Designing a Mechanism for Spectrum Trade toward Efficient Reallocation

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Contents (1/2)

I. Introduction
II. Spectrum as an economic resource  ---Overview
III. Overview of EMM, proposed
IV. Functioning of EMM, proposed
V. Secondary (indirect) users of spectrum with EMM
Contents (2/2)

VI. Introduction of reallocation as a forward trading, forward supply price

VII. Preventing speculation with EMM

VIII. Transition from the current system to EMM

Designing a Mechanism for Spectrum Trade toward Efficient Reallocation

1. INTRODUCTION
I. A. Objective of this paper

design and analyze
economic mechanism
for spectrum trade

extended market mechanism (EMM)

I. B. Strategy for the work

two-step work

(1) to design an “ideal” system from scratch

(2) to design transition process from current state to ideal system
I. C. Properties of the ideal system

(1) a process of stepwise reallocation
(2) each step Pareto-improves spectrum allocation (no user shall be hurt)

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II. SPECTRUM AS AN ECONOMIC RESOURCE --- OVERVIEW
II. A. What is spectrum? (1/2)

- a space resource with limited capacity
- no depletion, no depreciation
- can be used in exclusive or shared mode

II. A. What is spectrum? (2/2)

- externalities, positive and negative
- technological progress increases efficiency
II. B. Division of spectrum into bands/blocks (1/2)

band: a segment of one-dimensional frequency space

II. B. Division of spectrum into bands/blocks (2/2)

block: (of the terrestrial spectrum) a subset of three-dimensional space composed by the frequency space and the surface of the land
Figure 1: Examples of Spectrum Band in the Frequencies Axis

470  UHF TV band (300MHz)  770
512  518
6 MHz TV Channel

Frequencies

Figure 2: Example of Spectrum Block (B, A) in the 3-dimensional Spectrum Space

Frequencies

band B

block (B, A)

area A

Land
Figure 3: Example of 10 Spectrum Blocks

Figure 4: 2 Bands and 6 Areas for the Blocks of Figure 3A
II. C. Incumbent users of spectrum blocks

obtain returns from using block(s)
with externalities
investment made in the past
sunk cost

cost of holding block(s)
no physical cost
there may be institutional cost
ex.: spectrum usage fee
local monopoly
II. D. Potential users of spectrum blocks

(1/2)

may form a plan for using block(s)
usage plan
returns forecast

II. D. Potential users of spectrum blocks

(2/2)

may offer demand price for block(s)
ex.: through auction
II. E. Pareto-improving reallocation of block(s) (1)

For block(s) being reallocated,
(returns from the current use)
< (returns from a potential use)

II. F. Pareto-improving reallocation of block(s) (2)

For both incumbent and new users,
(returns before reallocation)
\leq (returns after reallocation)
II. G. Ordinary market mechanism (MM) for reallocation (1/3)

Offer by potential users:
- may be done with combinations of blocks
- considering (positive) externalities

II. G. Ordinary market mechanism (MM) for reallocation (2/3)

Response by incumbent:
- will use power of local monopoly
- strategic use of (positive) externalities
- may quote an extremely high price for yielding a block
II. G. Ordinary market mechanism (MM) for reallocation (3/3)

MM will not function for spectrum reallocation

II. H. Reasons that MM does not function for spectrum reallocation (1/5)

(1) conditions for MM to function efficiently:
   a. perfect information
   b. competition with both demand and supply
II. H. Reasons that MM does not function for spectrum reallocation (2/5)

c. goods to be traded: homogeneous or with perfect substitutes
d. no externalities
e. individuals have incentive to trade

II. H. Reasons that MM does not function for spectrum reallocation (3/5)

(2) with spectrum as an object of trade:
a. (perfect information) may be assumed
b. (competition) not satisfied; local monopoly with supply
II. H. Reasons that MM does not function for spectrum reallocation (4/5)

c. (perfect substitutes) do not exist;
spectrum block is unique areawise and frequencywise
d. (externalities) exist, positive and negative

II. H. Reasons that MM does not function for spectrum reallocation (5/5)
e. (incentive of trading) weak with incumbents because of sunk cost and zero holding cost
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III. OVERVIEW OF EMM, PROPOSED

III. A. Bill of spectrum rights and responsibilities (proposed) (1/5)

(1) Spectrum is a property owned by the society collectively.
III. A. Bill of spectrum rights and responsibilities (proposed) (2/5)

(2) Spectrum may be used exclusively by a user for an **indefinite period**; the right to use spectrum, however, is by no means permanent.

