Economics of Information and Communication

Hajime Oniki

Designing a Mechanism for Spectrum Trade

toward Efficient Reallocation

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Designing a Mechanism for Spectrum Trade
toward Efficient Reallocation

I. 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

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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

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

externalities, positive and negative

technological progress increases
efficiency

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**II. B. Division of spectrum
        into bands/blocks** (1/2)

band: a segment of one-dimensional

          frequency space

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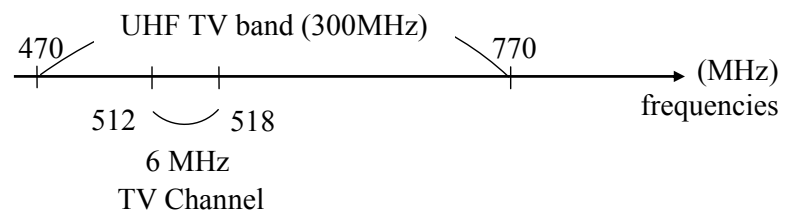   into bands/blocks** (2/2)

block: (of the terrestrial spectrum)

          a subset of three-dimensional

          space composed by the frequency

          space and the surface of the land

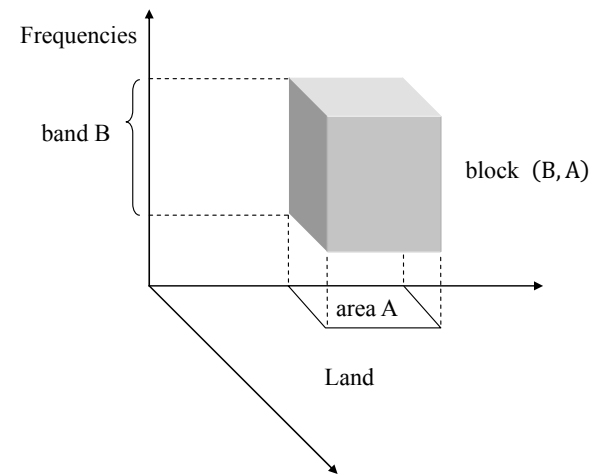Figure 1: Examples of Spectrum Band in the Frequencies Axis

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UHF TV band (300MHz)
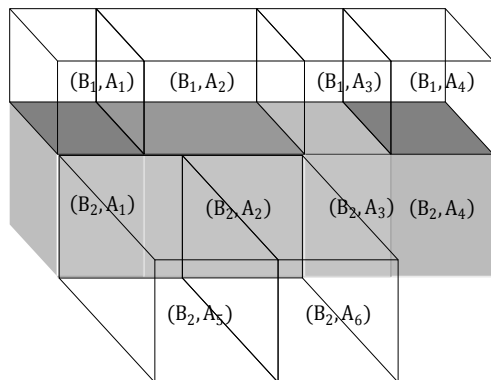
470   770

512   518

6 MHz
TV Channel

(MHz)
frequencies

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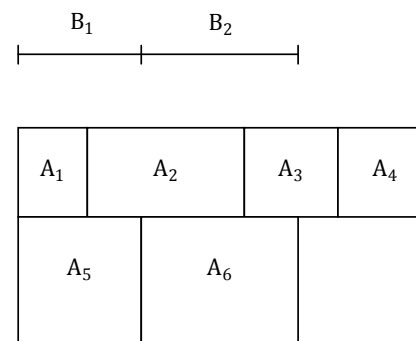Figure 2: Example of Spectrum Block (B, A) in the 3-dimentional Spectrum Space

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Frequencies

band B

block (B, A)

area A

Land

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Figure 3: **Example of 10 Spectrum Blocks**

Blocks labeled: (B_1, A_1), (B_1, A_2), (B_1, A_3), (B_1, A_4), (B_2, A_1), (B_2, A_2), (B_2, A_3), (B_2, A_4), (B_2, A_5), (B_2, A_6)

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Figure 4: **2 Bands and 6 Areas**
for the Blocks of Figure 3A

B_1 B_2

A_1 A_2 A_3 A_4

A_5 A_6

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II. C. Incumbent users of spectrum blocks
(1/2)

obtain returns from using block(s)

with externalities

investment made in the past

sunk cost

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II. C. Incumbent users of spectrum blocks
(2/2)

cost of holding block(s)

no physical cost

there may be institutional cost

ex.: spectrum usage fee

local monopoly

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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)

$\leqq$ (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

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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

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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

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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

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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

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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

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

(1) Spectrum is a property owned by the society collectively.

