Interest Rates and the Market for New Light Vehicles*

Adam Copeland
Federal Reserve Bank of New York†
George Hall
Brandeis University‡
Louis Maccini
Johns Hopkins University§

August 6, 2018

Abstract

We study the impact of interest rates changes on the demand and supply of new light vehicles in an environment where consumers and manufacturers face their own interest rates. Interest rate changes impact the auto market through both households and manufacturers. For the impact of rate changes on price and output growth, the household channel is quantitatively more important. A 100 basis-point increase in both interest rates causes annual growth rates of production to fall from 1.0 to -11.0 percent and sales to fall from 1.0 to -2.9 percent in the short run.

Keywords: interest rates, automobiles, inventories, Bayesian maximum likelihood.
JEL classification numbers: E44, G31.

*We thank James Kahn, Adrian Pagan, and numerous seminar participants for thoughtful comments. The views expressed do not represent the views of the Federal Reserve Bank of New York or the Federal Reserve System.

†Assistant Vice President, Research Group, Federal Reserve Bank of New York, 33 Liberty Street, New York, NY 10045; phone (212) 720-7490; email: adam.copeland@ny.frb.org

‡Professor, Department of Economics, Brandeis University, 415 South Street, Waltham, MA 02454-9110; phone: (781) 736-2242; email: ghall@brandeis.edu

§Professor Emeritus, Department of Economics, Johns Hopkins University, 3400 N. Charles Street, Baltimore, MD 21218; phone: (410) 322-9589; email: maccini@jhu.edu

1 INTRODUCTION

This paper measures the dynamic response of real prices, sales, production, and inventories to exogenous changes in real interest rates for a particular durable goods market—new cars and light trucks. Understanding how the demand and supply of a durable good are impacted by changes in interest rates is an important issue in economics; indeed the market for durable goods is a key channel through which monetary policy affects the real economy.

Changes in real interest rates affect both sides of the market for durable goods. For consumers who purchase durable goods on credit, higher real rates increase the cost of borrowing, inducing a decline in demand. Hence, sales and real prices should fall. Depending on the speed with which manufacturers reduce production in response to this shock, inventories may rise or fall in the short run. We refer to the effect of higher real interest rates on consumer purchases of durable goods as the *household expenditure channel*. For manufacturers of durable goods, higher real interest rates raise the cost of holding inventories, inducing them to economize on inventories by cutting real prices to raise sales and by reducing production. However, if higher inventories facilitate sales by making it easier for consumers to be matched with the precise product they want, the reduction in inventories will dampen sales. Hence, the overall impact of higher real interest rates on manufacturers' sales is ambiguous. We refer to the effect of higher real interest rates on durable goods producers as the *firm inventory channel*. These countervailing forces suggest that the responses of sales and inventories to changes in interest rates may be nonmonotonic, helping explain why previous research has found little effect of real interest rates on these two variables in durable goods markets.

We analyze how changes in real interest rates affect the U.S. market for new cars and light trucks through the household expenditure and firm inventory channels. New motor vehicles are the quintessential durable good comprising a little over 25 percent of all durable goods expenditures by U.S. households. Furthermore, given the industrial organization of the market for new vehicles, we expect interest rates to affect both sides of the market. On the supply side, the vast majority of automobiles are built to stock, with the typical dealer holding three months of sales in inventory. Because interest rates are an important component of inventory holding costs, theory suggests that firms will reduce inventory levels in response to increases in interest rates.[1] On the demand side, higher real interest rates raise the total cost of buying a vehicle for many consumers. In addition, the purchase of any durable good has an intertemporal component; the more the consumer discounts the future, the lower the return is to the consumer from buying the good in the present period. Consequently, we expect higher interest rates to dampen consumer demand. Although the automobile market is well suited for assessing the responses of both firms and consumers to interest rate changes, the mechanisms we identify should apply to other durable goods industries as well.

We construct a dynamic model of the market for new automobiles that embeds these two channels. On the demand side, the model consists of a representative household that incurs shopping costs when deciding on which cars to purchase and chooses between overall purchases of new automobiles and other consumption goods to maximize its discounted flow of expected utility. The household faces a stochastic interest rate, and to keep our analysis focused on the auto market, we require the household to finance a fixed fraction of their new car purchases and repay these loans over time. On the supply side, the model consists of a representative producer of new automobiles. This firm is a monopolistic competitor that maximizes the discounted flow of expected profits. The firm faces a stochastic interest rate and holds inventories to smooth production and facilitate sales.[2] Specifically, higher available supply—that is, beginning-of-period inventories plus current production—reduces the households' shopping costs. The solution of our model determines the equilibrium real prices, sales, and output of new cars.

There are high-quality data on automobiles, from total sales and output by producers to household expenditures on automobiles. Combining these time series with data on interest rates faced by producers and by households, we construct a monthly dataset from 1972 to 2011. With these data, we estimate our model by means of a Bayesian maximum likelihood procedure. As evidence of goodness of fit, we demonstrate that our estimated model successfully replicates results from recursive vector autoregressions, which indicate that an increase in interest rates paid by households and firms generates a modest but significant reduction in both the ratio of output to sales and the ratio of available supply to sales.

We first consider the relative importance of the household expenditure and firm inventory channels by considering a shock to only household rates and, separately, to only firm rates. We find that a shock to the households' interest rates has a much larger negative impact on price and output growth than a shock to the firms' interest rate. Hence, along these dimensions we find that the household channel has a greater impact compared to the firm channel. Further, there is a differential impact on sales growth; a shock to the households' interest rate causes sales growth to immediately fall and then slowly return to steady state, whereas a shock to firms' interest rate causes sales growth to spike up and then fall below its steady state value.

We then consider the impact of a joint shock to both interest rates. A 100 basis-point increase in both interest rates causes the annual growth rate of automobile production to fall from a steady state of 1.0 to -11.0 percent and sales to fall from a steady state of 1.0 to -2.9 percent in the short run. Since production falls by more than sales, available supply relative to sales also decreases. If we assume that 17 million new cars and light trucks are produced and sold in the United States each year, this response translates into about 180,000 fewer cars produced and 112,500 fewer cars sold over the following twelve months after the shock, relative to the steady state growth path. The growth rate of sales remains below its steady state for ten months; for many months thereafter, sales growth slightly exceeds its steady-state rate and only slowly drops back to the steady state. Our theory implies that firm-side and consumer-side responses reinforce each other in the equilibrium and that inventories play a key role in amplifying the impact on sales. Nevertheless, since both output and sales fall, the impact of higher interest rates on the ratio of available supply to sales is small. Overall, then, we find that changes in the interest rates faced by firms and consumers have a significant impact on the automobile market at the monthly frequency.

We build on a substantial literature on the market for automobiles. The vast majority of studies focus on either the consumer/demand side or the firm/supply side. On the demand side, much of the work focuses on the role of credit constraints in the auto loan market. Examples are Chah, Ramey, and Starr (1995); Alessie, Devereux, and Weber (1997); Ludvigson (1998); and Attanasio, Goldberg, and Kyriazidou (2008).[3] This literature, however, does not explicitly model the supply side of the market. We certainly agree that credit constraints on both consumers and firms play an important role in the auto market beyond simply the posted interest rate.[4] However, our model suggests that interest-rate changes will affect sales through both the demand side and the supply side. Hence, a market analysis is needed to understand the impact that interest rates, credit market conditions, and monetary policy have on sales in the market for automobiles.

On the supply side, a number of studies of automobile firms have explored the relationship between inventories and production. See, for example, Blanchard (1983); Kahn (1992); Kashyap and Wilcox (1993); Ramey and Vine (2006); and Copeland and Hall (2011). However, this literature takes quantity demanded as given. Furthermore, this literature assumes that real interest rates are constant and thus does not address the effects of interest rates on automobile production and inventories. This gap highlights a broader puzzle in empirical research on inventories: over a long period of time, very few studies have uncovered a significant relationship between real interest rates and inventories.[5] This is an important issue for several reasons. One is that, in theory, monetary policy changes short-term real interest rates and thereby influences inventory investment. The other is that the financial press is filled with ad hoc statements of how interest rates affect inventories both by influencing the cost to firms of holding inventories and by affecting sales, which, in turn, cause changes in inventory positions.[6] The lack of empirical evidence on the mechanism by which real interest rates affect inventories is therefore troubling.

Since our analysis attempts to look at both the consumer-side and the firm-side decisions simultaneously, this paper builds most closely on the work of Blanchard and Melino (1986), who also develop a model of the market for automobiles.[7] There are two primary innovations in our model relative to theirs. First, we allow real interest rates to be variable and stochastic. We are thus able to explore the effects of real interest rates on sales, production, prices, and inventories in the market, which they cannot do. We also distinguish between the real interest rates faced by households and those faced by firms. Second, Blanchard and Melino model the automobile industry as a perfectly competitive one. In contrast, we assume that producers of automobiles are monopolistic competitors, and we develop a shopping-cost model for the household to decide on automobile purchases, which yields a demand function for new automobiles that firms face. As in Bils and Kahn (2000), the demand function implies that inventories play a productive role in stimulating demand.

Finally, our market equilibrium modeling approach is in the tradition of the theoretical and empirical inventory literature dating back at least to Holt, Modigliani, Muth, and Simon (1960). This market framework allows us to derive results that highlight the role of the two inventory channels that are the focus of this work. Alternatively, we could embed this market analysis inside a dynamic stochastic general equilibrium (DSGE) model; however, doing so would require the specification and estimation of the 96 percent of the non-automobile sectors of the economy. Thus we would be adding complexities that would tend to muddy the intuition and complicate the estimation. Of course, there are disadvantages to a market equilibrium approach. For example, it does not account for any feedback from the automobile sector to monetary policy. We therefore view the current paper as a first step in better understanding these two inventory channels, much like partial equilibrium models of non-convexities in adjustment costs (e.g., Bertola and Caballero 1994) that have subsequently led to a rich vein of research in DSGE models (including, e.g., Khan and Thomas 2008 and Bachmann and Ma 2016).

In the remainder of this paper, we present our model of the market for new automobiles, discuss the construction of our dataset, present estimates of the model parameters, and illustrate the dynamic responses to interest rate shocks of key variables in our model.

2 MODEL OF THE MARKET FOR NEW AUTOMOBILES

2.1 *Model of the household*

The representative household undertakes a two-stage optimization process. In the first stage, the household minimizes the shopping costs of purchasing automobiles. Given this outcome, in the second stage the household maximizes utility.[8]

The costs of purchasing an automobile consist of both purchase costs and shopping costs. The inclusion of shopping costs implies that firm-held inventories directly impact consumer demand, and is motivated by results in the inventory literature, such as Kahn (1987, 1992), which find inventories are productive in generating greater sales for a given price.

Define P_{jt} as the real price of a new automobile of type j and S_{jt} as the quantity of new automobiles of type j purchased at time t.[9] Then $P_{jt}S_{jt}$ is the real cost of purchasing new automobiles of type j at time t.

