Interest Rates and the Market for New Automobiles

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1 Introduction

We measure the dynamic response of prices, sales, production and inventories to changes in interest rates for a particular durable goods market – new cars and light trucks. This is an important issue because markets for durable goods are key channels through which monetary policy affects the economy.

Changes in real interest rates affect both sides of markets for durable goods. For consumers that purchase durable goods on credit, higher real rates increase the cost of borrowing. For producers of durable goods that produce to stock, higher real interest rates raise the cost of holding inventories. However, it is difficult to predict the change in sales, production, inventories, and prices given a rise in real interest rates. When the cost of borrowing to consumers rises, sales and prices should fall. But in response to higher inventory-holding costs, firms will want to lower inventories by lowering prices, reducing production, and increasing sales. Further, since inventories facilitate sales by making it easier for consumers to be matched with the precise product they want, lower inventories due to higher real interest rates will dampen sales because it will be harder for firms to match consumers to the exact good they wish to purchase. These counter-veiling forces suggest that the sales, production, inventories and price responses to changes in interest rates may be non-monotonic, helping to explain why previous research has found little effect of real interest rates on sales and inventory behavior in durable goods markets.

We analyze all of the above channels through which real interest rates affect durable goods markets by focusing on the U.S. market for new cars and light trucks. Automobiles are the quintessential durable good comprising more than 20 percent of all durable goods sold in the U.S. High quality data on transaction prices as well as units produced, sold and held in inventory at the monthly frequency are available. Most importantly from our perspective, interest rates effect both sides of the market. On the supply side, automobiles are built-to-stock[1] with the typical dealer holding three months of sales in inventory. Because interest rates are an important component of the inventory holding costs, theory suggests that firms will reduce inventory levels in response to increases in interest rates. On the demand side, higher interest rates directly raise the total cost of buying a vehicle for many consumers. Further, the purchase of any durable good has an inter-temporal component; the more the consumer discounts the future, the lower is the return to the consumer from buying the good in the present period. Consequently, we expect higher interest rates should dampen consumer demand. While 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 good industries as well.

We construct a model of the market for new automobiles. On the demand side, the model consists of a representative household that incurs shopping costs to decide on which cars to purchase and maximizes discounted utility to decide

[1] While some particular make and models (e.g. the Mini-Cooper) are built-to-order, the vast majority of new vehicles sales are out of the existing inventory stock.

on over-all purchases of new automobiles and other consumption goods. The household faces a stochastic interest rate at which it can borrow and finances new car purchases with income and loans. On the supply-side, the model consists of a model of a representative producer-dealer of new automobiles. This firm is a monopolistic competitor who maximizes the discounted flow of profits. The firm faces a stochastic interest rate and holds inventories to facilitate sales. The solution of our model determines the equilibrium prices and quantities of new cars and light trucks. Our model is estimated via maximum likelihood using monthly data on new cars and light trucks. Our data mostly come from the Bureau of Economic Analysis and Wards Automotive, and include unit sales, inventories held by firms, production, and stocks of automobiles held by households from 1967 to 2007. Our prices are based on expenditures, and so reflect the vast increase in car quality that has occurred over the past forty years.

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 Ludvigson (1998), Chah, Ramey and Starr (1995), Alessie, Devereux and Weber (1997) and Attanasio, Goldberg and Kyriazidou (2006). This literature, however, ignores the supply side of the market. We certainly agree that credit constraints to both consumers and firms may play an important role in the auto market beyond simply the posted interest rate.[2] However, our model suggests that interest rate changes will affect sales in three different ways operating through both the demand side and 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, there are a number of studies of automobile firms that have explored the relationship between inventories and production. See, for example, Blanchard (1983), Kahn (1992), Kashyap and Wilcox (1993), and Ramey and Vine (2004). However, this literature ignores the damand-side of the automobile market. Further, 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 highlights a broader, important puzzle in empirical research on inventories which is that over a long period of time very few studies have uncovered a significant relationship between real interest rates and inventories.[3] This is an important issue for several reasons. One is that in theory a channel through which monetary policy operates is that it changes short-term real interest rates and thereby influences inventory investment. Sec-

[2] In the current financial crisis, despite a Fed Funds rate near zero, many consumers have been unable to obtain new car loans contributing to a plummet in auto sales and pushing G.M. and Chrysler to near bankruptcy.

[3] See Blinder and Maccini (1991) and Ramey and West (1999) for surveys of the literature. Maccini, Moore and Schaller (2004) are an exception in that they provide evidence that inventories respond to long-run movements or regime shifts in real interest rates. However, they treat sales as given and therefore do not take up the effect of real interest rates on inventories operating through sales.

ond, 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. The lack of empirical evidence on the mechanism by which real interest rates affects inventories is therefore troubling.

Since our analysis attempts to look at both the consumer-side and firm-side decisions simultaneously, this paper most closely builds on the work of Blanchard and Melino (1986) who also develop a model of the market for automobiles. There are three 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. Further, we distinguish between 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. Third, we construct a data set that is more extensive than that of Blanchard and Melino both in the size of the sample and the fact that we were able to obtain data on both stocks of inventories of new automobiles held by firms and the stock of automobiles held by households. Our market equilibrium model is thus able to capture movements in both types of stocks.

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

2 A 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 cost of purchasing automobiles. Given this outcome, in the second stage, the household maximizes utility.

In the first stage, the household minimizes the cost of purchasing automobiles. The costs consist of both purchase costs and shopping costs. Define P_{jt} as the price of a new automobile of type j, and S_{jt} as the quantity of new automobiles of type j that are purchased at time t. Then $P_{jt}S_{jt}$ is the cost of purchasing new automobiles of type j at time t. Define $\phi\left(\frac{N_{jt-1}}{N_{t-1}}\right)S_{jt}$ as the total real shopping cost of purchasing new automobiles of type j, where

$\phi\left(\frac{N_{jt-1}}{N_{t-1}}\right)$ as the real per unit shopping cost of purchasing new automobiles 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, N_{t-1} is the stock of inventories of all new autos in the industry, and where we assume that $\phi' < 0$. Shopping costs consist of the time cost and financial cost of searching for a new automobile. The basic idea is that the shopping cost to the household declines the higher is the inventory of new cars that firm j has relative to the size of inventory holdings in the industry. The higher is the level of inventories of firm j, the higher is the probability that there will be a match between the household's decision to buy an automobile of type j and firm j.[4] Then, $\phi\left(\frac{N_{jt-1}}{N_{t-1}}\right) P_{jt}S_{jt}$ the total shopping cost of purchasing new automobiles of type j valued at P_{jt}. Finally, the total cost of purchasing new automobiles of type j is the sum of the purchase costs plus the shopping costs, or

$$P_{jt}S_{jt} + \phi\left(\frac{N_{jt-1}}{N_{t-1}}\right) P_{jt}S_{jt} = \left[1 + \phi\left(\frac{N_{jt-1}}{N_{t-1}}\right)\right] P_{jt}S_{jt} \tag{1}$$

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

$$\int_0^1 \left[1 + \phi\left(\frac{N_{jt-1}}{N_{t-1}}\right)\right] P_{jt}S_{jt}dj \tag{2}$$

subject to

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

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

$$\phi\left(\frac{N_{jt-1}}{N_{t-1}}\right) = \left(\frac{N_{jt-1}}{N_{t-1}}\right)^{\nu} - 1 \tag{4}$$

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

$$S_{jt} = \left(\frac{P_{jt}}{P_t}\right)^{-\varepsilon} \left(\frac{N_{jt-1}}{N_{t-1}}\right)^{\theta} S_t \tag{5}$$

where S_t is aggregate purchases of new automobiles, P_t is the average price of new automobiles, and $\theta = -\epsilon\nu > 0$. This is the demand function faced by the firm that produces new automobiles of type j.

