Demographic Aging and the New Keynesian Phillips Curve

Gene Ambrocio

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The views and opinions expressed in this paper are those of the author(s) and do not necessarily represent those of the Bank of Finland.
Motivation

"While higher interest rates, slower growth, and softer labor market conditions will bring down inflation, they will also bring some pain to households and businesses. These are the unfortunate costs of reducing inflation."

- Jerome Powell (Jackson Hole, Aug. 26, 2022)

- Post-pandemic surge in inflation and consequent monetary tightening highlights the disinflation costs faced by a monetary authority.

- Slope of the Phillips Curve (NKPC) an important indicator for this trade-off
  - Many have argued that the slope has flattened (Del Negro et al., 2020, Stock and Watson, 2020, Hazell et al., 2022) thereby increasing the costs of disinflation.
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- Reasons for flattening NKPC slope: anchoring of inflation expectations (Barnichon and Mesters, 2021), optimal monetary policy (McLeay and Tenreyro, 2020), state dependence at low inflation (Forbes et al., 2021; Costain et al., 2021), evolving production networks (Hoeynck, 2020; Rubbo 2023), and Competition (Fujiwara and Matsuyama, 2022)

- Competition (market power) hypothesis also accounts for rise in markups (De Loecker et al., 2020, Autor et al., 2020)
  - Declining price sensitivities an important factor (Brand, 2021; Doepper et al., 2022; Atalay et al., 2023)

- There may also be a link to a third trend: demographic aging
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- Shift in consumption towards services among elderly: Aging leads to shift in demand and production towards services sector (Cravino et al., 2022) with stickier prices (Mangiante, 2023).

- However, average price sensitivities may also decline as one ages

  "Old people’s spending patterns may be dominated by strong habit patterns that make them less sensitive to price changes. Teenagers may be affected by peer pressures that explain their insensitivity to prices when compared with working-age adults; however they seem to show higher sensitivity when compared with old people."

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- Recent suggestive evidence [here](#)
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This Paper: Monetary policy implications of aging and consumption

Focus on the relation between aging and market power and develop a model to derive implications for monetary policy.

- Document a correlation between demographic factors and average markups
  - Larger old-age population $\Rightarrow$ higher markups (market power)
  - Not due to common trends or structural changes

- Embed age-dependent deep habits in a New Keynesian model
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Markups and demographic factors

\[ MU_{c,t} = \alpha_c + \alpha_t + \sum \beta_f Demog_{c,t}(f) + \sum \beta_k X_{c,t}(k) + \beta_l MU_{c,t-1} + \epsilon_{c,t} \]

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Panel Fixed Effects and Dynamic Panel methods: Country and Year fixed effects included. Additional control variables are Real GDP, current account and total trade to GDP, government spending to GDP, savings to GDP, share of Services to GDP, unemployment and labor force participation rates, population density, life expectancy, population growth, share female, stock market capitalization and credit to GDP. Country-year panel of 40 countries over 1980-2016. Data from World Bank and De Loecker and Eeckhout (2020).

Increase in old-age dependency can account for 10% of markups for OECD.
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- Association between aging and markups not due to common trends or structural changes - price sensitivities decline over lifetimes

- Hypothesis: Households develop tastes for specific products (deep habits) as they age and gain consumption experience - become more niche consumers as they grow older

- Implications for monetary policy: A New Keynesian Deep Habits model (Ravn et al., 2006) augmented with overlapping generations and age-specific deep habits
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New Keynesian Deep Habits and Aging: Key Features

- **Households**
  - Key assumption: Deep habits develop over lifetime
  - Tractability: Blanchard-Yaari overlapping generations with consumption risk sharing