Define $(A_{jt}/A_t)\, S_{jt}$ as the total shopping cost of purchasing new automobiles of type j, where (A_{jt}/A_t) is the per unit shopping cost of purchasing new automobiles of type j , $A_{jt} = N_{jt-1}+Y_{jt}$ is the supply of new automobiles available for sale in period t by producer of type j, N_{jt-1} is the stock of inventories of new autos of type j held by the producer of type j autos at the end of period $t \quad 1$, Y_{jt} is the current production of new automobiles by producer of type j , $A_t = N_{t-1} + Y_t$ is the supply of new automobiles available for sale in the industry as a whole, N_{t-1} is the stock of inventories of all new autos in the industry, Y_t is current production in the industry as a whole, and where we assume that $\;' < 0$. The basic idea is that the shopping cost to the household declines the higher is the supply of new cars that firm j has available for sale relative to the supply of new automobiles available for sale in the industry as a whole. The higher the supply of inventories that firm j has available for sale, the higher the probability is that there will be a match between the household's decision to buy an automobile of type j and firm j.[10] Then, $(A_{jt}/A_t)\, P_{jt}S_{jt}$ is the total real shopping cost of purchasing new automobiles of type j valued at P_{jt}. Finally, the total real cost of purchasing new automobiles of type j is the sum of the purchase costs plus the shopping costs, or

$$P_{jt}S_{jt} + \quad \left(\frac{A_{jt}}{A_t}\right) P_{jt}S_{jt} = \left[1 + \quad \left(\frac{A_{jt}}{A_t}\right)\right] P_{jt}S_{jt}. \tag{1}$$

Now, in the first stage, the representative household chooses S_{jt} to minimize

$$\int_0^1 \left[1 + \quad \left(\frac{A_{jt}}{A_t}\right)\right] P_{jt}S_{jt}dj \tag{2}$$

subject to

$$S_t = \left[\int_0^1 S_{jt}^{\frac{\varepsilon \quad 1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon \quad 1}} \tag{3}$$

where $\epsilon > 1$. Assume that shopping costs take the form

$$\left(\frac{A_{jt}}{A_t}\right) = \left(\frac{A_{jt}}{A_t}\right)^{\nu} \quad 1 \tag{4}$$

with $\nu < 0$. Then, in appendix A we show that the solution to this problem yields a demand function for new automobiles of type j of the form

$$S_{jt} = \left(\frac{P_{jt}}{P_t}\right)^{-\varepsilon} \left(\frac{A_{jt}}{A_t}\right)^{\theta} S_t \tag{5}$$

where S_t is the aggregate purchases of new automobiles, P_t is the average real price of new automobiles, and $\theta = \quad \epsilon\nu > 0$. This is the demand function faced by the firm that produces new automobiles of type j. We refer to ϵ as the own-price elasticity and to θ as the available-supply elasticity of the demand for new automobiles.

In the second stage, the representative household is assumed to choose $C_t,\ X_t,\ S_t,\ B_t$, and D_t to maximize

$$E_o \sum_{t=0}^{\infty} \zeta^t U(C_t, X_t) \tag{6}$$

subject to

$$I_t \;=\; C_t + \;1 \quad \overline{\xi} \;\; P_t S_t + r_{1t} B_{t-1} + \mu B_{t-1} \tag{7}$$

$$X_t \;=\; (1 \qquad) X_{t-1} + S_t, \qquad\quad 0 < \quad < 1 \tag{8}$$

$$B_t \;=\; (1 \quad \mu)\, B_{t-1} + D_t, \qquad\quad 0 < \mu < 1 \tag{9}$$

$$D_t \;=\; \overline{\xi} P_t S_t, \qquad\quad 0 \leq \overline{\xi} \leq 1 \tag{10}$$

where C_t denotes consumption excluding car services, X_t is the stock of existing cars, S_t is purchases of new cars, I_t denotes real labor income, B_t represents the stock of car loans, D_t is new loans incurred to purchase automobiles, P_t is the average real price of new cars, r_{1t} is the real interest rate on new car loans, $\overline{\xi}$ is the fraction of a new car purchase financed by a new loan, is the rate that cars depreciate, and μ is the fraction of existing loans repaid every period.

Following a number of papers in the literature, for example, Blanchard and Melino (1986) and Alessie, Devereux, and Weber (1997), we treat the stock of cars as a continuous variable and the household as a representative one whose purchases add to the stock of cars. The household derives utility from the services provided by the automobiles it possesses, which is proportional to the stock of automobiles where the proportionality factor is normalized to unity, and from consumption of goods other than automobiles, which we will refer to simply as "consumption." As equation (8) indicates, purchases of new automobiles, S_t, add to the stock, which in turn also depreciates at rate . Purchases of new automobiles are financed in part with income, $1 \quad \overline{\xi} \;\; P_t S_t$, and in part with new loans, $D_t = \overline{\xi} P_t S_t$. The budget constraint, equation (7), incorporates the payment of interest on loans, $r_{1t} B_{t-1}$, and the amount of the stock of loans that is paid back each period, μB_{t-1}, where the fraction that is paid back is assumed to be constant.[11]

This model of the household deviates from a standard consumption-saving model with a generic durable good (e.g., Mankiw (1985)) with the assumption that $\overline{\xi}$ and μ are fixed parameters rather than choices variables. Without these restrictions, household borrowing and lending would be de-linked from the consumption of the durable good. Since our focus is on lending to finance automobile purchases, we tie the borrowing decision directly to the consumption of the durable good. This implies that the only channels for consumer saving are the stock of cars and loans; note that without ad hoc constraints or frictions, the introduction of another asset (e.g. a risk-free bond) induces arbitrage opportunities that the household would wish to exploit.

Assume that the utility function is

$$U(C_t, X_t) \;=\; \pi_1 \ln C_t + \pi_2 \ln X_t, \tag{11}$$

where $\pi_1 > 0, \pi_2 > 0$, and use equation (10) to eliminate D_t. The first-order conditions are then

$$\frac{\pi_1}{C_t} = {}^{h}_{1t} \tag{12}$$

$$(1 \quad)\zeta E_t \; {}^{h}_{2t+1} + \frac{\pi_2}{X_t} = {}^{h}_{2t} \tag{13}$$

$${}^{h}_{2t} \quad 1 \quad \bar{\xi} \;\; P_t \; {}^{h}_{1t} + \bar{\xi} P_t \; {}^{h}_{3t} = 0 \tag{14}$$

$$(1 \quad \mu)\zeta E_t \; {}^{h}_{3t+1} \quad \zeta E_t \left(r_{1t+1} + \mu\right) \; {}^{h}_{1t+1} = {}^{h}_{3t} \tag{15}$$

together with equations (7), (8), and (9). The endogenous variables are then C_t, X_t, S_t, B_t and the multipliers are ${}^{h}_{1t}$, ${}^{h}_{2t}$ and ${}^{h}_{3t}$. In the on-line appendix A, we derive the household's second-order conditions.

The household expenditure channel is embodied in these first-order conditions. The three multipliers represent the marginal utility of non-auto consumption (${}^{h}_{1t}$), the marginal utility of the automobile stock (${}^{h}_{2t}$), and the marginal disutility from consumer automobile debt (${}^{h}_{3t}$). The first-order condition, equation (14), equates the marginal benefit of purchasing one more unit of autos (${}^{h}_{2t}$) to its marginal cost, the difference between $1 \quad \bar{\xi} \;\; P_t$ times the cost of the forgone current period non-auto consumption and $\bar{\xi} P_t$ times the marginal disutility from more debt. Since the household choice between C_t and S_t depends on future interest rates, an increase in the current interest rate, r_{1t}, acts just like a drop in income, reducing the demand for both goods. An increase in next period's interest rate r_{1t+1} increases future disutility of auto debt, thus increasing the price of purchasing a new automobile relative to non-auto consumption.

2.2 *Model of the firm*

We consider a representative firm, firm j, that produces and sells a single durable good, namely, a type of new automobile, type j. As mentioned in the introduction, we model the firm as an integrated dealer-producer. The firm is a monopolistic competitor that faces a stochastic downward-sloping demand curve for its product and a variable and stochastic interest rate at which it discounts future profits. Each period, the representative firm, firm j, maximizes:

$$PV_j = E_o \sum_{t=0}^{\infty} \left[\Pi^{t}_{s=0} \;\; {}_{s}\right] \;\; {}_{jt} \tag{16}$$

where

$${}_{s} = \frac{1}{1 + r_{2s}} \tag{17}$$

$${}_{jt} = \frac{P_{jt}}{P_t} S_{jt} \quad \frac{W_t}{P_t} L_{jt} \quad K_{jt} \tag{18}$$

subject to:

$$
\begin{aligned}
S_{jt} &= \left(\frac{P_{jt}}{P_t}\right)^{-\varepsilon}\left(\frac{A_{jt}}{A_t}\right)^{\theta} S_t, \qquad \epsilon > 1 \qquad \theta > 0 && (19)\\
K_{jt} &= \kappa_o\left(\frac{A_{jt}}{S_{jt}}\right)^{\kappa_1} N_{jt-1,} \quad \kappa_0 > 0 \quad \kappa_1 > 0 && (20)\\
A_{jt} &= N_{jt-1} + Y_{jt} && (21)\\
A_{jt} &= A_{jt-1} \quad S_{jt-1} + Y_{jt} && (22)\\
Y_{jt} &= \Gamma_{jt} L_{jt}^{\alpha}, \qquad 0 < \alpha < 1 && (23)
\end{aligned}
$$

where P_{jt} is the real price firm j sets for an automobile of type j, S_{jt} is sales of automobiles of type j by firm j, L_{jt} is labor services, N_{jt} is the stock of inventories of firm j of finished automobiles at the end of the period, A_{jt} is the stock of automobiles available for sale during period t, Y_{jt} is the output of automobiles of type j, Γ_{jt} is labor productivity, r_{2t} is the real interest rate faced by the firm, K_{jt} is inventory storage costs, S_t, is industry sales, N_t is the industry stock of inventories of finished automobiles at the end of the period, P_t is the real industry price level, and W_t is the real wage rate.

Observe that equation (19) is the demand function for new automobiles of type j that emerged from the shopping-cost model of the household. The demand for new cars from the representative household thus serves as the demand function faced by firm j, which is the firm that produces automobiles of type j. This connects the model of the household to the model of the firm.