[4] 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.

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

$$C_t + \left(1 - \overline{\xi}\right) P_t S_t + r_{2t} B_{t-1} + \mu B_{t-1} = I_t \tag{7}$$

$$X_t = (1 - \delta) X_{t-1} + S_t \tag{8}$$

$$B_t = (1 - \mu) B_{t-1} + D_t \tag{9}$$

$$D_t = \overline{\xi} P_t S_t \tag{10}$$

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 stock of car loans, D_t is new loans incurred to purchase automobiles, P_t is the real price of new cars, r_{1t} is the real interest rate on investments in net assets, r_{2t} is the real interest rate on new car loans, $\overline{\xi}$ is the fraction of a new car purchase financed by a new loan, δ is the rate that cars depreciate, and μ is the fraction of existing loans that need to be paid back every period.

Following a number of papers in the literature, for example, Blanchard and Melino (1983) 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 possess, 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 (8) indicates, purchases of new automobiles, S_t, add to the stock, which in turn also depreciates at rate δ. Purchases of new automobiles are financed in part with income, $\left(1 - \overline{\xi}\right) P_t S_t$, and in part with new loans, $D_t = \overline{\xi} P_t S_t$. On the latter, for simplicity, in this paper, we assume that the fraction of new purchases that are financed by loans is fixed at $\overline{\xi} = .8$, The budget constraint, (7), incorporates the payment of interest on loans, $r_{2t} B_{t-1}$, 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.

Now, assume now that the utility function is

$$U(C_t, X_t) = \pi_1 \ln C_t + \pi_2 \ln X_t$$

and use (10) to eliminate D_t. The first order conditions are then

$$\frac{\pi_1}{C_t} = \lambda_{1t}^h \tag{11}$$

$$(1-\delta)\zeta E_t \lambda_{2t+1}^h + \frac{\pi_2}{X_t} = \lambda_{2t}^h \tag{12}$$

$$\lambda_{2t}^h - \left(1-\overline{\xi}\right) P_t \lambda_{1t}^h + \overline{\xi} P_t \lambda_{3t}^h = 0 \tag{13}$$

$$(1-\mu)\zeta E_t \lambda_{3t+1}^h - \zeta E_t \left(r_{2t+1} + \mu\right) \lambda_{1t+1}^h = \lambda_{3t}^h \tag{14}$$

together with (7), (8), and (9). The endogenous variables are then: C_t, X_t, S_t, B_t and the multipliers, λ_{1t}^h, λ_{2t}^h and λ_{3t}^h

These three multipliers represent the marginal utility of consumption (λ_{1t}^h), the marginal utility of the automobile stock (λ_{2t}^h), and the marginal disutility from consumer automobile debt (λ_{3t}^h). The first-order condition (13) states that the cost to the household from purchasing more autos is the sum of $\left(1-\overline{\xi}\right) P_t$ times the cost of the forgone current period consumption and $\overline{\xi} P_t$ times the disutility of 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_{2t}, acts just like a drop in income reducing the demand for both goods. An increase in next period's interest rate r_{2t+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. The firm is an integrated dealer-producer.[5] 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, chooses P_{jt}, S_{jt}, Y_{jt}, L_{jt},and N_{jt} to maximize:

$$PV_j = E_o \sum_{t=0}^{\infty} \left[\Pi_{s=0}^{t} \beta_s\right] \Phi_{jt} \tag{15}$$

where

$$\beta_s = \frac{1}{1 + r_{1s}} \tag{16}$$

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

$$\Phi_{jt} = \frac{P_{jt}}{P_t} S_{jt} - \frac{W_t}{P_t} L_{jt} - \kappa N_{jt-1.} \tag{17}$$

subject to:

$$N_{jt} = N_{jt-1} + Y_{jt} - S_{jt} \tag{18}$$

$$Y_{jt} = \Gamma_{jt} \left(L_{jt} \right)^{\alpha} \tag{19}$$

$$S_{jt} = \left(\frac{P_{jt}}{P_t} \right)^{-\varepsilon} \left(\frac{N_{jt-1}}{N_{t-1}} \right)^{\theta} S_t \tag{20}$$

where P_{jt} is the 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, Y_{jt} is the output of automobiles of type j, Γ_{jt} is labor productivity, r_{1t} is the real interest rate faced by the firm, 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 industry price level , W_t is the nominal wage rate.

Observe that (20) 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 houshold 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. Now, use (20) to eliminate price as an explicit choice variable and rewrite net revenues as

$$\Phi_{jt} = S_{jt}^{1-\frac{1}{\epsilon}} \left(\frac{N_{jt-1}}{N_{t-1}} \right)^{\frac{\theta}{\varepsilon}} S_t^{\frac{1}{\epsilon}} - \frac{W_t}{P_t} L_{jt} - \kappa N_{jt-1.} \tag{21}$$

The firm then chooses S_{jt}, Y_{jt}, N_{jt}, and L_{jt} to maximize (15) subject to (18) and (19) and where net revenue is now defined as (21) and the discount factor is again (16). The first order conditions are

$$\left(\frac{\varepsilon - 1}{\epsilon} \right) \left(\frac{S_{jt}}{S_t} \right)^{-\frac{1}{\varepsilon}} \left(\frac{N_{jt-1}}{N_{t-1}} \right)^{\frac{\theta}{\varepsilon}} - \lambda_{1t}^f = 0 \tag{22}$$

$$E_t \frac{1}{1 + r_{1t+1}} \left[\frac{\theta}{\varepsilon} \left(\frac{S_{jt+1}}{S_{t+1}} \right)^{-\frac{1}{\varepsilon}} \left(\frac{N_{jt}}{N_t} \right)^{\frac{\theta}{\varepsilon}-1} \left(\frac{N_t}{S_{t+1}} \right)^{-1} - \kappa + \lambda_{1t+1}^f \right] = \lambda_{1t}^f \tag{23}$$

$$\frac{W_t}{P_t} + \lambda_{2t}^f \alpha \Gamma_{jt} L_{jt}^{\alpha - 1} = 0 \tag{24}$$

$$\lambda_{1t}^f + \lambda_{2t}^f = 0 \tag{25}$$

together with the inventory accumulation equation (18), and the production function (19), and where λ_{1t}^f and λ_{2t}^f are the multipliers associated with (18) and (19) respectively .

These optimality conditions summarize the endogenous dynamics of the supply-side of the model. The multiplier λ_{1t}^{f} measures the marginal value to the firm of an additional unit of inventory. Thus, equation (23) 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 benefit to the firm of having an additional unit of inventories (the value from the increase in demand for its vehicles) next period, 2) the marginal physical cost, κ, of holding an additional vehicle one more period, and 3) the marginal revenue from selling the vehicle next period. The higher is $r_{1,t+1}$, the smaller is the benefit to holding a vehicle in inventory one more period. Hence a firm which 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.

