AoM 2013 Annual Meeting

Architectural Strategy and Design Evolution in Business Ecosystems: Research Opportunities and Empirical Challenges

Measurement issues in product architecture and value network analysis

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Lake Bunea Vista, FL, Aug 10th, 2013
I am currently working on modularity and value networks in the air conditioning/refrigeration/humidification technologies.

Example 1: bottle coolers

Compressors and refrigeration parametric controls as key complementary technologies

Emphasis on environmental sustainability and energy savings
Refrigeration parametric controls

- Bottle cooler automatically adapts to the opening times by detecting when the cabinet door is open.
- When, during the day, the cabinet door is not opened for a certain set number of hours, the controller automatically switches to night mode.
Evolution of refrigeration parametric controls towards global monitoring systems

- Management
- Maintenance
- Market data
- Sustainability

Online parameters and alarms

Cloud Server

GPRS

Online parameters and alarms

- Management
- Maintenance
- Market data
- Sustainability
Example 2: High precision air conditioners
3 things (I think) I have learned so far about the structure and dynamics of the A/C business ecosystem

- OEMs’ strategic heterogeneity: modular design associated with both supplier integration \textit{and} supplier switching) («mirroring hypothesis» holding at the component level but not at the firm level) (OS, 2012)

- Technological change/innovation (even only at the component level with product architecture stability) makes it harder to OEMs to pursue a strategy of modular design + supplier switching («mirror gets misted up») (SMJ, 2013)

- Modular design often is (IJMR, 2010; RP 2013)
  - impossible (systems not decomposable)
  - Overly complex (architectural changes + hidden interdependencies): designers make guesses on the “appropriate” : 1) number of modules; 2) mapping of design elements to the modules; 3) interfaces within module; and 4) interfaces between modules
  - \textbf{Difficult to measure: how do designers know if they are progressing towards system decomposability?}
  - Inefficient (cost>benefits)
I have gotten stuck in modularity measurement: an empirical puzzle

- Picked three competing firms in A/C industry: OEM1, OEM2, and OEM3
- Analyzed three similar competing products from the three firms’ product lineups: product 1, product 2, product 3
- Applied the 7 most cited measures of product modularity (Ulrich, 1995; Ishii, 1998; Huang and Kusiak, 1998; Martin and Ishii, 2000; Stone and Wood, 2000; Whitfield et al., 2002; Fine et al., 2005; Fixson, 2005) to the key product components of the 3 analyzed products

Questions:
- Are the measures interchangeable?
- Do they lead to equal/similar/comparable outcomes in assessing the degree of product modularity?
### Modularity measures

<table>
<thead>
<tr>
<th>Product components</th>
<th>Interfaces</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>C31</td>
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</table>

- The relative degree of component modularity changes contingent on the measure used.
- The rank order of the measures is unstable, implying that the measures yield incomparable results.

Component modularity ranking according to 7 modularity measures (high precision air conditioner 1)
**Average degree of component modularity by measure and product**

<table>
<thead>
<tr>
<th></th>
<th>Ulrich</th>
<th>R Salvador</th>
<th>R Fine</th>
<th>R Modularity</th>
<th>R Interfaces1</th>
<th>R Interfaces3</th>
<th>R Functions</th>
<th>R Cross-measure max-variation</th>
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<tbody>
<tr>
<td>Product 1</td>
<td>0.32</td>
<td>3</td>
<td>0.25</td>
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<td>0.16</td>
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<td>7</td>
<td>6</td>
<td>0.13</td>
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</table>