III. A. Bill of spectrum rights and responsibilities (proposed) (3/5)

(3) The user shall pay a usage fee to the government.
III. A. Bill of spectrum rights and responsibilities (proposed) (4/5)

(4) The user shall yield spectrum right when requested with a compensation which exceeds the amount specified by the user himself/herself prior to such a request.

III. A. Bill of spectrum rights and responsibilities (proposed) (5/5)

(5) Reallocation of spectrum rights shall be Pareto-improving.
III. B. Division of spectrum management  
(1/2)

(1) government:
   specification of bands, blocks
   technological requirements
   formation of block structure (groups)
   (→ III.C)

III. B. Division of spectrum management  
(2/2)

(2) EMM:
   specifies block users
III. C. Block structure (1/3)

tree-type (hierarchical) grouping
of blocks

Figure 5: Overview of spectrum use with EMM

(A) Government
- Spectrum division (bands, blocks)
- Objectives and specifications of spectrum use
- Technological requirements
- Introduction of block structure

<table>
<thead>
<tr>
<th>Usage specifications</th>
<th>Spectrum Prices</th>
<th>Spectrum trade information</th>
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(B) Extended Market Mechanism (EMM)
- Users: participate spectrum trade
- Government: regulation of spectrum market
- disclosure of spectrum information
a spectrum *group* is either
a block, or
a collection of blocks, or
a collection of groups.

(may be defined mathematically
as a *tree*, a subcategory of *graphs*,
where end nodes (leaves) are
spectrum blocks)
III. D. Allocation and reallocation of spectrum to users (1/2)

to be determined by EMM

users: participate to EMM
incumbents and potential users
III. D. Allocation and reallocation of spectrum to users (2/2)

government: regulates EMM

does not determine spectrum users

--- this is the objective of the paper

Figure 7: Business resources of X with and without the block

A: With the block

B: Without the block
Figure 8: Possible pricing of block B for trade from X to Y with truthful revelation

\[(P_Y) \text{ (demand price)}\]

\[(0 < P_Y < P_X) \text{ (supply price)}\]

Not acceptable to X

Not feasible

Not acceptable to Y

Figure 9: Possible pricing of block B for trade as seen by X

\[(P_Y) \text{ (demand price)}\]

\[(0 < P_Y < P_X) \text{ (supply price)}\]

Not acceptable to X

Not feasible
Figure 10: Possible pricing of block B for trade as seen by Y

$P_Y (demand\ price)$

$P_Y^c (supply\ price)$

Not acceptable to X

Not acceptable to Y

Not feasible

Figure 11: Example of false pricing of block B by X and Y

$P_Y (demand\ price)$

$P_Y^c (supply\ price)$

Not acceptable to X

Not acceptable to Y

Not feasible

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IV. FUNCTIONING OF EMM, PROPOSED

Figure 12: Organization of Extended Spectrum Market (EMM)

Demand side (Potential Users, Y)
(1) Revelation of demand price ($D$)
(2) Participate auction
(3) If wins, obtain spectrum and become a user

Supply side (Incumbents, X)
(1) Revelation of supply price ($C$)
(2) Yield spectrum right if an offer > $C$ is made
Receive compensation ($C$)
(3) Pay spectrum holding fee ($R$)
($R = rC$)

Market operator and spectrum manager (Government, Z)
(1) Specify spectrum-holding fee rate ($r$)
(2) Receive spectrum-holding fees ($R$)
(3) Execute auction if excess demand arises
(4) Receive auction surplus
IV. A. Objective (1/2)

to realize possible Pareto-improving reallocation of spectrum blocks

IV. A. Objective (2/2)

the “speed” of improvement: to be controlled by the government
IV. B. Rights and obligations of incumbents (1/8)

(1) Revelation of supply price \( (c) \) of each group (block)

IV. B. Rights and obligations of incumbents (2/8)

c: the least amount of compensation for which incumbent agrees to yield the right of using the group
IV. B. Rights and obligations of incumbents (3/8)

(2) Payment of spectrum usage fee ($R$)

$$R = r C.$$
(3) Incumbents
   may continue using a group
   if there is no offer > c
must yield the block
   if there is an offer ≥ c

(4) Determination of c by incumbents:
   Incumbents tend to declare
   a high c for continuing the use
   of a group
   a low c for saving payment R
IV. B. Rights and obligations of incumbents

tradeoff to incumbents
“holding up” a block or a group may be costly

(5) Who are “incumbents”?
all users of spectrum
private, business, and government users
IV. C. Rights and responsibilities of potential users (1/4)

(1) Obtain information of c’s and C’s

IV. C. Rights and responsibilities of potential users (2/4)

(2) Make offers by showing demand price \((D)\) for groups (blocks) chosen
(3) If there is no competing offer, then potential user obtains spectrum right for paying $D$.

