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Money, Consumer Durables, User-Costs, and the Forward-Looking Theory of Consumption

Abstract: In this paper, we estimate the dynamic response of the market for consumer durables to money supply shocks and examine the ability of the standard forward-looking theory of consumption and intertemporal choice to explain these patterns in the data. We use standard vector autoregression techniques to identify the impulse response functions of the real price of durable goods and expenditures on durables. We then compare these estimated paths to simulations predicted by the theoretical model. For plausible parameter values, the model does a reasonable job of matching the estimated responses. We conclude that the basic intertemporal model, despite recent empirical failures, maintains explanatory power for the case of aggregate consumer durables.
1. Introduction

The focus of this paper is the transmission of money supply shocks to the market for durable goods. Using standard tools of time-series analysis, we estimate the dynamic responses of aggregate durable goods price and expenditures in the US. We then use simulation techniques to gauge how well these estimated responses can be understood within the framework of the standard forward-looking model of intertemporal choice. The objective is two-fold – to contribute to our understanding of the role of money in short-run aggregate fluctuations, and to determine the efficacy of this theoretical framework for explaining a precisely-defined set of facts. Although expenditures non-durable goods exceeds that on durable goods, it is well known that the latter are much more volatile than the former, and thus potentially crucial for understanding cycles and monetary transmission.

The standard dynamic theory of consumer choice, in which a representative agent makes intertemporal allocations by maximizing utility over the time path of consumption, subject to an asset accumulation constraint, has been subject to intense empirical evaluation over the years. Recent evidence has pointed to a number of anomalies that are inconsistent with the standard model. Frederick, et al. (2002), for example, focus on the inability of the constant discount rate version of this class of models to explain a number of facts. These critiques usually end up calling for an alternative framework for analyzing intertemporal choice, such as “behavioral economics” (e.g., Thaler 1994 and Akerlof 2002), or at least generalized versions of the basic model, such as hyperbolic discounting (e.g., Angeletos et al. 2001). On the other hand, Browning and Crossley (2001) maintain the viability of the basic life-cycle theory of consumption and intertemporal choice, at least in a form generalized to allow for many recent extensions to the theory.

When applied to households consuming both non-durable and durable goods, i.e. goods that provide utility while also having the properties of an asset, the standard model (see for example the textbook treatment by Obstfeld and Rogoff 1996, pp. 96-98) predicts that the demand for durables will depend on the user cost of durables – the value of other
goods given up to purchase, use and resell the durable good. The user cost depends in turn on real interest rates, which provide an obvious channel through which money supply shocks can influence the demand for durables, as well as on the expected future price of the durable good. Our simulations focus on the role of user cost in driving the response of the durable goods market to money supply shocks.¹

Our empirical strategy comprises two steps. In the first, we estimate a vector autoregression (VAR) of a basic set of macroeconomic variables, including the real price of durable goods and real expenditures on durables. To identify the response of these variables to money supply shocks, we impose long-run monetary neutrality, a restriction that is consistent with most theories of the macroeconomy. It is important to note that this identification strategy does not rely on the implications of the forward-looking theory of choice (though it is consistent with the theory), and avoids the contentious issue of specifying a complete general equilibrium macro model. In this sense, we take the estimated dynamic response coefficients (the impulse response functions) as the facts that the theory is intended to explain.

In the second step, we compare these facts with the implications of the theory. We first linearize the first order conditions of the representative consumer’s optimization problem, then equate the resulting demand equation with a simple model of the flow supply of consumer durables. The resulting equilibrium time path for the relative price of durables and expenditures on durables shows how these quantities are related to interest rates and inflation. We then determine the model’s predicted response for the durables market by feeding the estimated interest rate and inflation responses (i.e. the real interest rate response) obtained from the first step into the equilibrium expressions. The implicit assumption we make is that the money supply process is independent of the durable goods market, so that the change in interest rates and inflation amounts to an exogenous shock.²

¹ Mankiw (1985) is one of the first studies to examine empirically this link between real interest rates and the market for consumer durables.
² Lastrapes (2002) uses a similar strategy to analyze housing markets. Note that most
In this paper, we choose to focus on the simplest possible model of intertemporal choice. We ignore potential complications involving adjustment costs (Bernanke 1985, Eberly 1994, and Lam 1991), illiquidity and imperfections of secondary markets for durable goods (Mishkin 1976), borrowing constraints (Chah, Ramey and Starr 1995), non-separability between durables and non-durables (Startz 1989), and precautionary saving (Wilson 1998). We also emphasize that our approach, given its focus only on money supply shocks, is more modest and less ambitious than estimating and testing a fully specified dynamic general equilibrium model. While the more general strategy is ultimately necessary for full understanding and policy implications, it requires the proper specification of all behavior, a difficult task. Our approach will be robust to potential mis-specifications along other dimensions.