In the auto industry, newly produced vehicles are typically shipped within days to dealers lots; hence we assume the stock of automobiles for sale, A_{jt}, is the sum of residual inventories from the previous period and newly produced vehicles. Using the definition of A_{jt}, inventory storage costs, equation (20), can be written as

$$K_{jt} = \kappa_o\left(\frac{A_{jt}}{S_{jt}}\right)^{\kappa_1} N_{jt-1} = \kappa_o\left(\frac{N_{jt-1}+Y_{jt}}{S_{jt}}\right)^{\kappa_1} N_{jt-1}.$$

Due to dealer space constraints and insurance costs, current-period storage costs are assumed to rise with the stock of automobile inventories carried over from the previous period and with current production and to fall with current sales. Now, use equation (19) to eliminate price as an explicit choice variable and rewrite equation (21) to get $N_{jt-1} = A_{jt} \quad Y_{jt}$; then net revenues, equation (18), can be written as

$$_{jt} = \left(\frac{S_{jt}}{S_t}\right)^{1-\frac{1}{\varepsilon}}\left(\frac{A_{jt}}{A_t}\right)^{\frac{\theta}{\varepsilon}} S_t \quad \frac{W_t}{P_t} L_{jt} \quad \kappa_o\left(\frac{A_{jt}}{S_{jt}}\right)^{\kappa_1}(A_{jt.} \quad Y_{jt}). \tag{24}$$

The firm then chooses S_{jt}, Y_{jt}, A_{jt}, and L_{jt} to maximize equation (16) subject to equations (22) and (23) and where net revenue is now defined in equation (24) and the discount factor is again given by equation (17). The first-order conditions are

$$\left(\frac{\varepsilon \quad 1}{\varepsilon}\right)\left(\frac{S_{jt}}{S_t}\right)^{-\frac{1}{\varepsilon}}\left(\frac{A_{jt}}{A_t}\right)^{\frac{\theta}{\varepsilon}} + \kappa_o\kappa_1\left(\frac{A_{jt}}{S_{jt}}\right)^{\kappa_1}\left(\frac{A_{jt.} \quad Y_{jt}}{S_{jt}}\right) = E_t \quad {}_{t+1} \quad {}^{f}_{1t+1} \tag{25}$$

$$\kappa_o\left(\frac{A_{jt}}{S_{jt}}\right)^{\kappa_1} + \quad {}^{f}_{1t} = \quad {}^{f}_{2t} \tag{26}$$

$$\begin{aligned} E_t \quad {}_{t+1} \quad {}^{f}_{1t+1} + \left(\frac{\theta}{\varepsilon}\right)\left(\frac{S_{jt}}{S_t}\right)^{1-\frac{1}{\varepsilon}}\left(\frac{A_{jt}}{A_t}\right)^{\frac{\theta}{\varepsilon}-1}\left(\frac{S_t}{A_t}\right) & \\ \kappa_o\left(\frac{A_{jt}}{S_{jt}}\right)^{\kappa_1}\left[\kappa_1\left(\frac{A_{jt}}{S_{jt}}\right)^{-1}\left(\frac{A_{jt} \quad Y_{jt}}{S_{jt}}\right)+1\right] &= \quad {}^{f}_{1t} \end{aligned} \tag{27}$$

$$\alpha\lambda^{f}_{2t}\Gamma_{jt}L_{jt}^{\alpha-1} = \frac{W_t}{P_t} \tag{28}$$

where ${}_{t+1} = {}^1/_{1+r_{2t+1}}$, and ${}^{f}_{1t}$ and ${}^{f}_{2t}$ are the multipliers associated with the available-supply-accumulation process and the production function, equations (22) and (23), respectively. From equation (26), we see that the multiplier ${}^{f}_{2t}$ measures the negative of the marginal cost to the firm of producing an additional automobile. Equation (28) states that the firm will set the marginal cost of producing an additional vehicle to the marginal value of an additional unit of inventory. In the on-line appendix A, we derive the second-order conditions.

These optimality conditions summarize the endogenous dynamics of the supply side of the model. The multiplier ${}^{f}_{1t}$ measures the marginal value to the firm of an additional unit of inventory. Thus, equation (27) equates the costs and benefits to the firm of selling the marginal vehicle. The right-hand side of the equation is the marginal revenue from selling one more vehicle this period. The three terms on the left-hand side of the equation are: (1) the marginal revenue from selling the vehicle next period; (2) the marginal benefit to the firm of having an additional unit of inventory (the value from the increase in demand for its vehicles) next period; and (3) the marginal storage cost of holding an additional vehicle one more period. The higher is $r_{2,t+1}$, the smaller the benefit is to holding a vehicle in inventory one more period. This equation captures the firm inventory channel. A firm that faces an unexpected high interest rate next period will wish to hold fewer vehicles in inventory. Thus, higher interest rates should lead to lower prices and more sales in the short run. But a reduction in available supply will feed into the household's problem, reducing consumer demand.

2.3 *Exogenous variables*

We assume that each interest rate, r_{it}, is the sum of its mean, a common factor, f_t, and an idiosyncratic factor, x_{it}. All three latent factors are assumed to be autoregressive:

$$r_{1t} = \bar{r}_1 + \quad f_t + x_{1t} \tag{29}$$

$$r_{2t} = \bar{r}_2 + \quad f_t + x_{2t} \tag{30}$$

$$f_t = \rho_f f_{t-1} + \eta_t^f \tag{31}$$

$$x_{1t} = \rho_{x_1} x_{1t-1} + \eta_t^{x_1} \tag{32}$$

$$x_{2t} = \rho_{x_2} x_{2t-1} + \eta_t^{x_2}. \tag{33}$$

We specify the same joint process for wages and income:

$$w_t = \bar{w} + \omega j_t + z_{1t} \tag{34}$$

$$i_t = \bar{i} + \omega j_t + z_{2t} \tag{35}$$

$$j_t = \rho_j j_{t-1} + \eta_t^j \tag{36}$$

$$z_{1t} = \rho_{z_1} z_{1t-1} + \eta_t^{z_1} \tag{37}$$

$$z_{2t} = \rho_{z_2} z_{2t-1} + \eta_t^{z_2}. \tag{38}$$

Lastly, the growth rate of labor productivity, $_t$, depends on its own one-period lag and a stochastic disturbance:

$$_t = \bar{} \, (1 \quad \rho \;) + \rho \quad _{t-1} + \eta_t \tag{39}$$

There are seven mutually uncorrelated economic shocks in the model: η^{x_1},η^{x_2}, η^f, η^{z_1},η^{z_2}, η^j, and η . All seven shocks are normally distributed with a mean of zero and constant variance.

2.4 *Market equilibrium*

We solve for a symmetric equilibrium. Since all firms are identical and the total mass of firms in the economy is unity, in equilibrium $S_{jt} = S_t$, $A_{jt} = A_t$, $L_{jt} = L_t$, $Y_{jt} = Y_t$, and $\Gamma_{jt} = \Gamma_t$. The market equilibrium model thus contains thirteen equations in thirteen endogenous variables: S_t, Y_t, A_t, L_t, C_t, P_t, X_t, B_t, $^h_{1t}$, $^h_{2t}$, $^h_{3t}$, $^f_{1t}$, and $^f_{2t}$. We do not take these equations directly to the data, however, because our estimation approach relies on the data being stationary. Although unit sales of light vehicles and the firms' and households' interest rates are stationary, there are trends in real prices, real wages, and real disposable income. Consequently, we reformulate the model so that the relevant variables are in ratio form (see on-line appendix A for details).

3 DATA

The data in this paper are drawn from a number of sources, although the majority come from the Bureau of Economic Analysis (BEA) and Ward's Automotive Yearbook (various years). To estimate the model, we need data on the light motor vehicles industry (growth rates of sales, production, and prices as well as measures of available supply, sales, and output), interests rates (both those faced by households and firms), and households (income, wages, and light motor vehicle expenditures). Although most of the data extend farther back in time, our sample starts in February 1972 because of the availability of data on interest rates faced by households, and ends in December 2011. All the data are monthly.

3.1 *Interest rates*

We construct two interest-rate measures, of which one is the rate faced by automakers and the other is that faced by households. For both, we define the real interest as the difference between the nominal interest rate and inflation expectations. We assume the rate faced by automakers is the BAA-bond yield, the interest rate earned on investment-grade bonds.[12] For households, we take the interest rate reported on 48-month new car loans issued by commercial banks.[13] We construct a measure of inflation expectations using a regression approach. Inflation is calculated as the year-over-year change in the personal consumption expenditure price index at the monthly frequency. We then estimate a regression where inflation is the dependent variable and the independent variables are last month's inflation, contemporaneous values of nominal personal consumption expenditures, industrial production, and the triple-A bond yield.[14] We estimate inflation expectations in period t using the regression coe cients estimated on data up until and including t 1.

Using these ingredients, we construct our two measures of real interest rates, which are plotted in Figure 1. Interestingly, the interest rate faced by households is *not* always above the rate faced by automakers. Indeed, from the late 1990s onward, households could sometimes finance the purchase of their vehicles at rates equal to or below those faced by automakers. This is likely due in part to the competition banks face from automakers' financing entities that offer consumers extremely low financing packages to stimulate sales.[15] The substantial variation in real interest rates both in the 1970s and early 1980s as well as over the recent financial crisis of 2008-9 are crucial periods as they allow us to observe how households and automakers react to substantial swings in rates.

(insert Figure 1 here)

3.2 *Sales, production, inventories, and price*

We collect data on units sold, produced, and inventoried separately for automobiles and light trucks. For automobiles, the BEA publishes a comprehensive set of monthly statistics tracking units produced and sold in the United States. A large number of motor vehicles are assembled in Canada and Mexico but sold in the United States. Therefore we follow the BEA nomenclature and define a "domestic" vehicle as one produced in the United States, Canada, or Mexico but intended for the U.S. market.[16] Our sales data also reflect this domestic label.[17] We then infer domestic inventories from the sales and production flows.

The BEA data for light trucks are less comprehensive and sometimes also have a shorter history. As detailed in the on-line appendix B, we use Ward's Automotive data to extrapolate these data back to 1972. We then sum the automotive and light truck sales, output, and inventories data because our model does not distinguish between these two types of passenger vehicles. Consistent with our theoretical model, we are treating the automobile dealerships, which hold almost all of the retail inventory, and manufacturers, which assemble automobiles, as one entity.

We define average price to be equal to the total expenditures on vehicles divided by the number of vehicles sold. The BEA publishes this figure for domestic automobiles, but, once again, some work is needed to construct average prices for light trucks (see the on-line appendix B for details). Guided by the model, we deflate both automobile and light truck nominal prices by a nondurables consumer price index.[18] The resulting series is now a relative price, measuring how the price of a vehicle compares to the typical nondurable consumption bundle over time.[19] Finally, we take the sales-weighted average of real prices for automobiles and light trucks to arrive at the average real price for light motor vehicles.

3.3 *Personal disposable income, consumption, and wages*

To measure households' income, we use personal disposable income as published by the BEA. As with all our nominal variables, we deflate this income measure with the nondurables consumer price index. We use income to construct two ratios that are important variables in our theoretical model. The first is equal to expenditures on light motor vehicles over income, where expenditures are equal to the average vehicle price multiplied by sales. The second ratio is non-motor vehicle expenditures over income. For the numerator of this last ratio, we use the personal consumption expenditure data published by the BEA minus our measure of light vehicle expenditure. Finally, to measure wages in the light motor vehicle industry, we use the BLS's compensation data for workers in the durable goods sector.[20]

A more detailed analysis of the data, including figures illustrating the time-series properties of the key variables, is included in the on-line appendix B.

4 EMPIRICAL RESULTS

In this section, we discuss the methods we used to solve and estimate the model. We also report the estimation results. We then illustrate the mechanics and implications of the model through three sets of impulse-response functions.

4.1 *Solving and estimating the model*

Our model has five exogenous driving forces to which the households and firm react (see section 2.3). Our approach is to estimate the stochastic processes of interest rates directly from the data on household and automaker rates in a first step. We then estimate the remaining three stochastic processes of income, wages, and labor productivity, as well as the parameters of the model using Bayesian methods, based on the light motor vehicle data of sales, inventories, production, and real price as well as data on household income, consumption, and motor vehicle expenditure.