- **Firms**
  - Demand- and supply-side sources of market power: Two layers of monopolistic competitive production (consumption goods and intermediate inputs)
  - Link from market power to the Phillips Curve: Rotemberg price rigidities
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New Keynesian Deep Habits and Aging: Log-linearized 3 equations

\[\begin{align*}
\hat{r}_t &= \rho_r \hat{r}_{t-1} + (1 - \rho_r) [\alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t] + \epsilon_{r,t} \\
\hat{y}_t &= \frac{1}{1 + \tilde{\theta}} E_t \hat{y}_{t+1} + \frac{\tilde{\theta}}{1 + \tilde{\theta}} \hat{y}_{t-1} - \frac{1 - \tilde{\theta}}{1 + \tilde{\theta}} \sigma \left[ \hat{r}_t - E_t \hat{\pi}_{t+1} + \tilde{\beta}_t \right] \\
\hat{\pi}_t &= \tilde{\beta} E_t \hat{\pi}_{t+1} + \gamma \left[ \hat{\lambda}_{h,t} - \hat{\lambda}_{i,t} \right] + \tilde{\beta} E_t \hat{\lambda}_{i,t+1} - (1 + \tilde{\beta}) \hat{\lambda}_{i,t} + \hat{\lambda}_{i,t-1}
\end{align*}\]

- Cons. good marginal cost: \( \hat{\lambda}_{i,t} = \Theta_1 \hat{y}_t - \Theta_2 E_t \hat{y}_{t+1} - \Theta_3 \hat{y}_{t-1} + \Theta_4 \tilde{\beta}_t \)
- Interm. input marginal cost: \( \hat{\lambda}_{h,t} = (\kappa + \frac{\sigma}{1 - \tilde{\theta}}) \hat{y}_t - \Theta_5 \hat{y}_{t-1} - (1 + \kappa) \hat{A}_t \)
- Deep habits \( \tilde{\theta} \in [0, 1] \) is increasing in aging
  - \( \tilde{\theta} = 0 \Rightarrow \Theta_i = 0 \; \forall i, \; \hat{\lambda}_{i,t} = 0 \), and model collapses to Standard New Keynesian
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\[ \hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho_r)[\alpha \pi_t + \alpha y_t] + \epsilon_{r,t} \]

\[ \hat{y}_t = \frac{1}{1 + \tilde{\theta}} \hat{\pi}_{t+1} + \frac{\tilde{\theta}}{1 + \tilde{\theta}} \hat{y}_{t-1} - \frac{1 - \tilde{\theta}}{1 + \tilde{\theta}} \sigma \left[ \hat{r}_t - \hat{\pi}_{t+1} + \hat{\beta}_t \right] \]

\[ \hat{\pi}_t = \tilde{\beta} \hat{\pi}_{t+1} + \frac{\gamma - 1}{\delta} \left[ \hat{\lambda}_{h,t} - \hat{\lambda}_{i,t} \right] + \tilde{\beta} \hat{\pi}_{t+1} \hat{\lambda}_{i,t+1} - (1 + \tilde{\beta}) \hat{\lambda}_{i,t} + \hat{\lambda}_{i,t-1} \]

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New Keynesian Deep Habits and Aging: Cost of (dis)inflation

\[ \hat{\pi}_t = \tilde{\beta} E_t \hat{\pi}_{t+1} + \left[ \frac{\gamma - 1}{\delta} (\kappa + \frac{\sigma}{1 - \tilde{\theta}}) - \tilde{\beta} (\Theta_1 + \Theta_3) - (1 + \frac{\gamma - 1}{\delta}) \Theta_1 \right] \hat{y}_t 
\]

\[ - \Theta_2 \tilde{\beta} E_t \hat{y}_{t+2} + (\Theta_1 + (1 + \tilde{\beta} + \frac{\gamma - 1}{\delta}) \Theta_2) \tilde{\beta} E_t \hat{y}_{t+1} - \Theta_2 \tilde{\beta} E_{t-1} \hat{y}_t 
\]

\[ + (\Theta_1 + (1 + \tilde{\beta} + \frac{\gamma - 1}{\delta}) \Theta_3 - \frac{\gamma - 1}{\delta} \Theta_5) \hat{y}_{t-1} - \Theta_3 \hat{y}_{t-2} 
\]

