An Integrated Analysis of Mobile Application Usage and In-App Advertising Response

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Mobile Apps and In-App Ads

- Adults spend more media time on mobile than on newspapers and magazines combined (eMarketer 2011)
- 86% of mobile time is spent on mobile apps (Techcrunch 2014)
- Mobile advertising spending will exceed $100 billion in 2016 (eMarketer 2015)
  - In-app ad spend nearly triple mobile web ad spend (eMarketer 2015)
  - CTR on in-app ad twice that of mobile web ad (Forbes 2014)
Research Questions

- How does application usage vary over time?
  - How does consumers’ involvement in different activities drive their use of mobile applications?
  - How does consumer involvement evolve over time?

- How do consumers respond to mobile in-app ads?
  - How does the underlying state of mind affect ad response?
  - How does the context of mobile app affect ad response?
  - How does the response vary across ad types?

- Managerial Implication: optimal ad delivery strategy
  - When/whom to deliver to improve the result?
Contribution

- Propose an integrated framework for jointly modeling mobile application usage and in-app ad response
- Establish that the underlying involvement is a key driver of both decisions
- First to investigate the dynamic evolution of consumer’s involvement over time of day.
- Distinguish the involvement effect and contextual effect that drive consumer response to mobile ad
- Demonstrate the potential for improving ad targeting effectiveness by recognizing the real-time and multi-tasking nature of mobile usage
Data

- From a major mobile advertising platform
- Mobile app usage and in-app ad response data
Mobile Applications

- Four categories of mobile applications
- Usage varies significantly over time of day

![Application Usage By Hour By Category](image-url)
In-App Ad Response

- Ad response varies significantly over a day
- Current practice not optimal
In-App Ad Response

- Context matters!
- Underlying state of mind also matters!

<table>
<thead>
<tr>
<th>App Category</th>
<th>Ad CTR</th>
<th>Entertainment</th>
<th>Utility</th>
<th>Information</th>
<th>Social</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entertainment</td>
<td>1.72%</td>
<td>1.56%</td>
<td>0.81%</td>
<td>1.77%</td>
<td>5.78%</td>
</tr>
<tr>
<td>Utility</td>
<td>1.14%</td>
<td>0.52%</td>
<td>0.93%</td>
<td>1.40%</td>
<td>1.92%</td>
</tr>
<tr>
<td>Information</td>
<td>1.81%</td>
<td>1.99%</td>
<td>1.15%</td>
<td>1.68%</td>
<td>5.97%</td>
</tr>
<tr>
<td>Social</td>
<td>1.96%</td>
<td>1.18%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>1.96%</td>
</tr>
</tbody>
</table>
Theoretical Foundation

- Application usage
  - Activity/time-use driven by underlying involvement in different types of activity
  - Underlying involvement evolve dynamically; they also depend on the time of day

- In-app advertising response
  - Ad response depends on the underlying involvement
  - Ad response depends on the context
(1): Underlying involvement levels in different activities affect ad response
(2): Direct contextual effect of the mobile application on ad response
(3): Underlying involvement levels determine application usage
(4): Underlying involvement levels evolve over time
Model – Application Usage

App usage amount: \( \tilde{x}_{idt} = (x_{idt,0}, x_{idt,1}, \ldots, x_{idt,K}) \)

d: day, t: time, k: category of application

App usage driven by underlying involvement levels:

\[
\bar{U}_{idt,k} = \beta_{idtk0} + \beta_{k1} \ln(H_{idt,k} + 1)
\]

Effect of usage history

Underlying involvement level at the time
Model – Application Usage

Underlying involvement level evolves over time:

\[
\bar{U}_{idt,k} = \beta_{idtk0} + \beta_{k1} \ln(H_{idt,k} + 1)
\]

\[
\beta_{idtk0} = \beta_{ik} + \tilde{\beta}_{idtk0} + \delta_{tk}
\]