We begin by estimating the laws of motion for interest rates (equations 29-33). To estimate the six parameters in the interest-rate processes, we write the five equations in state-space notation:

$$x_{t+1} = Ax_t + Cw_{t+1} \tag{40}$$

$$y_t = Gx_t \tag{41}$$

where $x_t = [f_t \; x_{1t} \; x_{2t}]'$, $y_t = [r_{1t} \quad \bar{r}_1 \;\; r_{2t} \quad \bar{r}_2]'$, $w_{t+1} = [\eta^f_{t+1} \; \eta^{x_1}_{t+1} \; \eta^{x_2}_{t+1}]$ and

$$A = \begin{bmatrix} \rho_f & 0 & 0 \\ 0 & \rho_{x_1} & 0 \\ 0 & 0 & \rho_{x_2} \end{bmatrix}, \quad C = \begin{bmatrix} 0.001 & 0 & 0 \\ 0 & {}_{x_1} & 0 \\ 0 & 0 & {}_{x2} \end{bmatrix}, \text{ and } \quad G = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}.$$

In matrix C, we normalize the standard deviation of η^f to 0.001 because we can only identify two standard deviations from the two observed interest rate processes. Parameter values are estimated by maximizing the likelihood computed using the time-varying Kalman filter, where the data are the monthly household and firm real interest rates described in section 3.1.

The point estimates and standard errors are reported in Table 1. All the parameters are tightly estimated. The point estimates highlight the considerable persistence in real interest rates with all three autoregressive coe cients above 0.95. Thus, current high (low) interest rates imply high (low) interest rates for many periods in the future. The estimated processes do a good job of matching the second moments of the two interest rates. The standard deviation of r_1 and r_2 in the data are 0.00178 and 0.00198, respectively; for our estimated specification, they are 0.00198 and 0.00201. The autocorrelations of r_1 and r_2 in the data are 0.987 and 0.988, respectively; for our estimated specification, they are 0.991 and 0.990. On average, consumers pay 71 basis points more than firms for credit at an annual rate, although, as we illustrate in Figure 1, toward the end of our sample, consumers have, more often than not, paid less. In the data, consumers have paid less for credit than automakers 19.2 percent of the time. In our estimated process, this occurs 19.6 percent of the time. In the data, the contemporaneous correlation between the two interest rates is 0.945; in our estimated process, this correlation is 0.942.

(insert Table 1 here)

Our second step relies on our solving the model. Because it not possible to obtain an analytical solution to the market equilibrium model, we use DYNARE to approximate, solve, and estimate the model.[21] The basic strategy implemented through DYNARE is to linearize the model through a first-order Taylor approximation around its nonstochastic steady state to obtain a system of linear difference equations.[22] We then calibrate several parameters such that the model, in steady state, matches several key moments in the data. Finally, we use a Bayesian maximum likelihood procedure to estimate the posterior distributions of the remaining parameters.

We use our model to match the time series of the ratios of light vehicle expenditures to income, available supply to sales, output to sales, and consumption to income, as well as the growth rates of real prices, sales, and output. We calibrate six parameters so that the model, in its initial steady state, closely matches the mean values of our seven data series. We set the return on labor(α) to 0.6, implying that returns to labor are 60 percent, inline with the macroeconomics literature. We then chose the monthly scrappage rate for vehicles ( ) to be 0.015, which is equal to a 20 percent depreciation rate, in line with estimates from the U.S. Bureau of Economic Analysis.[23] We set the percentage of the stock of vehicle loans paid off each month (μ) to be 0.02, which roughly implies that the average loan lasts 4 years. This choice is consistent with the household interest rate, which is the rate on a 48-month new car loan. Next, we set households' monthly discount rate (ζ) to 0.995.

To calibrate the fraction of new vehicle purchases financed with an auto loan ($\bar{\xi}$), we use equations (9) and (10), which imply that in the steady state the mean value of the stock of light vehicle loans multiplied by μ is equal to the mean value of light vehicle expenditures multiplied by $\bar{\xi}$. We have already set μ to 0.02 and can use the BEA data to compute the mean value of light vehicle expenditures over our sample. We also compute the mean value of the stock of vehicle loans using data published in the Board of Governor's G.19 consumer credit report. Using these numbers, we back out that $\bar{\xi}$ is equal 0.35. A summary of the calibrated parameters is presented in Table 2.

(insert Table 2 here)

This leaves us with 13 parameters to estimate in addition to the standard deviations of the measurement error terms. We take a Bayesian approach to estimating the model and hence specify prior distributions for all the parameters (see Table 3 for a list of the prior distributions). In general, we set the standard deviations of the prior distributions large enough so as to make the priors fairly uninformative. We first consider ε and θ, the own-price elasticity of demand and the elasticity of sales with respect to available supply, respectively. Setting $\theta < \varepsilon$ guarantees that the second derivative of the firm's Lagrangian with respect to available sales is negative (see details in the on-line appendix A, in particular equation A.105). As such, we specify that $\varepsilon = \theta + \iota$, where $\iota > 0$, and consider prior distributions for θ and ι. Based on the literature, the average own-price demand elasticity for light motor vehicles is around 3. Berry, Levinsohn, and Pakes (1995), for example, report own-price elasticities that range, in absolute value, from 3 to 6, and Goldberg (1995) reports an average (unweighted) elasticity of 3.28. In contrast, there is little empirical work that measures the elasticity of sales with respect to available supply. We therefore set the mean of the prior distributions of θ and ι such that the sum of the two means is equal to 3. We do this by assuming that θ is normally distributed with a mean of 2.5 and ι has an inverse gamma distribution with a mean of 0.5. (We assume that ι has an inverse gamma distribution to ensure that $\iota > 0$.)

We model the growth rate of compensation and income as a joint process (equations 34-38). The mean values of these parameter's prior distributions are informed by the data. In particular, using the BEA's real disposable income and the BLS's compensation data for workers in the durable goods sector, we estimate the parameters of the joint process using maximum likelihood (using the same method described for estimating the joint process for interest rates). We use these estimated parameters as the means of our priors. We chose the standard deviation of the prior distributions to accommodate a reasonable amount of uncertainty around the means. Finally, the two constant terms of the joint process are taken from the data, 0.2 and 0.1 percent annual growth rate for income and compensation respectively.

The growth rate of productivity is characterized by three parameters. The constant term is set to 0.0002 (or 0.2 percent annual growth rate) and is not estimated. The prior distribution of the persistence term is assumed to be a beta distribution centered at 0.75, and we chose an inverse gamma prior for the standard deviation of the error term with a mean of 0.01. For the two terms characterizing the costs of holding inventory (κ_0, κ_1), we chose priors with means of 0.1 and 0.8, respectively. Finally, we normalize the utility weight on consumption (π_1) to 1 and chose a prior distribution for the utility weight on motor vehicle consumption (π_2) to be inverse gamma, with a mean of 0.1 and standard deviation of 0.1. With these chosen values, the steady state of our model closely matches the mean values of the variables in the data that we are trying to match.

Summarizing, we have three sets of parameters, $(\Theta_1, \Theta_2, \Theta_3)$, where Θ_1 is the set of parameters related to the joint interest rate process and are estimated in the first step described at the beginning of this section; Θ_2 is the set of calibrated parameters (listed in Table 2); and Θ_3 is the set of parameters estimated by Bayesian maximum likelihood. Formally, letting $\{X_t\}_{t=1}^{T}$ denote the data, the posterior distribution is given by

$$P(\Theta_3; \{X_t\}_{t=1}^{T}, \Theta_1, \Theta_2) \propto p(\Theta_3) L(\{X_t\}_{t=1}^{T}; \Theta_1, \Theta_2, \Theta_3), \tag{42}$$

where p denotes the prior distributions of the parameters in Θ_3 and L denotes the likelihood. The data we use to estimate the model are the growth rates of sales, production and real prices as well as the ratios of light motor vehicle expenditures to income, consumption to income, available supply to sales, and output to sales. (A summary of the equations describing the market equilibrium which we used to estimate the model are listed in the on-line appendix A.4-A.5.) The posterior distributions of the parameters are estimated using the suite of programs available in DYNARE. We chose a Markov chain Monte Carlo (MCMC) approach, which used a Metropolis-Hastings algorithm. Two independent Markov chains were used with average acceptance rates of 39 and 38 percent, and the MCMC diagnostics demonstrated that the draws from the posterior distributions of all parameters converged.

(insert Table 3 here)

In Table 3, we report moments of both the prior and the posterior distributions of the parameters in Θ_3. The estimated posterior distributions of the two elasticity parameters yield sensible results. θ, which is the available supply elasticity of the demand for a new vehicle, is estimated have a mean of 2.99.[24] ι is estimated to have a mean of 0.49, which implies that the mean of the posterior distribution of the own-price elasticity of the demand for a new vehicle is 3.48, consistent with the literature reviewed earlier.

The estimates of κ_0 and κ_1 imply that inventory holding costs are increasing and convex (see equations (20) and (21)). Their impact on manufacturers' behavior can be seen in the next section, which analyzes how households and firms react to various interest-rate shocks. Finally, we estimate that productivity is a somewhat persistent process and that the standard deviation of productivity growth is less than 0.005.

4.2 *Goodness of fit*

Before using the model to analyze how interest rates influence households' and firms' decision making, we demonstrate that the estimated model fits the data well using two different approaches. We first consider how well data generated by the model matches various moments of the data. To do this, we simulate the model so as to generate 1,000 panel datasets of the same size as our actual data. These simulated datasets mimic our actual data in that they capture the comovements of the growth rates of sales, real prices, and output as well as the ratios of new vehicle expenditures to income, consumption to income, available supply to sales, and output to sales. Using the actual data, we compute the mean and standard deviation of each variable. Using the simulated data, we first compute the mean and standard deviation of each variable for each data set. We then look at the distribution of each of these moments and report their mean and standard deviation in Table 4.

(insert Table 4 here)

As illustrated in the table, the model does well in matching the first and second moments of the ratios. The model slightly overpredicts the mean growth rates of real prices, sales, and output and generates a slightly more volatile time series of the growth rate of real prices, as evidenced by the larger standard deviation in the simulated data (6.119 versus 4.399). However, the model does captures the fact that prices are growing faster than sales and output.

Further exploring the match of the model to the data, we consider the persistence of the variables of interest and their correlations. We measure persistence by regressing a variable on its own lag, and we find that the 4 variables which are ratios are highly persistent both in the data and simulated data (see the first 4 rows of Table 5). The growth rate of prices is also highly persistent in the data (an auto-regressive coe cient of 0.921) whereas the growth rates of sales and output are somewhat persistent. In the simulated data, we also find that the growth rate of prices is more persistent than those of sales and output, however these three growth rates are less persistent compared to what we observe in the data.

(insert Table 5 here)

We turn next to correlations among the seven variables. In the data, these variables are correlated in a statistically significant way. Of the 21 pairwise correlations, 18 are statistically significant. In the simulated data, we find only 3 pairwise correlations are statistically significant (those between the growth rates of price, sales and output). This result partly reflects the amount of idiosyncratic noise in the model; if we smooth the simulated data using a 12 month moving average, the number of statistically significant correlations increases to 10 (all of which have the correct sign).