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- Coefficients \( \Theta_i \geq 0 \) are increasing in aging and zero if no deep habits
- Aging flattens the slope of the Phillips curve (coefficient on \( \hat{y}_t \))
- Slope is no longer a sufficient statistic for the relationship between inflation and output in the Phillips curve - simulate output response to a monetary policy
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- \Theta_2 \tilde{\beta}^2 \mathbb{E}_t \hat{y}_{t+2} + (\Theta_1 + (1 + \tilde{\beta} + \frac{\gamma - 1}{\delta}) \Theta_2) \tilde{\beta} \mathbb{E}_t \hat{y}_{t+1} - \Theta_2 \tilde{\beta} \mathbb{E}_{t-1} \hat{y}_t \\
+ (\Theta_1 + (1 + \tilde{\beta} + \frac{\gamma - 1}{\delta}) \Theta_3 - \frac{\gamma - 1}{\delta} \Theta_5) \hat{y}_{t-1} - \Theta_3 \hat{y}_{t-2} \\
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New Keynesian Deep Habits and Aging: Calibration

Demographics and markups for Japan in the 1980s and 2010s.

- Life expectancy and population growth give $\tilde{\theta}_s$ for $s \in \{1980s, 2010s\}$
- Markups

$$\mu_s = \left[ \frac{\gamma_s}{(\gamma_s - 1)} \right] \left[ \frac{\eta}{(\eta - 1)} \right] \left[ \frac{1 - \tilde{\theta}_s}{1 - \tilde{\theta}_s \left( \frac{\eta - \beta_s}{\eta - 1} \right)} \right]$$

- Demographic change accounts for about 3.8% of markups (10% average in OECD data)
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- Full Table

Steady state changes
### New Keynesian Deep Habits and Aging: Cost of (dis)inflation

#### Cumulated output response

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<thead>
<tr>
<th>Horizon</th>
<th>2 year</th>
<th>5 year</th>
<th>20 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980-1985 Baseline</td>
<td>-0.011</td>
<td>-0.012</td>
<td>-0.012</td>
</tr>
<tr>
<td>2011-2016 with no demog. change</td>
<td>-0.163</td>
<td>-0.174</td>
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</tr>
<tr>
<td>Share (%)</td>
<td>(157.5)</td>
<td>(91.3)</td>
<td>(68.8)</td>
</tr>
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<td>2011-2016 All changes</td>
<td>-0.108</td>
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- **Cost of disinflation order of magnitude higher in the 2010s**
- **Aging adds persistence but dampens initial output response**
- **About one-third of long-run increase in disinflation cost is due to aging**

#### Output IRF to monetary surprise

![Output IRF to monetary surprise](attachment:output_irf.png)
New Keynesian Deep Habits and Aging: Cost of (dis)inflation

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Output IRF to monetary surprise w/o deep habits
Concluding remarks

- **Stylized fact: Age-structure correlates well with average markups**
  - Particularly for the share of old dependents in OECD countries
  - Declining price sensitivities over lifetimes may explain this relationship

- A New Keynesian Deep Habits model with age-specific deep habits can replicate these features of the data
  - Aging raises markups and flattens the New Keynesian Phillips Curve
  - More broadly, aging raises the cost of disinflation for monetary policy
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Demographic Aging and the New Keynesian Phillips Curve

Gene Ambrocio

August 2023

The views and opinions expressed in this paper are those of the author(s) and do not necessarily represent those of the Bank of Finland.
Motivation

- Older households are more attached to specific brands (brand loyalty/capital)
  - Older households have more *niche* consumption (Neiman and Vavra, 2023)

- Consumption inertia more pronounced in older households (Bornstein, 2021)

- 2012 Eurobarometer survey evidence that older households care less about prices and more about non-price qualities in food purchases
Niche consumption by age

Source: Figure 3 in Neiman and Vavra (2023)
Consumer inertia by age

Figure 5: Consumer Inertia by Household Age Across Departments

Notes: This figure displays the average estimated consumer inertia by age groups in each product department. The center of each circle represents the weighted average point estimates, and each confidence interval represents the weighted average confidence interval. Weights are proportional to the number of observations in the regression of each product category.