Our findings suggest that money supply shocks are indeed transmitted to the durable goods market: positive shocks lead to temporary declines in real interest rates and increases in the relative price of durables and expenditures on durables. Furthermore, despite its simplicity, the basic model of intertemporal choice goes a long way toward tracking the responses of this market. The simulations show that the direction and magnitude of the responses of price and, especially, expenditures are consistent with the importance of user costs as predicted by the theory, for plausibly calibrated parameter values. However, since the theoretical predictions do deviate in some respects from the estimated responses, generalizations of the theory along the lines noted above would be worth exploring.

2. A dynamic equilibrium model of the market for consumer durables

In this section, we review the basic model of intertemporal choice, and its implications for the equilibrium response of the market for durable goods to money supply shocks. The model relies on the the assumption that the demand for durables reflects both the service flow and asset value of durable goods. On the margin, the return from durables must

previous studies of the market for durable goods ignore the supply of durables.
equal the return on alternative assets. We assume a representative agent who solves for the optimal path of consumption of non-durables and durables in a world of perfect foresight.\(^3\)

Suppose the representative household maximizes

\[
V_0 = \sum_{t=0}^{\infty} \beta^t [\gamma \log(c_t) + (1 - \gamma) \log(D_t)]
\]

subject to the accumulation constraint

\[
y_t + (1 + r_t) A_t = A_{t+1} + c_t + \mu p_t D_t + p_t(D_t - D_{t-1} + \delta D_{t-1}),
\]

where \(c_t\) is real expenditure on non-durable consumption goods during period \(t\), \(D_t\) is the stock of durable goods held by the household at time \(t\), \(\beta\) is the personal discount factor (implying a constant discount rate), \(y\) is real income, \(r\) is the real (after-tax) interest rate on alternative assets, \(A_t\) is the stock of alternative assets, \(p_t\) is the relative price of durables in terms of non-durables, \(\mu\) is maintenance and other costs that are proportional to the stock of durables owned, and \(\delta\) is the rate of depreciation of the durables stock. Equation (2) defines the sources and uses of funds in each period; the final term on the right-hand-side measures gross expenditures on durables during period \(t\). The model follows convention with its implicit assumption that the service flow of durables, which provides utility, is proportional to the stock, and that the service flow begins when the stock of durables is purchased.\(^4\) We impose Cobb-Douglas preferences through a log-linear instantaneous utility function.

The agent’s optimal time paths for \(c, D\) and \(A\) are obtained by differentiating the Lagrangean with respect to \(c_t, D_t\) and \(A_{t+1}\), for each period in the planning horizon. Combine the resulting Euler equations to obtain

\[
\frac{1 - \gamma}{\gamma} \frac{c_t}{D_t} = p_t \left[1 + \mu - \left(\frac{p_{t+1}}{p_t}\right) \left(\frac{1 - \delta}{1 + r_{t+1}}\right)\right].
\]

\(^3\) Obstfeld and Rogoff (1996) provide a standard treatment of the demand for durable goods in a dynamic optimization model. See Miles (1994) for a more general model with uncertainty.

\(^4\) See Obstfeld and Rogoff, p. 96, footnote 34.
The interpretation of this intratemporal condition is conventional and straightforward – the agent will allocate resources until the marginal rate of substitution of non-durables for durables (the left-hand-side of 3) equals the user cost (the right-hand-side). The user cost is the amount of non-durable consumption given up by purchasing one unit of durables, using it and paying requisite expenses, then selling the undepreciated remainder at next period’s price.

Equation (3) defines a nonlinear difference equation in the price of durables. To allow a tractable solution, we compute its log-linear approximation. To this end, first note that in the steady-state, the tangency condition (3) implies

\[ \frac{1 - \gamma}{\gamma} \frac{c_0}{D_0} = p_0(\mu + \delta + r_0), \]

assuming \( \frac{1 - \delta}{1 + r_t} \approx 1 - \delta - r_t \) and letting the 0 subscript denote steady-state values. Next, rearrange (3) and take natural logs of both sides:

\[ \log(p_t) = -\log(1 + \mu) + \log \left[ \frac{1 - \gamma}{\gamma} \frac{c_t}{D_t} + (1 - \delta - r_{t+1})p_{t+1} \right]. \]

Using a Taylor expansion to linearly approximate the second term on the right around steady-state values, we have

\[ \log(p_t) = K_1 - w_1 \log(D_t) + (1 - w_1)\log(p_{t+1}) - (1 - w_1)r_t, \]

where \( K_1 \) contains all the constants in the approximation, which depend on steady-state values and parameters, and

\[ w_1 = \frac{\mu + \delta + r_0}{1 + \mu}. \]

