Overview

- Background
- Why spectrum markets?
- Spectrum markets vs. auctions
- Opportunities
- Challenges
- Research in spectrum markets
- Conclusions
Background

  - Secondary use
  - Interference temperature
    - Receiver-based interference model
    - Ultra Wideband (UWB)
  - Unlicensed
- Bandwidth trading (late 1990s)
  - Enron
  - Band-X
  - RateXchange.com
- Spectrum transfer regulations
- De facto spectrum markets
  - Acquisitions of radio stations
  - Acquisitions of wireless carriers

Spectrum Value Chain

<table>
<thead>
<tr>
<th>Value Chain</th>
<th>Examples</th>
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</thead>
<tbody>
<tr>
<td>Content</td>
<td>Programmes, file-sharing</td>
</tr>
<tr>
<td>Physical assets</td>
<td>Towers and masts</td>
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<tr>
<td>Spectrum</td>
<td>Wholesale</td>
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<td>Licensees, intermediaries, commons</td>
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<td>Retail</td>
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<tr>
<td>Transmission</td>
<td>MNOs, broadcasting transmission</td>
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<td>Reselling</td>
<td>Airtime</td>
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<tr>
<td>Retail (and users)</td>
<td>Mobile telephony, broadcasting services</td>
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</tbody>
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(Martin Cave, 2006)
Why spectrum markets?

- Goals of spectrum management
  - Allocation vs. Assignment
  - "Public Interest"
  - Spectrum efficiency
  - Assignment to the most valuable uses
- Approaches
  - Command and Control
  - Lotteries
  - Auctions

Aren't auctions the same thing?

- Auctions are like the IPO in the stock market
- The stock market is a secondary market for securities
- Commodities markets may have useful attributes
Opportunities

- Transformation of the wireless industry
  - Dis-integration of the value chain
  - Explicit risk management
    - Spectrum derivatives
    - Speculation
- Spectrum control on a demand basis
- Explicit management of S/I

Economic Challenges

- Market liquidity
- Non-fungibility
  - Radio bands behave differently
  - Imperfect filters means some spectrum units are more or less valuable than others
  - Location matters
  - Time of day matters
- Lack of a "standard" trading unit
Technical Challenges

- De facto requirement of software/cognitive radios
- Structure and operation of exchanges
  - Should exchanges be band managers?
  - Should the exchange own the infrastructure?

Research

- Technical research
  - Software/cognitive radios
  - Trading infrastructure
- Economic research
  - Analytical economic modeling
  - Agent-based Computational Economics (ACE) models
- Legal research
  - Property rights
  - Efficient license management
ACE-Based Research

What is ACE?
- Simulation-based economics
- Create many software agents that interact
- Can incorporate
  - Opportunism
  - Bounded rationality
  - Technical factors
- Observe interactions

ACE-Based Research

Applying ACE to secondary use
- Agents buy and sell spectrum
- Agents are concerned with
  - Quality
  - Cost
- Agents can make choices on a spectrum from unlicensed through secondary use to licensed
Some Results

- What do consumers do?
- Function of
  - Number of providers
  - Number of other users

More Results

- A significant demand for secondary use seems to exist
- Exclusive use is more dominant when the number of providers is small
- Users only choose unlicensed spectrum for small coverage, regardless of the amount of unlicensed spectrum available
- Benefit of additional unlicensed spectrum is of marginal value to users requiring a large coverage area
Conclusions

- Auctions are a first step in spectrum markets
- Substantial opportunity to transform the wireless industry
- Technical and economic challenges remain
- Many opportunities for research and implementation