(4) If there is a competing offer, then auction will be conducted on such groups winning potential user obtains spectrum right for paying $D$. 
IV. D. Roles of government with EMM (1):
spectrum holding fee (1/2)

(1) determines a fee rate \((r)\):

to control the speed of reallocation
resembles to determination of
discount rate by central bank

IV. D. Roles of government with EMM (1):
spectrum holding fee (2/2)

(2) receives spectrum fees \((R)\)
IV. Roles of the government with EMM (2):
market auctioneer (1/3)

(1) conducts auction for each group with $D > c$
use combinatorial auction (computerized)
bidding rule, stopping rule

IV. Roles of the government with EMM (2):
market auctioneer (2/3)
determines winning bids so as to maximize the total amount of bid price minus $c$
( = total surplus)
IV. E. Roles of the government with EMM (2): market auctioneer (3/3)

(2) receives total surplus

Figure 13: “Supply” of Spectrum Blocks (1/2)

- Unit supply price
- Spectrum blocks traded
- Spectrum blocks
- Compensations declared
Figure 14: “Supply” of Spectrum Blocks (2/2)

Figure 15: Spectrum trade expressed by means of “Demand and Supply” Curves
IV. F. Roles of the government (3): collection and dissemination of information (1/2)

(1) $c, C, D$, auction process, auction results

IV. F. Roles of the government (3): collection and dissemination of information (2/2)

(2) the state of spectrum rights:
   registration
   information disclosure
IV. G. Outcome from EMM:

Pareto-improving reallocations will be realized gradually step by step. The speed of reallocation is controlled by $r$.

V. SECONDARY (INDIRECT) USERS OF SPECTRUM WITH EMM

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V. A. Commons users (1/3)

primary user:
a government administrator

secondary users:
general users (the public)

V. A. Commons users (2/3)

C: the sum of all compensations declared by the users
V. A. Commons users (3/3)

$R$: may be collected at purchasing a device for using a commons block (payment may be made together with that of insurance fees for breakage)

Figure 16: Supply Price Revealed by Commons Users
V. B. Subscribers to service using spectrum  
(1/3)

ex.: mobile phone users
wireless internet users
primary user: providers, broadcasters
secondary users: subscribers, “users”

V. B. Subscribers to service using spectrum  
(2/3)

C: the sum of compensations declared by the primary and the secondary users
V. B. Subscribers to service using spectrum (3/3)

$R$: may be collected by primary user from secondary users to remit to government

Figure 17: Supply Prices Revealed by a Service Provider and Subscribers

Operator (Service Provider)

Subscribers, End Users

Government
V. C. Transition to DTV in the presence of EMM

would have been a case of reallocation of commons blocks under EMM

VI. INTRODUCTION OF REALLOCATION AS A FORWARD TRADING, FORWARD SUPPLY PRICE
VI. A. Introduction of reallocation as a forward trading, forward supply price (1/4)

EMM with timing of reallocation specified

Figure 18: Supply Prices with Multiple Reallocation Periods

Note: denotes the increase in the supply price when the reallocation period is shortened by 1 year.
VI. A. Introduction of reallocation as a forward trading, forward supply price (2/4)

ex.: reallocation $x$ years after the current year

$x = 1, 3, 5$ and 10 years

VI. A. Introduction of reallocation as a forward trading, forward supply price (3/4)

$c, C, D, r$ to be specified for each $x$.

EMM is applied for each $x$.

actual reallocation to be done in the year $x$. 
VI. A. Introduction of reallocation as a forward trading, forward supply price (4/4)

both incumbent and potential users will be benefited.

VII. PREVENTING SPECULATION WITH EMM

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speculation is possible on a strategically positioned block wrt externalities

**Figure 19: Example of truthful supply prices**

- Supply Price of Blocks
- Demand Price for the Group
- Group of blocks with positive externalities
- Spectrum Blocks
- Truthful Supply Prices
Figure 20: Example of truthful and untruthful supply prices

VII. Preventing speculation with EMM (2/2)

regulation:

impose a penalty on a steep increase in $C$
VIII. Transition from the current system to EMM (1/2)

gradual transition is recommended

no “big bang”
VIII. Transition from the current system to EMM (2/2)

set $r$ at a level close to zero initially

increase $r$ gradually thereafter

decrease the rate for current spectrum fees simultaneously