Equation (6) shows the (log) demand price for durables as a function of the stock of durables, the price of durables next period, and the real interest rate.\(^5\)

We posit the following relationship between (gross) flow production of durables and the price of durables:

\[ D_t - D_{t-1} + \delta D_{t-1} = \alpha p_t^{\phi_1} p_{t-1}^{\phi_2}. \]
That is, we simply assume that the supply of durable goods is exponential in current and lagged price. The lagged price is included to allow differences between temporary and persistent changes in price. Although this supply behavior is basic, most studies of aggregate durable goods do not specify a supply relationship at all. Exceptions using housing are Miles (1994, eq. 2.19), Bruce and Holtz-Eakin (1999), and Topel and Rosen (1988). The latter paper considers a more complex model of the flow of investment in durables (housing) than in our model. The log linear approximation to this supply curve is

\[
\log(D_t) = \theta_1 \log(D_{t-1}) + (1 - \theta_1) \phi_1 \log(p_t) + (1 - \theta_1) \phi_2 \log(p_{t-1})
\]

where we have used the steady-state result that \( \delta D_0 = \alpha p_0 (\phi_1 + \phi_2) \).

Equations (6) and (8) comprise a bivariate first-order difference equation in \( p_t \) and \( D_t \), which describes equilibrium in the market for consumer durables. A straightforward strategy for solving for the equilibrium paths of durables price and expenditures is to first solve the difference equation (8) for \( \log(D_t) \) as a function of \( p_{t-1} \), then substitute the result into (6) to get a second-order expression for equilibrium price:

\[
\log(p_t) = a_0 \log(p_{t+1}) + a_1 \log(p_{t-1}) - a_0 (r_{t+1} - \theta_1 r_t),
\]

where \( a_0 = \left[ \frac{1-w_1}{1+(1-w_1)\theta_1 + w_1(1-\theta_1)\phi_1} \right] \) and \( a_1 = \left[ \frac{\theta_1-w_1(1-\theta_1)\phi_2}{(1+(1-w_1)\theta_1 + w_1(1-\theta_1)\phi_1)} \right] \). The saddlepath solution of this expression is

\[
\log(p_t) = -a_0 (1 - a_0 \lambda_1)^{-1} (1 - \lambda_1 L)^{-1} \sum_{i=0}^{\infty} \lambda_2^{-i} (r_{t+1} - \theta_1 r_t),
\]

where \( \frac{x_0}{y_0 + x_0} \log(x) \). When this approximation is applied to (5), \( w_1 = \frac{(1-\gamma)c_0}{\gamma p_0 \gamma p_0 + (1-\delta-r_0)p_0} \), from which the expression in the text is derived by using the steady-state relationship in (4). In deriving (5), we also assume that the marginal value of durables depends only on the stock of durables and not on the quantity of non-durable consumption. Such an assumption is common; for an example where the durable good is housing, see Poterba (1984) and Bruce and Holtz-Eakin (1999). This assumption allows us to write the demand for durables without incorporating income and wealth from the accumulation constraint. Our justification in making this simplification is that we choose to focus primarily on the role of user cost in transmitting money shocks to the market for durables.
where $\lambda_1$ and $\lambda_2$ are the stable and unstable roots, respectively, from the characteristic equation $a_0\lambda^2 - \lambda + a_1 = 0$. For the parameters values we use in the simulation below, both roots are positive.

This reduced form expression for price could be substituted into (8) to determine the equilibrium stock of durable goods. However, we focus on the flow of durable expenditures in the empirical work. The flow of durables is determined by the supply relationship in (7); i.e. $e_t = D_t - D_{t-1} + \delta D_{t-1}$. Taking logs yields

$$
\log(e_t) = \log(\alpha) + \phi_1 \log(p_t) + \phi_2 \log(p_{t-1}).
$$

Thus, the dynamics of durables expenditures depends only on the dynamics current and lagged equilibrium price.

The model works in a straightforward manner. Suppose there is a once-and-for-all decrease in the real interest rate. Because the marginal opportunity cost of buying and holding durable goods over the period falls, user cost falls and the demand to hold the stock of durables rises, ceteris paribus. As long as the supply of durables is not perfectly elastic, the price of durables will rise. The higher price will induce greater production of durables, and the stock will rise over time. The interplay between price and flow production will continue until a new steady-state is reached with a higher price and larger stock of durable goods. The effects of interest rates on user costs is an obvious channel through which money supply innovations can affect the market.