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**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.

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

(3) The user shall pay a usage fee
    to the government.

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**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.

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

(5) Reallocation of spectrum rights
shall be Pareto-improving.

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III. B. Division of spectrum management
(1/2)

(1) government:

    specification of bands, blocks

    technological requirements

    formation of *block structure (groups)*

       ($\rightarrow$ III.C)

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

(2) EMM:

    specifies block users

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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*

Usage specifications   Spectrum Prices   Spectrum trade information

(B) Extended Market Mechanism **(EMM)**
Users: participate spectrum trade
Government: regulation of spectrum market
disclosure of spectrum information

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III. C. Block structure (1/3)

tree-type (hierarchical) grouping

of blocks

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III. C. Block structure (2/3)

a spectrum ***group*** is either
a block, or
a collection of blocks, or
a collection of groups.

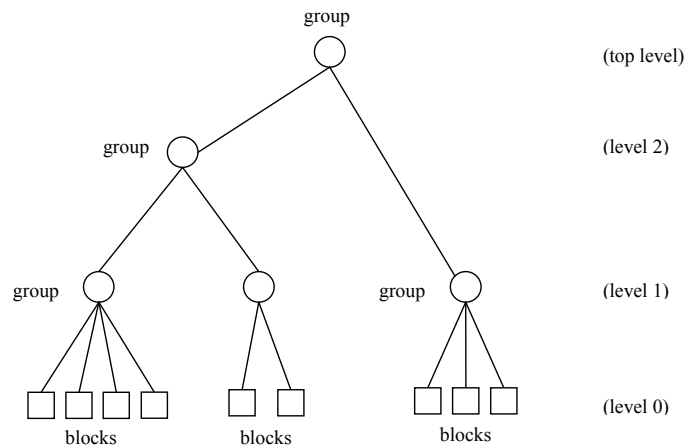**III. C. Block structure** (3/3)

(may be defined mathematically
as a *tree*, a subcategory of *graphs*,
where end nodes (leaves) are
spectrum blocks)

Figure 6: **Spectrum Groups (Block Structure)**

group
(top level)

group
(level 2)

group   group
(level 1)

blocks   blocks   blocks
(level 0)

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**III. D. Allocation and reallocation
of spectrum to users** (1/2)

to be determined by EMM

users: participate to EMM
incumbents and potential users

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III. D. Allocation and reallocation
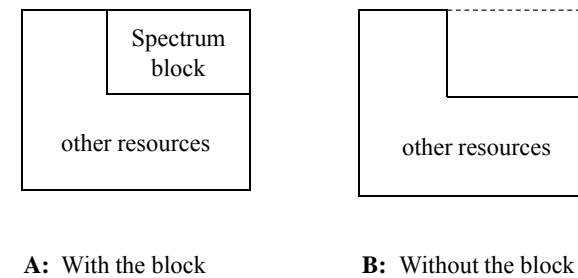### of spectrum to users (2/2)

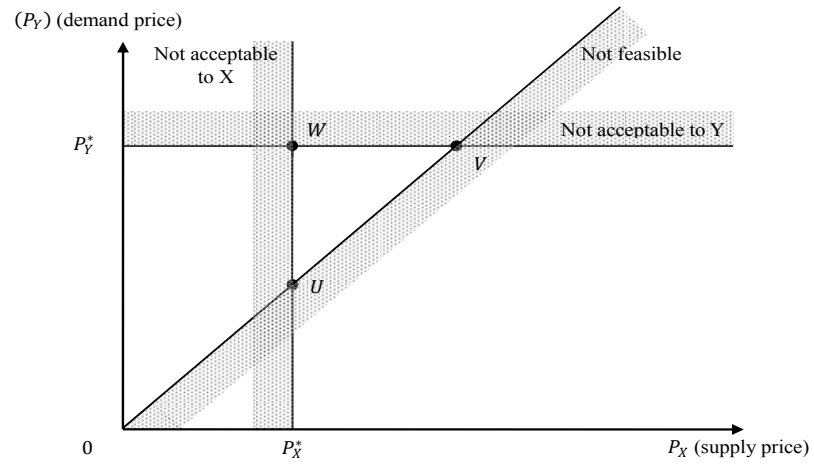government: regulates EMM

does not determine spectrum

users

--- this is the objective of the paper

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

A: With the block   **B:** Without the block

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Figure 8: Possible pricing of block B for trade from X to Y[47] with truthful revelation