Source: Figure 5 in Bornstein (2021)
# Price sensitivities and age: EU household food purchases

<table>
<thead>
<tr>
<th>Dep. var.:</th>
<th>(1) Price</th>
<th>(2) Quality</th>
<th>(3) Geographic Origin</th>
<th>(4) Brand</th>
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</thead>
<tbody>
<tr>
<td>25 - 34 years</td>
<td>0.018</td>
<td>0.020</td>
<td>-0.035*</td>
<td>-0.145***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.034*</td>
<td>-0.148***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.055*</td>
<td>-0.063**</td>
</tr>
<tr>
<td>35 - 44 years</td>
<td>0.023</td>
<td>0.024</td>
<td>-0.038</td>
<td>-0.238***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.038*</td>
<td>-0.245***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.058</td>
<td>-0.071**</td>
</tr>
<tr>
<td>45 - 54 years</td>
<td>0.016</td>
<td>0.016</td>
<td>-0.051**</td>
<td>-0.285***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.050**</td>
<td>-0.298***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.068</td>
<td>-0.082**</td>
</tr>
<tr>
<td>55 - 64 years</td>
<td>0.070**</td>
<td>0.071**</td>
<td>-0.081***</td>
<td>-0.342***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.081***</td>
<td>-0.349***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.062</td>
<td>-0.077*</td>
</tr>
<tr>
<td>65 years and older</td>
<td>0.135***</td>
<td>0.127***</td>
<td>-0.083***</td>
<td>-0.370***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.080***</td>
<td>-0.376***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.072</td>
<td>-0.093*</td>
</tr>
<tr>
<td>With children</td>
<td>-0.030**</td>
<td>-0.030**</td>
<td>0.022</td>
<td>0.057***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.023*</td>
<td>0.056***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.028*</td>
<td>0.026</td>
</tr>
</tbody>
</table>

| Additional controls | YES       | YES         | YES                    | YES       |
| Fixed effects       | CNTRY     | NUTS2       | CNTRY                 | NUTS2     |
| Adj. R-squared      | 0.175     | 0.188       | 0.053                 | 0.120     |
| Observations        | 15977     | 15977       | 16092                 | 15946     |

Dependent variables are survey responses regarding importance of feature (decreasing scale) for food purchases. Omitted age category is 15-24 years old. Additional controls are education, occupation, home ownership, difficulties paying bills, marital status, gender, community, social status, internet use and ability, online purchases, and food logo awareness. Data from the March 2012 Eurobarometer survey covering 26 thousand respondents from 27 European countries.
Related Literature

- Economic implications of aging on savings, real rates, and asset returns (Poterba, 2001; Krueger and Ludwig 2007; Ludwig et al., 2012; Carvalho et al., 2016; Lunsford and West, 2019), labor markets and productivity (Feyrer, 2007; Liang et al., 2018; Aksoy et al., 2019; Acemoglu and Restrepo, 2022), and inflation and monetary policy (Fujiwara and Teranishi, 2008; Goodhart and Pradhan, 2020; Katagiri et al., 2020; Juselius and Takats, 2021; Leahy and Thapar, 2022)
  - I focus on consumption behavior $\Rightarrow$ market power and monetary policy

- Decline in markups and price sensitivities (De Loecker et al., 2020, 2021; Autor et al., 2020; Brand, 2021; Liu et al., 2022; Doepper et al., 2022; Atalay et al., 2023) and demographic aging
  - Bornstein (2021) on formation of new firms and Cravino et al. (2022) and Mangiante (2023) on changing consumption baskets while I focus on changing price sensitivities via deep habits.
Markups and demographic factors


