta h_i) - \beta h_i L^{-1}],$$

and

$$v_{it} = \varepsilon^d_{it} - \varepsilon^s_{it}$$

represents the net shock (demand shock minus supply shock) to firm $i$. There are analogous expressions for firm $j$ ($\Gamma_i$ and $v_{jt}$). $L$ is a lag operator, such that $LQ_{it}=Q_{i,t-1}$. The expectations operator on the left-hand side of Eq. (5) is maintained since $Q_{i,t+1}$, which enters the equation through $L^{-1}$, is unknown in period 0.

### 3.2. Long-run equilibrium and comparative statics

Our interest is in the long-run impact of changes in each of the exogenous variables in our model – income, exchange rates, and oil prices – on the quantity sold by firm $i$ ($Q_{it}$), firm $j$ ($Q_{jt}$), and both firms (aggregate quantity, $\boldsymbol{Q}_t=Q_{it}+Q_{jt}$). For firm $i$ to increase its market share ($Q_{it}/\boldsymbol{Q}_t$) from one period to the next, the percentage change in quantity sold by firm $i$ must be greater than the percentage change in quantity sold by firm $j$. Obviously, this condition is met if one firm increases quantity while the other firm decreases it. When we refer to market-share losses in the following discussion, it is to this situation that we are referring. Though adjustment costs affect the short-run dynamics and are important in the econometric specification of the model, they do not affect the long-run equilibrium. Thus, in the long-run solution, we assume $h_i=h_j=0$. In the discussions that follow, we refer to firm $i$ as the U.S. automaker and firm $j$ as the Japanese automaker.

Solving the system of Euler equations (Eq. (5)) for $Q_{it}$ yields the following long-run Cournot–Nash equilibrium value of $Q_{it}$ for firm $i$ (the American automaker):

$$Q_{it} = \frac{2[a_i Y_t - f_i e_t - (c_i + g_i)O_t + v_{it}][b_{jj} + d_j] - [a_j Y_t - f_j e_t - (c_j + g_j)O_t + v_{jt}]b_{ij}}{4(b_{jj} + d_j)(b_{ii} + d_i) - b_{ij}b_{ji}} \tag{6}$$

There is an analogous expression for firm $j$ (the Japanese automaker). To ensure that the quantity sold is positive, we assume both, the numerator and the denominator of Eq. (6) are positive. The denominator would be positive if own-substitution parameters are greater than cross-substitution parameters ($b_{jj}>b_{ji}$ and $b_{ii}>b_{ij}$) for both Japanese and American automakers and marginal costs do not decline with an increase in output ($d_i$, $d_j\geq 0$).

First, consider the long-run impact of a change in the U.S. income on the quantity sold by U.S. automakers, $\partial Q_{it}/\partial Y_t$. The quantity increases with income if:

$$\frac{a_j}{a_i} < \frac{2(b_{jj} + d_j)}{b_{ij}} \tag{7}$$

This condition would be met if, for example, (1) both American and Japanese automakers face the same income coefficient, (2) the own-substitution parameter of Japanese automakers is greater than the cross-substitution parameter ($b_{jj}>b_{ij}$), and (3) marginal costs do not decline with output ($d_j\geq 0$). Similar arguments yield a positive income effect for Japanese automakers.[7] Of course, the aggregate quantity unambiguously increases with an increase in income ($\partial \boldsymbol{Q}_t/\partial Y_t>0$), since the automobile is assumed to be a normal good.

Second, consider the long-run impact of a change in the dollar/yen exchange rate on the quantity sold by American automakers, $\partial Q_{it}/\partial e_t$. The quantity increases with the exchange rate if:

$$\frac{f_j}{f_i} > \frac{2(b_{jj} + d_j)}{b_{ij}}. \tag{8}$$

The impact of an increase in the dollar/yen exchange rate on American automakers is probably positive. For example, in the limit, if they rely on virtually *no* Japanese imports in the manufacture of automobiles ($f_i\rightarrow 0$), American automakers will gain market share as consumers substitute away from the now more expensive Japanese cars (assuming $f_j>0$). Conversely, the quantity sold by Japanese automakers decreases with the dollar/yen exchange rate, since they rely quite heavily on imported inputs and consumers substitute away from the now more expensive cars. The size of the American gain increases with the substitutability of Japanese and American automobiles ($b_{ij}$), and decreases with the price coefficient of Japanese cars ($b_{jj}$) and the quadratic element of total costs for Japanese automakers ($d_j$). Though American automakers are likely to gain and Japanese automakers – to lose, the aggregate quantity sold decreases with an increase in the dollar/yen exchange rate $\partial \boldsymbol{Q}_t/\partial e_t<0$ under a typical situation (described in Appendix A) because industry costs and prices have increased.

[7] It is possible for the quantity sold by American automakers to decline as income increases, if the cross-substitution parameter is sufficiently larger than the own-substitution parameter ($b_{ij}\gg b_{jj}$). This possibility seems unlikely.

Finally, consider the long-run impact of a change in oil prices on the quantity sold by American automakers, $\partial Q_{it}/\partial O_t$. The quantity decreases as oil prices increase, if:

$$\frac{(c_j + g_j)}{(c_i + g_j)} < \frac{2(b_{jj} + d_j)}{b_{ij}} \tag{9}$$

We expect this to hold. The right-hand side of Eq. (9) is probably greater than two, since own-price substitution parameters are greater than cross-substitution parameters for both firms ($b_{jj}>b_{ji}$) and marginal costs do not decline as output increases ($d_j \geq 0$). The left-hand side of Eq. (9) is likely to be less than one, since we expect $c_j<c_i$ and $g_i \approx g_j$. Thus, American automakers would reduce the quantity sold as oil prices increase. The result for Japanese automakers is, however, ambiguous. If the fuel-efficiency of Japanese automobiles is sufficiently greater than that of its American counterparts ($c_j \ll c_i$), it is possible that Japanese automakers could increase the quantity sold (and thus market share), even in the face of higher costs of production. Similar to exchange rate shocks, the aggregate quantity sold decreases with an increase in oil prices $\partial \boldsymbol{Q}_t/\partial O_t<0$ (see Appendix A).

The comparative statics identify the parameters that determine whether one firm might gain market share, given a change in one of the three exogenous macroeconomic variables in our model. Our primary interest, however, is in estimating the magnitude of these effects. In order to accomplish this goal, we now turn to the econometric specification of the model.

### 3.3. Econometric specification

Solutions to the system of Euler equations (Eq. (5)) are in the form of a schedule of quantities for each firm (contingency plans), $\{Q_{it}\}_{t=0}^{\infty}$ and $\{Q_{jt}\}_{t=0}^{\infty}$, which are functions of expectations of future levels of the exogenous macroeconomic variables and firm-specific shocks, $\{Y_t, e_t, O_t, v_{it}, v_{jt}\}_{t=0}^{\infty}$ and the quantity sold by each firm in the initial period (the initial condition), $Q_{i,t=-1}$ and $Q_{j,t=-1}$. Formulations of each firm's contingency plan for quantity can be derived by specifying the expectations of the exogenous macroeconomic variables and firm shocks, $\{Y_t, e_t, O_t, v_{it}, v_{jt}\}_{t=0}^{\infty}$, as a function of known current, and past, variables.[8]

We assume initially that the macroeconomic variables – income, exchange rates, and oil prices – follow covariance-stationary time-series processes and that expected future values for each of the macroeconomic variables can be expressed as a linear combination of current, and past, values of the three variables.[9] Consider the case when the macroeconomic variables have the following autoregressive representation:

$$\begin{bmatrix} \rho_{yy}(L) & \rho_{ye}(L) & \rho_{yo}(L) \\ \rho_{ey}(L) & \rho_{ee}(L) & \rho_{eo}(L) \\ \rho_{oy}(L) & \rho_{oe}(L) & \rho_{oo}(L) \end{bmatrix} \begin{bmatrix} Y_t \\ e_t \\ O_t \end{bmatrix} = \begin{bmatrix} u_{yt} \\ u_{et} \\ u_{ot} \end{bmatrix}, \tag{10}$$

[8] For details of the solution techniques, see Chapter IX, Section 10 on Multivariate Dynamic Optimization and Chapter XI on Projections of Geometric Distributed Leads in Sargent (1987).

[9] In empirical estimation, however, all variables are determined to be difference-stationary, so levels of variables are replaced with their first differences.

where $u_{yt}$, $u_{et}$, and $u_{ot}$, are white-noise 'shocks' to the variables and are orthogonal to each other. This represents the macroeconomy, where firms $i$ and $j$ compete. The contemporaneous parameters of the polynomial distributed lags form the identity matrix. For example, $\rho_{yy}(L)=(1-\rho_{yy,1}Y_{t-1}-\rho_{yy,2}Y_{t-2}-\ldots$, but $\rho_{ye}(L)=(-\rho_{ye,1}e_{t-1}-\rho_{ye,2}e_{t-2}-\ldots)$. A moving average representation of Eq. (10) provides expressions for $Y_t$, $e_t$, and $O_t$ as summations of the past shocks to each macroeconomic variable.

Solutions to the system of Euler equations in Eq. (5), given the structure of the macroeconomy in Eq. (10), can be expressed as autoregressive moving average (ARMA) representations for $Q_{it}$ and $Q_{jt}$. Combining the moving average representation of the macroeconomy and the ARMA representation of the quantity sold by firms $i$ and $j$ yields the 'law of motion' of the vector $X_t$:

$$A(L)X_t = B(L)C(L)u_t \tag{11}$$

where

$$X_t' = [Y_t, e_t, O_t, Q_{it}, Q_{jt}],$$

$$u_t' = [u_{yt}, u_{et}, u_{ot}, u_{it}, u_{jt}],$$

$$u_{it} = \rho(L)v_{it},$$

$$u_{jt} = \rho_j(L)v_{jt},$$

and $A(L)$, $B(L)$, and $C(L)$ are five-by-five matrices of polynomials in the lag operator from the theoretical model. This is the final version of the structural model. Complete details of the derivation of Eq. (11) are provided in Appendix B.