From equation (24) we see that the multiplier λ_{2t}^{f} measures the negative of the marginal cost to the firm of producing an additional automobile. Equation (25) states that the firm will set the marginal cost of producing an additional vehicle to the marginal value of additional unit of inventory.

2.3 Market Equilibrium

In market equilibrium, we assume that $S_{jt} = S_t$, $N_{jt} = N_t$, $L_{jt} = L_t$, $Y_{jt} = Y_t$, and $\Gamma_{jt} = \Gamma_t$. Then, eliminating the multipliers from the first order conditions, the optimality conditions and constraints for the firm become

$$E_t \frac{1}{1+r_{1t+1}} \left[1 + \frac{\theta}{\varepsilon - 1} \left(\frac{N_t}{S_{t+1}} \right)^{-1} - \frac{\varepsilon}{\varepsilon - 1} \kappa \right] = 1 \tag{26}$$

$$\frac{\alpha (\varepsilon - \theta - 1)}{\varepsilon} \frac{Y_t}{L_t} = \frac{W_t}{P_t} \tag{27}$$

$$N_t = N_{t-1} + Y_t - S_t \tag{28}$$

$$Y_t = \Gamma_t (L_t)^{\alpha} \tag{29}$$

For the representative household, use (11) to eliminate λ_{1t}^h, then the optimality conditions and the constraints the household faces are

$$(1-\delta)\zeta E_t \lambda_{2t+1}^h + \frac{\pi_2}{X_t} = \lambda_{2t}^h \tag{30}$$

$$\lambda_{2t}^h + \bar{\xi} P_t \lambda_{3t}^h = \left(1-\bar{\xi}\right) P_t \frac{\pi_1}{C_t} \tag{31}$$

$$(1-\mu)\zeta E_t \lambda_{3t+1}^h - \zeta E_t \left(r_{2t+1}+\mu\right) \frac{\pi_1}{C_{t+1}} = \lambda_{3t}^h \tag{32}$$

$$C_t + \left(1-\bar{\xi}\right) P_t S_t + \left(r_{2t}+\mu\right) B_{t-1} = I_t \tag{33}$$

$$X_t = (1-\delta) X_{t-1} + S_t \tag{34}$$

$$B_t = (1-\mu) B_{t-1} + \bar{\xi} P_t S_t \tag{35}$$

The market equilibrium model thus contains ten equations in ten endogenous variables: S_t, Y_t, N_t, L_t, C_t, P_t, X_t, B_t, $\lambda_{2t}^h$and λ_{3t}^h.

Finally, we assume that the exogenous variables in the model obey the following processes:

$$\begin{aligned}
r_{1t} &= \bar{r}_1 + \rho_{r_1} r_{1t-1} + \phi_1 f_t + \eta_t^{r_1} && (36)\\
r_{2t} &= \bar{r}_2 + \rho_{r_2} r_{2t-1} + \phi_2 f_t + \eta_t^{r_2} && (37)\\
f_t &= \rho_f f_{t-1} + \eta_t^f && (38)\\
\ln \Gamma_t &= (1-\rho_\Gamma)\bar{\Gamma} + \rho_\Gamma^1 \ln(\Gamma_{t-1}) + \rho_\Gamma^{12} \ln(\Gamma_{t-12}) + \eta_t^\Gamma && (39)\\
\ln W_t &= \overline{W} + \rho_W \ln W_{t-1} + \eta_t^W && (40)\\
\ln I_t &= \overline{I} + \rho_I \ln I_{t-1} + \eta_t^I && (41)
\end{aligned}$$

where f_t is a common factor to real interest rates. Thus each interest rate has a common and an idiosyncratic component. We allow labor productivity, Γ_t to depend on its one-period and twelve-period lags as well as a stochastic disturbance, η^Γ. This specification allows us to capture the seasonality observed in automobile production (e.g. regular shutdowns in July and December). There are six, mutually uncorrelated, economic shocks in the model: η^Γ, η^{r_1},η^{r_2}, η^f, η^W, and η_t^I. All six shocks are normally distributed with a mean of zero and constant variance.

3 Data

The data in this paper are drawn from a number of sources, though the majority come from the Bureau of Economics Analysis (BEA) and Wards' Automotive

Yearbook (various years). As detailed in the model, we need data on light motor vehicles describing sales, production, inventories, and prices. Further, we need information on the automakers' inputs as well as the real interest rate they face. Finally, we collect information on consumers' income, the interest rate consumers face to finance the purchase of a motor vehicle, and the stock of vehicles held by households..

3.1 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 US along with average price from January 1967 to the current period. A large number of motor vehicles are assembled in Canada and Mexico, but sold in the US. Therefore we follow the BEA nomenclature and define a "domestic" vehicle as one which is produced in the US, Canada, or Mexico, but intended for the US market.[6] Our sales and pricing figures also reflect this domestic label. Finally, we infer domestic inventories from the sales and production flows.

For light trucks, more work is required. The BEA publishes domestic light trucks sales from January 1967 onwards, but not domestic production nor domestic inventories. From 1985 onwards, Wards' Automotive provides detailed data on light truck inventories for the US. While this measure includes some foreign light truck inventories, we use this measure as an approximation of domestic inventories. The key assumption behind our approximation is that changes in Wards' inventories mainly reflect changes in domestic inventories, a reasonable conjecture given that light trucks are dominated by US manufacturers.

Because Wards' data only reaches back to 1985, we use a different technique to approximate domestic inventories from 1967 to 1985. We assume that the days supply figures for light trucks and automobiles are equal over this period. Days supply is a measure of the number of days vehicles can be sold at the current rate out of the current stock of inventories. This statistic is often used in the industry as a gauge of whether automakers are holding too many or too few vehicles in inventory. Hence we are assuming that automakers choose to target the same days supply figures for automobiles and light trucks. Indeed, from 1985 onwards, days supply for automobiles and light trucks have a correlation of 0.69. An advantage to this approach is that automotive days supply will pick up macroeconomic shocks and allow us to incorporate them into our domestic light truck inventory measure. With light truck domestic sales and our estimate of days supply, we can back out domestic light truck inventories from 1967 to 1985. Finally, we use the time series of domestic sales and inventories to back

[6] A small number of cars and trucks are assembled in the US 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 US market, they look at North America as a whole.

out domestic light truck production.[7] The model does not distinguish between automobiles and light trucks. Hence, we add together the sales, inventory and production data for these two types of vehicles.

Figure (1) plots the sum of automobile and light truck production, sales and inventories from January 1967 to April 2008. All three figures demonstrate the strong seasonal patterns in this industry. Unit production of light motor vehicles has stayed largely flat over this period time. Although not shown, there has been a large mix shift from automobile to light truck production. Over our sample, consumer demand has been growing for pickups, minivans, and SUVs, all classified as light trucks, at the expense of automobiles. The boom years of the early 1990's are most clearly seen in light motor vehicle sales, which surged from the early 1990's to early 2000's. Lastly, the amount of inventories held at dealerships has slowly grown over our sample, reflecting the difference in sales and production flows. To better analyze the relation between sales and inventories, we construct days supply, which is the ratio of the inventory stock at dealerships over the flow of sales in a particular month. This ratio is the number of days that firms could sustain the current sales flow when only drawing from inventories. This statistic is often used in the motor vehicle industry as a gauge of how well production and sales are aligned. Figure 2 plots days supply, and reveals this ratio has been roughly constant, although quite volatile, over our sample period.

