The Depreciation of Apple iPhones: A First Look

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Views expressed here are the author’s, not necessarily those of BEA or the U.S. Department of Commerce.
Depreciation...

*Defined:* Loss of *resale* value of an asset (individual/variety/vintage/net-stock) of a given type as it ages

*versus* “Deterioration”:

Loss of *rental* value

*Taxonomy:* Resale value declines because...

- Asset **wears out** (individual level)
- Asset is approaching its **retirement** (individual level)
- Asset is **obsolesc**ing (variety/vintage level)

Net Stock depreciation combines them all, even retirees.
High-Tech Depreciation...

**Taxonomy:** Electronic good’s resale value declines because...

- **Asset wears out** (individual level) ← “Good as new”
- Asset is approaching its **retirement** (individual level)
- Asset is **obsolescing** (variety/vintage level)

Net Stock depreciation combines them all, even retirees.

- Q: What do you call an asset that does not wear out, but then is retired?
- A: One-Hoss Shay:

  ...but with obsolescence (and inflation)
Model Individual Efficiency...

• ...of obsolescing, inflating, 1HS *individual*
• ...that was built/bought/installed in year $v$
• ...$s$ years later, in year $t$

\[
\phi_{v,t}^{s,j} = e^{\pi(t-v)} \times e^{-b(t-v)} \times 1
\]

so... $s = t - v$ (Hall, 1968)

- **Age-Efficiency Profile** = Ratio of $s$-year old rent to new
- **Constant-Quality Inflation Rate**
- **Rate of “Betterment”**
- **Individual $j$’s service Life**

...if $s < L_j$

...else 0
Model Individual Resale Value...

- Discount and sum efficiencies through future ages \((u)\) from current age \((s)\) to service-Life \((L_j)\)
- Do same from age-0 to service-Life \((L_j)\)
- Divide

\[
\theta_{v,t}^{s,j} = \frac{\int_s^{L_j} e^{-i(u-s)} \phi \, du}{\int_0^{L_j} e^{-i(u-0)} \phi \, du}
\]

Resale-Price Profile
= Ratio of \(s\)-year old price to new

\[
= e^{(\pi-b)(t-v)} \frac{e^{(i-\pi+b)s} - e^{(i-\pi+b)L_j}}{1 - e^{(i-\pi+b)L_j}}
\]
Fit Individuals into Cohort (=vintage/variety)

Cohort resale price = weighted average of members’ resale prices:

\[ e^{-(\delta+b)s} = \int_0^S 0 \times f(L) dL + \int_s^{\infty} \theta(L) \times f(L) dL \]

Cohort-Level Non-Obsolescence Depreciation Rate

Recover weights:

\[ f(L) = \delta \left(1 + \frac{\delta}{r - \pi + b}\right) e^{-\delta L} (1 - e^{-(i-\pi+b)L}) \]

Resulting density “looks like” a Gamma density; has mean, variance, and mode;

And integrates up to reveal the fraction that survives to age \( s \) →
Adjust Age-Price Regression for Retirements

Fraction of cohort that survives as of age $s$:

$$S(L > s) = \int_{s}^{\infty} f(L) dL = e^{-\delta s} \left( 1 + \left( 1 - e^{-(i-\pi+b)s} \right) \frac{\delta}{i-\pi+b} \right)$$

Why care? The “idealized” regression, $P_{t}^{S} = P_{0}^{0} e^{-(\delta+b-\pi)s} + \varepsilon$, is supposed to represent the average price of the whole cohort, but only survivors make it into the data. So divide RHS by $S(L>s)$ to account for lost survivors, cancel, take logs, add variety dummies:

$$\ln P_{v,t}^{S} = \ln P_{v}^{0} + (\pi - b)t - \ln \left[ 1 + \left( 1 - e^{-(i-\pi+b)s} \right) \frac{\delta}{i-\pi+b} \right] + \varepsilon$$

78 variety-specific intercepts absorb $v$ from $(\pi-b)$. Timing assumption will separate $\pi$ from $b$. $i$ not identified, so set $= 5.265\%$ (Baa 2010-15)
Data

• 10,372 obs, from 1/15/2010 to 12/30/2015, 78 varieties

• Used Price.com ... “Orion Bluebook Online” 

• “Price-Points” at specific dates (irregular weekly)

• 5 continuous (camera resolution, memory, processor speed, screen size, storage capacity) and 44 discrete characteristics

...which are locked into the particular iPhone variety

...and Apple only releases new varieties once a year

• So use Apple’s six included iPhone release-dates as perfect proxies for characteristics!!
### iPhone Release Dates