The example above assumes a one-time permanent change in the real interest rate. In general, though, interest rate responses to money will exhibit more interesting dynamics than a once-and-for-all change. As is clear from (10) and (11), the theoretical model implies that the durable goods market depends on the entire (expected) future path of interest rates. This implication of the theory will be considered carefully in the simulations of the model below.
3. Estimating the dynamic response of durables to money

This section describes the method we use to identify the relevant facts pertaining to the durable goods market and money. We use standard VAR techniques to estimate how the price of and expenditures on durables respond to money supply shocks. The identifying strategy we use does not rely on the theoretical model discussed above (that is, we do not impose the optimizing model’s restrictions in estimation). However, the identifying restrictions are consistent with the long-run implications of the theory.

a. The VAR and identifying restrictions

Let $z_t$ be an $n \times 1$ vector of endogenous random variables at time $t$ representing the macro economy and the aggregate market for durable goods. We assume that the variables included in $z$ are sufficient to identify exogenous shocks to the supply of money, as discussed below. Furthermore, assume that $z_t$ is generated by the following linear, dynamic structural model:

$$A_0 z_t = A_1 z_{t-1} + \cdots + A_p z_{t-p} + u_t,$$

(12)

where $u_t$ is an $n \times 1$ vector of serially and contemporaneously uncorrelated shocks, each with unit variance. This behavioral system represents the agent’s decision rules and market equilibrium conditions. The elements in $u_t$ are exogenous random shocks to these equations, reflecting our inability to specify all factors that determine optimal behavior. One of the equations represents the behavior of those sectors in the economy that determine the supply of money; the element in $u_t$ corresponding to this equation is taken to be an exogenous shock to the money supply. This shock is to be distinguished from shocks originating in other sectors, such a money demand shock.

The implied moving average representation of the structure is:

$$z_t = (D_0 + D_1 L + D_2 L^2 + \cdots) u_t$$

$$= D(L) u_t,$$

(13)
where $D(L) = (A_0 - A_1 L - \cdots - A_p L^p)^{-1}$ and $L$ denotes the lag operator. The coefficient matrices in this representation are dynamic multipliers, which show the equilibrium response of the endogenous variables to impulses in the exogenous shocks.

To estimate these multipliers, first note that $z$ can also be expressed as a moving average of the reduced form parameters:

$$z_t = (I + C_1 L + C_2 L^2 + \cdots)\epsilon_t$$

$$= C(L)\epsilon_t,$$

where $\epsilon_t = D_0 u_t$, $C_i = D_i D_0^{-1}$ and

$$E\epsilon_t \epsilon_t' \equiv \Sigma = D_0 D_0' \cdot$$

The reduced form parameters $C(L)$ and $\Sigma$ are directly estimable from the VAR representation of $z_t$. To identify the structure from the VAR, the typical identification strategy imposes a sufficient number of restrictions on $D_0$ to identify the structural coefficients from $\Sigma$ and $C(L)$. This identification strategy is “weak” in the sense that it does not require imposing the restrictions from a fully specified dynamic equilibrium model; e.g., the lag structure in (13) is left unrestricted. Our strategy is even weaker – we just-identify only the multipliers corresponding to money supply shocks while the system in (13) as a whole remains underidentified

The particular set of restrictions we use is based on the commonly held view, supported by substantial evidence, that money is neutral in the long-run (see, for example, Lucas 1996). To be specific, let $z_t = (\Delta p_t \; \Delta e_t \; \Delta R_t \; \Delta y_t \; \Delta m_t \; \Delta M_t)$, where $p_t$ is the real price of durable goods and $e_t$ are real gross expenditures on durables, as above, and $R_t$ is the interest rate on alternative assets, $y_t$ is aggregate output, $m_t$ is real money balances and $M_t$ is nominal stock of money (all but $R$ in natural logs). We suppose that each of these variables has a single unit root, so that the vector process is stationary, and that

\[ ^6 \text{For a discussion of such partial identification in VARs, see Christiano, Eichenbaum and Evans (1999).} \]
there are no compelling cointegrating relationships (both of which we verify with the usual battery of tests). Thus, the VAR representation in first-differences is correctly specified.

In this case,

\[ \lim_{k \to \infty} \frac{\partial z_{t+k}}{\partial u_t} = D_0 + D_1 + D_2 + \cdots = D(1) \]

is the matrix of infinite horizon multipliers showing the dynamic response of the levels of the variables in \( z \) to the exogenous shocks. Given the ordering of the variables in \( z_t \), long-run monetary neutrality implies that all coefficients in the final column of \( D(1) \) are zero except for that in the final row. That is, a shock that has a permanent effect on nominal money but no permanent effect on the real variables in the system is defined to be a money supply shock. Hence, the last equation in (12) and (13) represents money supply behavior by assumption.\(^7\) It is straightforward to show that although this set of restrictions is not sufficient to fully identify the structural model, it is sufficient to just-identify the responses to money supply shocks (the final columns of \( D_i \)) by exploiting the Cholesky factor of the “long-run” covariance matrix, \( C(1)\Sigma C(1)' \).\(^8\)