We define average price to be equal to the total expenditures on vehicles divided by vehicles sold. BEA publishes this figure for domestic automobiles. We construct this figure for light trucks. We compute total expenditures on light trucks using quarterly data on personal consumption expenditures and private investment.[8] Before 1987, only investment in trucks is published. We approximate the level of light truck investment from 1967 to 1986 by assuming that light truck investment has the same growth rate as total truck investment over this time period. We then divide the sum of the personal consumption expenditures and private investment by unit sales to arrive at an average price. This average price is for all light trucks, but we assume it is a good approximation of domestic light trucks based on the small market share of foreign light trucks. Because we computed average light prices at the quarterly frequency, we use linear interpolation to construct a monthly series. Finally, we deflate both the average automobile and light truck price series using the nondurables consumer price index. The resulting series is now a relative price, measuring how the price of a vehicle compares to the typical nondurable consumption bundle over time.[9] Finally, we take the sales-weighted average of automobile and

[7] We checked our inferred measure of domestic light truck production against US light truck assemblies. As expected, the correlation between these two series is a high 0.976. Further, domestic production is typically higher than US assemblies; the average difference between monthly domestic light truck production and US assemblies is more than 44,000 units.

[8] Because government investment in light trucks is small and, for most of the time periods we examine, not published separately from medium and heavy truck investment, we do not include it in our average price calculations.

[9] In contrast to our approach, Blanchard and Melino (1986) use the CPI component for new cars divided by the PCE deflator to construct their relative price measure. We do not use

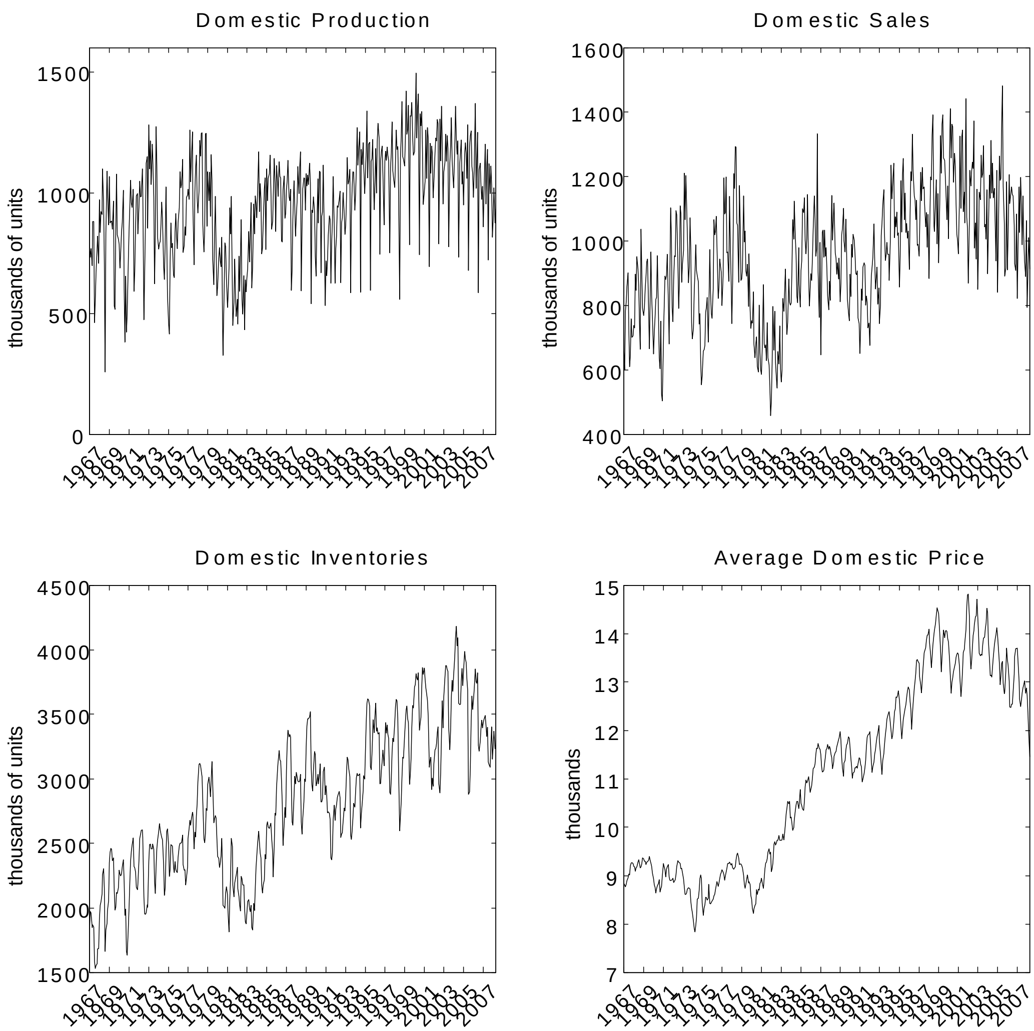

Figure 1: Production, Sales, Inventories and Prices

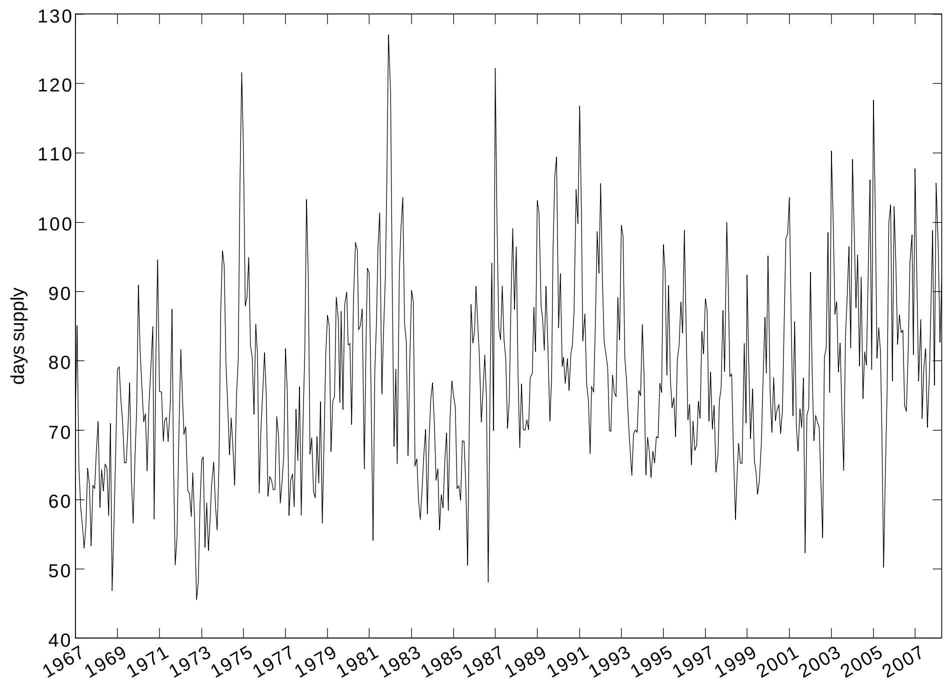

Figure 2: Inventory-Sales Ratio

light truck prices to arrive at the average light motor vehicle price. As shown in figure (1) these prices have doubled over our sample period, in part reflecting the increased quality of motor vehicles.