(P_Y) (demand price)

Not acceptable to X

Not feasible

P_Y^*

W

V

Not acceptable to Y

U

0

P_X^*

P_X (supply price)

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Figure 9: Possible pricing of block B for trade as seen by X[48]

(P_Y) (demand price)

Not acceptable to X

Not feasible

P_Y^*

W

V

U

0

P_X^*

P_X'

P_X (supply price)

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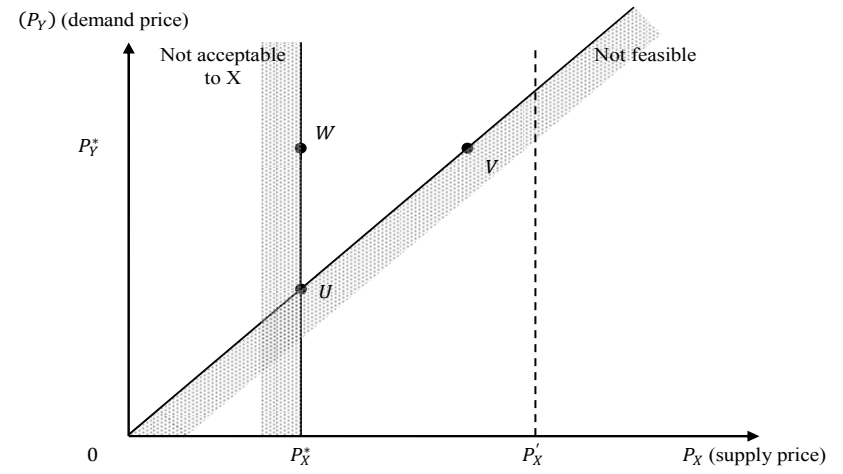
Figure 10: **Possible pricing of block B for trade as seen by Y**

(P_Y) (demand price)

Not acceptable
to X

Not feasible

P_Y^* ——————— W ● ●———————— Not acceptable to Y
　　　　　　　　　　　V

P_Y' -

　　　　　●
　　　　　U

0　　　　P_X^*　　　　　　　P_X (supply price)
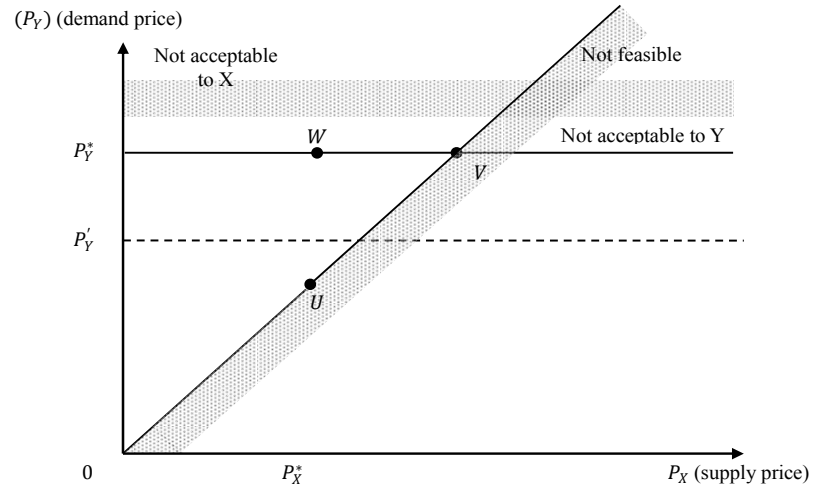
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Figure 11: **Example of false pricing of block B by X and Y**

(P_Y) (demand price)