**Baseline Involvement**

**Dynamic Evolution** \( \tilde{\beta}_{id,t,k0} = \phi_{ik}\tilde{\beta}_{id,t-1,k0} + \varepsilon_{idtk} \)

**Time-of-day Effect**

**Persistence**
Model – Ad Response

The utility of consumer $i$ clicking ad $j$ at the $n$-th delivery:

$$
\bar{U}_{ijn}^A = \theta_i q_j + \sum_{a \in \{S,D\}} \theta_{aT(j)}^S A_{ijna} + \sum_{k=0}^{K} \theta_k^\beta \beta_{idt_{ijn}k0} + \sum_{k=0}^{K} \theta_{kT(j)}^C C_{ijn}^k + \theta_t^{T(ijn)}
$$

Individual & Ad Effect

Sequential Effect:

$A_{ijnS}$: number of times the consumer has seen the same ads for the day

$A_{ijnD}$: number of times the consumer has seen other different ads for the day

$T(j)$: type of ad $j$
Model – Ad Response

The utility of consumer $i$ clicking ad $j$ at the $n$-th delivery:

$$\bar{U}_{ijn} = \theta i q j + \sum_{a \in \{S, D\}} \theta^S a_{T(j)} A_{ijn} + \sum_{k=0}^{K} \theta^\beta \beta_{idt_{ijn}k0} + \sum_{k=0}^{K} \theta^C_{kT(j)} C_{ijn} + \theta^T_{t(ijn)}$$

Involvement Effect: consumer’s underlying involvement:

$$\theta^\beta_k > 0(<0): \text{higher involvement in category } k \Rightarrow \text{higher (lower) interest in ad}$$

Contextual effect of App:

$$\theta^C_{kT(j)} > 0(<0): \text{category } k \text{ app more (less) suitable for type } T(j) \text{ ad}$$
## Result – App Usage

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>SD</th>
<th>2.5% CI</th>
<th>97.5% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effect of prior usage ($\beta_{k1}$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entertainment</td>
<td>-0.063</td>
<td>0.025</td>
<td>-0.097</td>
<td>-0.015</td>
</tr>
<tr>
<td>Utility</td>
<td>-0.167</td>
<td>0.019</td>
<td>-0.193</td>
<td>-0.126</td>
</tr>
<tr>
<td>Information</td>
<td>-0.123</td>
<td>0.020</td>
<td>-0.149</td>
<td>-0.081</td>
</tr>
<tr>
<td>Social</td>
<td>0.618</td>
<td>0.027</td>
<td>0.564</td>
<td>0.656</td>
</tr>
<tr>
<td><strong>Persistence of involvement level ($\phi_{k}$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entertainment</td>
<td>0.865</td>
<td>0.005</td>
<td>0.855</td>
<td>0.875</td>
</tr>
<tr>
<td>Utility</td>
<td>0.884</td>
<td>0.012</td>
<td>0.860</td>
<td>0.907</td>
</tr>
<tr>
<td>Information</td>
<td>0.768</td>
<td>0.021</td>
<td>0.726</td>
<td>0.808</td>
</tr>
<tr>
<td>Social</td>
<td>0.298</td>
<td>0.031</td>
<td>0.227</td>
<td>0.352</td>
</tr>
</tbody>
</table>

- **Substitutes of Utility/Information Apps**: more use earlier => less need later
- **Complements of Social Apps**: more use earlier => more need later
- **Entertainment**, **Utility**, and **Information involvement levels** are highly persistent through time
Result – App Usage

Time patterns of involvement levels:

- Utility and information involvements peak earlier in the day, and drop later
- Entertainment involvement peaks somewhat later in the day
- Social involvement remain more stable with two peaks
Result – Ad Response

Effect of the underlying involvement:

<table>
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<tr>
<th>Parameter</th>
<th>Mean</th>
<th>SD</th>
<th>2.5% CI</th>
<th>97.5% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effect of Involvement Levels ($\theta_k^\beta$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entertainment</td>
<td>-0.174</td>
<td>0.016</td>
<td>-0.203</td>
<td>-0.141</td>
</tr>
<tr>
<td>Utility</td>
<td>-0.107</td>
<td>0.008</td>
<td>-0.122</td>
<td>-0.092</td>
</tr>
<tr>
<td>Information</td>
<td>-0.076</td>
<td>0.013</td>
<td>-0.100</td>
<td>-0.051</td>
</tr>
<tr>
<td>Social</td>
<td>0.363</td>
<td>0.012</td>
<td>0.342</td>
<td>0.387</td>
</tr>
</tbody>
</table>

- Higher involvement in entertainment/utility/information => less interested in Ad
- Higher involvement in social => more interested in ad
Result – Ad Response

Sequential effect:

<table>
<thead>
<tr>
<th>AdType</th>
<th>Sequential Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Same Ad</td>
</tr>
<tr>
<td>Promotion</td>
<td>0.260</td>
</tr>
<tr>
<td>Product Trial</td>
<td>-0.176</td>
</tr>
<tr>
<td>Product Launch</td>
<td>0.034</td>
</tr>
</tbody>
</table>

- Repeated exposure helps promotion ads, but hurts product trial ads
- Exposure to other ads hurts promotion ads

Contextual effect:

<table>
<thead>
<tr>
<th>AdType</th>
<th>Utility</th>
<th>Information</th>
<th>Social</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promotion</td>
<td>-0.045</td>
<td>-0.436</td>
<td>-0.486</td>
</tr>
<tr>
<td>Product Trial</td>
<td>0.281</td>
<td>0.622</td>
<td>-2.108</td>
</tr>
<tr>
<td>Product Launch</td>
<td>0.058</td>
<td>-1.063</td>
<td>-0.181</td>
</tr>
</tbody>
</table>

- Information apps better than Utility apps
- Social apps provide the worst context
Ad Delivery Optimization

- **Key idea:** deliver the ad at the right time and right context

- **Strategies evaluated:**
  - Even-distribution: constant rate over time, used as benchmark
  - Time-only targeting: by time fixed-effect
  - Population-level targeting: by involvement effect and contextual effect
  - Individual-level targeting: by involvement and contextual effects at individual consumer level
Ad Delivery Optimization

- Incorporating individual level involvement and contextual effects into targeting increases CTR by more than 200%

<table>
<thead>
<tr>
<th>Target Number of Impressions</th>
<th>Even-Distribution (Benchmark)</th>
<th>Target By Time Only</th>
<th>Target By Population Level Estimate</th>
<th>Target By Individual Level Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000</td>
<td>0.58%</td>
<td>1.07%</td>
<td>1.59%</td>
<td>2.10%</td>
</tr>
<tr>
<td>10000</td>
<td>0.52%</td>
<td>0.82%</td>
<td>1.45%</td>
<td>1.91%</td>
</tr>
<tr>
<td>20000</td>
<td>0.50%</td>
<td>0.93%</td>
<td>1.45%</td>
<td>1.61%</td>
</tr>
<tr>
<td>50000</td>
<td>0.55%</td>
<td>0.87%</td>
<td>1.09%</td>
<td>1.28%</td>
</tr>
<tr>
<td>100000</td>
<td>0.59%</td>
<td>0.74%</td>
<td>0.87%</td>
<td>0.98%</td>
</tr>
</tbody>
</table>
In Summary

- Application usage driven by dynamic underlying involvements
  - Utility and information involvements peak early while social involvement sustains to later in the day
  - Underlying involvement is persistent
  - Utility and information apps are inter-temporal substitutes while social apps are inter-temporal complements

- Ad response driven by both underlying involvement and the application context
  - Entertainment, utility and information involvement decreases interest in ad; social involvement increases interest in ad
  - Information apps provide the best context for ad delivery, while social apps provide the worse context