<table>
<thead>
<tr>
<th>Description</th>
<th>Mean</th>
<th>St. dev.</th>
<th>Obs.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Markups</td>
<td>1.34</td>
<td>0.31</td>
<td>1382</td>
<td>Average markups</td>
</tr>
<tr>
<td>Age dependency ratio (total)</td>
<td>54.57</td>
<td>10.81</td>
<td>1480</td>
<td>Share of young (0-14) and old (65+) to working age pop.</td>
</tr>
<tr>
<td>Share young to total pop.</td>
<td>24.37</td>
<td>8.22</td>
<td>1480</td>
<td>Share of young (0-14) to total pop.</td>
</tr>
<tr>
<td>Share old to total pop.</td>
<td>10.64</td>
<td>5.27</td>
<td>1480</td>
<td>Share of old (65+) to total pop.</td>
</tr>
<tr>
<td>Life exp. at birth (years)</td>
<td>74.22</td>
<td>6.24</td>
<td>1480</td>
<td>Life expectancy at birth, total (years)</td>
</tr>
<tr>
<td>Population growth (annual %)</td>
<td>1.08</td>
<td>0.82</td>
<td>1479</td>
<td>Population growth in annual %</td>
</tr>
<tr>
<td>Fertility rate</td>
<td>2.18</td>
<td>0.94</td>
<td>1480</td>
<td>Fertility rate (births per woman)</td>
</tr>
<tr>
<td>Share young to total pop.</td>
<td>24.37</td>
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</tr>
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<td>Real GDP growth (annual %)</td>
<td>3.30</td>
<td>3.59</td>
<td>1478</td>
<td>Real GDP growth in annual %</td>
</tr>
<tr>
<td>CPI inflation</td>
<td>24.30</td>
<td>250.70</td>
<td>1404</td>
<td>Consumer price index (2010=100) inflation in annual %</td>
</tr>
<tr>
<td>Unemployment rate</td>
<td>6.96</td>
<td>4.77</td>
<td>1122</td>
<td>Unemployment rate as % of labor force</td>
</tr>
<tr>
<td>Labor force participation rate</td>
<td>60.65</td>
<td>5.10</td>
<td>1308</td>
<td>Labor force participation rate as % to population aged 15+</td>
</tr>
<tr>
<td>Current account to GDP</td>
<td>0.24</td>
<td>5.40</td>
<td>1339</td>
<td>Current account balance as % of GDP</td>
</tr>
<tr>
<td>Market cap of listed firms (% of GDP)</td>
<td>77.87</td>
<td>113.39</td>
<td>1147</td>
<td>Market cap. of listed dom. firms as % of GDP</td>
</tr>
<tr>
<td>Private domestic credit (% of GDP)</td>
<td>80.31</td>
<td>51.05</td>
<td>1221</td>
<td>Domestic credit to private sector as % of GDP</td>
</tr>
<tr>
<td>Services value-added (% of GDP)</td>
<td>57.13</td>
<td>9.70</td>
<td>1225</td>
<td>Services sector value added as % of GDP</td>
</tr>
</tbody>
</table>
Markups and demographic factors

Average markups

Life expectancy

Share old dependents

Share young dependents

Median values and interquartile range.
Markups and demographic factors

- Difficult to add full age distribution as variables
- Factor shrinkage of age dist:

\[
\begin{align*}
\text{Age}_{c,t}(a) &= \sum \gamma_{a,p} F_{c,t}(p) + \xi_{c,t,a} \\
\text{MU}_{c,t} &= \sum \beta_p F_{c,t}(p) + \sum \beta_k X_{c,t}(k)
+ \beta_l \text{MU}_{c,t-1} + \alpha_c + \alpha_t + \epsilon_{c,t} \\
\frac{\partial \text{MU}_{c,t}}{\partial \text{Age}_{c,t}(a)} &= \sum \hat{\gamma}_{a,p} \hat{\beta}_p
\end{align*}
\]
Age-specific deep habits

- Suppose that a household $j$ born at time $t - J$ consumes a product variety $k \in [0, 1]$ in sector $i \in [0, 1]$ and prefers to consume some subset of varieties $\Sigma_{j,i}$ of length $0 \leq s \leq 1$. Household obtains higher marginal utility from consuming the preferred good:

\[
\frac{\partial U_{j,t}}{\partial c_{k,i,j,t}} = \begin{cases} 
\bar{x} \left[ c_{k,i,j,t} \right]^{-1/\eta} & \text{if } k \notin \Sigma_{j,i} \\
\bar{x} \left[ c_{k,i,j,t} - \bar{c} \right]^{-1/\eta} & \text{if } k \in \Sigma_{j,i}
\end{cases}
\]