3.2 Production Inputs

In the production function, equation (19), we specify the relationship between inputs and output for light motor vehicles. The inputs we consider are the number and average weekly hours of production workers, two series published by the Bureau of Labor Statistics (BLS). Two issues arise with these series. First, the BLS started publishing these series for light motor vehicles in January 1990. Before this date, the BLS only published these series for all motor vehicles, which includes medium and heavy truck production. Using the percent change in the appropriate total motor vehicle series, we extrapolate each light motor vehicles series back-in-time from January 1990. Because medium and heavy trucks production is small relative to light motor vehicle production, this extrapolation should produce a good approximation.[10]

The second issue is the data only reflects production in the US. Our unit measures of production, sales and inventories, however, reflect domestic production– a figure that includes imports from Canada and Mexico. Because US production makes up most of domestic production, however, our input measures should serve as good approximations.

3.3 Personal income, Interest Rates, and the Household Stock of Vehicles

To measure consumers' income, we use personal income as published by the BEA, deflated with the personal consumption expenditure price index. We define the real interest as the difference between the nominal interest rate and inflation expectations. We construct two real interest rates, one is the rate faced by automakers and the other is the rate faced by households.

We assume the rate faced by automakers is the triple-A bond yield, the interest rate earned on investment-grade bonds. For households, we take the interest rate reported on car loans financed by the financial arms of General

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this relative price measure, however, because the CPI component for new cars is a quality-adjusted price, while our measure of units sold, produced, and inventories are not quality adjusted. Because there is substantial quality adjustment for new cars and light trucks, there is a large mis-match between the quality-adjusted prices and regular units sold. Using the Frisch product rule, we can construct an quality-adjusted quantity index for new automobiles 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 not insignificant 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.

[10] From January 1990 until March 2003 these two series overlap. In this overlap period, there is a high correlation between the two series. For the number of production workers, the correlation between the light motor vehicle and total motor vehicle series is 0.943. For average hours worked, the correlation is 0.993.

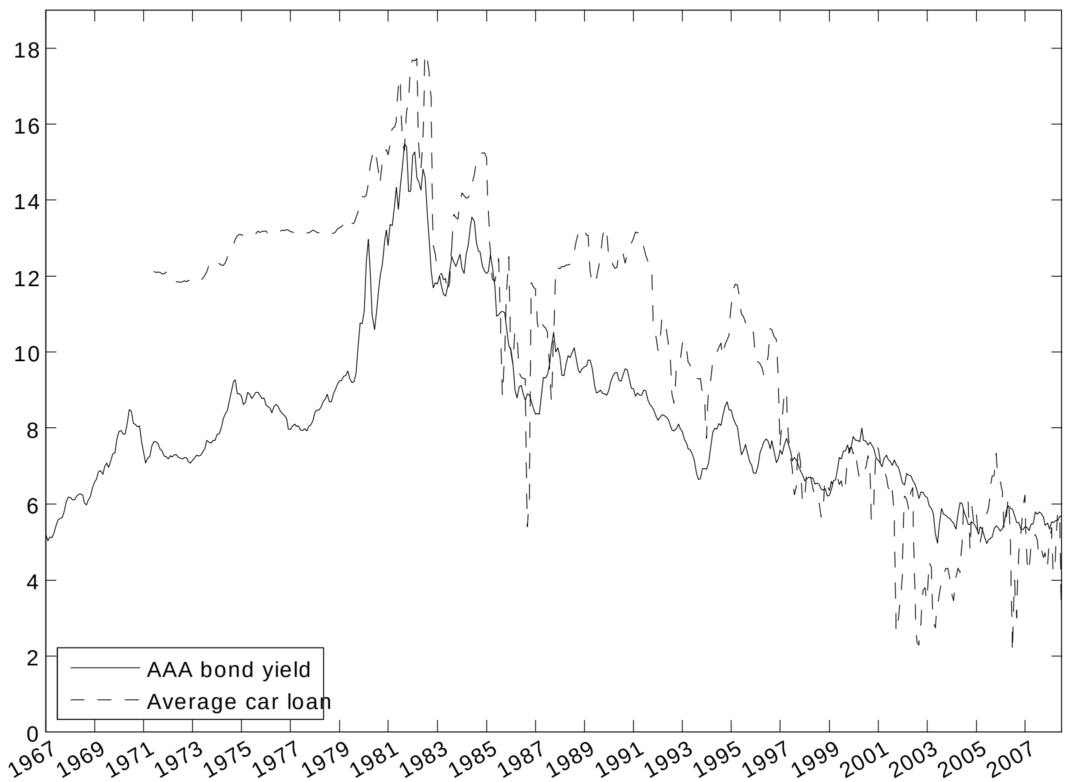

Figure 3: Nominal Interest Rates

Motors, Ford and Chrysler.[11] We plot both nominal interest rate series in figure (3).

Interestingly, the interest rate faced by households is *not* always above the rate faced by automakers. Indeed, from the late 1990's onwards, households can often finance the purchase of their vehicles at rates below those faced by automakers. This reflects the incentives that automakers, through their financing arms, are offering consumers in order to stimulate sales.[12]

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 PCE, industrial production, and the triple-A bond yield. We estimate inflation expectations in period t using the regression coefficients estimated on data up until and including $t-1$.

[11] These data are published by the Federal Reserve Board back to 1971.

[12] Over the past seven years, for example, US manufacturers have been advertising their financing incentives under the "Zero percent financing" slogan.

Finally, we construct the vehicle stock held by households. Using registration data purchased by the BEA from Polk, we know the age distribution of cars and trucks from 1969 to 2001. By applying the BEA's depreciation rate for cars, we arrive at a quality-adjusted unit value of the household stock of cars and trucks in each year.

4 Empirical Results: Very Preliminary

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.

Since it not possible to obtain an analytical solution to market equilibrium model specified in (26) - (35), we use the Matlab programs in DYNARE written by Michel Julliard to approximate, solve, and estimate the model. The basic strategy is to linearize the model via a first-order Taylor approximation around its' non-stochastic steady state to obtain a system of linear difference equations

$$E_t \mathcal{D} x_{t+1} = \mathcal{A} x_t + \mathcal{B} u_t + \mathcal{C} \eta_{t+1} \quad (42)$$

$$u_t = \mathcal{F} x_t \quad (43)$$

where x_t denotes the 21×1 vector of time t state variables:

$$x_t = [1 \; X_{t-1} \; B_{t-1} \; N_{t-1} \; \ln(\Gamma_{jt}) \; ... \; \ln(\Gamma_{j,t-12}) \; r_{1t} \; r_{2t} \; f_t \; \ln(W_t) \; \ln(I_t) \;]' .$$

The term u_t denotes the 9×1 vector of control variables:

$$u_t = [S_t \; C_t \; X_t \; B_t \; D_t \; P_t \; Y_t \; L_t \; N_t]',$$

and η_t denotes the 6×1 vector of shocks:

$$\eta_t = [\eta_t^{\Gamma} \; \eta_t^{r_1} \; \eta_t^{r_2} \; \eta_t^{f} \; \eta_t^{W} \; \eta_t^{I}]'.$$

The DYNARE programs solve for $\mathcal{F}$ as a function of $\mathcal{D}$, $\mathcal{A}$ and $\mathcal{B}$ and determine the stable trajectory of the state variables, allowing the the system to written as

$$x_{t+1} = \tilde{\mathcal{A}} x_t + \tilde{\mathcal{C}} \eta_{t+1} \quad (44)$$

where $\tilde{\mathcal{A}} = \tilde{\mathcal{A}}(\mathcal{D}^{-1}, \mathcal{A}, \mathcal{B})$ and $\tilde{\mathcal{C}} = \tilde{\mathcal{C}}(\mathcal{D}^{-1}, \mathcal{C})$.