Our second goodness-of-fit approach compares impulse-response functions generated by a recursive vector autoregression (RVAR). In the empirical literature, researchers have used structural VARs to estimate the response of real variables to innovations in interest rates. A challenge with this type of analysis is properly identifying the causal impact of changes to interest rates on real variables such as output or sales. One approach is to make an identifying assumption based on timing, whereby the contemporaneous real variables can respond to an interest-rate innovation only with a lag (e.g., see Bernanke and Blinder (1992)). This approach allows for the estimation of RVARs, which seek to measure the impact of an innovation to interest rates on real variables (Ludvigson (1998) used such an approach to measure the impact of changes to nominal rates on automobile credit and sales). In the spirit of these papers, we estimate a 6 variable RVAR with 4 lags where the order of the variables is index of industrial production, consumer price index, production price index, ratio of available supply to sales, ratio of output to sales, and firms' interest rate.[25] The three indexes capture macroeconomic trends, and the two ratios are the variables of interest. We then calculate the impulse responses of the two ratios to a one-standard-deviation positive innovation to firms' interest rate (see panel A of Figure 2).

(insert Figure 2 here)

To determine how well the model matches these estimated impulse-response functions, we estimate a RVAR on the simulated data. Mimicking the RVAR that we estimated on the data, this is a 3 variable RVAR with 4 lags, where the variables and their order are ratio of available supply to sales, ratio of output to sales, and firms' interest rate.[26] The order of these variables matches the RVAR estimated on the data, and we do not include the macroeconomic variables because our model does not generate business cycle trends. For each of the 1,000 simulated data sets, we estimate this RVAR and calculate the impulse response of the two ratios to an innovation to firms' interest rate, as well as the deviation of firms' interest rate from the steady-state value. We then average across the 1,000 impulse responses to arrive at an average estimated impulse response (see panel B of Figure 2).

The equilibrium responses of the ratios of available supply to sales and output to sales have the same dynamics across the two RVARs, strong evidence that our model is capturing well the impact of changes in interest rates faced by vehicle manufacturers. The RVARs from the simulated data, however, do predict smaller responses of these two ratios to the interest-rate innovation, roughly an order of magnitude less for the ratio of output to sales and about half for the ratio of available supply to sales. Almost identical results arise when replacing the firms' interest rate in the above exercise with the households' interest rate. For the sake of brevity, those results are not presented here.

4.3 *Impulse-response functions*

With our estimated parameters, we analyze the impact of innovations to real interest rates on equilibrium real prices, sales, output, and inventories. Most important, we measure how interest-rate shocks to households affect vehicle sales, output, and inventories as well as interest rate shocks to manufacturers. Furthermore, our equilibrium model allows both households and manufacturers to react to changes to either interest rate. As discussed in the introduction, this approach builds on the existing literature, which has focused on either the household side or the manufacturer side.

We begin by considering an innovation to households' interest rate and manufacturers' interest rate separately. This allows us to quantitatively compare the household expenditure and firm inventory channels with respect to their impact on the real automobile market. For each 100 basis-point rate increase, we use impulse-response functions to trace the impact on the growth rates of sales, real prices, and output as well as the ratios of new vehicle expenditures to income, available supply to sales, and output to sales. To aid in interpreting the quantitative magnitude of each response, we center each response on its mean. Using this same approach, we then examine the equilibrium responses when there is a shock to the common component of both rates.

(insert Figure 3)

A 100 basis-point increase in a households' interest rate increases the cost of borrowing \$25,000 (say, to purchase a \$30,000 car) over 4 years by \$11 per month or \$528 over the life of the loan. Thus the demand for new vehicles will decline. As illustrated in Figure 3, sales fall immediately as the growth rate of sales falls from its mean of 1.012 percent per year to -0.56 percent in the first two months following the shocks. This is a large response. Given that roughly 17 million cars and light trucks are currently sold in the United States each year, a swing in the sales growth rate of 1.5 percent is 255,000 cars per year or about 21,250 cars per month. After 7 months, the market does eventually recover, as the growth rate of sales exceeds its steady-state value and then drops back to its steady state. The model also captures manufacturers' response to this interest-rate shock. Reacting to the persistently lower demand from households, the representative manufacturer looks to lower its available supply by cutting prices and output. The manufacturer's response is large and immediate. To dampen the decline in sales, manufacturers lower prices by 3.2 percent in the period immediately following the shock and output is cut by 5.5 percent. Since the decline in output is greater than that of sales, the ratios of output to sales and available supply to sales both fall.

The decline in available supply has a secondary, negative impact on sales because its decline raises the household's shopping cost. Hence, the manufacturer's response amplifies and propagates the demand-dampening effects of a rise in the household interest rate. This equilibrium effect, along with the persistence in the household interest rate, causes the growth rate of sales to recover only slowly to its steady-state value, despite the much quicker reversion to the steady state of the real price and output growth rates.

(insert Figure 4)

In Figure 4, we report the responses to a 100 basis-point increase in manufacturers' interest rates, which raises their cost of holding inventories. To more easily compare the quantitative impact of this shock to the 100 basis-point shock to the household interest rate, we hold fixed the scale of the impulse-response functions. Because the price and output growth rate responses are small, we included close-ups for these two graphs.

To put the 100 basis-point rate increase to the manufacturer in perspective, if a dealer finances a \$30,000 car, it raises her inventory holding costs by \$25 per month. For a dealer who keeps 200 vehicles in stock, a 100 basis-point increase raises total holding costs by \$5,000 per month. Automakers can lower inventories by lowering prices or reducing output. Despite convex production costs which, by themselves, induce production smoothing, automakers reduce inventories by immediately lowering output growth. Lower output impacts households by reducing available supply and so increasing shopping costs both in the current period and, to a larger extent as available supply continues to decline, in the future. Consumers anticipate this and react by shifting sales forward in time, creating a one-period spike in the growth rate of sales in first period after the interest rate innovation (see the middle lower panel of Figure 4). If anything, automakers slightly increase the growth rate of prices, although this effect is economically trivial. Manufacturers' and households' actions result in ratios of output to sales and available supply to sales that fall below their steady-state values and slowly recover. Furthermore, the ratio of new vehicle expenditures to income is positively shocked and remains above its steady-state value for 4 months.

The different responses to innovations to households' and to firms' interest rates can be seen by comparing Figures 3 and 4. In particular, the 100 basis point shock to households' interest rate has a much larger negative impact on price and output growth than the 100 basis-point shock to manufacturers' interest rate. The response of sales growth also differs across the two exercises. When households' interest rate is shocked, sales growth falls in the first period and remains negative for 6 months. Whereas when manufacturers' interest rate is shocked, sales growth initially spikes up and then falls below its steady-state value. A final difference across these two exercises is highlighted by the impulse response of the ratio of new vehicle expenditures to income. In response to an increase in households' interest rate, this ratio drops and only slowly reverts to its steady state (see the northwest panel in Figure 3). In contrast, the increase in manufacturers' interest rate causes an initial jump in this ratio as households purchase vehicles now in anticipation of higher shopping costs in the future (see the northwest panel in Figure 4).

Finally, we consider a 100 basis-point positive shock to both households' and manufacturers' interest rates, such as would occur under a restrictive monetary policy (see Figure 5 and note we continue to hold fixed the scale of the impulse-response functions). Formally, we consider a shock to the common component of the interest rate processes (f_t, see equations (29-31)), where the size of the shock is chosen such that the initial innovation to both the interest rates is 100 basis-points. This allows for a easy comparison of the resulting impulse-response functions with the previous two sets of impulse-response functions. Note, however, that the persistence of the common shock, at 0.9919, is greater than the persistence of the household and manufacturer interest rate (see Table 1 as well as Figure A4 in the on-line appendix C).

(insert Figure 5 here)

The responses of households and manufacturers to this common interest-rate shock reinforce one another along some dimensions, while offsetting each other along others. As expected, the model predicts that the shock to the common component of interest rates leads to output and price growth below their steady-state values. Output growth declines from its steady state rate of 1 percent to -11.0 percent at an annual rate in the period immediately following the shock. This swing in the growth rate translates into a decline of about 180,000 light vehicles produced over the following twelve months. Interestingly, sales growth is initially above to its steady-state value, as the demand-dampening effect of higher household rates is offset by the manufacturer's desire to shed inventories through lower prices. Sales growth then falls from its steady state annual rate of 1.0 percent to -2.9 percent in the second month after the interest-rate shock and then slowly revert to the steady-state value. Reflecting the dynamics of sales and price growth, the ratio of new vehicle expenditures to income falls in the initial period and remains below its steady-state value for many periods. As with the previous exercises where households' and manufacturers' interest rates were increased separately, the increase the common component of interest rates leads to a decline in both the ratio of output to sales and the ratio of available supply to sales. Moreover, the decline in both ratios from the increase in the common component is quantitatively larger than the decline in both ratios from separate increases in the households' and manufacturers' interest rates, reflecting the fact that the responses are re-enforcing.

The magnitudes of these responses are consistent with previous studies that find that purchases of consumer durables and business expenditures on long-lived investment goods are sensitive to temporary changes in cost. Both consumers and automakers are willing to shift the timing of sales and production into periods with low costs and away from periods with high costs. In their study of President Obama's "Cash for Clunkers" program, Mian and Sufi (2012) reckon that average payments to consumers of $4,209 per car led to 370,000 more cars sold in July and August 2009 (or 185,000 cars/month). As mentioned in our discussion of the model's predictions given a change to the households' interest rate, in our model a 100 basis point decrease in the (household) interest rate saves the average consumer $528 on the price of a car and increases the monthly sales rate by 21,250 cars in the short term. If we multiply our numbers by 8, we get that a $4,224 price reduction yields an increase of 170,000 in monthly auto sales, numbers in line with Mian and Sufi.

Our model of the household is a modest deviation from the standard permanent-income consumption-saving model with a durable good, but since we model the household and firm separately, we distinguish between the timing of the production and sales responses. In his benchmark model of durable good consumption, Mankiw (1985) concludes that a 100 basis point rise in the real interest rate for one year reduces annual consumer expenditures on durables by about 13.6 percent. In our monthly model, both the 100 basis point interest rate increase and the household and manufacturers response are much more short-lived; in the month immediately after the shock, production growth drops -11.0 percent and sales growth drops to -2.9 percent at an annual rate. But over the course of the following twelve months, sales and production growth rebounds resulting in cumulative output drop of a little more than 1 percent. While this estimate is well below Mankiw's annual semi-elasticity, the difference in response is due primarily to the persistence in the interest rate change.

Within the framework of a New Keynesian macro model, Kryvstov and Midrigan (2013) find that a 150 basis point decrease in the real interest rate raises output by 1.5 percent and sales by 1.4 percent above their steady states values. Both output and sales then return gradually to their steady-state levels. Since their model is linear in levels, these responses imply for both series a large positive growth rate in the initial period and small negative growth rates thereafter. Both our model and theirs generates a similar production response; but in our model, auto demand is a function of inventories. Thus, our sales response is initially smaller, and the growth rate of sales does not return to its steady state for almost a year as the impact of the change in inventories propagates the sales response.

On the firm side, House and Shapiro (2008) find that investment in long-lived capital goods is highly sensitive to investment tax incentives with intertemporal elasticities between 6 and 14. In our model, firms invest in inventories and the analog of a tax incentive is an increase in labor productivity, . Like a tax incentive, a positive shock to labor productivity temporarily reduces the cost of producing the investment good. Since follows an AR(1) process, the impact of an innovation, η , is propagated over many periods. We compute the impulse response function and find that a one percent increase in has a maximal response after four periods. In this period the growth rate in prices falls by 2/10 of 1 percent and the sales rate growth increases by 2.75 percent. Firms increase their inventory-to-sales ratio by 2.6 percent and the output-to-sales ratio by 6.8 percent. Interestingly, House and Shapiro find little empirical evidence that temporary tax incentives have an impact on prices, while in our market equilibrium model a positive supply shock reduces prices and increase sales.