- Every period, the household is matched with a store offering one random variety for each sector. The household can then choose to consume this variety or any one that she has previously encountered.
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- Every period, the household is matched with a store offering one random variety for each sector. The household can then choose to consume this variety or any one that she has previously encountered.
Age-specific deep habits

- The likelihood that a household of age $J$ has encountered (one of) a preferred variety is increasing over their lifetime:

$$Pr(\{k\}_{t-J} \cap \Sigma \neq \emptyset) = 1 - (1 - s)^J$$

- Random $\Sigma$ across households $\Rightarrow$ above is also share of households of age $J$ consuming their preferred variety.
  - Generates deep habits: $\theta_{i,j,t} = \theta Pr(\{k\}_{t-J} \cap \Sigma \neq \emptyset)$

- Aggregate deep habits depend on age distribution:

$$\tilde{\theta} = \sum_{J=1}^{\infty} \int_{j \in J} \theta_{i,j,t} dj f(J)$$
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New Keynesian Deep Habits: Households

- Blanchard-Yaari Overlapping Generations: Fraction $g_b$ born and $g_d$ exit each period. Ex-ante identical households with parsimonious age distribution,

\[
f(J) = g(1 - g)^{J-1} \quad \text{where} \quad g = \frac{g_b}{1 + g_b - g_d}
\]

- Standard deep habits household problem: max CRRA utility from consumption bundle $U(x_{j,t}, h_{j,t})$ where

\[
x_{j,t} = \left[ \int_0^1 \left( c_{i,j,t} - \theta_{i,j,t} c_{i,t-1} \right)^{\frac{\eta-1}{\eta}} \, di \right]^{\frac{\eta}{\eta-1}}
\]
New Keynesian Deep Habits: Households

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New Keynesian Deep Habits: Households

\[ \max \quad \mathbb{E}_t \sum_{t'=0}^{\infty} [(1 - g_d) \beta]^{t'} U(\{c_{i,j,t+t'}\}, h_{j,t+t'}) \]

subject to:

\[ U = \frac{x_{j,t}^{1-\sigma}}{1 - \sigma} - \frac{h_{j,t}^{1+\kappa}}{1 + \kappa} \]

\[ x_{j,t} = \left[ \int_0^1 (c_{i,j,t} - \theta_{i,j,t} c_{i,t-1}) \frac{n-1}{n} di \right] \frac{n}{n-1} \]

\[ \int_0^1 P_{i,t} c_{i,j,t} di + B_{j,t} = R_{t-1} B_{j,t-1} + W_{t} h_{j,t} + \Phi_t \quad \forall t \]
New Keynesian Deep Habits: Consumption good Firms

• Firms max profits given household stochastic discount factor and demand curve:

\[ c_{i,t} = x_t \left[ \frac{P_{i,t}}{P_t} \right]^{-\eta} + \tilde{\theta} c_{i,t-1} \]

• Produce using intermediate inputs \( y_{m,t} \) at cost \( P_{m,t} \):

\[ y_{i,t} = \left[ \int_{m=0}^{1} Y_{m,t}^{\gamma-1} \right]^{\frac{\gamma}{\gamma-1}} \]

• Production elasticity of substitution \( \gamma \) captures supply side factors
New Keynesian Deep Habits: Consumption good Firms

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  \[ c_{i,t} = x_t \left[ \frac{P_{i,t}}{P_t} \right]^{-\eta} + \tilde{\theta}C_{i,t-1} \]

- Produce using intermediate inputs \( y_{m,t} \) at cost \( P_{m,t} \):
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- Production elasticity of substitution \( \gamma \) captures supply side factors
New Keynesian Deep Habits: Intermediate input Firms

Firms use labor to meet demand for inputs and max profits subject to Rotemberg costs