Let y_t denote the 9×1 vector of observed variables:

$$y_t = [S_t \; Y_t \; L_t \; X_t \; P_t \; I_t \; r_{1t} \; r_{2t} \; W_t].$$

These observed variables are written as linear functions of the state variables:

$$y_t = \mathcal{G} x_t. \quad (45)$$

If classical measurement error is added to equation (45), the linear system (44) and (45) can be used to compute a Gaussian likelihood function. Replace (45) with

$$y_t = \mathcal{G} x_t + \nu_t \tag{46}$$

where ν_t is measurement error such that $E\nu_t = 0$, $E\nu_t\nu_t' = R$ where R is diagonal matrix. We assume S_t, Y_t, L_t, X_t and P_t are measured with i.i.d. classical measurement error. To summarize, we have 9 observed series, 6 economic shocks η_{t+1} and 5 measurement errors in v_t. Using the Kalman filter we evaluate the likelihood function implied by (44) and (46) and find the parameters that maximize its value.

While the quantity series and the interest rates are stationary, there are trends in real prices, real wages and real disposable income. To make these series stationary, we detrend by removing a mean-zero linear trend. Prior to estimating the model, we fixed μ, the fraction of principal repaid each month on the auto-loans, to 0.03 and $\bar{\xi}$, the fraction of auto purchases financed, to 0.8.

parameter	point estimate	standard error	parameter	point estimate	standard error
$\bar{r_1}$	4.07	0.84	$\bar{r_2}$	5.99	9.81
ρ_{r_1}	0.975	0.10	ρ_{r_2}	0.957	0.014
ϕ_1	2.87	1.09	ϕ_2	1.79	0.67
σ_{η_1}	0.134	0.214	σ_{η_2}	0.715	0.032
ρ_f	0.365	0.202			
$\bar{W}$	0.961	0.270	$\bar{I}$	17,804	21,732
ρ_W	0.934	0.019	ρ^I	0.964	0.019
σ_{η_W}	0.183	0.006	σ_{η_I}	2851	96

The standard deviation of the innovation to f_t, σ_{η_f}, is normalized to 0.10.

Table 1: Parameter Estimates and Standard Errors for the Laws of Motion for f, r_1, r_2, W, and I.

We estimated the laws of motion for interest rates (36), (37), and (38), wage rates (40), and income (41) independently from the rest of the model. The point estimates and standard errors from maximizing the likelihood function are reported in table 1. These estimated processes do a good job matching the means, standard deviations, first-order auto correlations of the two interest rates. The means and standard deviations are reported in Table 4. The autocorrelations of r_1 and r_2 in the data are 0.990 and 0.960 respectively; for our estimated specification they are 0.989 and 0.960. On average, consumers pay 106 basis points more than firms for credit, though, as we illustrate in figure 3, recently consumers have, more often than not, paid less. In the data, consumers have paid less for credit than automakers 28 percent of the time. In our estimated process, this occurs 25.5 percent of the time. In the data, the contemporaneous correlation between the two interest rates is 0.61; in our estimated process, this

α	θ	ε	κ	$\bar{\Gamma}$	ρ_{Γ}^{1}	ρ_{Γ}^{12}	σ_{η_G}	δ	π_1
0.720	0.472	8.02	0.124	11.68	0.750	0.134	0.0192	0.0156	0.605
0.001	0.011	0.100	0.000	0.040	0.014	0.012	0.0007	0.0000	0.072

Table 2: Point Estimates and Standard Errors of the Economic Parameters

σ_{ν_P}	σ_{ν_L}	σ_{ν_S}	σ_{ν_Y}	σ_{ν_X}
0.680	96.3	180.3	212.7	0.1
0.023	3.6	6.0	7.4	–

Table 3: Estimated Standard Deviations of the Measurement Errors

correlation is 0.40. The common factor, f_t, explains 92 percent of the variance of r_1 and 13 percent of the variance of r_2.

In Table 2 we report the point estimates and standard errors for the remaining economic parameters for the model. The estimated parameters all have the expected sign and are generally of reasonable magnitudes. The estimated value for the production function parameter α of 0.72 is in the expected range. The elasticity of sales to inventories, θ, is .472, which seems reasonable. The depreciation rate of autos, δ, is estimated to be 1.56 percent per month or 18.7 percent per year. An exception is the (negative of the) price elasticity of demand, ε; which is estimated to be 8.02, which is high. Previous work on automobile demand (e.g. BLP) has typically found price elasticities around one at the industry level. The reported standard errors are quite small. The small standard errors appear to be to due jaggedness in the likelihood function near the optimum.

In Table 3 we report the estimated standard deviations of the five measurement error processes. The likelihood function was maximized at σ_{ν_X} equal to zero. Therefore we fixed this value at s very small number, 0.1.

As a measure of the goodness-of-fit, we report the implied means and standard deviations of the ten observed series along with their data counterpart. The current version of the model does a very good job matching the first and second moments of the data for sales, production, prices, employment and the stock of automobiles held by households . Further, the model does capture well other features of the data. As in the data, production is estimated to be more volatile than sales. And the model predicts the ratio of sales to the stock of automobiles to be 1.55% which is very close to that observed in the data of 1.60%. However, the model seriously underestimates the mean and standard deviation for inventories held by firms. The inventory-to-sales ratio is predicted to be just .47, whereas in the data it is 2.98.

In Figure 4 we plot the responses of eight series to a positive 125 basis point (at an annual rate) innovation to the r_2 process, η^{r_2}. This increase in r_2,which is an increase in the cost of borrowing to households, reduces the demand for autos and thus reduces sales. In response to the reduction in demand, firms

Series	data mean	sim mean	data std	sim std no meas err	sim std with meas err
Sales	973.3	974.7	188.5	122.0	217.8
Inventories	2900.2	453.1	530.0	54.0	
Prices	11.15	11.00	0.65	0.21	0.71
Production	974.9	974.7	217.8	127.2	246.8
Employment	424.2	465.2	82.5	65.3	116.6
Stock of Autos	60,681	62,447	2,385	2260	4,943
Income	488,786	487,828	10,701	10,567	
Wages	14.59	14.53	0.49	0.51	
AAA Bond Rate	4.34	4.44	2.38	2.31	
Auto Loan Rate	5.40	5.80	2.58	2.69	

Sales, inventories, production, and the household stock of automobiles are in thousands of vehicles per month. Prices and income are in thousands of dollars. Employment is in thousands of persons. Interest rates are at an annual rate.

Table 4: Means and Standard Deviations of the Data and Model

cut prices. Firms also reduce production initially and thus reduce employment immediately. In the model, the drop in production is larger than the drop in sales so inventories fall initially.