A vector autoregression (VAR) representation of the structural model is, therefore:

$$[B(L)C(L)]^{-1}A(L)X_t = u_t \tag{12}$$

which is an estimable form. Furthermore, since the shocks to each of the macroeconomic variables and the firm-specific shocks are assumed orthogonal, $E[u_t u_t'] = \Omega$ is a five-by-five matrix in which the off-diagonal elements are zero.

The moving average representation of the structural model is:

$$X_t = A(L)^{-1}B(L)C(L)u_t \equiv D(L)u_t \tag{13}$$

where $D(L) \equiv A(L)^{-1}B(L)C(L)$. The comparative statics of the long-run equilibrium, developed in Section 3.2, indicates there are qualitative restrictions on certain elements of $D(1)$, the matrix of long-run multipliers. The long-run impact of a shock to income on the quantity sold by the U.S. and Japanese automakers is likely to be positive:

$$D_{iy}(1) > 0,$$

$$D_{jy}(1) > 0.$$

The long-run impact of a shock to the exchange rate on the quantity sold by the U.S. automakers is likely positive, but the impact on the quantity sold by Japanese automakers is likely to be negative:

$$D_{ie}(1) > 0,$$
$$D_{je}(1) < 0.$$

Furthermore, $D_{ie}(1)+D_{je}(1)<0$. The long-run impact of a shock to oil prices on quantity sold by the U.S. automakers is likely to be negative, although the impact on the quantity sold by Japanese automakers is ambiguous because higher demand may or may not offset higher costs:

$$D_{io}(1) < 0,$$
$$D_{jo}(1) \lesseqgtr 0.$$

Furthermore, $D_{io}(1)+D_{jo}(1)<0$. Section 4 considers identification of these long-run parameters from a reduced-form VAR, and the following section empirically estimates the long-run parameters.

## 4. Data and empirical methodology

### *4.1. Data*

Estimation of the model uses monthly data on the quantity of automobiles sold (plotted in Fig. 1) and the three macroeconomic indicators (plotted in Fig. 2) for the period from January 1973 through December 1994. Inspection of Fig. 1 reveals that Japanese automakers nearly tripled the quantity of automobiles sold since the early 1970s. Conversely, American automakers have experienced flat-to-declining sales levels.

Based on augmented Dickey–Fuller unit root tests, the macroeconomic series are determined to be nonstationary in levels but stationary in differences. This is a typical finding among macroeconomic variables, which implies that the variables follow 'random walks' such that innovations are permanent. These permanent innovations, in turn, have permanent effects on the sales quantities of automobile producers. Difference-stationarity suggests that the vector autoregression can be estimated in first differences, which allows for permanent responses to the exogenous shocks. Furthermore, Engle-Granger tests for co-integration are generally ambiguous, and the estimated co-integrating vectors are dubious. We therefore conclude that, in the absence of strong evidence of co-integration, a VAR estimated using first differences is appropriate. For the full details of the data, unit root tests, and co-integration analysis, see Appendix C.

### *4.2. Empirical methodology*

The structural VAR in Eqs. (12) and (13) is a specific representation of a five-variable VAR in income, exchange rates, oil prices, the quantity sold by all the U.S. firms, and the quantity sold by all Japanese firms. This model produces a five-by-one vector, $X_t' = [Y_t, e_t, O_t, Q_{it}, Q_{jt}]$, and a corresponding five-by-one vector of shocks ($u_t$). In this case,

$$E[u_t u_t'] \equiv \Omega = \mathrm{diag}[\omega_y, \omega_e, \omega_o, \omega_i, \omega_j].$$

Given the finding that all variables are difference-stationary, $X_t$ is simply replaced by $\Delta X_t$ in both Eqs. (12) and (13), and the shocks $u_t$ represent innovations to the differences of

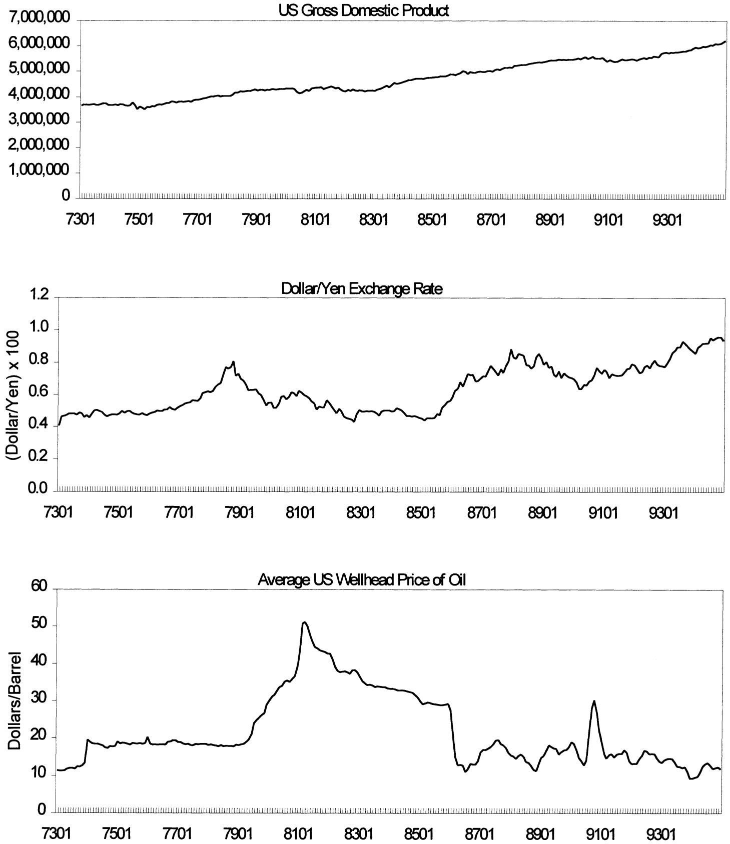



Fig. 2. Real U.S. gross domestic product, real Dollar/Yen exchange rate and real U.S. Wellhead oil price: January 1973–December 1994 (nominal series are deflated by consumer price indexes with a base year of 1990).

variables. The reduced form of the VAR, which we estimate, is represented by:

$$\Lambda(L)\Delta X_t = \eta_t, \qquad (14)$$

where $\eta_t$ is a five-by-one vector of white noise, $E[\eta_t \eta_t'] = \sum$, and $\Lambda(L)$ a five-by-five matrix of polynomial distributed lags with contemporaneous parameters that form the identity matrix. Rewriting as a moving average representation yields:

$$\Delta X_t = \Lambda(L)^{-1}\eta_t. \qquad (15)$$

Identification of the model is achieved by matching the reduced form of the VAR (Eq. (15)) with the structural form of the VAR (Eq. (13) in first differences). Hence,

$$D(L)u_t = \Lambda(L)^{-1}\eta_t,$$

$$D(0)u_t = \eta_t,$$

and

$$\Sigma = E[D(0)u_t u_t' D(0)'] = D(0)\Omega D(0)',$$

where $D(0)$ represents a five-by-five matrix containing the contemporaneous parameters of $D(L)$, and $\Lambda(L)^{-1}$ is dropped from the middle equation since its contemporaneous parameters form the identity matrix. Thus, we can match the residuals from the estimated vector autoregression ($\eta_t$) to the shocks in the structural form of the model ($u_t$) using a procedure developed by Bernanke (1986) and Sims (1986), which places identifying restrictions on the matrix $D(0)$. The restrictions on $D(0)$ all come from the contemporaneous effects of the structural shocks on the variables in the system. Once $D(0)$ is identified, the matrix of long-run parameters, $D(1)$, can be computed from $D(1)=\Lambda(1)^{-1}D(0)$. Note that we are using contemporaneous restrictions to identify long-run parameters, a particularly simple approach.[10] These long-run, empirically identified responses can then be checked against the qualitative restrictions from the theoretical model outlined at the end of Section 3.3.

The identifying restrictions we impose on $D(0)$ take three forms. First, five elements can be set to one by normalization along the diagonal ($D_{yy}=D_{ee}=\ldots=D_{jj}=1$). Second, since the three macroeconomic variables are assumed exogenous, six elements of the matrix can be set to zero ($D_{yi}=D_{ei}=D_{oi}=D_{yj}=D_{ej}=D_{oj}=0$). Third, empirical estimation of the VAR reveals that the macroeconomic shocks are contemporaneously uncorrelated, so the contemporaneous cross-effects of shocks to the macroeconomic variables are set to zero ($D_{ye}=D_{yo}=D_{ey}=D_{eo}=D_{oy}=D_{oe}=0$).[11] These restrictions are sufficient to identify the impact of shocks to each of the macroeconomic variables on quantity sold by American and Japanese automakers.

The VAR methodology is particularly appropriate for our investigation of the effects of macroeconomic variables on the U.S. sales of American and Japanese automakers because dynamics are important – especially for quantities sold – to allow for short-run deviations from long-run equilibrium. Since research on exposure (e.g. Amihud, 1994; Bartov and Bodnar, 1994) indicates that lags of variables are statistically significant while contemporaneous values are not, we simply implement their findings in the form of a VAR. Note that our model offers a partial explanation of their findings, in that adjustment costs cause quantities to respond gradually over time. Furthermore, we argue that unanticipated innovations in the variables – or 'shocks' – are more important than the levels of the variables themselves because any anticipated changes have probably already caused some adjustment. The VAR methodology allows us to trace the effects of the unanticipated shocks over time (through impulse response functions) and to assess their importance relative to the overall uncertainty regarding sales quantities (through forecast error variance decompositions).

