The Dynamics of Car Sales: A Discrete Choice Approach

Adda and Cooper, 2006

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December 4, 2016

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Theme

- Behavior of household durable consumption expenditures over time

Motivation: Aggregate Perspective(dynamic)

- Mankiw puzzle(Mankiw 1982): permanent income hypothesis(PIH) is inconsistent with observed data
  - Theory: ARMA(1,1) process
  - Empirical results: AR(1) process; depreciation rate is 100%.

Motivation: Household's Perspective(heterogeneous, discrete)

- A model of **heterogeneity** and **discrete adjustment** can qualitatively match relevant parts of the data.
  - Lam(1991): households only **occasionally adjust** their stock of durables
  - Bar-Ilan and Blinder (1988,1992), Bertola and Caballero (1990) and Caballero (1990,1993): view aggregate observations on durable purchases as the outcome of the aggregation over **heterogeneous** microeconomic agents

Overview

- Framework: Determinants of the **time series representation** of durable expenditures in an explicit **dynamic**, **discrete choice** framework
  - ARMA(1,1) underlies the "Mankiw puzzle"
  - VAR of sales, price and income - impulse reponse function
- Goals:
  - Confronting the Mankiw puzzle for car sales
  - Whether an aggregated discrete choice model can match and explain this rich time response to an income shock

Overview

- Model:
  - Basis: Adda and Cooper(2000a)
  - Difference: Drawn directly form the dynamic optimization problem without imposing any structure directly on agents' decision rules(specify (S,s) bands or "desired stock" directly)
  - Reasons:
    - PIH assumptions underling "desired stock" approach are not supported by data
    - More consistent theoretically

Overview

- Findings:
    -

Overview

- Sources of these dynamics:
    -
    - Sources of these dynamics
        - Fluctuations or shocks in the replacement probability - most important
        - Evolution of the cross sectional distribution of car vintages - surprisingly little

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Outline

- Show the raw data on sales and cross sectional distribution over sample period
- Test the ARMA(1,1) representation again
- Impulse response functions from VAR on car sales, income and prices
  - Illustrate why ARMA(1,1) is inadequate
  - Evaluate the time series implication of estimated model

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Car Sales(Figure 1)

- Measured as registrations of new cars
- Considerable volatility

Cross Sectional Distribution(Figure 2)

Pattern:

- New -> Old(ripple) -> Scrapped or destroyed
- Echo effects: burst of sales -> bulge in the CDF; tempered by scrapping at earlier ages

Usage:

- Match moments from the CDF in the estimation of parameters
- Variations in the CDF plan a role in explaining time series variation in sales

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Extended Permanent income hypothesis model for durability

- A durable good: expenditure - e_t; depreciation - δ
- Uncertain income: innovation to income?? - ε_t
- Quadratic utility function

$$e_{t+1} = \delta\alpha_0 + \alpha_1 e_t + \varepsilon_{t+1} - (1-\delta)\varepsilon_t$$

Estimation Results

- Hypothesis that the rate of depreciation is close to 100% per year would not be rejected for most of the specifications
- robust across
  - Categories of durables
  - Countries
  - Time periods
  - Detrending method

Impulse Response Functions

- VAR model:
  - Reason: joint dynamics of durables, income and prices over time
  - Variables: automobile sales, automobile prices relative to the CPI, income
  - Order: income, prices, sales(innovations to income are exogenous, prices respond to both price and income innovations and sales respond to innovations in all three variables)
  - Imposed on actual data as well as the simulated data
  - No structural interpretation
- Empirical results(Figure 3, P31):
  - Income on sales: dampened oscillation around the baseline
    - Endogenous evolution of the stock of cars can potentially produce replacement cycles
    - Income and prices are serially correlated and have some cross dynamics

Can the ARMA model match the IRFs?

- ARMA(1,1) cannot reproduce the oscillations
- ARMA(1,1) model is structurally unable to deliver a "depreciation rate" low enough to be credible - Mankiw puzzle

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Starting Point

- An agent with a car of age i=0,1,....
- State(z,Z):
  - z: vector of household specific taste **shocks**
  - $Z \equiv (p, Y, \varepsilon)$: vector of aggregate state variables
  - p: relative price of the durable good
  - Y: aggregate income
  - ε: taste shock

Household Decision

- Decision: whether to retain a car of age i or scrap it
  - Scrap: receive the scrap value of π; purchase a new car.
  - Retain: receive the flow of services; cannot purchase another car by assumption
  - Choices influenced by a choice specific i.i.d shock z_j,j=k,r
  - Constant utility gain,α_k, from keeping the car

Initial Restrictions

- No second-hand market
- No borrowing or lending

Formal Model

- $V_i(z, Z)$: value of having a car of age i to a household
- $V_i^k(z, Z)$ and $V_i^k(z, Z)$: values from keeping and scrapping an age i car in state (z,Z)
- δ: probability of car destroyed
- $p' - \pi$: Cost of a new car
- scrap value independent of replacement value

Formal Model

$$V_i(z,Z) = max[V_i^k(Z) + \alpha_k + z_k, V^r(Z) + z_r] \tag{1}$$

where

$$V_i^k = u(s_i, Y, \varepsilon) + \beta(1-\delta)E_{(Z',z|Z,z)}V_{i+1}(z',Z') + \beta\delta E_{Z'|Z}V^r(Z') \tag{2}$$

and

$$V^r = u(s_1, Y - p + \pi, \varepsilon) + \beta(1-\delta)E_{(Z',z|Z,z)}V_2(z',Z') + \beta\delta E_{Z'|Z}V^r(Z \tag{3}$$