Inventories play a key role in this timing. Because of the persistence in interest rates, the firm anticipates that demand will be low for many periods, hence it wants to hold fewer inventories. Thus it keeps prices low to stimulate sales and reduces production generating a drop in inventories. This drop in inventories reduces demand further thus amplifying and propagating the demand-dampening effect of the interest rate increase. These forces causes sales, prices, and output to remain below their steady-state values taking over three years to return to the their steady-state values.

As we argued above, increases in interest rates not only influence consumer decision making, but firm decisions as well. In Figure 5 we report the response of seven series within our estimated model to a 125 basis point (at an annual rate) innovation to r_1, which is the real interest rate faced by firms. From the optimality condition (23), we see than an increase in r_1 lowers the future benefit to firms of holding an additional unit of inventory; thus, an increase in r_1 causes firms to desire fewer inventories. Consequently firms lower prices to increase sales and decrease production. In the initial period of the shock sales rise above its steady-state level. However as the inventory-to-sales ratio drops, demand falls, and sales return to its steady-state value from below.

So far, we have explored the effects of changes in r_1 and r_2 separately. There are two implications to be stressed: First, the effects on output, prices, inventories and labor input are quantitatively different. Although the direction of the effects on each of these variables is the same, the quantitative effects will depend on whether the interest rate increase comes through a higher cost of borrowing to consumers or through higher interest costs faced by firms. Second, the effects on sales are qualitatively different. An increase in r_2, which is an increase in borrowing costs to consumers, reduces sales, but an invcrease in r_1, which is an increase in interest rates faced by firms, raises sales. Hence, a complete understanding of the effects of higher real interest rates, and monetary policy more generally, requires a market analysis which can explore the various channels through which interest rates influence sales.

Generally, a restrictive monetary policy will raise the over-all level of real interest rates. To see the effects of an over-all increase in real interest rates, we report in Figure 6 the response of nine series to a five standard deviation increase in the common interest rate factor, f_t. Since the various channels through which interest rates operate have differential effects on sales and output, an increase in the common interest factor, which raises both r_1 and r_2, will capture their combined effect. A positive impulse to f_t generates a hump-shaped response in the two interest rates. As can be seen by the coefficients reported in Table 1, a five standard deviation impulse to f implies an initial increase in r_1 by 125 basis points and r_2 by 90 basis points (at an annual rate). The responses to the simultaneous increases in the two interest rates to some degree re-enforce each other. However, the responses to an increase in r_1 dominate. Firms cut prices dramatically, so that sales on balance increase, and production and labor input are cut drastically, so that inventories fall substantially in the first few months. Sales return close to steady state levels relatively quickly, but output, prices, inventories and labor adjust to steady state levels quite gradually.

5 Conclusions and Future Work

Summary of the results-Forthcoming.

In research that is underway, we are investigating the following extensions:

1. The model needs to be re-formulated so that the relevant variables in the market equilibrium model are in ratio form. During estimation, this would guard against any statistical problems with non-stationarity. An example of a model of the firm that holds inventories that is expressed in ratio form is that of Maccini and Pagan (2009).

2. In the above model of the firm, we specified labor input as simply the total number of hours worked per period. This needs to be extended to distinguish between hours worked per worker and the number of workers, and adjustment costs need to be introduced at least on the hiring and firing of workers. Also, compensation needs to reflect both wages and fringe benefits.

3. In the model of the household, we assumed that the household does not possess any assets beyond the stock of motor vehicles and we assumed that new automobiles are purchased out of current income and new loans where the new loans are eighty percent of the purchase price of the new car. This needs to be extended to allow households to hold liquid and illiquid assets as well as motor vehicles. And a decision on how much to borrow needs to be permitted.

Different forms of credit constraints need to be explored.

4. The model of the firm needs to be extended to take into account the usage of materials in the production process and the holding of materials and work-in-progress inventories.

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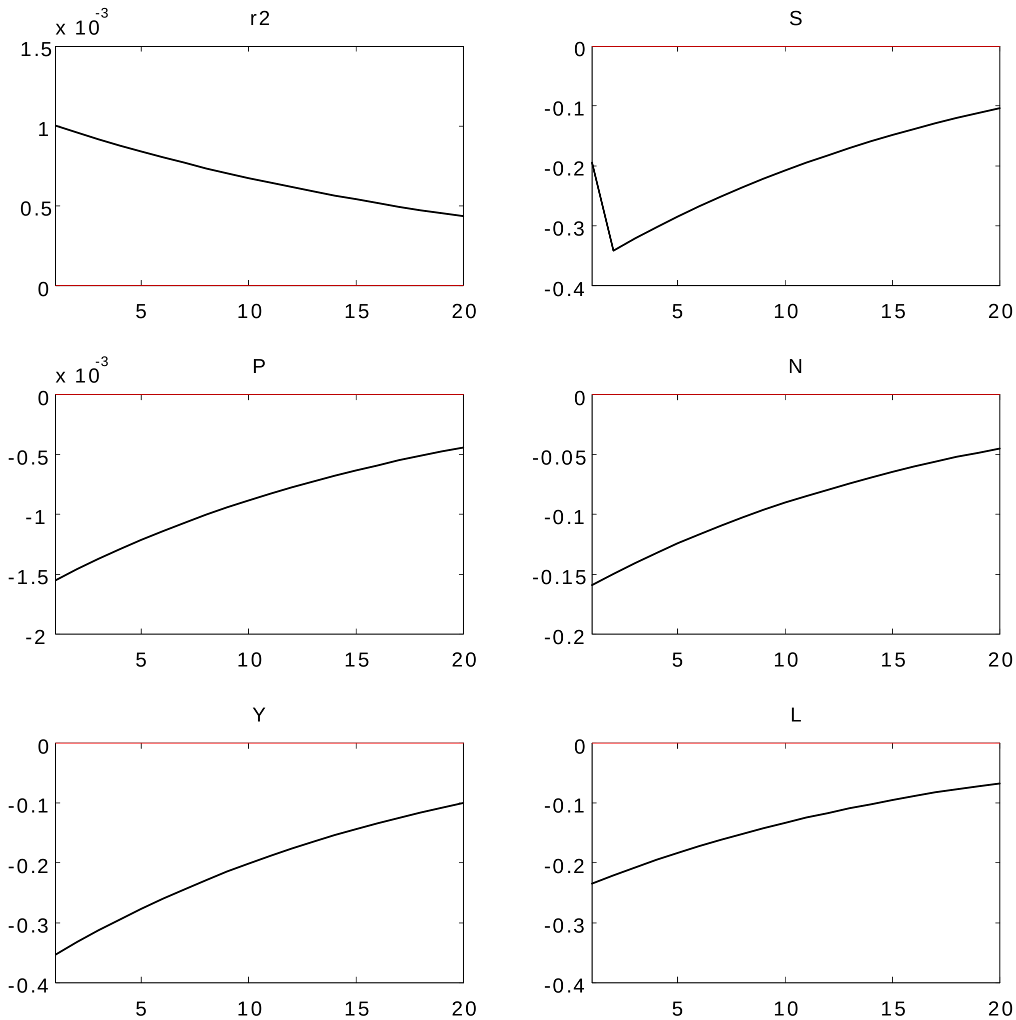

Figure 4: Impulse Response Functions of a 125 Basis Point Shock to the Consumer Auto Loan Rate, r_2