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[10] We also experimented with restrictions on the long-run parameters in $D(1)$ and what they may imply for the contemporaneous parameters in $D(0)$ as developed by Blanchard and Quah (1989). The results are quite similar to those using restrictions on $D(0)$ and are not presented.

[11] Ordinarily, one would specify an ordering of the shocks to these variables and proceed to orthogonalize the shocks according to the chosen ordering. However, estimation of the system produces shocks that are already contemporaneously uncorrelated, implying that the order of the variables does not matter and that orthogonalization is not necessary. Hence, we take $u_{yt}=v_{yt}$, $u_{et}=v_{et}$, and $u_{ot}=v_{ot}$.

## 5. Results

### 5.1. Preliminaries

We estimate the VARs in first differences using five lags for each of the variables. Differencing imposes permanence on the effects of shocks to the macroeconomic variables, which is appropriate given the focus of the model on long-run *changes* in quantities sold. Diagnostics from the model with five lags are unable to reject the hypothesis that the residuals are white noise. We estimate models with longer and shorter lags to check the sensitivity of our results to changes in the lag structure, but increasing the lags to six and decreasing the lags to four does not materially alter the shape of the impulse response functions presented here.

Preliminary diagnostics reveal systematic seasonalities in the quantity data. Therefore, we estimate the VARs using a full set of deterministic monthly dummy variables in the quantity equations. We interpret these dummy variables as allowing for parallel shifts in the demand curve from one month to the next.

### 5.2. The macroeconomic environment

We begin by discussing the empirical properties of the macroeconomy in which automakers compete. Since we identify the shocks by using the fact that they are empirically contemporaneously uncorrelated, we impose no long-run restrictions on the impulse-response functions of the macroeconomic variables. Therefore, we are agnostic in our approach to estimating the long-run effects of shocks to the macroeconomic variables. Thus, the results presented in this section should be interpreted as purely descriptive. The impulse response functions display the dynamic effects of one standard deviation shocks to each of the variables. The nine impulse-response functions, through 24 months for the macroeconomy, are presented in Fig. 3. Since we restrict the contemporaneous cross-effects in the macroeconomy to be zero, all the impulse-response functions depicting cross-effects begin at zero in period 0.

Over our sample period, a one standard-error shock to real income is \$34 160 million, to oil prices it is \$1.09 per barrel, and to the cent/yen exchange rate – 0.017. These are the 'one standard-error shocks' to macroeconomic variables that we refer to when we later assess the impact of shocks to the macroeconomic variables on quantity sold by American and Japanese automakers. To place these shocks in perspective, note that the shock to real income represents approximately 0.7 percent of the time-series mean (\$4 708 billion), to oil prices it is approximately 5.0 percent of the mean (\$21.80), and to exchange rate it is approximately 2.7 percent of the mean (0.631 cents/yen). Though the impulse-response functions of the cross-effects (exchange rates on oil prices, income on oil prices, etc.) suggest some interdependence among the macroeconomic variables, the own-effects are certainly the largest. (These results are similar when the model is estimated over two subperiods – 1973–1983 and 1984–1994.) Also note that each shock has a long-run effect slightly higher than the contemporaneous effect: the income shock has a long-run effect of \$39 001, the oil price shock \$1.62, and the exchange rate shock 0.027.

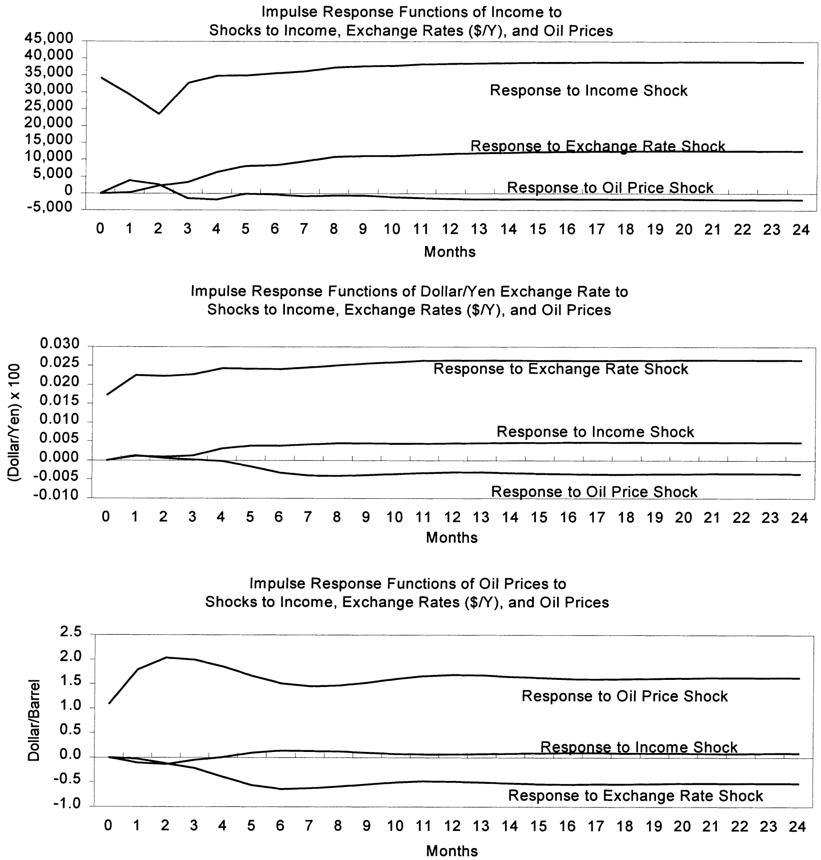


Fig. 3. Impulse-response functions of macroeconomic variables to one standard-deviation shock to each of the macroeconomic variables: 1973–1994. (Income is the real U.S. GDP; oil prices the real U.S. wellhead price/barrel; exchange rate the real dollar/yen ratio).

### 5.3. *Macroeconomic shocks and automobile sales*

To determine the impact of macroeconomic shocks on the total quantity of automobiles sold in the U.S., we conduct preliminary investigations of a four-variable VAR using the three macroeconomic variables and total sales quantity.[12] In this model, the income shock increases total sales by 19 679 units in the long run, the exchange rate shock increases total sales by 7731 units in the long run, and the oil shock decreases total sales by 7899 units in the long-run. The income and oil shock effects are qualitatively, as expected, based on the comparative statics of the theoretical model of Section 3. However, the increase in sales quantity due to an exchange-rate shock contradicts the comparative statics of the theoretical model. Note, however, exchange-rate shocks and income shocks are not

[12]The aggregated sales data represent total automobile sales in the U.S., both import and domestic.

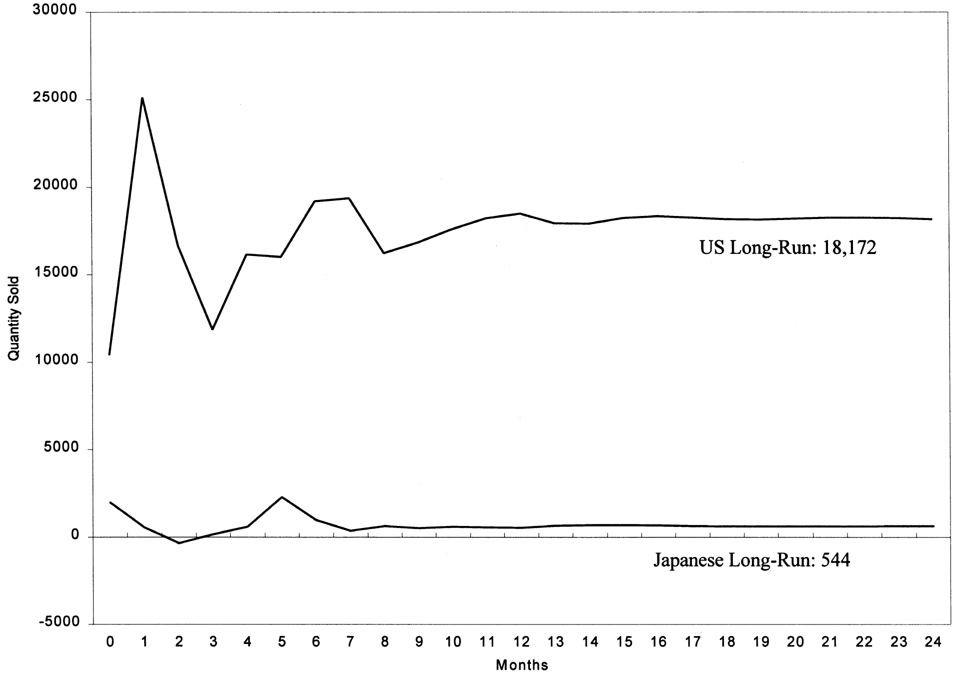


Fig. 4. Impulse-response functions of monthly quantity sold by American and Japanese automakers to one standard-deviation 'shock' to the real U.S. gross domestic product: 1973–1994.

independent in the long run. An exchange-rate shock has empirically led to an increase in income which, in turn, would have increased total auto sales. Hence, the result may not be so puzzling. In order to examine this possibility further, we estimate the four-variable VAR restricting all cross-effects – both contemporaneous and long-run – in the macroeconomy to be zero. Although this did not eliminate the effect, it reduces the magnitude of the increase in sales quantity due to an exchange rate shock to just 476 units. (In this VAR, the income shock alone increases total units by 19 299 and the oil shock alone decreases total units by 6963.) The positive effect of an exchange rate shock on total quantity sold, which can be predominantly attributed to the negative impact of an exchange-rate shock on income, is present in all models that we estimate.

Our main results are based on the five-variable VAR using the three macroeconomic variables, total sales quantity for the three American automakers, and total sales quantity for the three Japanese firms. Figs. 4–6 depict the impact on quantity sold of a one standard-deviation shock to income, the exchange rate, and oil prices, respectively. In addition, Table 1 presents the long-run impact of shocks to each of the macroeconomic variables on quantity sold and quantity sold as a percentage of mean monthly unit sales.