Utility function separable between durables and nodurables:

Formal Model

$$u(s_i, c) = [i^{-\gamma} + \varepsilon \frac{(c/\lambda)^{1-\xi}}{1-\xi}] \tag{4}$$

- c: consumption of non-durable goods
- γ: curvature for the service flow of car ownership
- ξ: curvature for consumption
- λ: scale factor
- Taste shock ε influences the contemporaneous marginal rate of substitution between car services and nondurables

Formal Model

Specify the stochastic process for income, prices and the aggregate taste shocks:

$$Y_t = \mu_y + \rho_{YY} Y_{t-1} + \rho_{Yp} p_{t-1} + u_{Yt}$$
$$p_t = \mu_p + \rho_{pY\,t-1} + \rho_{pp} p_{t-1} + u_{pt}$$
$$\varepsilon_t = \mu_\varepsilon + \rho_{\varepsilon Y} Y_{t-1} + \rho_{\varepsilon p} p_{t-1} + u_{\varepsilon t}$$

Covariance matrix of the innovations $u = \{u_{Yt}, u_{pt}, u_{\varepsilon t}\}$:

$$\Omega = \begin{bmatrix} \varpi_Y & \varpi_{Yp} & 0 \\ \varpi_{pY} & \varpi_p & 0 \\ 0 & 0 & \varpi_\varepsilon \end{bmatrix}$$

Formal Model

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Estimation Steps

- Step 1: Parameters for the joint process of aggregate income and prices(Appendix A)
- Step 2: Parameters from the policy functions

Estimation Strategy

- Strategy: To find the parameters that bring data from the simulated model as close as possible to the data
  - γ: matching three moments characterizing the cross sectional distribution as well as three moments characterizing the probability of scrapping a car(hazard function)
  - θ: find the one to minimize the distance between the actual and simulated data
- Types of observations:
  - Time series observations on sales, prices and income to match the sales predicted by our model
  -

Estimating θ

- Overall criterion:

$$L(\theta) = \phi L^1(\theta) + L^2(\theta)$$

- First component: standard nonlinear least square criterion measuring the squared distance between observed and average predicted values of the variables

$$L^1(\theta)$$

- Second piece:

$$L^2(\theta)$$

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Estimation Results(Table 2)

- Rate of depreciation of service flow(γ): 34% for France, 41% for US; significant
- Curvature estimates from nondurable consumption(ξ): 1.7-1.8
- Actual and predicted moments
- Probability of car breakdown(δ):1-2%
- R^2:
- Over-identifying restrictions:

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ARMA Representation(Table 3

- Methods:
  -
- Results:
  -

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Sources of the dynamics

- A shock to income produces a dynamic in durable expenditures as agents respond differentially(i.e, agents with younger cars are less likely to respond to income variations than are agents with older cars)
- Dynamics induced by prices and income as these processes are serially correlated. Movements in these variables are represented by shifts in the probability of adjustment(hazard)

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Sales

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Decomposing the IRFs

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Robustness

Restriction relaxed:

- Market for the sale of used cars
- Borrow and lend

Methods:

- ARMA(1,1)
- Impulse response functions from a linear VAR model.

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Used Car Markets

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Capital Markets

- Cost of buying a durable good cannot be spread over time, thus implicity increasing the cost of such expenditures.

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Robustness of Implied Dynamics of Car Sales

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Conclusion

- Theme: aggregate time series implications of a model of consumption of both durables and nondurables at the household level
- Model: Dynamic discrete choice, infrequent purchases of durables - impulse response functions
- Contribution:
  - Solving the "durables puzzle" of Mankiw(1982)
  - Focus on the underlying parameters of the individualï¿$\frac{1}{2}$ï¿$\frac{1}{2}$s dynamic discrete choice problem;
  - Emphasized properties of the cross sectional distribution of car ages;
  - Time series implications that match certain features of the data
- Decomposition: hazard function(most) and evolution of the cross

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Estimation Results for Joint Process

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Used Car Markets

Capital Markets

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Permanent Income Hypothesis(PIH)

- Definition: a person's consumption at a point in time is determined not just by their current income but also by their expected income in future yearsï¿½ï¿½their "permanent income"
- Permanent income: expected long-term average income.

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Autoregressive(AR) Model[1]

AR(p):

$$y_t = c + \sum_{i=1}^{p} \varphi_i y_{t-i} + \sigma v_t + \varepsilon_t$$

- φ_i: parameters of the model
- c: constant
- ε_t: white noise

[0] https://en.wikipedia.org/wiki/Autoregressive$_m$*odel*

Moving-Average(MA) Model[2]

MA(q):

$$X_t = \mu + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \ldots + \theta_q \varepsilon_{t-q}$$

- μ: mean of the series
- θ_i: parameters of the model
- ε_{t-i}: white noise

[1] https://en.wikipedia.org/wiki/Moving-average$_m$*odel*

Autoregressive-Moving-Average Model

ARMA(p,q): the model with p autoregressive terms and q moving-average terms

$$X_t = c + \varepsilon_t + \sum_{t=1}^{p} X_{t-i} + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i}$$

Vector Autoregression(VAR)

VAR(p): evolution of a set of k endogenous variables over the same sample period

$$y_t = c + \sum_{i=1}^{p} A_i y_{t-i} + e_t$$

- y_t: k*1 vector

VAR: structural vs. reduced form

- Structural:

$$B_0 y_t = c_0 + \sum_{i=1}^{p} B_i y_{t-i} + \varepsilon_t$$

- Reduced-form:

$$y_t = c + \sum_{i=1}^{p} A_i y_{t-i} + e_t$$