Not acceptable
to X

Not feasible

P_Y^* ——————— W ● ●———————— Not acceptable to Y
　　　　　　　　　　　V

P_Y' - - - - - - - - - - - - - - - ● Z

　●
　U

0　　　P_X^*　　　　P_X'　　　P_X (supply price)
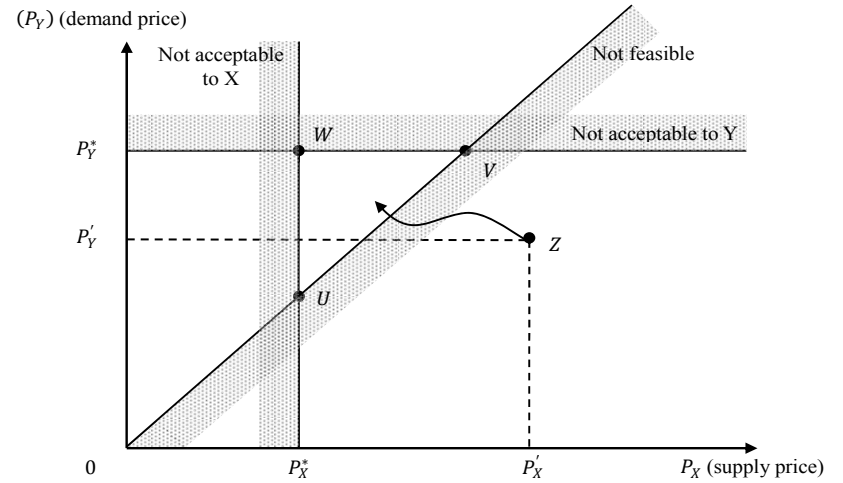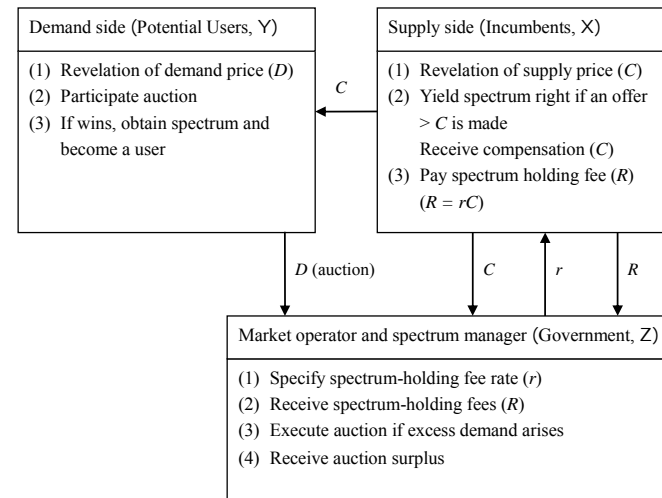
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IV. FUNCTIONING OF EMM, PROPOSED

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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)
   ($R = rC$)

C

D (auction) C r R

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

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IV. A. Objective (1/2)

to realize possible Pareto-improving

reallocation of spectrum blocks

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IV. A. Objective (2/2)

the "speed" of improvement:

to be controlled by the government

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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)

$R = r\,C.$

IV. B. Rights and obligations of incumbents
(4/8)

C: the sum of c's declared with
top-level groups

r: (annual) rate of spectrum usage fee
to be determined by the government

IV. B. Rights and obligations of incumbents
(5/8)

(3) Incumbents

 may continue using a group

  if there is no offer $> c$

 must yield the block

  if there is an offer $\geqq c$

IV. B. Rights and obligations of incumbents
(6/8)

(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
(7/8)

tradeoff to incumbents

"holding up" a block or a group may
be costly

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

(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

IV. C. Rights and responsibilities of
          potential users (3/4)

(3) If there is no competing offer,

   then potential user obtains spectrum

   right for paying D.

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

(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

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

(2) receives spectrum fees (R)

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IV. E. 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

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IV. E. Roles of the government with EMM (2): market auctioneer (2/3)

determines winning bids so as to

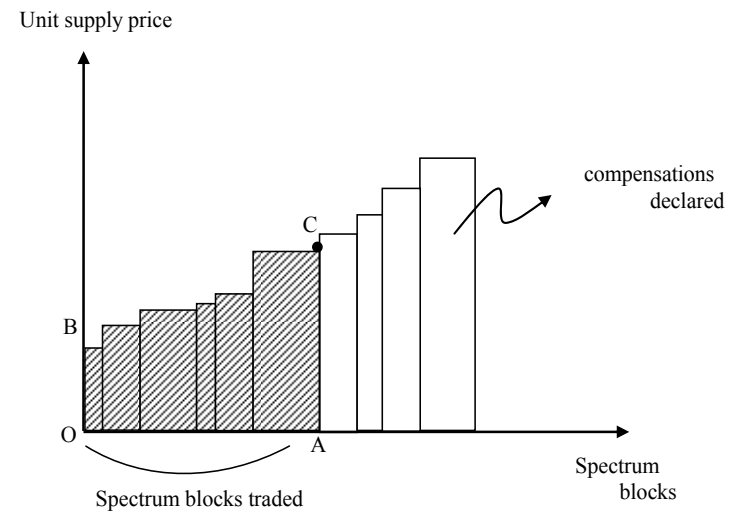maximize the total amount of bid

price minus c

(= total surplus)