As predicted, the long-run multipliers for shocks to income are positive for both, American and Japanese automakers. For American automakers, the magnitude is large (at 3.09 percent), and the long-run multiplier exceeds the contemporaneous multiplier, indicating that shocks to income lead to increases in quantity sold through a gradual

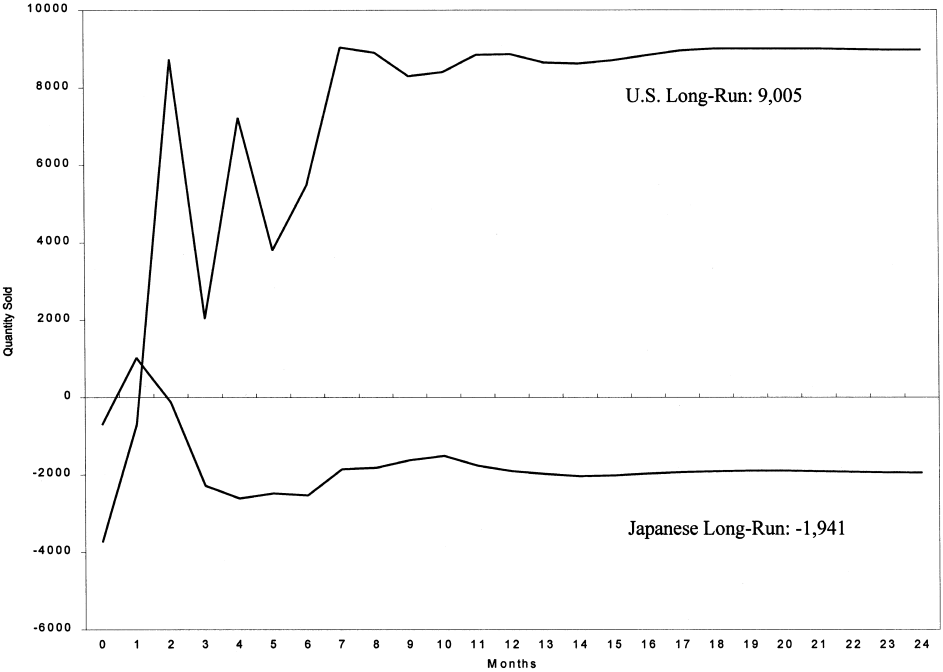


Fig. 5. Impulse-response functions of monthly quantity sold by American and Japanese automakers to a one standard-deviation 'shock' to the real dollar/yen exchange rate: 1973–1994.

adjustment process (see Fig. 4). For Japanese automakers, the magnitude is fairly small (at 0.44 percent). We attribute this result to the larger emphasis that American automakers have placed on the production of luxury automobiles. This result further implies that American automakers gain market share when real income increases.

After a short-run adjustment process, a shock to the dollar/yen exchange rate increases the quantity sold by American automakers and reduces the quantity sold by Japanese automakers (see Fig. 5). This is consistent with the qualitative results from the structural model implying that the long-run multipliers for shocks to the exchange rate are positive for the U.S. firms and negative for Japanese firms. American automakers increase unit sales by 1.53 percent in response to a one standard error shock, while their Japanese counterparts reduce sales by 1.57 percent (see Table 1, Panel B, column 3). These results confirm that exchange rates are an important factor in determining the relative market share of the Japanese and American automakers in the U.S. automobile market.

A shock to oil prices decreases the quantity sold by American automakers (see Fig. 6), as anticipated by the structural model which indicates that the long-run multiplier for oil shocks is negative for the U.S. automakers. American automakers decrease unit sales by 1.14 percent (see Table 1, Panel B, column 4) in response to a one standard-error shock. Though Japanese automakers also lose sales in response to a shock to oil prices, the magnitude of the loss (at 0.36 percent) is less than that experienced by the American automakers. Thus, as anticipated by the structural model, Japanese automakers

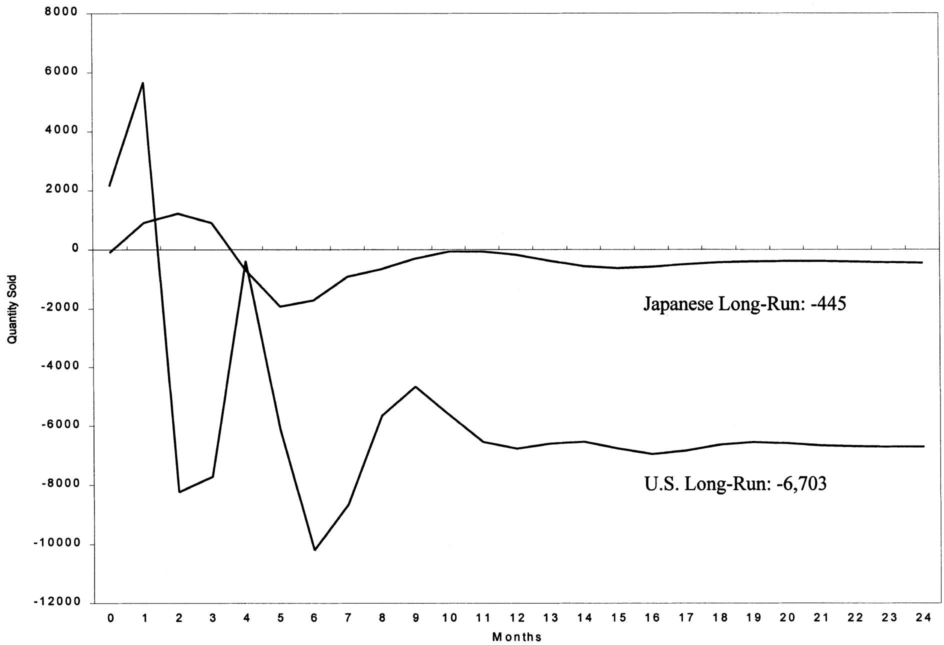


Fig. 6. Impulse-response functions of monthly quantity sold by American and Japanese automakers to a one standard-deviation 'shock' to real oil prices: 1973–1994.

have gained market share as a result of shocks to oil prices during the period that we analyze.

The impulse-response functions indicate the magnitudes of the effects of macroeconomic shocks, but not their importance relative to overall changes in sales quantities. Decompositions of the forecast error variance at various horizons are used to assess the importance of various shocks. For the approach used in producing the impulse response functions, the decompositions at 0-, 6-, 12-, and 24-month horizons showing the percent of the variance due to oil price, exchange rate, and GDP shocks are presented in Table 2. These decompositions indicate that the macroeconomic shocks are more important for the American manufacturers than for the Japanese manufacturers. For the American automakers, the macroeconomic shocks account for nearly 20 percent of the forecast-error variance at the one- and two-year horizons: approximately nine percent is due to income shocks, four percent to exchange rate shocks, and 6.5 percent to oil price shocks. For the Japanese automakers, the macroeconomic shocks account for a little more than 10 percent of the forecast error variance at the one- and two-year horizons: approximately four percent due to income shocks, four percent due to exchange rate shocks, and 2.5 percent due to oil price shocks.

The long-run qualitative results presented in Figs. 4, 5, 6 are remarkable considering that they have been generated using only minimal contemporaneous exclusion restrictions in identification. Furthermore, they are highly robust to changes in the model specification with regard to both, the level of aggregation and the lag length employed. However, there is

Table 1
The long-run impact of shocks to income, exchange rates, and oil prices on the quantity of automobiles sold in the U.S. by American and Japanese automakers; January 1973–December 1994. (The long-run effect represents the impact of a one standard-deviation shock to each of the macroeconomic variables on the quantity of automobiles sold at the infinite horizon (based on the VAR estimation). These results correspond to the impulse-response functions plotted in Figs. 4, 5, 6. Mean monthly unit sales are 588 373 for the American automakers (Chrysler, Ford, and GM) and 123 994 for the Japanese automakers (Honda, Nissan, and Toyota).)

| Company | The impact of a one standard-deviation shock to real | | |
|---|---|---|---|
| | income | dollar/yen exchange rate | oil price |
| | *Panel A: on quantity sold* | | |
| U.S. automakers | 18 172 | 9 005 | −6 703 |
| Japanese automakers | 544 | −1 941 | −445 |
| | *Panel B: on quantity sold as a percentage of mean monthly unit sales* | | |
| U.S. automakers | 3.09 | 1.53 | −1.14 |
| Japanese automakers | 0.44 | −1.57 | −0.36 |

Table 2
Variance decomposition of changes in the quantity of automobiles sold in the U.S. by American and Japanese automakers: January 1973–December 1994. (The numbers presented denote the percentage of the variation of changes in monthly sales that can be attributed to shocks to income, exchange rates, and oil prices.)

| Company | Horizon (months) | Percent due to shocks to | | |
|---|---|---|---|---|
| | | income | exchange rate | oil price |
| U.S. automakers | 0 | 4.02 | 0.48 | 0.16 |
| | 6 | 8.93 | 4.01 | 6.32 |
| | 12 | 9.03 | 4.22 | 6.53 |
| | 24 | 9.04 | 4.22 | 6.54 |
| Japanese automakers | 0 | 1.75 | 0.27 | 0.01 |
| | 6 | 4.13 | 3.73 | 2.08 |
| | 12 | 4.27 | 3.92 | 2.41 |
| | 24 | 4.27 | 3.93 | 2.45 |

no indication as to the level of significance of the results. We, therefore, estimated confidence intervals for the impulse-response functions using the Monte-Carlo simulation. The confidence intervals produced are quite large, however, and are therefore difficult to interpret. Within the macroeconomy, the variable responses to their own shocks are bounded by confidence intervals that do not cross zero. The cross-effects, however, begin at zero (by construction) and have confidence intervals that fan out from there. For the response of firms sales quantities to the macroeconomic shocks, the contemporaneous effects tend to be contained within bounds that do not include zero, but then fan out to become fairly large quickly. These types of models, in fact, are known to produce fairly large confidence intervals. Runkle (1987a), Sims (1987), Blanchard (1987), Watson (1987), and Runkle (1987b), all discuss the problematic interpretation of confidence intervals in the types of model that we employ. However, in much the same way that macroeconomists expect the variable shocks to have long-run effects on other variables in the types of system presented above, there is convincing evidence that the shocks also affect firm sales quantities even though the confidence intervals are large.