- Profits: \( \Phi_{m,t} = P_{m,t} Y_{m,t} - W_t \delta h_{m,t} - \frac{\delta}{2} P_{M,t} C_t \left( \frac{P_{m,t}}{P_{m,t-1}} - \pi^* \right)^2 \)

- Demand: \( Y_{m,t} = \int_{i=0}^{1} Y_{i,t} \lambda_{i,t} \left[ \frac{P_{m,t}}{P_t} \right]^{-\gamma} di \)

- Production: \( Y_{m,t} \leq A_t h_{m,t} \)

Markups (consumption goods price over productivity-adjusted nominal wages):

\[
\mu \equiv \frac{PA}{W} = \lambda_h^{-1} = \frac{\gamma}{\gamma - 1} \lambda_i^{-1} = \left[ \frac{\gamma}{\gamma - 1} \right] \left[ \frac{\eta}{\eta - 1} \frac{1 - \tilde{\theta}}{1 - \tilde{\theta} \left( \frac{\eta - \tilde{\beta}}{\eta - 1} \right)} \right]
\]
### New Keynesian Deep Habits and Aging: Calibration

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.69</td>
<td>0.69</td>
<td>-0.14</td>
<td>-0.14</td>
<td>0.69</td>
</tr>
<tr>
<td>Life expectancy.</td>
<td>76.90</td>
<td>76.90</td>
<td>83.40</td>
<td>83.40</td>
<td>76.90</td>
</tr>
<tr>
<td>Average Deep habits</td>
<td>0.75</td>
<td>0.75</td>
<td>0.95</td>
<td>0.95</td>
<td>0.75</td>
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<tr>
<td>Consumption elasticity</td>
<td>56.91</td>
<td>56.91</td>
<td>56.91</td>
<td>56.91</td>
<td>56.91</td>
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<tr>
<td>Production elasticity</td>
<td>59.85</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td></td>
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<tr>
<td>Markups</td>
<td>1.036</td>
<td>1.036</td>
<td>1.280</td>
<td>1.280</td>
<td>1.275</td>
</tr>
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</table>

- Aging accounts for 3.8% of increase in markups
- Other parameters
### Calibrated parameters

#### Model calibrated parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount factor</td>
<td>$\beta$</td>
<td>0.99</td>
<td>Annual real rate of 4%</td>
</tr>
<tr>
<td>Risk aversion</td>
<td>$\sigma$</td>
<td>3.0</td>
<td>Following Ravn et al. (2010)</td>
</tr>
<tr>
<td>Inverse labor elasticity</td>
<td>$\kappa$</td>
<td>1.0</td>
<td>Following Fernandez-Villaverde et al. (2015)</td>
</tr>
<tr>
<td>Demand elasticity</td>
<td>$\eta$</td>
<td>56.9</td>
<td>Match 1980s average markups</td>
</tr>
<tr>
<td>Production elasticity</td>
<td>$\gamma$</td>
<td>59.9,4.9</td>
<td>Match 1980s-2010s average markups</td>
</tr>
<tr>
<td>Price rigidity</td>
<td>$\delta$</td>
<td>187</td>
<td>Equivalent to average Calvo parameter of 0.75</td>
</tr>
<tr>
<td>Maximum habits</td>
<td>$\theta$</td>
<td>1.02</td>
<td>Average deep habits of 0.85 as in Ravn et al. (2010)</td>
</tr>
<tr>
<td>Deep habits rate</td>
<td>$s$</td>
<td>0.03</td>
<td>Deep habits flatten out at age 55 years</td>
</tr>
<tr>
<td>Birth rate</td>
<td>$gb$</td>
<td>0.011-0.002</td>
<td>Population growth in Japan 1980s-2010s</td>
</tr>
<tr>
<td>Death rate</td>
<td>$gd$</td>
<td>0.004-0.0037</td>
<td>Life expectancy in Japan 1980s-2010s</td>
</tr>
</tbody>
</table>