5 CONCLUSION

After the financial crisis of 2008, the Federal Reserve kept interest rates in the United States at near-historic lows. But currently, interest rates appear to be returning to their long-run averages. Thus both policy makers and the public are once again asking one of the classic questions in monetary economics: what is the impact of rising interest rates on the real economy? Part of the answer to this question centers on the durable goods sector. It is well known that durable goods are much more interest-rate sensitive than are nondurable goods or services. In this paper, we take a first step to answering this question by estimating how exogenous changes to interest rates impact the market for new cars and light trucks, which constitute over 25 percent of durable-goods expenditures in the United States. For this market, we describe two channels through which changes in interest rates operate:

- *A household expenditure channel*: An increase in the interest rate faced by households increases the cost of financing the purchase of a new automobile, thus decreasing the demand for new cars and light trucks.

- *A firm inventory channel*: An increase in the interest rate raises the cost to the firm of holding inventories of new cars and light trucks. To reduce inventories, firms decrease prices to stimulate sales and reduce current production. Since consumer demand is itself a function of vehicles available for sale, the decrease in inventories and reduction in output reduce the available supply of new automobiles. This dampens demand and further propagates the impact of the increase in interest rates.

Within the framework of a dynamic model of the market for new automobiles, we find evidence of the impact of interest-rate changes operating through both channels.

References

Adda, Jerome, and Russell Cooper. 2006. "The Dynamics of Car Sales: A Discrete Choice Approach." Manuscript, May.

Alessie, Rob, Michael Devereux, and Guglielmo Weber. 1997. "Intertemporal Consumption, Durables, and Liquidity Constraints: A Cohort Analysis." European Economic Review 41, 37-59.

Attanasio, Orazio, Pinelopi Goldberg, and Ekaterini Kyriazidou. 2008. "Credit Constraints In The Market For Consumer Durables: Evidence From Micro Data On Car Loans." International Economic Review 49(2), 401-436.

Bachmann, Rudiger, and Lin Ma. 2016. "Lumpy Investment, Lumpy Inventories." Journal of Money, Credit, and Banking 48(5), 821-855.

Baines, Arthur, and Marsha Courchane. 2013. "Automotive Finance: Will Dealership Finance Reserve go the way of Mortgage Yield Spread Premiums?" Charles River Associates.

Benati, Luca, and Thomas Lubik. 2014. "Sales, Inventories and Real Interest Rates: A Century of Stylized Facts." Journal of Applied Econometrics 29, 1210-1222.

Bernanke, Ben, and Alan Blinder. 1992. "The Federal Funds Rate and the Channels of Monetary Transmission." American Economic Review 82(4), 901-921.

Berry, Steven, James Levinsohn, and Ariel Pakes. 1995. "Automobile Prices in Market Equilibrium." Econometrica 63(4), 841-890.

Bertola, Guiseppe, and Ricardo Caballero. 1994. "Irreversibility and Aggregate Investment." Review of Economic Studies 61(2), 223-246.

Bils, Mark, and James Kahn. 2000. "What Inventory Behavior Tells Us about Business Cycles." American Economic Review 90, 458-481.

Blanchard, Olivier. 1983. "The Production and Inventory Behavior of the American Automobile Industry." Journal of Political Economy 91, 365-400.

Blanchard, Olivier, and Angelo Melino. 1986. "The Cyclical Behavior of Prices and Quantities: The Case of the Automobile Market." Journal of Monetary Economics 17, 379-407.

Blinder, Alan, Lou Maccini. 1991. "Taking Stock: A Critical Assessment of Recent Research on Inventories." Journal of Economic Perspectives 5, 73-96.

Bresnahan, Timothy, and Valerie Ramey. 1994. “Output Fluctuations at the Plant Level.” Quarterly Journal of Economics 109(3), 593-624.

Caballero, Ricardo. 1995. “Near-rationality, Heterogeneity, and Aggregate Consumption”. Journal of Money, Credit and Banking 27(1), 29–48.

Chah, Eun Young, Valerie Ramey, and Ross Starr. 1995. “Liquidity Constraints and Intertemporal Consumer Optimization: Theory and Evidence from Durable Goods.” Journal of Money, Credit and Banking 27, 272-287.

Chen, Jiawei, Susanna Esteban, and Matthew Shum. 2013. “When do Secondary Markets Harm Firms?” American Economic Review 103(7), 2911-2934.

Copeland, Adam. 2014. “Intertemporal Substitution and New Car Purchases.” RAND Journal of Economics 45, 624-644.

Copeland, Adam, Wendy Dunn, and George Hall. 2011. “Inventories and the Automobile Market.” RAND Journal of Economics 42, 121-49

Copeland, Adam, and George Hall. 2011. “The Response of Prices, Sales, and Output to Temporary Changes in Demand.” Journal of Applied Econometrics 26, 232-269

Eberly, Janice. 1994. “Adjustment of Consumers’ Durables Stocks: Evidence from Automobile Purchases.” Journal of Political Economy 102(3), 403-436.

Esteban, Susanna, and Matthew Shum. 2007. “Durable-Goods Oligopoly with Secondary Markets: The Case of Automobiles.” RAND Journal of Economics 38(2), 332-54.

Goettler, Ronald, and Brett Gordon. 2011. “Does AMD Spur Intel to Innovate More?” Journal of Political Economy 119(6), 1141-1200.

Goldberg, Pinelopi., 1995. “Product Differentiation ad Oligopoly in International Markets: The Case of the U.S. Automobile Industry.” Econometrica 63(4), 891-951.

Holt, Charles, Franco Modigliani, John Muth, and Herbert Simon. 1960. Planning Production, Inventories, and Work Force. Prentice-Hall Inc, Englewood Cliffs, New Jersey.

House, Christopher, and Matthew Shapiro. 2008. ”Temporary Investment Tax Incentives: Theory with Evidence from Bonus Depreciation” American Economic Review 98:3,737-768.

Humphreys, Brad, Louis Maccini, and Scott Schuh. 2001. “Input and Output Inventories.” Journal of Monetary Economics 47(2), 347-375.

Iocoviello, Matteo, Fabio Schiantarelli, and Scott Schuh. 2011. "Input and Output Inventories in General Equilibrium." International Economic Review, 52, 1179-1213.

Jung, Yongseung, and Tack Yun. 2007. "Inventory and Dynamic Effects of Monetary Policy Shocks." Manuscript, November.

Kahn, James. 1987. "Inventories and the Volatility of Production." American Economic Review 77, 667-679.

Kahn, James. 1992. "Why is Production More Volatile than Sales? Theory and Evidence on the Stockout-Avoidance Motive for Inventory-Holding." Quarterly Journal of Economics 109(3), 565-92.

Khan, Aubhik, and Julia Thomas. 2008. "Idiosyncratic Shocks and the Role of Nonconvexities in Plant and Aggregate Investment Dynamics." Econometrica 76(2), 395-436

Kashyap, Anil, and David Wilcox. 1993. "Production and Inventory Control at the General Motors Corporation during the 1920's and 1930's." American Economic Review 83, 383-401.

Kryvtsov, Oleksiy, and Virgiliu Midrigan. 2013. "Inventories, Markups, and Real Rigidities in Menu Cost Models." Review of Economic Studies 80, 249-276.

LaReau Jamie. 2013. "Interest Rates Spike Would Trim Inventories: The Industry Could Live with a Modest Increase." Automotive News July 15, 2013.

Lubik, Thomas, Pierre-Daniel Sarte, and Felipe Schwartzman. 2015. "What Inventory Behavior Tells Us about Business Cycles Have Changed." Journal of Monetary Economics 76, 264-283.

Ludvigson, Sydney. 1998. "The Channel of Monetary Transmission to Demand: Evidence from the Market for Automobile Credit." Journal of Money, Credit and Banking 30, 365-383.

Mankiw, Gregory. 1985. "Consumer Durables and the Real Interest Rate," The Review of Economics and Statistics 67, 353-362.

Maccini, Louis, Bartholomew Moore, and Huntley Schaller. 2004. "The Interest Rate, Learning, and Inventory Investment." American Economic Review 94, 1303-1327.

Maccini, Louis, Bartholomew Moore, and Huntley Schaller. 2015. "Inventory Behavior with Permanent Sales Shocks." Journal of Economic Dynamics and Control 53, 290-313.

Maccini, Louis, and Adrian Pagan. 2013. "Inventories, Fluctuations and Business Cycles." Macroeconomic Dynamics 17(1), 89-122.

Mian, Atif, and Amir Sufi. 2012. "The Effects of Fiscal Stimulus: Evidence from the 2009 Cash for Clunkers Program." The Quarterly Journal of Economics 127(3), 1107-1143.

Nair, Harikesh. 2007. "Intertemporal Price Discrimination with Forward-Looking Consumers: Application to the US market for Console Video-Games." Quantitative Marketing and Economics 5(3), 239-92.

Ramey, Valerie, and Daniel Vine. 2006. "Declining Volatility in the U.S. Automobile Industry." American Economic Review 96, 1876-1889.

Ramey, Valerie, and Kenneth West. 1999. "Inventories." in Handbook of Macroeconomics, J.B. Taylor, M. Woodford (eds.), Amsterdam: North-Holland.

Schiraldi, Pasquale. 2011. "Automobile Replacement: A Dynamic Structural Approach." RAND Journal of Economics 42(2), 266-291.

Wen, Yi. 2011. "Input and Output Inventory Dynamics." American Economic Journal: Macroeconomics 3, 181-212.

Notes

[1]For the sample of dealerships reported in appendix 1 of Baines and Courchane (2013), from 2002 to 2011 these "floorplan interest expenses" averaged \$288,000 per year per dealership or \$166 per vehicle sold. The average gross profit per new vehicle sold was roughly \$2,300, so that these interest costs represent roughly 7 percent of gross profits.

[2]We integrate the dealership into the automaker and consider a unified pricing decision. See Blanchard (1983, page 370) for the argument for treating the manufacturer and the dealer as a single entity.

[3]Additional influential papers on the demand for automobiles include Adda and Cooper (2006), Copeland (2014), Eberly (1994), and Schiraldi (2011).

[4]In the recent financial crisis, despite a Fed Funds rate near zero, many consumers were unable to obtain new car loans, which contributed to a plummet in auto sales and pushed G.M. and Chrysler into bankruptcy.

[5]See Blinder and Maccini (1991) and Ramey and West (1999) for surveys of the literature. Recent studies that have investigated the effects of changes in real interest rates, credit market frictions, and monetary policy shocks on inventory movements include Jung and Yun (2007); Kryvstov and Midrigan (2013); Benati and Lubik (2014); Lubik, Sarte, and Schwartzman (2015), and Maccini, Moore, and Schaller (2004, 2015).

[6]A search of industry publications such as *Automotive News* and *WardsAuto.com* illustrates that dealers are keenly aware of these expenses in articles with headlines such as "Interest rate spike would trim inventories: The industry could live with a modest increase" (see LaReau 2013).