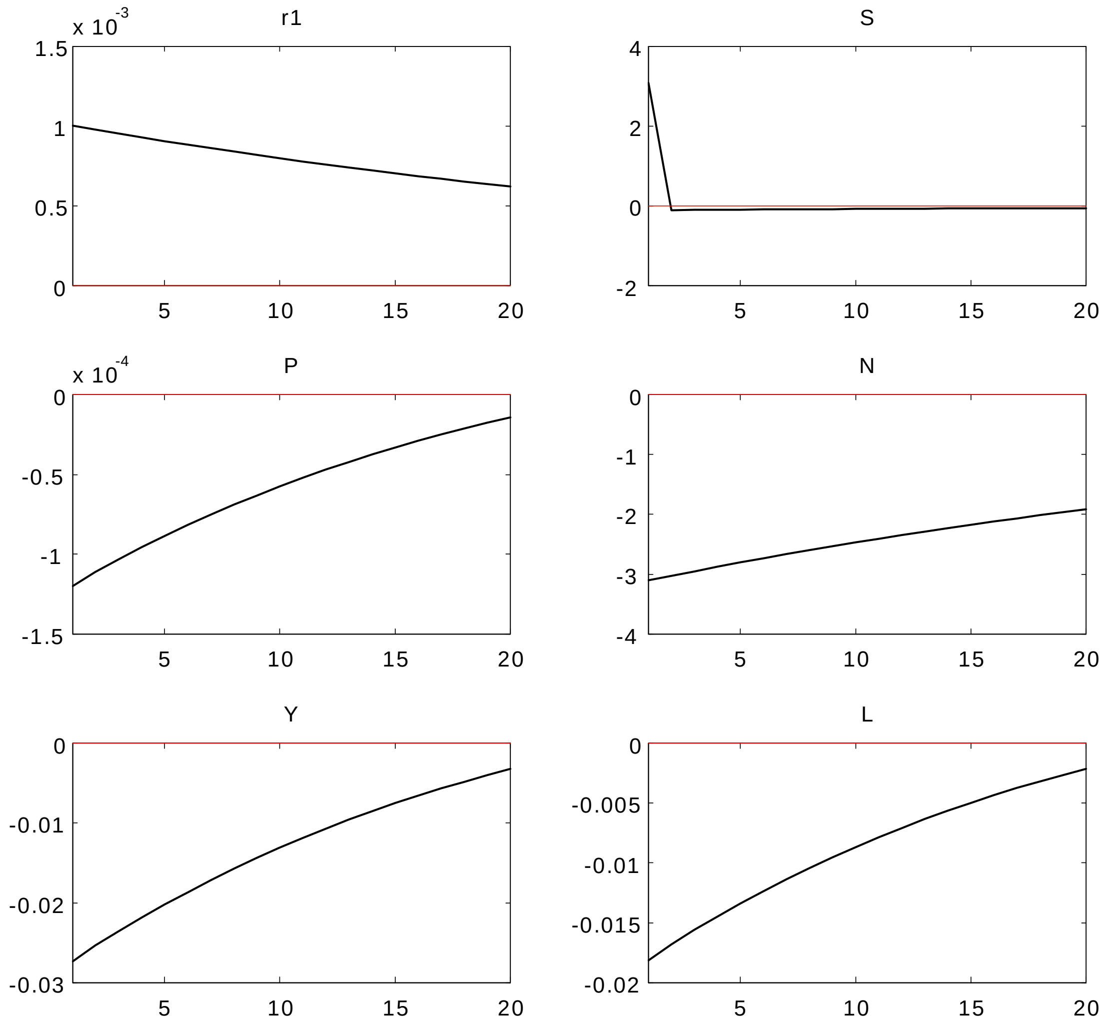

Figure 5: Impulse Response Functions of a 125 Basis Point Shock to the AAA Bond Rate, r_1

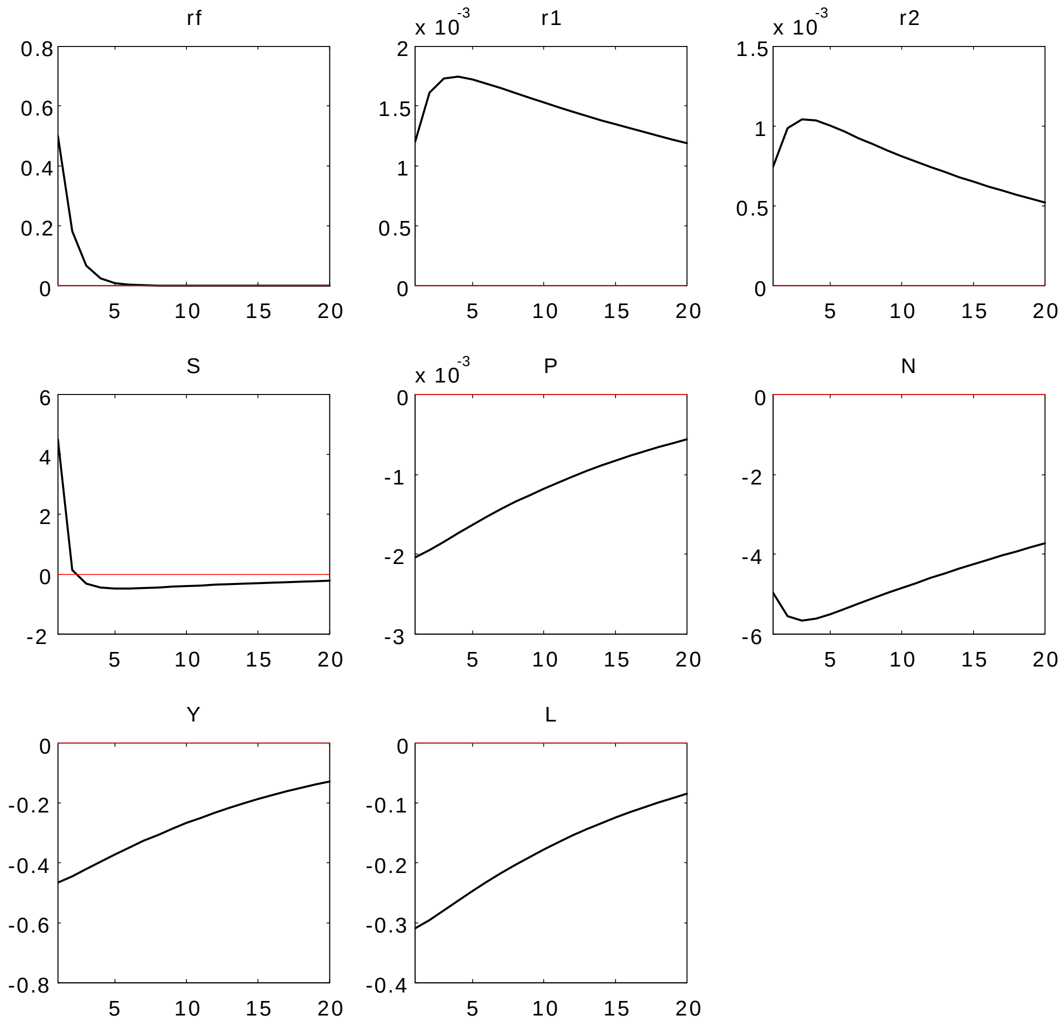

Figure 6: Impulse Response Functions of a Five Standard-Deviation Shock to the Common Interest Rate Factor, f