Structure & Evolution of Regional Industrial Ecosystems

Case study of Barceloneta, Puerto Rico
Outline

• Objective – Inductive theory-building using case study research to understand how regional industrial systems function and change

• Approach – An integrative framework to study different elements of structure and their evolution in such systems

• Case study – Barceloneta, Puerto Rico 1950-2005

• Preliminary findings

• Summary
A framework for studying regional industrial ecosystems

• Region industrial systems can be studied using
  – Industrial ecology (community ecology concepts)
  – Economic geography
  – Organizational sociology
  – Complex systems theory

• This research integrated these approaches by first determining similarities and differences in how each field perceives system structure and evolution

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“Structure & Evolution of Regional Industrial Ecosystems”
System structure

• Three aspects to consider
  – Context in which the system exists, actors/components within the system, and interactions among the actors

• External forces determine conditions that act on the system
  – Biophysical resource availability and stochastic events
  – Social, economic and political conditions and changes

• Within system: structure results from patterns in relationships among actors
  – Diversity and dominance of different types of actors
  – Biophysical (material and energy) flows
  – Economic trade (buying and selling goods and services)
  – Social interactions, norms, culture
## Structural components of integrative framework

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Ecological forces</th>
<th>Regional socio-economic forces</th>
<th>Industrial ecosystem measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Context</strong></td>
<td>Climate, biogeography</td>
<td>Institutional context</td>
<td>Climatic and biogeographic conditions</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Political, economic, social, cultural, and institutional conditions</td>
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<tr>
<td></td>
<td>Factors of production</td>
<td></td>
<td>Stocks of natural (water, land use, air quality), financial, human, social and knowledge capital</td>
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<tr>
<td><strong>Actors</strong></td>
<td>Species</td>
<td>Industries</td>
<td>Identification of industrial sectors and firms present, diversity and dominance of industrial sectors</td>
</tr>
<tr>
<td></td>
<td>Functional groups, trophic levels</td>
<td>Industrial sectors</td>
<td>Categorization of industrial firms into functional groups, including producers, consumers and recyclers; identification of specialization</td>
</tr>
<tr>
<td><strong>Interactions</strong></td>
<td>Energy flows</td>
<td></td>
<td>Energy supply and demand and the flow of energy among industries</td>
</tr>
<tr>
<td></td>
<td>Material flows</td>
<td></td>
<td>Material use within region, with special attention to use of recycled materials and recycling loops</td>
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<tr>
<td></td>
<td>Competition</td>
<td>Competition</td>
<td>Consumption of locally available resources, development of symbiosis</td>
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<td></td>
<td>Predation</td>
<td>Demand conditions</td>
<td>Supply chain, local and export markets</td>
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<tr>
<td></td>
<td>Migration, colonization</td>
<td>Threat of substitutes or new entrants</td>
<td>Entrance of new firms and new industries</td>
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<tr>
<td></td>
<td>Social networks</td>
<td></td>
<td>Inter-firm and inter-personal relationships</td>
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</tbody>
</table>
Puerto Rico context

- **Climate and geography**
  - Tropical climate, susceptible to hurricanes
  - Diverse island ecosystems
  - Area ~9000 km$^2$
  - Population ~3.9 million

- **Political economy**
  - US commonwealth territory with internal self government
  - Economy based on manufacturing and tourism
  - Island is politically stable but currently in economic recession
• Natural resources
  – Zone of highest permeability in vast north coast aquifer system
  – 30km proximity to San Juan and its ports
  – Proximity to ocean for treated wastewater discharge
Barceloneta
industrial evolution

Pre-1950: Rural, agricultural region, sugar cane plantations
1960s: Labor intensive manufacturing industry – food, textiles, footwear
Post-2000: Decline of manufacturing, rise of services

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Industrial structure diversity & dominance

\[
LQ_i = \frac{re_i}{re_t} \times \frac{ne_i}{ne_t}
\]

\[
H = \sum \left(\frac{n_i}{n}\right) \times \ln\left(\frac{n_i}{n}\right)
\]

\[
E = \frac{H}{\ln(s)}
\]

where

- \( re \) - regional employment
- \( ne \) – national employment
- \( i \) – \( i^{th} \) industry
- \( n \) – number of firms
- \( s \) – number of industries

*Manufacturing sector only

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<tbody>
<tr>
<td><strong>Location Quotient (LQ)</strong></td>
<td>0.304</td>
<td>0.253</td>
<td>0.277</td>
<td>0.208</td>
<td>0.205</td>
</tr>
<tr>
<td><strong>Shannon Weiner Diversity Index (H)</strong></td>
<td>2.064</td>
<td>2.117</td>
<td>1.868</td>
<td>1.757</td>
<td>1.710</td>
</tr>
<tr>
<td><strong>Species Evenness (E)</strong></td>
<td>0.861</td>
<td>0.852</td>
<td>0.752</td>
<td>0.732</td>
<td>0.743</td>
</tr>
</tbody>
</table>

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Hypothesized economic structure: 1956

- Households
- Wholesale & Retail
- Services
- Manufacturing
- Construction
- Utilities
- Waste mgt & recycling
- Agriculture, forestry, fishing, mining

Linkages
- Existing _____
- Probable -----

Exports
Imports

103
19
19
4
2
1

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“Structure & Evolution of Regional Industrial Ecosystems”
Economic structure: 2002

Households

Wholesale & Retail

Services

Manufacturing

Construction

Utilities

Waste mgt & recycling

Agriculture, forestry, fishing, mining

~23000

285

44

30

3

2

2

313

313

2

3

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Industrial symbiosis
energy & material conservation

Wastewater Treatment Facility

Hay Farm
Animal feed

Proposed Cogeneration Facility

Paint Manufacture
Energy Recovery

Pharmaceutical Firms

Waste Management Firms

Existing

Proposed

waste
industrial
wastes

energy

recovered
solvents

off-spec
solvents

fermentation
waste

waste
water

treated
sludge

energy

recovered
solvents

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Industrial Symbiosis
network relationships

Byproduct Exchanges

Other Firms

Advisory Council/
Utility Sharing

Solvent Recovery
Service Sharing

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Social structure in 2004

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Barceloneta system evolution

Complex system cycle

- Collapse of agriculture led to release of resources and subsequent exploitation by manufacturing firms
- Increasing no. and types of structural linkages among firms
- Increasing amount of local resource conservation and recycling
- Shifting industrial composition, but system maintains high level of diversity
- Pharmaceutical industry entering transition period

Increasing organization and connectedness

Mobilization
Exploitation
Conservation
Creative destruction

Holling 1987

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Summary

• Industrial ecosystem described
  – Economic, material, and social structures
  – System evolution followed complex system cycle

• Further work
  – Complete natural history of the system by aligning changes in external events and local resource availability to observed patterns in industry structure and evolution
  – Examine lessons of this case for theory building