#### Monetary policy rule

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistence</td>
<td>$\rho_r$</td>
<td>0.70</td>
<td>Following Fernandez-Villaverde et al. (2015)</td>
</tr>
<tr>
<td>Inflation coefficient</td>
<td>$\alpha_\pi$</td>
<td>1.5</td>
<td>Conventional values</td>
</tr>
<tr>
<td>Output coefficient</td>
<td>$\alpha_y$</td>
<td>0.0</td>
<td>Conventional values</td>
</tr>
<tr>
<td>Inflation target</td>
<td>$\pi^*$</td>
<td>1.00</td>
<td>Conventional values</td>
</tr>
</tbody>
</table>
New Keynesian Deep Habits and Aging: Steady state changes

- Aging raises average deep habits $\tilde{\theta}$ and raises markups,

$$
\mu = \left[ \frac{\gamma}{(\gamma - 1)} \right] \left[ \frac{\eta}{(\eta - 1)} \right] \left[ \frac{1 - \tilde{\theta}}{1 - \tilde{\theta} \left( \frac{\eta - \bar{\beta}}{\eta - 1} \right)} \right]
$$

- Lowers labor share, $Wh/PY = \mu^{-1}$,

- and lowers output if $\tilde{\theta} \lesssim \sigma / (\sigma + 1)$:

$$
Y = \left[ A^{1+\kappa} \mu^{-1} (1 - \tilde{\theta})^{-\sigma} \right]^{\frac{1}{\kappa+\sigma}}
$$
New Keynesian and Aging: No Deep habits

- Instead of deep habits, $\eta_j = \bar{\eta} + (\bar{\eta} - \eta)(1 - s)^{j-1}$ and $\bar{\eta} = \sum \eta_j f(j)$
- Rotemberg costs on consumer and intermediate goods producers
- SS markups: $\mu = \left[ \frac{\gamma}{\gamma - 1} \right] \left[ \frac{\bar{\eta}}{\bar{\eta} - 1} \right]$ where aging $\to \downarrow \bar{\eta}$

\[
\begin{align*}
\hat{y}_t &= \bar{\beta} E_t \hat{y}_{t+1} - \sigma^{-1}(\hat{r}_t - E_t \hat{\pi}_{t+1}) \\
\hat{\pi}_t &= \bar{\beta} E_t \hat{\pi}_{t+1} + ((\bar{\eta} - 1)/\delta_c)\hat{\lambda}_{i,t} \\
\hat{\pi}_{m,t} &= \bar{\beta} E_t \hat{\pi}_{m,t+1} + ((\gamma - 1)/\delta_m)\hat{\lambda}_{h,t} \\
\hat{\lambda}_{i,t} + \hat{\lambda}_{h,t} &= (\kappa + \sigma)\hat{y}_t - (1 + \kappa)\hat{A}_t \\
\hat{\pi}_{m,t} - \hat{\pi}_t &= \hat{\lambda}_{i,t} - \hat{\lambda}_{i,t-1}
\end{align*}
\]
New Keynesian and Aging: No Deep habits

- Calibrate as before. This time, changes in $\tilde{\eta}$ account for 10% increase in markups
- Output cost of disinflation is about four times higher in 2010s relative to 1980s
- Contribution of aging to inflation output trade-off in line with contribution to change in markups

<table>
<thead>
<tr>
<th></th>
<th>Horizon</th>
<th>2 year</th>
<th>5 year</th>
<th>20 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980-85 Baseline</td>
<td>-1.7460</td>
<td>-1.7399</td>
<td>-1.7399</td>
<td></td>
</tr>
<tr>
<td>2011-2016 with no demog. change</td>
<td>-5.9882</td>
<td>-5.7785</td>
<td>-5.7781</td>
<td></td>
</tr>
<tr>
<td>Share (%)</td>
<td>(85.4)</td>
<td>(89.8)</td>
<td>(89.8)</td>
<td></td>
</tr>
<tr>
<td>2011-2016 All changes</td>
<td>-6.7075</td>
<td>-6.2384</td>
<td>-6.2360</td>
<td></td>
</tr>
<tr>
<td>Share (%)</td>
<td>(100.0)</td>
<td>(100.0)</td>
<td>(100.0)</td>
<td></td>
</tr>
</tbody>
</table>