Employing Market Mechanisms to Manage Spectrum

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Spectrum Market Environment

- Rapid growth in bandwidth-intensive applications (e.g., user-generated content)
- Service providers are packing more data into a given slice of spectrum with some possible negative service quality effects
- Potential spectrum congestion is particularly problematic for spectrum designated to unlicensed operations
  - Free entry of unlicensed service providers
  - Use of common spectrum leads to well known "tragedy of the commons" overuse

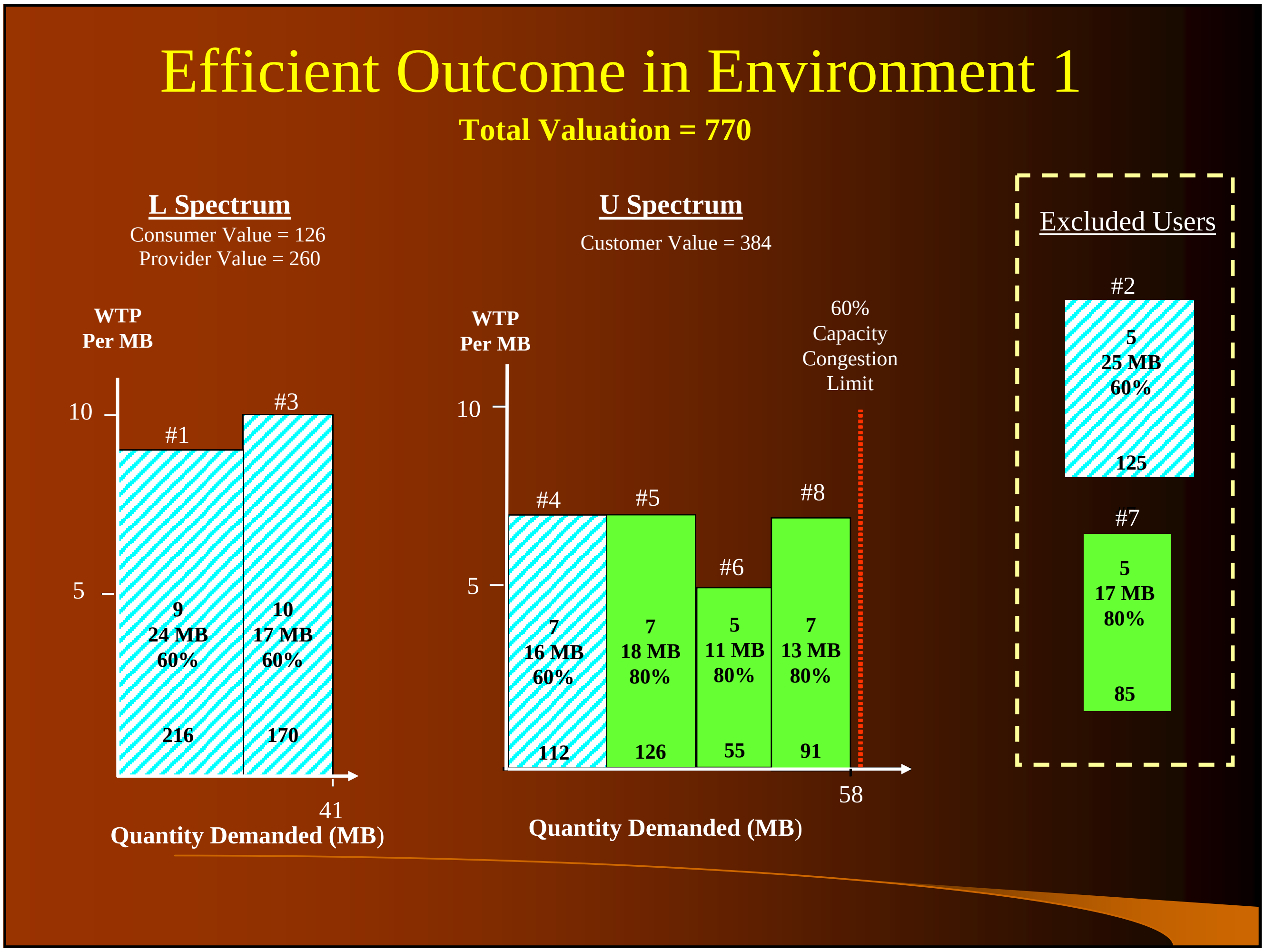
Spectrum Policy Questions

- How much money is society "leaving on the table" as a result of spectrum congestion?
- Are there ways in which the efficiency can be improved?
  - Give users incentives to make efficient selections
  - Efficiently allocate unlicensed spectrum among users
- How should spectrum be allocated between licensed and unlicensed use?