We also conducted auxiliary analyses to determine if automakers other than the American and Japanese firms are affected by the macroeconomic shocks that we investigate. We estimated a six-variable VAR using the macroeconomic variables, total quantities sold by American, Japanese, and other automakers. In this model, income shocks increase the quantity of sales by all groups (American, Japanese, and others), oil-price shocks decrease the quantity of sales by all groups, and exchange-rate shocks cause a shift away from Japanese sales toward American sales. In response to an exchange-rate shock, sales by firms other than the three American and three Japanese firms are only slightly positively affected in the long-run (by 816 units), so there is no compelling reason to include them in the analysis.

### 5.4. *Additional results*

The results in Section 5.3 represent the main findings of our investigation. To examine the robustness of the results and the influence of other factors, several additional models have been estimated. However, the results of these additional models are substantially similar to the main results, so they are only briefly surveyed here. In particular, in this section we present results by subperiod, models that explicitly allow for differential effects during periods of steep currency appreciation or depreciation to allow for hysteresis in the U.S. automobile market, models that estimate the impact of voluntary export restraints, and models estimated using individual firm sales data.

#### 5.4.1. *Subperiod analysis*

We estimated the five-variable VAR over two subperiods, 1973–83 and 1984–94, in order to examine subsample stability for two reasons. First, at a minimum, the subperiod analysis provides another test of the robustness of our results. Second, and perhaps more importantly, there were significant changes in the environment in which the Japanese and American automakers competed during the second half of our sample period. These changes include the emergence of Japanese production facilities (transplants) in the U.S., large swings in the value of the dollar that may have caused hysteresis, the introduction of voluntary export restraints by the Japanese, and alteration of the product mixes of both American and Japanese automakers, potentially affecting the substitutability between domestic and foreign brands.

We first examined the macroeconomy in the two subperiods and (perhaps surprisingly) concluded that the two subperiods are identical.[13] We next examined the responses of American and Japanese automakers to the macroshocks, restricting the macroeconomy to

[13]The null hypothesis that an unrestricted model with two subperiods is identical to a restricted model for the whole period (imposing equality of coefficients across the two subperiods) cannot be rejected; $\chi^2_{48} = 58$ with a *p*-value of 0.15.

Table 3
The long-run impact of shocks to income, exchange rates, and oil prices on the quantity of automobiles sold in the U.S. by American and Japanese automakers over a subperiod. (The long-run effect represents the impact of a one standard-deviation shock to each of the macroeconomic variables on the quantity of automobiles sold at the infinite horizon (based on the VAR estimation restricting the macroeconomy to be the same across subperiods). From 1973–1983, mean monthly unit sales are 626 561 for the American automakers (Chrysler, Ford, and GM) and 88 332 for the Japanese automakers (Honda, Nissan, and Toyota). From 1984–1994, the means are 550 184 and 159 656, respectively.)

| Company | The impact of a one standard deviation shock to real: | | | | | |
|---|---|---|---|---|---|---|
| | income | | dollar/yen exchange rate | | oil price | |
| | 1973–1983 | 1984–1994 | 1973–1983 | 1984–1994 | 1973–1983 | 1984–1994 |
| | *Panel A: on quantity sold* | | | | | |
| U.S. automakers | 17 060 | 14 759 | 10 715 | 8 344 | −9 204 | −7 556 |
| Japanese automakers | 1 733 | −58 | −1 587 | −1 779 | 221 | −1 827 |
| | *Panel B: on quantity sold as a percentage of mean monthly unit sales* | | | | | |
| U.S. automakers | 2.72 | 2.68 | 1.71 | 1.52 | −1.46 | −1.37 |
| Japanese automakers | 1.96 | −0.04 | −1.80 | −1.11 | 0.25 | −1.14 |

be identical across the two subperiods, and detected some differences between the two subperiods.[14]

To further examine the magnitude of differences, the results of the subperiod analysis are presented in Table 3. Three interesting observations emerge from this analysis. First, the American automakers' sensitivity to income shocks is virtually unchanged in the 1984–1994 subperiod, while the Japanese automakers' sensitivity is less pronounced (Table 3, Panel B, columns 2–3). This is somewhat surprising, since the American automakers were perceived to have changed their product mix to include more small cars during this period as a response to Japanese competition. Second, the impact of exchange rates on the relative competitiveness of American and Japanese automakers has perhaps diminished, but certainly not disappeared, during the 1984–1994 subperiod (Table 3, Panel B, columns 4–5). This is, probably, the result of Japanese transplant operations. Japanese automakers, which produced no cars and trucks in the U.S. until 1982, now assemble 1.4 million of them annually on the American mainland.[15] This reduced reliance on Japanese production facilities has, to some degree, insulated Japanese automakers from the vagaries of the dollar/yen exchange rate. However, the Japanese transplants have imported significant amounts of auto parts from Japanese suppliers, so a strong yen still favors American automakers. Third, the impact of shocks to oil prices on the Japanese and American automakers are quite similar during the 1984–1994 subperiod (Table 3, Panel B, columns 6–7). Apparently, oil shocks benefited the Japanese automakers during the 1973–1983 subperiod. However, as American automakers have introduced more small cars and Japanese automakers introduced more luxury cars (at least partially in response to

[14]The null hypothesis that an unrestricted model with two subperiods is identical to a restricted model for the whole period can be rejected at conventional significance levels; $\chi^2_{74} = 120$ with a $p$-value of 0.00.

[15]*Fortune*, November 16, 1992, p. 52.

voluntary export restraints, Feenstra, 1989), the differential impact of oil price shocks on American and Japanese automakers has virtually disappeared.

This subperiod analysis should be interpreted with caution because the number of degrees of freedom is low. Nevertheless, the results demonstrate that, although the parameters of the model may be different in the two subperiods, the impacts of shocks are remarkably similar across subperiods, validating the robustness of our conclusions.

#### 5.4.2. Hysteresis

*5.4.2.1. Exchange rates*. Baldwin (1988), Baldwin and Krugman (1989), and Dixit (1989) suggest that large exchange-rate shocks can have persistent effects on markets. A sufficiently large appreciation of the domestic currency can induce entry by foreign firms. If the entry cost is a sunk cost, then the subsequent reversal of exchange rates would not induce the firms to exit from the market. Hence, there is hysteresis. During the period of our study, both, the exchange rate and oil prices experienced significant changes. In the case of the dollar/yen exchange rate, there were both secular as well as cyclic changes. The oil price, on the other hand, experienced periods of rapid increases and decreases, yet ended up about where it started during the period of our study. Thus, we examined whether hysteresis might be able to explain the market share gains experienced by the Japanese over the two decades covered by our analysis.

Before proceeding, we should note that the theoretical models of hysteresis are couched in terms of sunk costs of entry. Since the Japanese automakers were already in the U.S. market by 1972, these models do not apply to our study in their purest form. One relevant question is whether the establishment of transplants induced hysteresis. Thus, we interpret the notion of hysteresis in a broader sense and examine whether a large exchange rate movement caused any asymmetric effect on the auto market shares in the U.S. without specifying the exact mechanism through which such effects take place.

To test for hysteresis, we identified a subperiod of significant dollar appreciation (October 1978–October 1982) that was undone during a subsequent subperiod of dollar depreciation (November 1982–November 1987). (We discuss later why this ex-post selection of subperiods most likely overstates the effect of hysteresis.)[16] Hysteresis would predict large gains (losses) by the Japanese (American) automakers during the period of dollar appreciation, which are not reversed during the period of dollar depreciation. We tested for these effects by constructing two dummy variables: one for the subperiod of dollar appreciation and another for the subperiod of dollar depreciation. These two dummy variables were then interacted with the exchange rate data in our vector autoregressions, allowing for differential coefficients on exchange rates during these periods. Thus, the model allows for asymmetric responses to exchange-rate shocks during the two subperiods.

To evaluate whether hysteresis during the two subperiods can explain the large change in market share, we used the dummy-variable model described above to estimate the units sold by the American and Japanese automakers as if there were no shocks to exchange rates between October 1978 and November 1987. The Japanese (American) automakers held an

[16] The real dollar/yen exchange rate was 0.007875 in October 1978 and fell to 0.004394 in October 1982. The real dollar/yen exchange rate was up to 0.007909 in November 1987. See Fig. 2.

average monthly market share during 1973 of 5.7 percent (94.3 percent). In 1994, the average Japanese (American) market share was 26.2 percent (73.8 percent). Consistent with the prediction of hysteresis, our results indeed indicate that the Japanese (American) automakers gained (lost) more during the period of dollar appreciation than they lost (gained) during the period of dollar depreciation. The results of this counterfactual analysis reveal that the Japanese (American) market share would have been 19.7 (80.3 percent) in 1994 in the absence of the large swings in exchange rates. Yet, even if we attribute all of the asymmetry in the response to exchange rates during our two subperiods to hysteresis, we can only explain less than half of the market share gains experienced by the Japanese automakers.