The use of infinite-horizon restrictions has been criticized by Faust and Leeper (1997), and Pagan and Robertson (1998), among others, as relying on weak instruments. However, the approach has the advantage of being consistent with a wide range of policy rules and informational assumptions, unlike most strategies that rely on short-run restrictions. In addition, the most common means for judging the results of impulse response analysis based on just-identifying schemes is to determine how well the estimates jive with prior views of behavior. The results presented below seem plausible along all dimensions, whereas our

\(^7\) Although the interest rate in \( z_t \) are nominal, its long-run behavior in response to a permanent change in the level of the money supply is assumed to be identical to real rate behavior, since such a change in the stock of money will not cause a permanent change in the inflation rate.

\(^8\) See Keating (1996) and Lastrapes (1998, appendix). The use of infinite horizon restrictions to identify VARs was pioneered by Blanchard and Quah (1989) and Shapiro and Watson (1988) and is by now a standard method of identification.
experimentation with common short-run restrictions tended to yield less plausible dynamic responses. We feel that our results present a valid estimate of the response of the aggregate durables market to money.

b. Data and estimated responses

The US data we use to estimate the VAR are monthly, ranging from 1959:01 to 2001:3. The macro variables are standard: M1, 3-month t-bill rate, the industrial production index and the producer price index to deflate nominal money and durable goods prices (the results below were not sensitive to using the CPI as a general measure of prices). We obtained these data from the St. Louis Federal Reserve Bank Electronic Database.

We consider two alternative measures of the aggregate price of durable goods. One is the producer price index for consumer durables goods published by the Bureau of Labor Statistics; the other is the chain-weighted price index for consumer durables computed by the Bureau of Economic Analysis.\(^9\) We measure the quantity of consumer durables as personal consumption expenditures on durable goods (excluding housing) from the National Income and Product Accounts, which consists primarily of purchases of new durable goods by US residents. A durable good is defined to be a tangible product that can be stored or inventoried with an average life of at least three years.

The baseline VAR includes a constant and seasonal dummies, as well as 12 common lags of the system-variables in each equation. Q-tests for residual serial correlation are consistent with the absence of such correlation for typical test sizes. Allowing for differencing and conditioning on lagged values implies a sample range of 1960:2 to 2001:3 for estimation, or 495 monthly observations.

Figure 1 reports the estimated dynamic response functions, showing the response coefficients for each variable in the system in reaction to a money supply shock identified by assuming long-run monetary neutrality. The dashes represent standard error bands.

\(^9\) For details on the construction of the chain-weighted index, see Landefeld and Parker (1997).
computed from the usual Monte Carlo integration techniques with 1000 antithetically accelerated simulations. We plot the responses up to a forecast horizon of 60 months.

The response functions are plausible, both qualitatively and quantitatively, lending credence to the identification scheme. A money supply shock causes the stock of money to gradually increase to a steady-state value about 1% higher than it would have been had there been no shock. Stickiness in the price level leads to a temporary rise in real money balances. The 3-month t-bill rate falls by between 40 and 45 basis points on impact, then returns to near its pre-shock value in about a year. Aggregate output responds positively, but with a lag, a pattern found in many recent studies (e.g. Christiano, Eichenbaum and Evans 1999). The maximum response of output is about 0.5% at the 15 month horizon.

The real interest rate response cannot be estimated directly from these results, since only the nominal rate is observable and included in the VAR. However, it can be inferred from the nominal interest rate response and the price level response (the latter of which is simply the difference between the nominal money and real money responses), as in Gali (1992) and Lastrapes (1998). Let $k$ denote the forecast horizon of the dynamic response functions and $\pi_{h,t+k}$ denote the rate of overall inflation at time $t+k$ over the following $h$ months; i.e. $\pi_{h,t+k} \equiv \left(\frac{1}{h}\right)(lnP_{t+k+h} - lnP_{t+k})$. Then,

$$ \frac{\partial \pi_{h,t+k}}{\partial u_{mt}} = \left(\frac{1}{h}\right) \left( \frac{\partial lnP_{t+k+h}}{\partial u_{mt}} - \frac{\partial lnP_{t+k}}{\partial u_{mt}} \right), $$

(17)

where $u_{mt}$ is the exogenous shock to the money supply. This equation gives the response of the per period inflation rate to the exogenous money impulse. But if agents use the VAR to form expectations, then (17) shows how the path of inflationary expectations will be revised in light of the money shock. Hence, (17) can be interpreted as the response of expected inflation under this assumption of expectation formation. If $R$ is the (continuously-compounded) nominal yield-to-maturity on $h$-period bonds and $r$ the corresponding real

\[ 10 \text{ Multiply the values reported in the figure by 1200 to annualize in percentages.} \]
yield, then
\[
\frac{\partial r_{t+k}}{\partial u_{mt}} = \frac{\partial R_{t+k}}{\partial u_{mt}} - \frac{\partial \pi_{h,t+k}}{\partial u_{mt}}.
\]  
That is, the real rate response is the difference between the nominal rate response (directly estimated from the identified VAR) and the response of expected inflation as computed in equation (17). We set \( h = 3 \) since our interest rate measures is the 3-month t-bill. Figure 1A reports the estimate effect of money shocks on the time path of inflation and the real interest rate.