**Cross-model max-variation**

|         | 0.19   | 0.12   | 0.08   | 0.10   | 0.14   | 0.23   | 0.22   |

**Ranking**

<table>
<thead>
<tr>
<th></th>
<th>Product 1</th>
<th>Product 2</th>
<th>Product 3</th>
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<tbody>
<tr>
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<tr>
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<tr>
<td>Product 3</td>
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</table>
Tests of the «mirroring hypothesis» using different measures of component modularity. Dependent variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Questionnaire items, scales and reliability analysis</th>
<th>Description</th>
</tr>
</thead>
</table>
| Buyer-Supplier integration in NPD activities | N= 3 (α= 0.87) 
1-5 scale 
5=“I completely agree” 
1=“I completely disagree” | 1) You frequently exchange, with the analyzed supplier, detailed information as concerns new product development and new component development; 2) You and the analyzed supplier frequently and extensively use ICTs (CAD, Internet, e-mail, etc.) to coordinate the new product development activities 3) You and the analyzed supplier frequently and extensively use direct contacts (visits, meeting, working groups, etc.) to coordinate the new product development activities. |
| Degree of instability of the supply relationship | N= 3 (α= 0.66) 
1-5 scale 
5=“I completely agree” 
1=“I completely disagree”) and 1-4 scale | 1) The analyzed supplier can’t be easily substituted by a competitor; 2) Your firm has made major investments specifically for its relationship with the analyzed supplier (e.g., time and effort to learn the supplier’s business practices, in tooling, etc.); 3) Your relationship with the analyzed supplier is: a relationship that will last more than five years (4), relationship that will last some years (3), a short-term relationship (1 year) (2); a spot relationship (1). |
OLS results for the relationship between each multidimensional measure of modularity and buyer-supplier integration in NPD activities (Robust standard errors in parentheses). N=100

<table>
<thead>
<tr>
<th>Variables</th>
<th>Buyer-supplier integration in NPD activities</th>
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</thead>
<tbody>
<tr>
<td>Constant</td>
<td>3.32*** 3.06*** 3.03*** 2.73***</td>
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<td></td>
<td>(.79)   (.78)   (.82)   (.81)</td>
</tr>
<tr>
<td>Ulrich</td>
<td>-1.01**</td>
</tr>
<tr>
<td></td>
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<tr>
<td>Salvador</td>
<td>-90</td>
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<td>(.59)</td>
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<tr>
<td>Fine</td>
<td>- .57</td>
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<td>(.68)</td>
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<tr>
<td>Modularity</td>
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<tr>
<td></td>
<td>(1.06)</td>
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<tr>
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*p ≤ 0.1; ** p ≤ 0.05; *** p ≤ 0.01.
OLS results for the relationship between each multidimensional modularity measure and the degree of instability degree of stability of the supply relationship (Robust standard errors in parentheses). N=100.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Degree of instability of the supply relationship (ISR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-.10 (.57) -.04 (.56) -.05 (.56) .06 (0.54)</td>
</tr>
<tr>
<td>Ulrich</td>
<td>.49** (.24)</td>
</tr>
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</tr>
<tr>
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<td>Modularity</td>
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<td>Vendor rating</td>
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<td>Demand predictability</td>
<td>-.03 (.11) -.00 (.11) -.00 (.11) .00 (.11)</td>
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<tr>
<td>Standard</td>
<td>30*** (.04) 30*** (.04) 31*** (.04) 31*** (.04)</td>
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<tr>
<td>OEM$_1$</td>
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</tr>
<tr>
<td>OEM$_2$</td>
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</tr>
<tr>
<td>$R^2$</td>
<td>.69 .67 .67 .67</td>
</tr>
</tbody>
</table>

*p ≤ 0.1; ** p ≤ 0.05; *** p ≤ 0.01
Implications

- Existing modularity measures may be misleading in assessing product and component modularity when designing complex products and organizations (supply networks)
- Measures that include *both* functions and interfaces are better but are *not* perfectly substitutes
- Measures should be chosen contingent on the goals of the analysis, the design purpose, the industry setting, and the product technology
- Overall, current measures of modularity non satisfactory:
  - Fixed at a given tier of the product architecture
  - Hide cross-tier interdependences (and related product performance effects)
  - Do not consider cyclical interdependences (Herbst, 1974) missing to consider cyclicity and propagation effects (largest impact on design and system performance) (Baldwin and others, 2013; Sosa and others, 2013)
  - Require complex function/component mapping and DSM exercises
- Unclear the impact of uncoordinated nested modularization efforts by multiple actors in the value network and their value migration effects