**Table 2: Obsolescing Events**

<table>
<thead>
<tr>
<th>Release Dates: “t*”</th>
<th>What Apple Released</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 24, 2010</td>
<td>iPhone 4 (8/16/32 GB)</td>
</tr>
<tr>
<td>October 14, 2011</td>
<td>iPhone 4S (8/16/32/32/64 GB)</td>
</tr>
<tr>
<td>September 21, 2012</td>
<td>iPhone 5 (16/32/64 GB)</td>
</tr>
<tr>
<td>September 20, 2013</td>
<td>iPhone 5c (16/32 GB × AT&amp;T/Boost/Cricket¹⁴/Sprint/ T-Mobile/Verizon/Virgin/ GSM Non-Sim Card)</td>
</tr>
<tr>
<td></td>
<td>iPhone 5s (16/32/64 GB × AT&amp;T/Boost/Cricket¹⁴/Sprint/ T-Mobile/Verizon/ GSM Non-Sim Card)</td>
</tr>
<tr>
<td>September 19, 2014</td>
<td>iPhone 6 (16/64/128 GB × AT&amp;T/Sprint/T-Mobile/Verizon)</td>
</tr>
<tr>
<td></td>
<td>iPhone 6 Plus (16/64/128 GB × AT&amp;T/Sprint/T-Mobile/Verizon)</td>
</tr>
<tr>
<td>September 25, 2015</td>
<td>iPhone 6s (16/64/128 GB × AT&amp;T/Sprint/T-Mobile/Verizon)</td>
</tr>
<tr>
<td></td>
<td>iPhone 6s Plus (16/64/128 GB × AT&amp;T¹⁵/Sprint/T-Mobile/Verizon)</td>
</tr>
</tbody>
</table>
Final Regression Specification

\[ \ln P_{v,t}^S = \ln P_{v}^0 + \pi \; t - \sum_{t \geq t^*} b_t^* D_t^* \]

- \( \ln \left[ 1 + \left( 1 - e^{-\left( \frac{t - \pi + \sum_{t^*} b_{t^*} s}{t - t^*} \right)} \right) \right] + \delta \frac{\sum_{t^*} b_{t^*}}{t - t^*} + \varepsilon \)

Fit by NLLS

Allow clustered standard errors
## Selected Regression Results

### Parameters

<table>
<thead>
<tr>
<th></th>
<th>( \delta )</th>
<th>( b_{6/24/10} )</th>
<th>( b_{10/14/11} )</th>
<th>( b_{9/21/12} )</th>
<th>( b_{9/20/13} )</th>
<th>( b_{9/19/14} )</th>
<th>( b_{9/25/15} )</th>
<th>( \pi )</th>
<th>( i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \pi )</td>
<td>.387</td>
<td>.292</td>
<td>.100</td>
<td>.175</td>
<td>.102</td>
<td>.142</td>
<td>.031</td>
<td>−.193</td>
<td>.051</td>
</tr>
</tbody>
</table>

### Point Values

<table>
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<tr>
<th></th>
<th>.387</th>
<th>.292</th>
<th>.100</th>
<th>.175</th>
<th>.102</th>
<th>.142</th>
<th>.031</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annualized</td>
<td>.321</td>
<td>( \frac{.132}{100} )</td>
<td>.053</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Std. Errs. (simple)

<table>
<thead>
<tr>
<th></th>
<th>(.017)</th>
<th>(.033)</th>
<th>(.010)</th>
<th>(.011)</th>
<th>(.011)</th>
<th>(.007)</th>
<th>(.007)</th>
<th>(.009)</th>
</tr>
</thead>
</table>

### Std. Errs. (clustered by 78 varieties)

<table>
<thead>
<tr>
<th></th>
<th>(.063)</th>
<th>(.048)</th>
<th>(.022)</th>
<th>(.036)</th>
<th>(.026)</th>
<th>(.014)</th>
<th>(.010)</th>
<th>(.031)</th>
</tr>
</thead>
</table>

### Std. Errs. (clustered by 7 obsolescence regimes)

|   | (.035) | (.045) | (.051) | (.050) | (.049) | (.041) | (.031) | (.056) |
Service-Life Density

Figure 4
Implied iPhone Service-Life Density
(and Gamma Density with Same Moments)

Mean = 3.875 years
Mode = 1.782 years
Summary of Findings

Substantive:
• Aggregate iPhone depreciation
  \[32.1 + 13.2 = 45.3\text{ percent per year}\]
• Constant-quality inflation
  17.5 percent \textit{deflation} per year
• Distribution of individual phones’ service lives
  About 2-year mode (~contract length), 4-year mean

Methodological:
• Use working hypothesis about individual-level depreciation to infer retirement density within geometric aggregate.
• Distinguish wearing-out and retirements, which happen to individuals, from inflation and obsolescence, which happen to cohorts.
Thank you!

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