A Hedonic Approach to Product Innovation in an Agent-Based Macroeconomic Model

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1. Introduction

Consider Large Scale Agent-Based Macroeconomic Modeling:

- Ongoing Innovation and Adaptation
- Bounded Rationality
- Perpetual Disequilibrium

How To Introduce Product Innovation in Tractable and Flexible Way?

- Product Space
- Decisions by Firms and Consumers

Study Effects of Product Innovation on Growth, Fluctuations, and Welfare
2. Empirical Background

Considerable Churning in Modern Market Economies:

- Firm Entry and Exit: Dunne, Roberts and Samuelson (1988)
- Credit Expansion and Contraction: Contessi and Fancis (2009)
Gross Product Creation and Destruction Flows are Large: Broda and Weinstein (2007):

- About 1/2 of consumer products purchased in 2003 (by UPC code) did not exist in 1999.
- About 4/5 of consumer products purchased in 2003 (by UPC code) did not exist in 1994.
- These products account for about 1/3 and 2/3 of expenditures respectively in 2003.
- About 2/3 of consumer products purchased in 1994 were no longer offered in 2003.
- These product flows are dominated by product turnover within existing firms, not firm entry and exit.
- Net product creation is procyclical.
• Macro Effects? Less Clear Due (in part) to Problems of Measurement


• Growth and business cycle accounting: role of product innovation
3. Theory Background

Representative Agents in Rational Expectations Equilibrium


ACE models of final goods innovation: Chen and Chie (2005, 2007)

- Products and preferences are parse trees
- Modularity – building blocks
- Product innovation modeled by genetic programming
4. Our Approach

Revisit Lancaster (1966)

- Preferences are defined over a set of product characteristics
- Products offer various bundles of these characteristics
- Flexible approach for product innovation and turnover
5. Hedonic Framework and Innovation

Basics:

- $n$ possible products at any time
- $m$ characteristics valued by consumers
- For consumer $c$:
  - $y_c \in R_n$ is vector of products consumed
  - $z_c \in R_m$ is corresponding vector of characteristics consumed
  - $z_c = g_c(y_c)$ map from products to characteristics (home production function)
  - $u_c = u_c(z_c)$ map from characteristics to utility (utility function)
Complicating Factors:

- Realistic home production function complex due to:
  - Potentially vast number of products
  - Complementarities across products
  - Specialization of products in the characteristics space
  - Indivisibilities
  - Heterogeneity across consumers
6. Implementation

Each product $i$ offers consumer $c$:

- Base set of characteristics $z$-base$_{c,i} \in R_m$ (per unit of good $i$)
- Additional characteristics from complementarities with other goods
  - For complementary good $k$: $z$-comp$_{c,i,k} \in R_m$ (per common unit of the two goods)
  - $z$-comp$_{c,i,k}$ is associated with good $i$ and is independent of other complementarities
Aggregation of products and characteristics for consumer $c$:

- Characteristic magnitudes are additive at the level of the individual product
  
  - $z_{c,i,j} = z_{\text{base},c,i,j} \cdot q_{c,i} + \sum_k z_{\text{comp},c,i,j,k} \cdot q_{c,i,k}$
  
  - where $q_{c,i,k} = \text{floor}(\min\{q_{c,i}, q_{c,k}\})$.

- Characteristic magnitudes are aggregated over products by a CES aggregator:
  
  - $z_{c,j} = \left[\sum_{i=1}^{n} z_{c,i,j}^\rho\right]^{1/\rho}$

- Utility function is also CES

- So utility is nested CES: consumers have preference for variety in both characteristics and products

- Utility function may be translated (shifted) to form hierarchy of characteristics
7. Consumer Behavior

Consumer Search via Evolutionary Algorithm:

- Consumer establishes budget constraint
- Searches for optimal bundle of goods by experimentation and imitation
- Experimentation takes form of testing random mutations in which nominal spending shares are shifted between pairs of goods (subject to possible integer constraints).
- Search is subject to election operator. Adopt only mutations that increase utility.
8. Implementation in Simple Macro Model

Basics:

- $n$ firms, one product per firm
- Each firm sells to consumers and to one upstream neighbor
- Representative consumer
- Hedonic quality is intrinsic to product
- Characteristic magnitudes take only integer values
- Product innovation is a set of increments (pos or neg) by 1 to specific elements of base and/or complementary characteristic vectors of the product
- Preferential Attachment
- Process innovation may also occur – change in labor productivity
Other Details:

- Markup pricing (markup $\eta$)
- Leontief technology: constant labor and intermediate good requirements. For output $y_i$
  - Labor requirement is $y_{i,t}/A_{i,t}$
  - Intermediate good requirement is $h_i + y_{i,t}/\gamma_i$
  - $h_i$ is overhead
- Firms forecast demand by simple extrapolation of past nominal demand
- Trade takes place on the short side of the market. Products and residual income are perishable
- Firm/product is replaced if working capital falls to zero
9. Analysis I: Representative Agent Benchmark

- If firms are homogenous, then equilibrium production and sales of consumption good is

\[ Y = Y^* = \left( \frac{1}{\eta \gamma} \right) \cdot h \cdot n \]

- Independent of labor productivity \( A \) and preferences over characteristics

- Is a locally stable steady state

- A common positive (negative) shock to \( A \) will cause a temporary increase (decrease) in \( Y \) as firms adjust price while incorrectly expecting nominal spending to remain unchanged.

- Common shocks to preferences over characteristics have no effect on \( Y \).
10. Analysis II: Heterogeneous Firms

- If firms are heterogeneous, then the steady state equilibrium depends on the distribution of productivities \( A_i \).
  - If firms have identical \( A_i \) but heterogeneous hedonic characteristics, then consumer search and will lead to temporary (negative) deviations in \( Y \) from \( Y^* \) as firms do not anticipate the change in demand.
  - If firms have heterogeneous \( A_i \) and hedonic characteristics, then consumer search will cause changes in the production weighted distribution of \( A_i \) and thus in the steady state of \( Y \).
11. Representative Preliminary Simulation

FIGURE 1: $n = 1000$, $m = 50$, $\rho = 0.8$, static heterogeneity in labor productivities. Consumer search and product innovation is ongoing. Parameters are set so that the representative agent equilibrium is $Y^* = n$. 
FIGURE 2: Hedonic characteristics and demand shares in round 5000. Same run as Figure 1.
FIGURE 3: Selection from Figure 2.