[7]In the literature on industrial organization, there are papers that model both sides of a durable goods market, such as Nair (2007), Esteban and Shum (2007), Goettler and Gordon (2011), Copeland, Dunn, and Hall (2011), and Chen, Esteban, and Shum (2013). Relative to our paper, this literature focuses on different questions and employs different methods.

[8]An equivalent household's problem can be written as a one-stage problem.

[9]Specifically, P_{jt} is the nominal price of new automobiles of type j divided by the price of consumption, excluding car services.

[10]See Jung and Yun (2007) for a similar specification of shopping costs that is used to derive a demand function faced by a monopolistic firm.

[11]We model automobile loans as having a variable rate, although in reality these loans are often fixed rate. This assumption simplifies the household's problem and keeps it tractable, because with fixed rate loans we would have to keep track of the cross-section of the stock of loans.

[12]Over our sample period, the ratings of automakers' debt has varied substantially. Automakers' debt, however, are typically investment grade. The BAA designation is investment grade, but captures some of the risks investors have faced when purchasing automakers' debt. Moody's describes its BAA designation as meaning that the quality of the bond is medium grade and subject to moderate credit risk. We used Moody's seasoned BAA-corporate bond yield published by the Board of Governors in its H.14 Selected Interest Rates table.

[13]Note that we do not use the interest rates offered by the financing arms of automakers, which are hard to disentangle from the price of the car. Indeed, the BEA data we use to compute automobile prices captures automakers' cash-back incentives. The 48-month new car loan data we use are published by the Federal Reserve Board in its G.19 Consumer Credit table and start in February 1972.

[14]Both personal consumption expenditures and the personal consumption expenditures price index are published by the BEA. The industrial production index and Moody's AAA corporate bond yield are published by the Board of Governors in its G.17 Industrial Production and Capacity Utilization and H.15 Selected Interest Rates table, respectively.

[15]In the mid-2000s, for example, U.S. manufacturers advertised their financing incentives under the "zero percent financing" slogan.

[16]A small number of cars and trucks are assembled in the United States and exported. These vehicles are not considered part of domestic production. Blanchard and Melino (1986) also note that automobile production "is rather arbitrarily distributed" across countries. Rather than determine which vehicles built in Canada and Mexico are sent to the U.S. market, they look at North America as a whole. We do not consider foreign vehicles because of the lack of data on overseas production and inventories.

[17]For our empirical work, we assume that all sales are to the household although in fact some sales are to firms and the government.

[18]We use the seasonally adjusted U.S. city average nondurables price index published by the Bureau of Labor Statistics.

[19]In contrast to our approach, Blanchard and Melino (1986) use the consumer price index (CPI) component for new cars divided by the personal consumption expenditures (PCE) deflator to construct their relative price measure. We do not use this relative price measure, however, because the CPI component for new cars is a quality-adjusted price, while our measures of units sold, produced, and inventoried are not quality adjusted. Because there is substantial quality adjustment for new cars and light trucks, there is a large mismatch between the quality-adjusted prices and regular units sold. Using the Frisch product rule, we can construct a quality-adjusted quantity index for new automobile sales. By the end of the 1967-2008 period, quality-adjusted units sales are twice the level of regular unit sales. Finally, the use of quality-adjusted prices is not appropriate for our model. Automakers spend significant resources investing in quality-improving technology. We take these quality improvements as given, and consider the firm's pricing and production decisions. As such, vehicle prices in our model should reflect the increase in quality over time.

[20]Although the BLS publishes wages for workers in the light motor vehicle sector, this measure does not include benefits. Because we think benefits are an important component of workers' total earnings in the motor vehicle sector, we decided to use measures of compensation, even though it is only available at the more aggregate durable goods sector for our sample period. A disadvantage of this data-series is its focus on only U.S. compensation, whereas our unit production data reflects production of vehicles in the U.S., Canada, or Mexico but intended for the U.S. market.

[21]For more information on DYNARE and the terms of its license, go to http://www.dynare.org/.

[22]See the on-line appendix A for a statement of the model as well as the nonstochastic steady state.

[23]We arrive at this number using the current-cost depreciation tables published by the BEA over the 1972-2011 period.

[24]Copeland, Dunn, and Hall (2011) estimate a similar elasticity (how changes in an inventory-based variety measure increase sales) to be roughly 0.5. Their discrete-choice static model identifies this elasticity from the variation in the cross-section, whereas in the current paper the available supply elasticity is pinned down by the steady state, specifically, by the mean values of the ratios of available supply to sales and output to sales.

[25]Consistent with our theoretical model, the interest rate in the RVAR is adjusted for inflation. The consumer price index is for all urban consumers, and the producer price index is for all commodities; both series are published by the Bureau of Labor Statistics. We seasonally-adjust both the ratios using a backward-looking average, which for a given date t, used data from $t-12$ to t.

[26]Following how we treated the data, we use a backward-looking average of the ratios , which for a given date t, used data from $t-12$ to t.

Table 1: Parameter Estimates for the Laws of Motion for Real Interest Rates.

	Parameter	Point estimate	Standard error
		household rate	
persistence	ρ_{x_1}	0.9548	0.0759
standard deviation	$_{x_1}$	0.0001	0.00001
		firm rate	
persistence	ρ_{x_2}	0.9643	0.0244
standard deviation	$_{x_2}$	0.0002	0.00001
		common shock to both rates	
persistence	ρ_f	0.9919	0.0063
impact coe cient		0.2444	0.0069

Note: The standard deviation of the innovation to f_t is normalized to 0.001.

Table 2: Calibrated Parameters

Parameter		Value
Return on labor	α	0.6
Vehicle scrappage rate		0.015
Fraction of vehicle loan paid off	μ	0.02
Household discount rate	ζ	0.995
Fraction of new vehicle purchases financed with a loan	$\bar{\xi}$	0.35

Table 3: Prior and Posterior Distributions of Estimated Parameters

Parameter		Prior			Posterior	
		mean	std dev	dist	mean	CI
Available supply elasticity	θ	2.5	1.0	normal	2.995	(1.90, 4.15)
Additive term	ι	0.5	1.0	inv gam	0.49	(0.34, 0.65)
Own-price elasticity	$\varepsilon = \theta + \iota$	3.0	2.0	–	3.48	(2.46, 4.71)
Linear inventory cost	κ_0	0.1	0.05	normal	0.04	(0.03, 0.06)
Nonlinear inventory cost	κ_1	0.8	0.3	beta	0.79	(0.47, 1.05)
Utility weight on motor vehicle expenditures	π_2	0.1	0.1	inv gam	0.06	(0.059, 0.062)
Income growth: persistence	ρ_i	0.7	0.15	beta	0.96	(0.95, 0.97)
Income growth: standard deviation	$_i$	0.01	∞	inv gam	0.002	(0.0017, 0.0022)
Compensation growth: persistence	ρ_w	0.7	0.15	beta	0.44	(0.33,0.57)
Compensation growth: standard deviation	$_w$	0.01	∞	inv gam	0.003	(0.002, 0.003)
Persistence in common shock to income and compensation	ρ_j	0.2	0.1	normal	0.2003	(0.032, 0.388)
Impact coe cient of common shock to income and compensation	ω	0.001	0.001	normal	0.0011	(-0.001, 0.003)
Persistence in productivity growth	ρ	0.75	0.15	beta	0.41	(0.30, 0.52)
Standard deviation of productivity growth		0.01	∞	inv gam	0.002	(0.0017, 0.0022)

Standard deviations on measurement errors	Prior			Posterior	
	mean	std dev	dist	mean	CI
Ratio of new vehicle expenditure to income	0.01	∞	inv gam	0.0058	(0.0054, 0.0061)
Ratio of consumption to income	0.01	∞	inv gam	0.0083	(0.0078, 0.0087)
Ratio of available supply to sales	0.50	∞	inv gam	0.508	(0.478, 0.537)
Ratio of output to sales	0.10	∞	inv gam	0.14	(0.136, 0.151)
Growth rate of real sales	0.01	∞	inv gam	0.007	(0.0068, 0.0078)
Growth rate of real output	0.01	∞	inv gam	0.010	(0.0095, 0.011)

Note: std dev is standard deviation, dist is distribution, CI is credible interval and inv gam is inverse gamma. The table reports 90 percent credible intervals. .

Table 4: Data and Model Moments

Time-series	Data	Model	
	mean	mean of the mean	std of the mean
Ratio of new vehicle expenditures to income	0.047	0.045	0.002
Ratio of consumption to income	0.953	0.953	0.001
Ratio of available supply to sales	3.769	3.7481	0.027
Ratio of output to sales	1.007	1.002	0.007
Growth rate of real prices (annual rate, percent)	1.038	1.353	1.138
Growth rate of sales (annual rate, percent)	0.234	1.013	1.733
Growth rate of output (annual rate, percent)	0.219	1.0056	1.792
	std	mean of the std	std of the std
Ratio of new vehicle expenditures to income	0.010	0.007	0.001
Ratio of consumption to income	0.010	0.008	0.0003
Ratio of available supply to sales	0.507	0.507	0.017
Ratio of output to sales	0.146	0.144	0.005
Growth rate of real prices (annual rate)	4.399	6.119	0.513
Growth rate of sales (annual rate)	14.765	12.052	0.690
Growth rate of output (annual rate)	19.670	16.398	0.657

Note: std is standard deviation. Model is the simulated data generated by the model. The first and second moments of the variables in the simulated data are computed from 1,000 simulated datasets.

Table 5: Persistence of Variables in the Data and Model

Time-series	Data		Model
	Persistence	CI	Persistence
Ratio of new vehicle expenditures to income	0.992	(0.981, 1.003)	0.984
Ratio of consumption to income	1.000	(0.999, 1.001)	1.000
Ratio of available supply to sales	0.994	(0.984, 1.004)	0.982
Ratio of output to sales	0.985	(0.969, 1.000)	0.980
Growth rate of real prices	0.921	(0.886, 0.956)	0.611
Growth rate of sales	0.703	(0.639, 0.767)	0.396
Growth rate of output	0.678	(0.612, 0.744)	0.276

Note: Persistence is is the estimated coe cient in a regression of a variable on its lag. CI is the 95 percent confidence interval generated from this regression. The persistence of the variable in the simulated data is the average coe cient computed from 1,000 simulated datasets