The market for durable goods reported in Figure 1 also behaves reasonably. The real aggregate price of durables rises by about 0.2% initially before declining to zero over the first year or so after the shock. Real durables expenditures follow a similar pattern to aggregate output, but are more sensitive to the money shock: it is almost 0.9% greater than its steady-state value within the first year. On impact, real durables expenditures rise by about 0.5%. When the producer price index for durables is replaced by the chain-weighted index, as reported in Figure 2, the basic pattern of the responses are unchanged. The magnitude of the durables expenditures response is smaller than in figure 1, but the excess sensitivity relative to the total output response remains.

4. Are the estimated responses consistent with theory?

In this section, we are interested in determining whether the facts established above are consistent, both qualitatively and quantitatively, with the basic forward-looking model of intertemporal choice discussed above. Our approach is to compare the estimated response functions in section 3 with the simulated predictions of those responses from the theory developed in section 2. We make an important assumption to make the simulations tractable: real interest rates are exogenous with respect to the market for durable goods.

The predictions of the theory are evident from the reduced form expressions (10) and (11). As in the previous section, let \( u_{mt} \) denote the money supply shock in (12). From
the effect of this shock on the equilibrium price is given by
\[ \frac{\partial \log(p_{t+k})}{\partial u_{mt}} = a_0(1 - a_1 \lambda_1)^{-1} \lambda_1^k \sum_{i=1}^{\infty} \lambda_2^{-i} \left( \frac{\partial r_{t+1}}{\partial u_{mt}} - \theta_1 \frac{\partial r_{t}}{\partial u_{mt}} \right). \] (19)

From (11), it is clear that the predicted response of log real expenditures depends only on the current and lagged responses of price as given in (19).

Equation (19) makes it clear that we focus on the transmission of money shocks to the market for durables in the model through the effect of money on real interest rates and thus on user cost. By assuming that interest rates are exogenous, and given plausible values for the theoretical parameters, we can simulate how the market for consumer durables responds to changes in the real interest rate due to money supply shocks. That is, we calibrate the simulate to the estimated change in the path of real interest rates in response to money supply shocks, thus allowing for the effects of the complex interest rate dynamics on the durables market.

As mentioned above, we have developed the model as one of perfect foresight, yet the simulations can be more generally interpreted in a world of certainty equivalence in which actual values are replaced with expectations. It is well-known that estimated impulse response functions can be interpreted as revisions in the expected path of the endogenous variables in the face of unanticipated shocks (Hamilton 1994, pp. 319-20). This is exactly what is implied by the model of dynamic choice under uncertainty when certainty equivalence holds (Blanchard and Fischer 1989, pp. 261-64).

To perform the simulation, we assume values for the theoretical coefficients contained in equations (6) and (8). We initially let \( \delta \), the rate of depreciation, be 25%, \( \mu \), the rate of maintenance and repairs be 10%, and the steady-state, after-tax real interest rate be 3% (all on an annualized basis). When converted to a monthly basis, these values imply a value of \( w_1 = 0.0314 \). For this value of \( \delta \), \( \theta_1 = 0.975 \). In our baseline simulations, we set \( \phi_1 = 5 \) and \( \phi_2 = 1 \), but since we don’t have very good priors on these values, we consider the sensitivity to alternative values.
The final row in each of Figures 3 and 4 reports the results of the durable goods price and expenditure simulations for the baseline case, when the producer price index measure of the durables price and the chain-weighted measure are used, respectively. The solid plot is the estimated response functions (repeated from Figures 1 and 2), while the dashed plot is the simulated theoretical prediction of the response. The figures indicate that the simulations, for the baseline parameters, are successful in mimicking the dynamic patterns of the responses, but are less successful in picking up the magnitudes of the responses. In each case, the theory predicts a smaller response at almost all horizons than what is actually observed.