Enhancing Spectrum's Value Through Market-Informed Congestion Etiquettes

- Demand side model
  - Users select licensed (type L) or unlicensed (type U) spectrum over a finite time horizon (e.g. 2 year contractual basis for L spectrum)
  - User demands are heterogeneous
    - Users vary by bandwidth requirement, message value and congestion tolerance
    - L customers pay fixed subscription fees
    - U customers face expected congestion (given etiquettes)
    - Different U customers have different congestion tolerance levels
- Supply assumptions
  - Perfectly elastic supply of L spectrum capacity
    - Subscription fee = 130 in examples which follow
    - System capacity chosen so that minimal congestion is expected
  - Fixed supply of U spectrum
    - Capacity equal to 100 MB in examples which follow
    - Congestion is possible if too many users select U type service

Spectrum Users' Willingness to Pay in Environment 1



Efficient Outcome in Environment 1
Total Valuation = 770
L Spectrum
Consumer Value = 126
Provider Value = 260
U Spectrum
Customer Value = 384
Excluded Users
WTP
Per MB
10
5
#1
9
24 MB
60%
216
#3
10
17 MB
60%
170
41
Quantity Demanded (MB)
WTP
Per MB
10
5
#4
7
16 MB
60%
112
#5
7
18 MB
80%
126
#6
5
11 MB
80%
55
#8
7
13 MB
80%
91
60%
Capacity
Congestion
Limit
58
Quantity Demanded (MB)
#2
5
25 MB
60%
125
#7
5
17 MB
80%
85

Proposed Congestion Etiquettes

- Non-market-informed Etiquette
  - Fairness Etiquette
    - Spectrum is assigned to all demanders without regard to congestion tolerance
- Marked-informed Etiquettes
  - Pay to Connect
    - Users of unlicensed spectrum pay a nominal but non-refundable user fee
  - Informed Randomization
    - Users report their personal congestion tolerance
    - Users are randomly assigned spectrum subject to the constraint that all included users receive satisfactory service quality
  - Spectrum Market
    - Users report their personal congestion tolerance <u>and</u> willingness to pay
    - An algorithm balances demand with supply so that the amount of “money left on the table” is minimized

Analysis

- Economic theory used to predict competitive (Nash equilibrium) user selections
- Experimental methods used to provide an alternative test of market performance
- In experimental setting, each user knows:
  - Personal level of demand
  - The number of possible spectrum users
  - The price of the subscription service
  - Private value (V_i) for successfully sending a message
  - Private congestion tolerance
  - Payoffs:
    - Licensed use: Payoff $_i$= V_i – Fee
    - Unlicensed use: Payoff $_i$ = V_i if system congestion is less than private congestion tolerance and zero otherwise

Nash Equilibrium Predictions and Experimental Results

Etiquettes		Environment #1		Environment #2	
		Observed Efficiency	Theory	Observed Efficiency	Theory
Non-Market-Informed/Fairness		42%	50%	57%	91%
Market-informed	Pay to Connect	52%	97%	74%	91%
	Informed Randomization (Greedy Algorithm)	70%	72%	63%	54%
	Spectrum Market (Full Optimization)	75%	-	73%	-

A Market-Based Approach to Establishing Licensing Rules

- Potential providers and beneficiaries of licensed (type L) and unlicensed (type U) service compete in an auction for available bandwidth
- Demand assumptions
  - Each bidder for L or U spectrum has a distinct business model
    - L bidders expect to receive subscription fees
    - U bidders expect to receive advertising revenues (fix this)
  - Customer demands
    - For L customers are based on subscription fees
    - For U customers are based on expected congestion (given etiquettes)
- Auction participants bid against each other for available spectrum
  - L bidders specify a bid for exclusive ownership rights
  - U bidders bid for open access rights
    - Free rider issues arise
    - Both theory and experimental results suggest that an auction leads to a good, though not first best allocation of spectrum

Concluding Comments

- Under the examined conditions, spectrum congestion involving unlicensed use can cause society to leave nearly 50 percent of the available money on the table.
- “Market- informed” congestion etiquettes can substantially reduce this inefficiency.
- Despite paying for access to “unlicensed spectrum” during times of congestion, users may be substantially better off.
- Market mechanisms can potential improve efficiency in both supply side and demand side spectrum management.