In this analysis, we gave hysteresis the best possible chance to explain the changes in market share for two reasons. First, we identified ex-post a period of dollar appreciation followed by dollar depreciation, which would favor the Japanese automakers. Thus, these results can clearly be criticized as data mining. In fact, during our sample period, there is an equally striking period of dollar depreciation (from November 1976 to October 1978) followed by dollar appreciation (from November 1978 to March 1980), which would favor the American automakers. Yet, during these two subperiods, we find no evidence of hysteresis gains by the American automakers. Second, the hysteresis effects might be due partially to the asymmetry in shocks to exchange rates themselves. The changes in exchange rates are, by construction, symmetric. However, two-thirds of the dollar appreciation is due to unanticipated exchange-rate shocks, while only one-third of the dollar depreciation is due to unanticipated exchange-rate shocks. Thus, even in the absence of hysteresis effects, the Japanese would be expected to gain market share during this cycle of dollar appreciation and depreciation.

In sum, when liberally interpreted, we find some evidence of hysteresis in the U.S. automobile market due to exchange-rate changes. Yet, at best, hysteresis can only partially explain the Japanese gains in market share during our sample period.

*5.4.2.2. Oil prices*. There were also wide swings in oil prices during our period of analysis. From December 1978 to March 1981, the real price of oil rose from \$18.266 to \$51.228 per barrel, then fell below \$18 in March 1986 (see Fig. 2). If, during the period of oil-price increases, consumers switched from gas-guzzling American cars to fuel-efficient Japanese cars and developed a newfound taste for Japanese cars, we would observe a hysteresis effect from these large swings in oil prices.

Empirically, we tested for hysteresis due to oil prices in the same manner as hysteresis due to exchange rates. We constructed two dummy variables: one for the subperiod of oil price increases and one for the subperiod of oil price declines. We then estimated vector auto-regressions using these subperiod dummy variables. This empirical analysis, however, did not reveal any hysteresis effects of oil price changes. Thus, the popular notion that the U.S. consumers dropped their allegiance to U.S. cars in response to sharp oil-price increases does not hold at least during this period in which the largest oil-price increase took place.

### *5.4.3. Do voluntary export restraints (VERs) matter?*

We extend our analysis to evaluate the impact of the Japanese voluntary export restraints (VERs) introduced in 1981. The effect of VERs on sales quantities remains unresolved in the economics literature. Gagnon and Knetter (1995) find that pass-through did not substantially change from a 1973–1980 period to a 1981–1987 period, suggesting that the overall effect of VERs was modest. Although introduced in 1981, the recession in the U.S. probably meant that VERs were not initially binding. Goldberg (1995) reports that VERs were binding in 1983 and 1984 (even though the VER was increased between these two years). In contrast, Berry et al. (1995), utilizing dummy variables to capture the effect of the tariff implicit in the VER on automobile prices, find that VERs were most binding in 1986–1988. By this time, however, Japanese transplant operations in the U.S. (not subject to VERs) were fully operational: Honda started production in Ohio in 1982, Nissan started production in Tennessee in 1985, and Toyota started production at its joint venture with GM in 1985. Levinsohn (1994), p. 349) suggests that, while the VER may have been binding, "the marginal car was being produced in the U.S., where production was not constrained." Thus, there is disagreement over the ultimate effects of VERs on competition between American and Japanese automakers in the U.S. market.

In our analysis, we first examined subperiods for 1973–1980 and 1981–1994 to introduce a break upon the introduction of VERs. For the 1973–1980 and 1981–1994 subperiods, the results are similar to those reported in Table 3. To further consider the effects of VERs, we examined several combinations of annual dummy variables in the VARs for the periods in which VERs were imposed. The dummy variables are designed to capture supply shifts for the Japanese automakers and demand shifts for the American automakers. We tested many combinations of dummy variables over the period 1981 (the introduction of VERs) through 1992 (when Japan officially dropped VERs), with particular attention to the periods when other research suggests that the VERs were binding. However, none of the regressions produced statistically significant coefficients on the dummy variables (except for two instances when the coefficient had the wrong sign). Hence, we find no evidence that VERs deterministically altered the quantities of automobiles sold in the U.S. One reason for this is that the effects of VERs on quantities sold, if there are any, may be relatively small. Alternatively, the effects of VERs may be varying over time such that they are incorporated into the VAR as a part of the firm-specific shocks.

#### *5.4.4. Individual firm models*

As another way of examining the effects and importance of macroeconomic shocks, we estimated several models using data on the quantities of automobiles sold by each of the six largest individual firms: GM, Ford, Chrysler, Honda, Nissan, and Toyota. This disaggregation provides another check on the robustness of the main results, because it provides three observations each on both, the American and the Japanese manufacturers.

We first estimated nine-variable VARs with the three macroeconomic shocks and each firm's sales quantity. These models provide further confirmation of the results already reported, both with respect to the magnitude of effects in the impulse response functions and with respect to the importance of the shocks in the variance decompositions. Table 4 presents the long-run impact of shocks on quantity sold by each of the six firms. In response to an income shock, five of the six automakers increase sales (and the loss by Nissan is quite small). In response to an exchange-rate shock, each of the three Japanese automakers loses, while each of their three American counterparts gains sales. In response to an oil-price shock, each of the three American automakers loses sales; in contrast, Nissan and Toyota

Table 4
The long-run impact of shocks to income, exchange rates, and oil prices on the quantity of automobiles sold in the U.S. by the largest American and Japanese automakers: January 1973–December 1994. (The long-run effect represents the impact of a one standard-deviation shock to each of the macroeconomic variables on the quantity of automobiles sold at the infinite horizon (based on the VAR estimation).)

| Company | The impact of a one standard-deviation shock to real: | | |
|---|---|---|---|
| | income | dollar/yen exchange rate | oil prices |
| | *Panel A: on quantity sold* | | |
| Chrysler | 3 020 | 1 683 | −1 188 |
| Ford | 5 262 | 2 245 | −1 772 |
| GM | 9 483 | 5 079 | −4 405 |
| Honda | 15 | −116 | −514 |
| Nissan | −51 | −717 | 172 |
| Toyota | 341 | −740 | 100 |
| | *Panel B: on quantity sold as a percentage of mean monthly unit sales* | | |
| Chrysler | 3.45 | 1.92 | −1.36 |
| Ford | 3.16 | 1.35 | −1.06 |
| GM | 2.84 | 1.52 | −1.32 |
| Honda | 0.04 | −0.29 | −1.27 |
| Nissan | −0.14 | −1.96 | 0.47 |
| Toyota | 0.72 | −1.57 | 0.21 |

gain sales, while Honda loses sales. Hence, the firm-specific results indicate that one or two firms do not drive results on using data aggregated by nationality.

We also examined a series of VARs for each individual firm: both a four-variable VAR of the three macrovariables and the specific firm's sales quantity and a five-variable VAR of the macrovariables, the specific firm's sales, and sales by all other firms. These results all confirmed the results of the nine-variable model, and thereby suggest that the firms' responses to shocks are robust to changes in the exact specification of the VAR. Furthermore, the results of the four-variable model are similar enough to the five-variable and nine-variable models to suggest that examining individual firms and excluding competing firms in the market captures all the important effects of macroeconomic shocks; cross-firm effects are not essential.

One other set of results is based on individual firm models of five-variable VARs in which the three macroeconomic variables are combined with separate series for the firm's U.S.-produced automobiles and imported automobiles. For Japanese automakers, this separates transplants from imports. For American automakers, this separates domestic production from the 'captive imports' – cars produced abroad and imported for sale in the U.S. market by Chrysler, Ford, and GM. This decomposition does not offer many insights, however, because the phenomena of transplants and captive imports are recent and still small. In particular, although the firm effects from the exchange-rate shock are generally correct, it does not appear that an exchange rate shock affects the imported cars any more than the same firm's U.S.-produced cars. This may indicate that there is little difference between production of a U.S.-produced car and a similar imported car, perhaps due to a common origin of the parts for both cars. However, the results for Japanese firms do suggest why the responses to income shocks are so small: imports rise but U.S. production falls. This may be because, with the introduction of transplant operations, imports represent larger luxury cars, whereas the transplants represent smaller budget cars.

## 6. Conclusion

This paper studies the effects of macroeconomic shocks – particularly exchange-rate and oil-price shocks – on the relative competitiveness of American and Japanese manufacturers selling in the U.S. automobile market. We first develop a simple linear-quadratic model of firms choosing optimal quantities of sales to investigate the comparative statics of long-run equilibrium. This model is next expressed as a structural vector autoregression (VAR), so that an empirical investigation can identify the structural parameters from a reduced-form VAR. In selecting this methodology, we exploit results from the literature on foreign exchange exposure, which suggest that lagged effects are typically more important than contemporaneous effects. This econometric technique focuses attention on dynamics, and allows for short-run deviations from long-run equilibrium. In addition, it examines unanticipated shocks to the macroeconomy, rather than the actual changes in the variables, and how such shocks affect the quantity of automobiles sold by firms contemporaneously and over time. Using simple contemporaneous identifying restrictions of the type developed by Bernanke (1986) and Sims (1986), all the long-run parameters are shown to have the signs predicted by the model, with generally reasonable magnitudes. We focus on the impacts to quantities of vehicles sold in order to make inferences about the relative market shares of American and Japanese competitors. We summarize three major empirical findings of our research.

First, favorable shocks to income substantially increase the quantities of automobiles sold by American automakers, but only modestly increase the quantity of automobiles sold by Japanese manufacturers. This result, which is more pronounced in the most recent subperiod that we analyze (1984–1994), indicates that American automakers gain market share during periods of real income growth in the U.S.

Second, exchange-rate shocks representing yen appreciation reduce the quantity sold by Japanese automakers in the U.S. market. Thus, the small price changes documented previously in the pass-through literature (e.g. Goldberg, 1995) have demonstrable effects on the quantity sold by Japanese firms, suggesting that demand is relatively elastic. Furthermore, these exchange-rate shocks translate into market share gains by the American automakers, since the quantity sold increases following yen appreciation.