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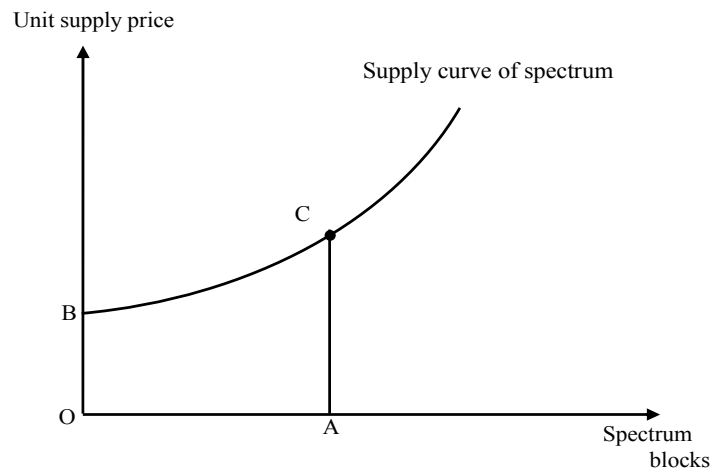**IV. E. Roles of the government with EMM (2): market auctioneer** (3/3)

(2) receives total surplus

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

Unit supply price

compensations declared

Spectrum blocks traded

Spectrum blocks

Figure 14: **"Supply" of Spectrum Blocks (2/2)**

Unit supply price

Supply curve of spectrum

C

B

O

A

Spectrum blocks

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Figure 15: **Spectrum trade expressed by means of "Demand and Supply" Curves**

D

Supply curve

B

Surplus

F

Demand curve

C

O

A

Spectrum blocks

Spectrum traded

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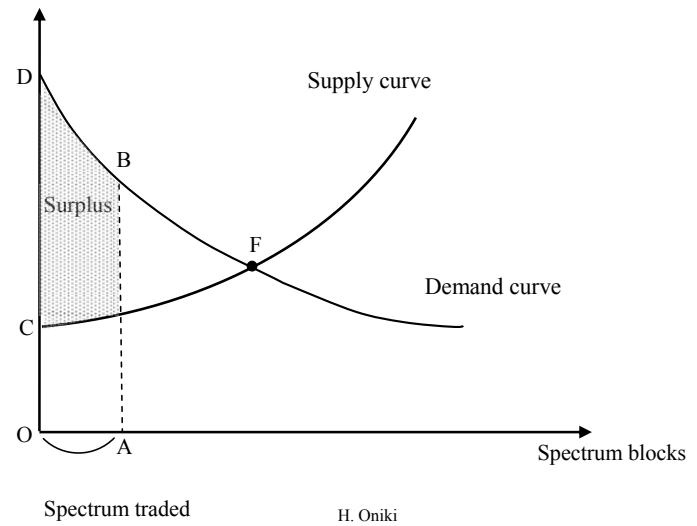
IV. F. Roles of the government (3): collection and dissemination of information (1/2)

(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

speed of reallocation is controlled
by r

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**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)

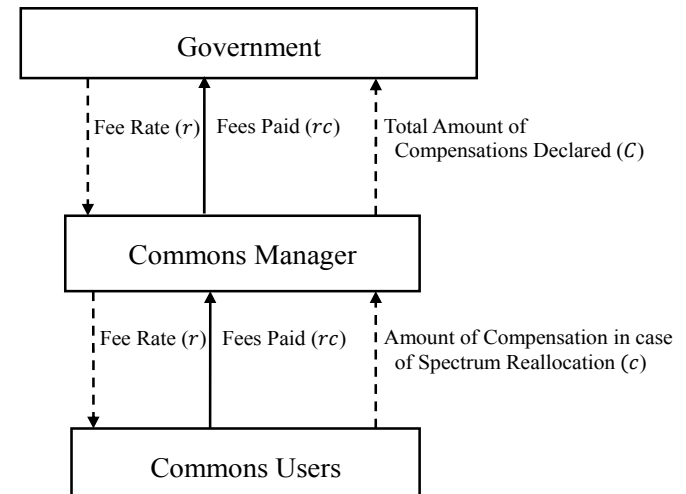C: the sum of all compensations
  declared by the users