The remaining rows in the figures show what happens to the simulations when $\theta_1$ is set independently of the value of $\delta$. Given the simplicity of the specification for the supply of durables, it seems reasonable to allow this minor deviation from the linear approximation of the model. Clearly, the “fit” of the theory noticeably improves for values of $\theta_1$ that are smaller than implied by the value of $\delta$. For example, for the PPI system, the match of the durables expenditure responses are remarkably close for values of $\theta_1$ between 0.5 and 0.8. The fit for the chain-weighted system appears less precise, but it is reasonably close for $\theta_1 = 0.9$ (and is even closer for a value of $\theta_1$ around 0.92). In both cases, the theory has a difficult time in achieving the strong estimated price response over the 8 to 12 months, but does approach the estimated values over this horizon for smaller values of $\theta_1$. In all cases for $\theta_1$ in the range of 0.5 to 0.9, the theory predicts too much persistence for the price response.

Two aspects of the simulations should be kept in mind. First, we again emphasize that the simulations reflect the theoretical model’s prediction of the response of consumer durables to a permanent change in nominal money that has a temporary effect on real interest rates. Thus, we imagine that a positive shock to money supply causes an initial increase in the demand for durables as real interest rates fall, but that the demand shifts back to its original level over time as the interest rate returns to its initial steady-state
value. And second, both the estimated responses and the theoretical predictions seem to show that the stock of durables permanently increases due to money supply shocks, since the accumulation of the expenditures response is clearly positive. However, we are looking at gross, as opposed to net, expenditures on durables. The accumulation of gross expenditures can be permanently affected, even if the model predicts a fixed steady-state value for the stock of durables.

The remaining figures provide additional information about the sensitivity of the simulations to alternative parameter values. In figures 5 and 6, $\phi_1$ is doubled from 5 to 10. This tends to increase the volatility of the predicted expenditure response, while maintaining a reasonable fit. Price responses are not affected. In figures 7 and 8, the demand parameters are lowered to reduce $w_1$ from 0.031 to 0.025. The key impact of this change is to substantially improve the fit for price over very short horizons. The explanatory power for durables expenditures, especially the PPI system, remains reasonably good.

5. Conclusion

In this paper, we present convincing evidence that money supply shocks have been transmitted through the market for aggregate consumer durable goods in the US, at least over our monthly sample from 1960 to 2001. Impulse response analysis reveals that unexpected shocks to money supply lead to temporary increases in the relative price of durables and gross expenditures on durables. Importantly, the response of durable expenditures is stronger than that of overall output, which suggests that money shocks can explain some of the relatively high volatility of durable goods expenditures.

We also show that the standard model of intertemporal choice, when extended to allow for durable goods, does a reasonable, though not perfect, job of predicting the estimated responses of durables price and expenditures. We focus on the model’s implication that real interest rates, through user cost, potentially play an important role in how money affects the market. Our simulations show that when the estimated impulse responses of
real interest rates are filtered through the predictions of the theory, these predictions fairly closely match the responses of the durables variables, especially expenditures.

The lesson we take from the simulation results is that, despite recent empirical failures of the forward-looking model, it still has substantial power in explaining certain types of aggregate behavior. The generality of these results is not known, but for the specific case of aggregate durables, the standard intertemporal choice model seems to be a reasonable framework for analyzing the effects of monetary policy. This conclusion is consistent with the views espoused by Browning and Crossley (2001) and others that households behave systematically when making intertemporal choices.

Of course, the basic model does not yield a perfect fit to the aggregate durables market, especially for the relative price of durables. It is worth investigating the extent to which richer models of dynamic optimization can narrow the gap between the simulations and the estimated response functions. Consideration in future research of adjustment costs, liquidity constraints and non-separabilities in utility may improve the ability of the theory to explain the facts in the market for durables.
References


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Figure 1. Dynamic responses to money supply shocks, with standard error bands.

- Response of real durables price
- Response of real durables expenditure
- Response of interest rate
- Response of output
- Response of real money
- Response of money
Figure 2. Dynamic responses to money supply shocks, with standard error bands (chain-weighted index)
Figure 3. Theoretical simulations for durables price and expenditures (PPI for durables)

Durables Price: $w_1 = 0.031, \phi_1 = 5, \phi_2 = 1, \theta_1 = 0.60$

Durables Price: $w_1 = 0.031, \phi_1 = 5, \phi_2 = 1, \theta_1 = 0.70$

Durables Price: $w_1 = 0.031, \phi_1 = 5, \phi_2 = 1, \theta_1 = 0.80$

Durables Price: $w_1 = 0.031, \phi_1 = 5, \phi_2 = 1, \theta_1 = 0.90$

Durables Price: $w_1 = 0.031, \phi_1 = 5, \phi_2 = 1, \theta_1 = 0.98$

Durables Expenditures: $w_1 = 0.031, \phi_1 = 5, \phi_2 = 1, \theta_1 = 0.60$

Durables Expenditures: $w_1 = 0.031, \phi_1 = 5, \phi_2 = 1, \theta_1 = 0.70$

Durables Expenditures: $w_1 = 0.031, \phi_1 = 5, \phi_2 = 1, \theta_1 = 0.80$

Durables Expenditures: $w_1 = 0.031, \phi_1 = 5, \phi_2 = 1, \theta_1 = 0.90$

Durables Expenditures: $w_1 = 0.031, \phi_1 = 5, \phi_2 = 1, \theta_1 = 0.98$
Figure 4. Theoretical simulations for durables price and expenditures (chain-weighted index)