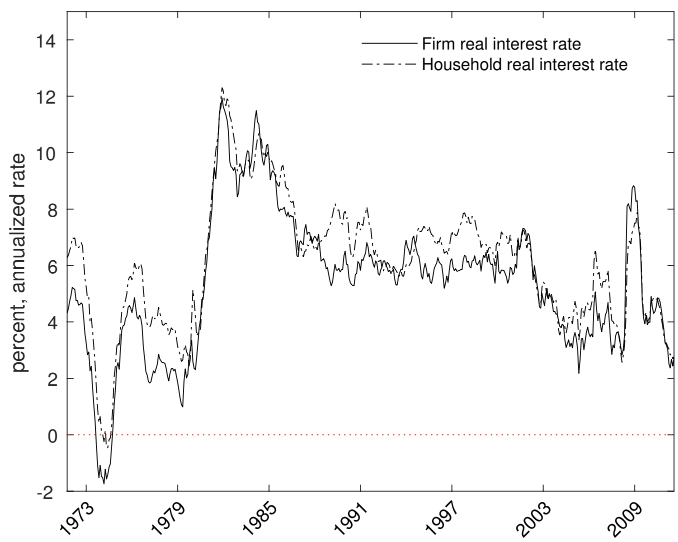
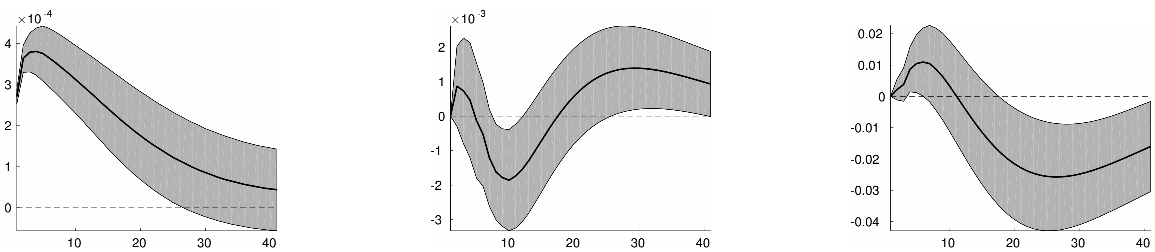
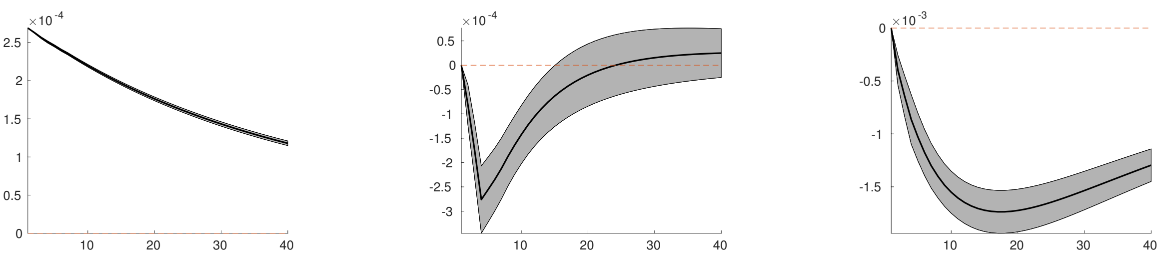


Figure 1: Evolution of Real Interest Rates: 1972-2011



firm interest rate | ratio of output to sales | ratio of available supply to sales

Panel A: Data: Shock to Firms' Interest Rate



firm interest rate | ratio of output to sales | ratio of available supply to sales

Panel B: Model: Shock to Firms' Interest Rate

Figure 2: Recursive Impulse Responses on the Output to Sales and Available Supply to Sales Ratios to a One-Standard-Deviation Interest-Rate Shock

Note: The bands around the impulse responses are 95 percent confidence intervals. A period is a month.

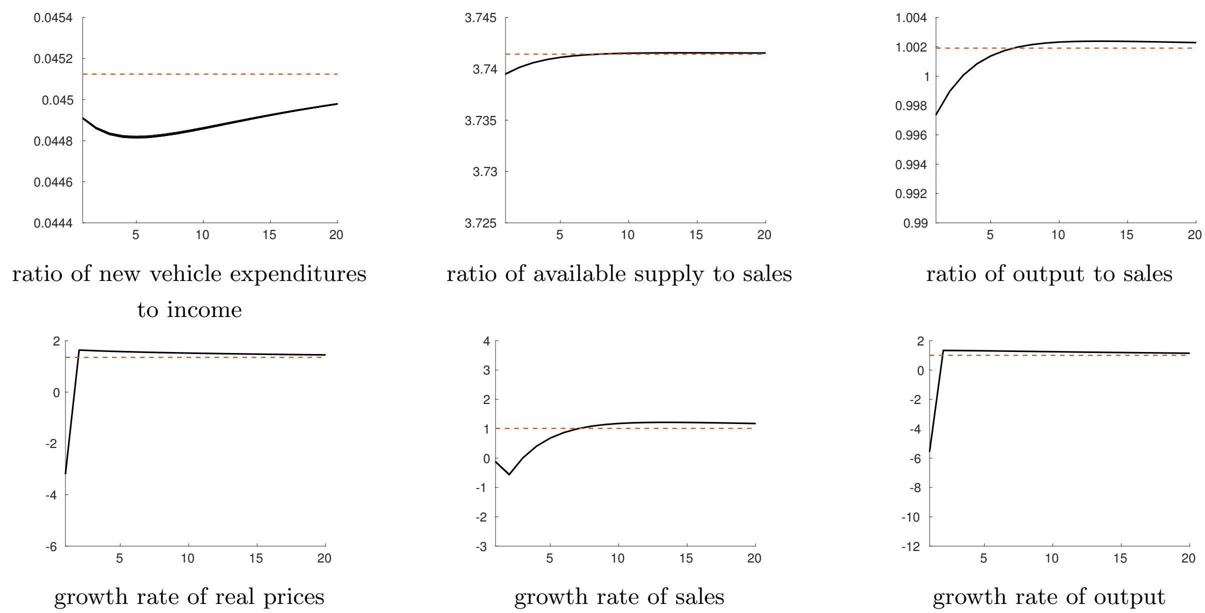


Figure 3: Impulse Response to a 100 Basis-Point Positive Shock to Households' Interest Rate

Note: Each impulse response is centered on its mean, represented by the dashed line. The growth rates of real prices, sales, and output are reported at an annual rate. A period is a month. The impulse responses are computed using the mean of the parameters' posterior distributions. The bands around the impulse responses are 90 percent credible intervals which reflect different initial values of the other shocks.

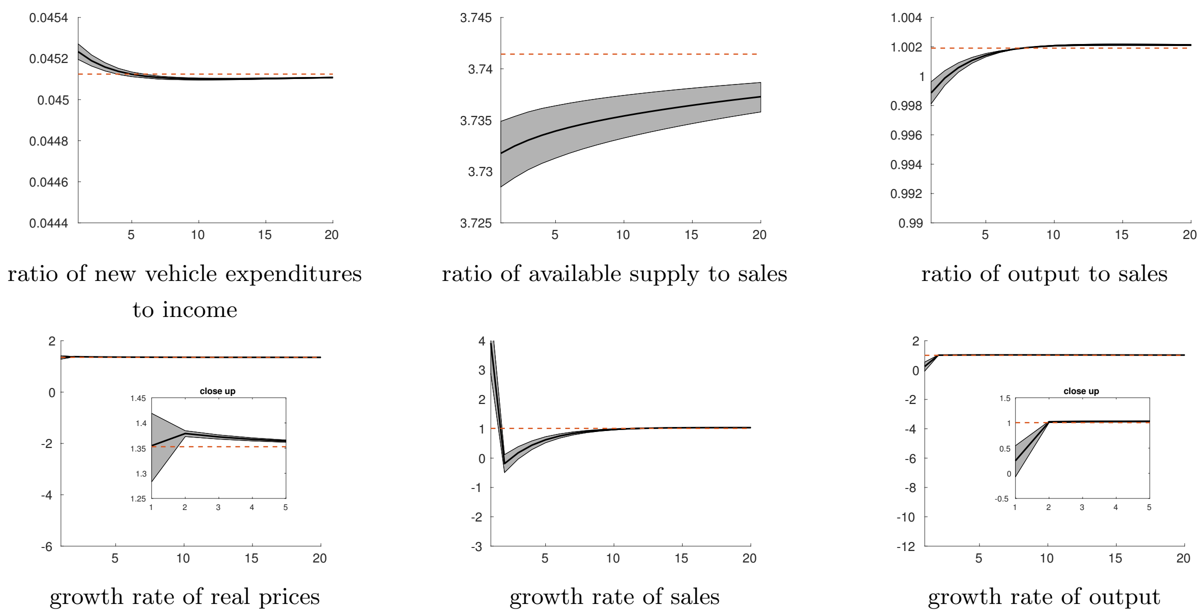


Figure 4: Impulse Response to a 100 Basis-Point Positive Shock to Firms' Interest Rate

Note: Each impulse response is centered on its mean, represented by the dashed line. The growth rates of real prices, sales, and output are reported at an annual rate. A period is a month. The impulse responses are computed using the mean of the parameters' posterior distributions. The bands around the impulse responses are 90 percent credible intervals which reflect different initial values of the other shocks.

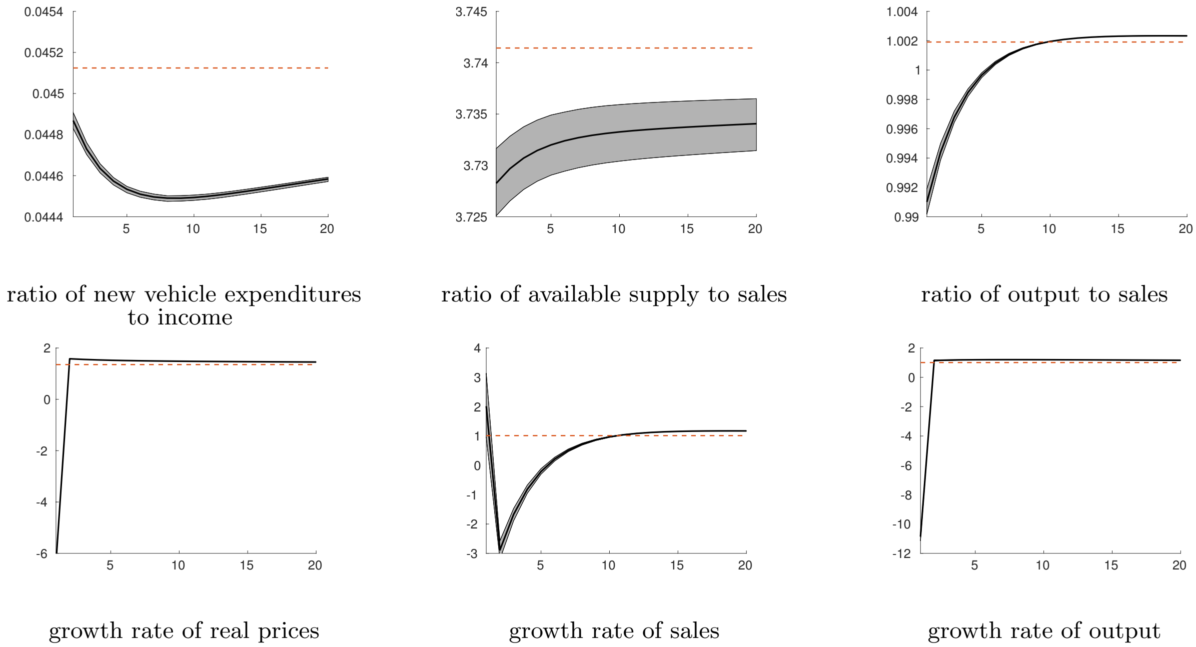


Figure 5: Impulse Response to a Shock to the Common Component of Interest Rates, Where the Shock Generates a 100 Basis-Point Innovation to both Interest Rates

Note: Each impulse response is centered on its mean, represented by the dashed line. The growth rates of real prices, sales, and output are reported at an annual rate. A period is a month. The impulse responses are computed using the mean of the parameters' posterior distributions. The bands around the impulse responses are 90 percent credible intervals which reflect different initial values of the other shocks.