Third, oil-price increases have historically reduced the quantities sold by American manufacturers, but have had little effect on Japanese manufacturers. The exposure of American automakers to oil-price shocks is most evident in the 1973–1983 subperiod. However, in the most recent subperiod (1984–1994) analyzed, American and Japanese firms are not systematically different. Thus, though historically important in the initial market share gains experienced by the Japanese, oil-price shocks no longer favor the Japanese (or American) automakers.

In addition to measuring the magnitudes of the effects of macroeconomic variables on firms' sales quantities, the VARs also suggest that the importance of these effects relative to overall changes in sales quantities is moderate. Variance decompositions suggest that the macroeconomic shocks are more important for the American manufacturers than for the

Japanese manufacturers. For the American automakers, the macroeconomic shocks account for nearly 20 percent of the forecast error variance at the one- and two-year horizons. For the Japanese automakers, the macroeconomic shocks account for a little more than 10 percent of the forecast error variance at the one- and two-year horizons. The remaining variance is due to the firm-specific shocks that we do not separately identify. Managers should be concerned about the macroeconomic variables, however, because they account for an important source of uncertainty over future sales.

Although this research documents that income, exchange rates, and oil prices are important factors in determining the quantities of automobiles sold by American and Japanese manufacturers, these macroeconomic variables cannot explain the actual market-share gains experienced by Japanese firms (and the market-share losses by American firms) during the 1973–1994 period. The actual changes in the macroeconomic variables have generally favored the American automakers, so the Japanese automakers have gained market share *despite* a generally unfavorable macroeconomic environment. Income has steadily increased during this period – a favorable development for American automakers. The yen has generally appreciated relative to the dollar during this period – again, a favorable development for American automakers. And real oil prices are no different at the end of the period from those at the beginning of the period. Although dramatic increases in oil prices during 1973–1974 and 1979–1980 led to increased market share by Japanese automakers, these short-run increases in oil prices cannot explain the large market share that the Japanese automakers continue to hold in the 1990s. Ultimately, we conclude that although the macroeconomic environment is an important consideration in assessing the relative competitiveness of American and Japanese automakers, firm-specific policies account for the bulk of market share gains and losses experienced by the Japanese and American automakers.

## Acknowledgements

We are grateful for the comments of Barbara Alexander, Peter Clark, Lisa Cook, Joshua Coval, Kathy Dewenter, Robert Feenstra, Linda Goldberg, Richard Henricsson, Ken Kasa, Ryuzo Sato (the Editor), Adrian Tschoegl, Robert Weiner, two anonymous reviewers, and seminar participants at UC-Davis, Clark, George Washington, the 1996 Multinational Finance Society meetings, the 1996 Academy of International Business meetings, and the 1998 American Economic Association meetings. All errors are our own.

## Appendix A

### Relationship between exchange rate and total equilibrium quantity

This appendix provides the proof that total equilibrium quantity decreases as the exchange rate increases.

Rewrite the Euler equations in Eq. (5) as:

$$E_0\left\{\begin{bmatrix}\Gamma_i & b_{ij}\\ b_{ji} & \Gamma_j\end{bmatrix}\begin{bmatrix}Q_{it}\\ Q_{jt}\end{bmatrix}\right\}=\begin{bmatrix}K_i\\ K_j\end{bmatrix}$$

Then the long-run equilibrium quantity chosen by firm $i$, expressed by Eq. (6), is simplified as

$$Q_{it} = \frac{2K_i(b_{ij} + d_j) - b_{ji}K_j}{\Gamma_i\Gamma_j - b_{ij}b_{ji}}.$$

Since a change in the exchange rate, $e_t$, affects the cost of production of (possibly) both firms, we have

$$\frac{dQ_{it}}{de_t} = \frac{\partial Q_{it}}{\partial K_i}\frac{\partial K_i}{\partial e_i} + \frac{\partial Q_{it}}{\partial K_j}\frac{\partial K_j}{\partial e_t}$$

But,

$$\frac{\partial K_i}{\partial e_t} = -f_i,$$

$$\frac{\partial K_j}{\partial e_t} = -f_j,$$

$$\frac{\partial Q_{it}}{\partial K_i} = \frac{2(b_{jj} + d_j)}{D},$$

$$\frac{\partial Q_{it}}{\partial K_j} = \frac{-b_{ji}}{D},$$

where $D=\Gamma_i\Gamma_j-b_{ij}b_{ji}$. Thus,

$$\frac{d\boldsymbol{Q}_t}{de_t} = -\frac{\Gamma_j}{D}f_i + \frac{b_{ij}}{D}f_j + \frac{b_{ji}}{D}f_i - \frac{\Gamma_i}{D}f_j = -\frac{1}{D}\{(\Gamma_j - b_{ji})f_i + (\Gamma_i - b_{ij})f_j\} < 0,$$

since $\Gamma_j=b_{jj}+d_j$, $\Gamma_i=b_{ii}+d_i$, $b_{jj}>b_{ji}$, and $b_{ii}>b_{ij}$.

A completely analogous proof applies to the case of oil price.

## Appendix B

## Derivation of Eq. (11)

This appendix provides the details for the derivation of Eq. (11) in the main text. The moving average representation of the macroeconomy in Eq. (10) is:

$$\begin{bmatrix} Y_t \\ e_t \\ O_t \end{bmatrix} = \begin{bmatrix} \mu_{yy}(L) & \mu_{ye}(L) & \mu_{yo}(L) \\ \mu_{ey}(L) & \mu_{ee}(L) & \mu_{eo}(L) \\ \mu_{oy}(L) & \mu_{oe}(L) & \mu_{oo}(L) \end{bmatrix} \begin{bmatrix} u_{yt} \\ u_{et} \\ u_{ot} \end{bmatrix},$$

where the three-by-three matrix of polynomially distributed lags, denoted by $\mu$'s, is the inverse of the matrix of polynomially distributed lags, denoted by $\rho$'s in Eq. (10). Again, the contemporaneous parameters of the polynomially distributed lags form the identity matrix.

Though the firm-specific shocks to firm $i$ and $j$ in Eq. (5) ($v_{it}$ and $v_{jt}$) are assumed orthogonal, they may be serially correlated. By specifying the time-series processes, we can isolate the innovations in the firm-specific shocks (denoted by $u_{it}$ and $u_{jt}$):

$$\rho_i(L)v_{it} = u_{it}$$
$$\rho_j(L)v_{jt} = u_{jt},$$

where $\rho_i(L)$ and $\rho_j(L)$ are polynomial distributed lags with contemporaneous parameters equal to one.

Solutions to the system of Euler equations in Eq. (5) utilize the moving average representation of the macroeconomy and the autoregressive properties of the firm specific shocks. (See Chapter XI of Sargent (1987) for details.) Therefore, there exist autoregressive moving-average (ARMA) representations for $Q_{it}$ and $Q_{jt}$ such that:

$$\begin{bmatrix} \alpha_{ii}(L) & \alpha_{ij}(L) \\ \alpha_{ji}(L) & \alpha_{jj}(L) \end{bmatrix} \begin{bmatrix} Q_{it} \\ Q_{jt} \end{bmatrix} = \begin{bmatrix} \lambda_{iy}(L) & \lambda_{ie}(L) & \lambda_{io}(L) \\ \lambda_{jy}(L) & \lambda_{je}(L) & \lambda_{jo}(L) \end{bmatrix} \mu \begin{bmatrix} u_{yt} \\ u_{et} \\ u_{ot} \end{bmatrix}$$
$$+ \begin{bmatrix} \lambda_{ii}(L) & \lambda_{ij}(L) \\ \lambda_{ji}(L) & \lambda_{jj}(L) \end{bmatrix} \begin{bmatrix} \rho_i(L)^{-1} & 0 \\ 0 & \rho_j(L)^{-1} \end{bmatrix} \begin{bmatrix} u_{it} \\ u_{jt} \end{bmatrix},$$

where $\mu$ is the three-by-three matrix of polynomial distributed lags from the moving average representation of the macroeconomy. The $\alpha$ and $\lambda$ parameters are polynomial distributed lags with unrestricted contemporaneous parameters, since the contemporaneous impact of the three macroeconomic shocks and firm-specific shocks on quantity depends on the parameters of the theoretical model (each firm's sensitivity to income, exchange rates, and oil prices, cross-substitution effects, own-price effects, etc.).

Combining the moving average representation of the macroeconomy with the ARMA representation of the quantity sold by firms $i$ and $j$ yields the 'law of motion' of the vector $X_t$:

$$A(L)X_t = B(L)C(L)u_t,$$

which is Eq. (11) in the main text, where

$$X_t' = [Y_t, e_t, O_t, Q_{it}, Q_{jt}],$$
$$u_t' = [u_{yt}, u_{et}, u_{ot}, u_{it}, u_{jt}].$$

From the time series representation above, it is clear that:

$$A(L) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \alpha_{ii}(L) & \alpha_{ij}(L) \\ 0 & 0 & 0 & \alpha_{ji}(L) & \alpha_{jj}(L) \end{bmatrix}.$$

$$B(L) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ \lambda_{iy}(L) & \lambda_{ie}(L) & \lambda_{io}(L) & \lambda_{ii}(L) & \lambda_{ij}(L) \\ \lambda_{jy}(L) & \lambda_{je}(L) & \lambda_{jo}(L) & \lambda_{ji}(L) & \lambda_{jj}(L) \end{bmatrix},$$

and

$$C(L) = \begin{bmatrix} \mu_{yy}(L) & \mu_{ye}(L) & \mu_{yo}(L) & 0 & 0 \\ \mu_{ey}(L) & \mu_{ee}(L) & \mu_{eo}(L) & 0 & 0 \\ \mu_{oy}(L) & \mu_{oe}(L) & \mu_{oo}(L) & 0 & 0 \\ 0 & 0 & 0 & \rho_i(L)^{-1} & 0 \\ 0 & 0 & 0 & 0 & \rho_i(L)^{-1} \end{bmatrix}.$$

## Appendix C

## Data, stationarity and co-integration

This appendix summarizes the data and examines stationarity and co-integration.