Durables Price: $w_1 = 0.031$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.60$

Durables Price: $w_1 = 0.031$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.70$

Durables Price: $w_1 = 0.031$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.80$

Durables Price: $w_1 = 0.031$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.90$

Durables Price: $w_1 = 0.031$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.98$

Durables Expenditures: $w_1 = 0.031$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.60$

Durables Expenditures: $w_1 = 0.031$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.70$

Durables Expenditures: $w_1 = 0.031$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.80$

Durables Expenditures: $w_1 = 0.031$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.90$

Durables Expenditures: $w_1 = 0.031$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.98$
Figure 5. Theoretical simulations for durables price and expenditures (PPI for durables)

Durables Price: $w_1 = 0.031, \phi_1 = 10, \phi_2 = 1, \theta_1 = 0.60$

Durables Price: $w_1 = 0.031, \phi_1 = 10, \phi_2 = 1, \theta_1 = 0.70$

Durables Price: $w_1 = 0.031, \phi_1 = 10, \phi_2 = 1, \theta_1 = 0.80$

Durables Price: $w_1 = 0.031, \phi_1 = 10, \phi_2 = 1, \theta_1 = 0.90$

Durables Price: $w_1 = 0.031, \phi_1 = 10, \phi_2 = 1, \theta_1 = 0.98$

Durables Expenditures: $w_1 = 0.031, \phi_1 = 10, \phi_2 = 1, \theta_1 = 0.60$

Durables Expenditures: $w_1 = 0.031, \phi_1 = 10, \phi_2 = 1, \theta_1 = 0.70$

Durables Expenditures: $w_1 = 0.031, \phi_1 = 10, \phi_2 = 1, \theta_1 = 0.80$

Durables Expenditures: $w_1 = 0.031, \phi_1 = 10, \phi_2 = 1, \theta_1 = 0.90$

Durables Expenditures: $w_1 = 0.031, \phi_1 = 10, \phi_2 = 1, \theta_1 = 0.98$
Figure 6. Theoretical simulations for durables price and expenditures (chain-weighted index)

Durables Price: $w_1 = 0.025$, $\phi_1 = 10$, $\phi_2 = 1$, $\theta_1 = 0.60$

Durables Price: $w_1 = 0.025$, $\phi_1 = 10$, $\phi_2 = 1$, $\theta_1 = 0.70$

Durables Price: $w_1 = 0.025$, $\phi_1 = 10$, $\phi_2 = 1$, $\theta_1 = 0.80$

Durables Price: $w_1 = 0.025$, $\phi_1 = 10$, $\phi_2 = 1$, $\theta_1 = 0.90$

Durables Price: $w_1 = 0.025$, $\phi_1 = 10$, $\phi_2 = 1$, $\theta_1 = 0.98$

Durables Expenditures: $w_1 = 0.025$, $\phi_1 = 10$, $\phi_2 = 1$, $\theta_1 = 0.60$

Durables Expenditures: $w_1 = 0.025$, $\phi_1 = 10$, $\phi_2 = 1$, $\theta_1 = 0.70$

Durables Expenditures: $w_1 = 0.025$, $\phi_1 = 10$, $\phi_2 = 1$, $\theta_1 = 0.80$

Durables Expenditures: $w_1 = 0.025$, $\phi_1 = 10$, $\phi_2 = 1$, $\theta_1 = 0.90$

Durables Expenditures: $w_1 = 0.025$, $\phi_1 = 10$, $\phi_2 = 1$, $\theta_1 = 0.98$
Figure 7. Theoretical simulations for durables price and expenditures (PPI for durables)

Durables Price:
- $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.60$
- $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.70$
- $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.80$
- $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.90$
- $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.98$

Durables Expenditures:
- $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.60$
- $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.70$
- $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.80$
- $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.90$
- $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.98$
Figure 8. Theoretical simulations for durables price and expenditures (chain-weighted index)

Durables Price: $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.60$

Durables Price: $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.70$

Durables Price: $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.80$

Durables Price: $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.90$

Durables Price: $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.98$

Durables Expenditures: $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.60$

Durables Expenditures: $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.70$

Durables Expenditures: $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.80$

Durables Expenditures: $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.90$

Durables Expenditures: $w_1 = 0.025$, $\phi_1 = 5$, $\phi_2 = 1$, $\theta_1 = 0.98$