### *A.1 Data*

The model uses monthly data on the quantity of automobiles sold and the three macroeconomic indicators for the period from January 1973, through December 1994. Descriptive statistics are presented in Table 5.

Data on the quantity of automobiles sold (U.S. new dealer car sales) are from *Ward's Automotive Yearbook*. We use these quantity data for the three largest American automakers (aggregating Chrysler, Ford, and GM) and the three largest Japanese automakers (aggregating Honda, Nissan, and Toyota).

We use three macroeconomic variables in the model. Monthly real GDP in 1990 dollars is calculated from the quarterly real GDP series in *International Financial Statistics* interpolated within quarters using the monthly industrial production index from the same source. The real exchange rate is in cents/yen and is calculated as the average nominal exchange rate for the month times the ratio of the monthly CPI for Japan to the monthly CPI for the United States (both with a base year of 1990). The exchange rate and CPI series are

Table 5
Descriptive statistics on real gross domestic product, real dollar/yen exchange rates, real oil prices, and monthly automobile sales in the US by selected American and Japanese auto companies: January 1973–December 1994. (All three macroeconomic series are expressed in 1990 real dollars. Real GDP is calculated by interpolating the quarterly real GDP series using the monthly industrial production index. Real oil prices are the US wellhead average oil price (dollars per barrel), as recorded by the Department of Energy, deflated by the CPI. The real exchange rate is calculated by multiplying the nominal rate by the ratio of the CPI for Japan to the CPI for the U.S. The quantities of automobiles sold are taken from Ward's Automobile Yearbook and represent U.S. new dealer car sales.)

| | Mean | Median | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Real GDP ($ billions) | 4 708.2 | 4 583.9 | 736.8 | 3 509.5 | 6 213.3 |
| Real dollar/yen exchange rate ($\times$100) | 0.631 | 0.606 | 0.144 | 0.406 | 0.958 |
| Real oil prices ($/barrel) | 21.80 | 18.30 | 9.60 | 9.30 | 51.23 |
| U.S. automakers quantity sold | 588 373 | 571 720 | 130 754 | 347 040 | 953 938 |
| Japanese automakers quantity sold | 123 993 | 128 890 | 46 113 | 25 226 | 222 994 |

Table 6
Augmented Dickey–Fuller (ADF) unit root tests

| Series | Levels | | | Differences | |
|---|---|---|---|---|---|
| | specification | $\rho$ | ADF test | specification | ADF test |
| Oil price | trend | 1.00 | 0.04 | 1 lag | −9.68 [b] |
| Exchange rate | trend, 1 lag | 0.97 | −2.53 | | −12.11 [b] |
| GDP | trend | 0.97 | −0.76 | 2 lags | −8.92 [b] |
| U.S. automakers | 4 lags | 0.91 | −2.60 [a] | 3 lags | −12.27 [b] |
| Japanese automakers | 2 lags | 0.96 | −2.11 | 3 lags | −10.61 [b] |

[a] Significant at the 10 percent level.
[b] Significant at the 5 percent level.

also from *International Financial Statistics*. Data on oil prices are from the Department of Energy and represent the average U.S. wellhead price of oil in dollars per barrel. The nominal oil price is deflated by the U.S. CPI.

### 6.2. *Unit root tests*

The data series have been checked for stationarity using Augmented Dickey–Fuller (ADF) unit root tests, which are summarized in Table 6. The macroeconomic data have been examined as presented, with the ADF test allowing for a time trend. The automobile sales data have been examined by first removing deterministic monthly components. The ADF tests generally reveal that the variables are nonstationary in levels but stationary in first differences. This suggests that the vector autoregression should be run in first differences, which provide for permanent responses to the exogenous shocks.

### 6.3. *Co-integration tests*

Although the data series are individually stationary only after differencing, there may be a linear combination of the series that is stationary without differencing. In this situation, the variables are co-integrated and estimating a vector autoregression in first differences, as proposed in the text, is inappropriate. Instead, when the variables are co-integrated, an error-correction model imposing the co-integrating relationship in a vector autoregressive model in differences should be estimated. The theory and empirical methodology in the paper are designed for a structural vector autoregression because such a framework enables us to impose restrictions based on the structural relationships in the theory in order to extract empirical estimates of responses to shocks. Since the theory does not provide an exact co-integrating relationship, the error-correction model would require imposing atheoretical constraints that may not be sensible. We, therefore, briefly consider some simple co-integration tests in order to confirm that the vector autoregression in differences is appropriate. The series have been tested using the Engle–Granger methodology, which estimates the long-run equilibrium co-integrating vector and checks the residuals from the regression for stationarity. The test results are summarized in Tables 7 and 8.

Table 7
Engle–Granger co-integration tests for macroeconomic variables

| Dependent variable | Specification | $\rho$ | ADF test |
|---|---|---|---|
| Oil price | 2 lags | 0.96 | −2.86 |
| Exchange rate | 1 lag | 0.94 | −3.32 [a] |
| GDP | 1 lag | 0.94 | −2.44 |

[a] Significant at the 10 percent level.

Table 8
Engle-Granger co-integration tests for five-variable system

| Dependent variable | Specification | $\rho$ | ADF test | Co-integrating vector (omitting constant) |
|---|---|---|---|---|
| Oil price | | 0.86 | −4.16 [a] | |
| Exchange rate | 1 lag | 0.94 | −3.32 | |
| GDP | | 0.72 | −6.38 [b] | |
| U.S. Sales | 3 lags | 0.83 | −3.51 | 5 712; 40.201; 0.161; 1.000; −1.185 |
| Japansese sales | | 0.60 | −7.86 [b] | −1 197; 4 310; −0.063; −0.042; 1.000 |

[a] Significant at the 10% level.
[b] Significant at the 5% level.

The three macroeconomic variables were first checked for co-integrating relationships among themselves. The ADF statistics in Table 7 are compared to the critical values in Engle and Yoo (1987), which reports critical values of 3.37 and 3.02 for the 5 and 10 percent levels, respectively, with a sample size of 200 observations in a system of three variables. The ADF tests, therefore, suggest that the macroeconomic variables are not co-integrated. This implies that the three macroeconomic variables can move independently of each other, which is not surprising since there is no obvious theory positing a long-run equilibrium linkage.

Next, the five variables taken together were checked for co-integration. The results here are less conclusive, partially because the ADF statistics are difficult to interpret when the exact co-integrating vector is not known. The problem is that the regression residuals are estimates of errors from an estimated long-run equilibrium relationship rather than actual errors of a known or hypothesized relationship, so the ADF statistics are biased upward. Our theoretical model considers a long-run equilibrium solution for sales as a function of the exogenous macroeconomic variables, firm-specific shocks, and various parameters in the demand and supply functions. This provides signs on the long-run comparative statics of sales with respect to changes in the exogenous macroeconomic variables, but does not specify exact coefficients. Furthermore, the model does not provide specific information on comparative statics with respect to the other firm's sales (although it does with respect to the other firm's sales shocks). Hence, the theoretical model does not specify an exact co-integrating vector. Engle and Yoo (1987) addresses this problem and presents critical values for ADF tests.

The ADF statistics for the five normalizations of the five-variable system, provided in Table 8, are compared to the critical values provided in Engle and Yoo (1987) for systems of five variables, which are 3.89 at the 10 percent significance level, 4.18 at the five percent level, and 4.70 at the one percent level. The results in Table 8 are generally inconclusive: two statistics are above the critical values and two are below the critical values, and one depends on the significance level chosen. With large sample sizes, all normalizations would produce the same conclusions, but there is clearly mixed evidence on co-integration in our sample.

One additional source of guidance is based on an examination of the estimated co-integrating vectors themselves, which are also presented in Table 8 for all but the first three dependent variables (which we consider unnatural normalizations). For normalizations around a firm's sales quantity, the theoretical model implies the following signs in the co-integrating vector: positive on oil price for U.S. firms and uncertain for Japanese firms, negative on exchange rate for U.S. firms and positive for Japanese firms, negative on GDP, and positive on the other firm's sales (here assuming that an additional car sold by the competing firm at least partially reduces the sales of a given firm). Using these qualitative implications, we examined the co-integrating vectors to decide whether they appear reasonable. A majority of the signs on coefficients in the co-integrating vector are inconsistent with the theory presented, so the possible co-integrating vectors do not reveal a long-run relationship that we are comfortable using. Hence, imposing these estimated co-integrating vectors in the absence of an appropriate theory is not prudent.

By design, our theoretical model is much better suited for the simpler VAR in differences than for the error-correction model. Based on the ambiguity of the simple tests for co-integration, along with the dubiousness of the estimated co-integrating vectors, we therefore conclude that the series are not co-integrated so that a VAR in differences is appropriate. The implication of running the model as a VAR in differences is that the five variables can move independently of each other. Although this can be defended by wanting to avoid imposing an atheoretical long-run equilibrium, it can also be defended by pointing out that there are variables not included in the system. Omission of other macroeconomic variables, such as wage levels and productivity factors, or firm-specific variables (such as capital intensity or labor productivity) provides a reason for our five variables to be allowed to move independently of each other. Furthermore, there are other firms selling (or potentially selling) in the U.S. market, and omission of these firms provides an additional reason for sales by U.S. and Japanese firms to move independently of each other. Quite simply, our theory does not necessarily suggest that the sales quantities of individual firms cannot move independently of one another in the long-run equilibrium.

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