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**

	Government	
Fee Rate (r)	Fees Paid (rc)	Total Amount of Compensations Declared (C)
	Commons Manager	
Fee Rate (r)	Fees Paid (rc)	Amount of Compensation in case of Spectrum Reallocation (c)
	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"

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

C: the sum of compensations
declared by the primary and
the secondary users

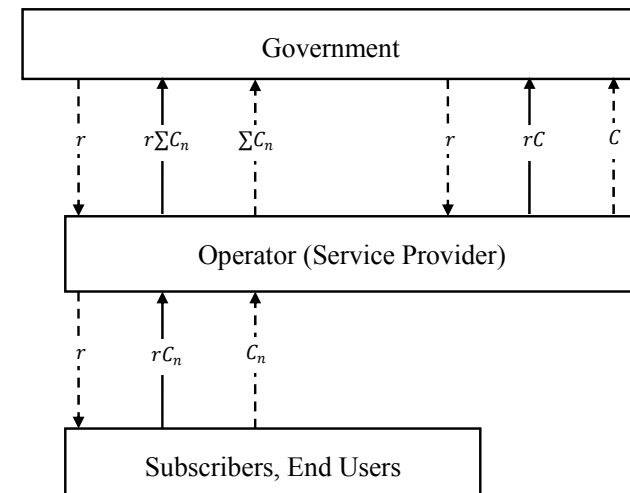H. Oniki   2008/10/15

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

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

would have been a case of reallocation

of commons blocks under EMM

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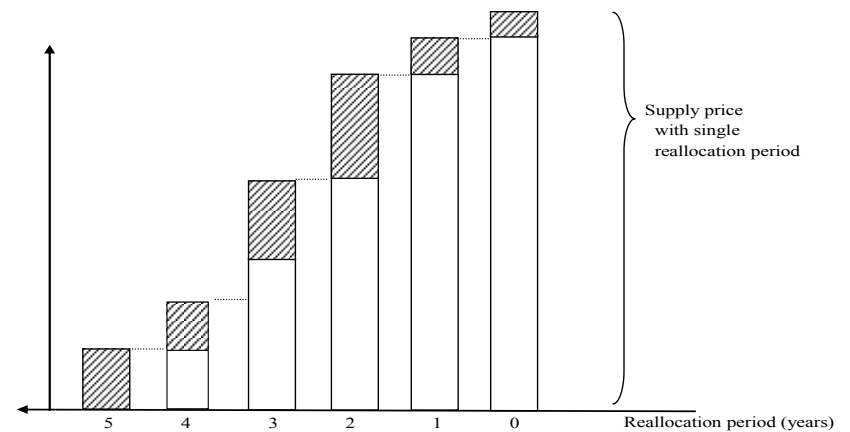
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VI. A. Introduction of reallocation as a forward trading, forward supply price (1/4)

EMM with timing of reallocation

specified

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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.

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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

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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.

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

both incumbent and potential users

will be benefited.

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**VII. PREVENTING SPECULATION
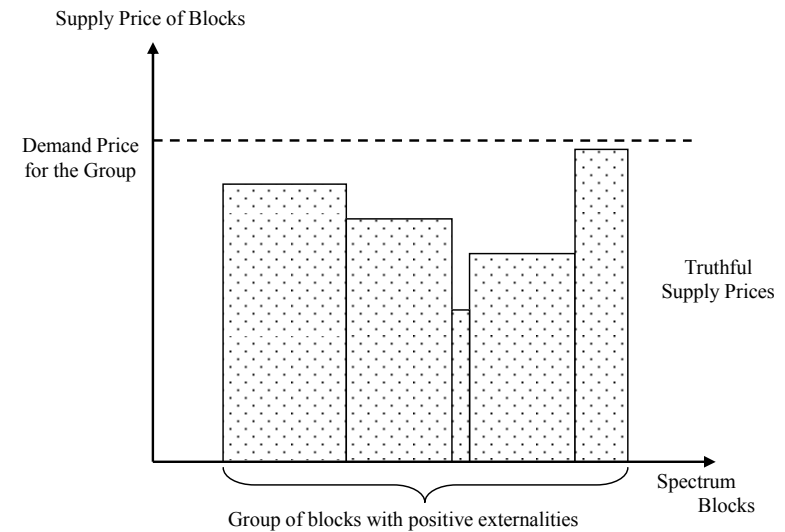WITH EMM**

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VII. Preventing speculation with EMM(1/2)

speculation is possible on a
   strategically positioned block wrt
   externalities

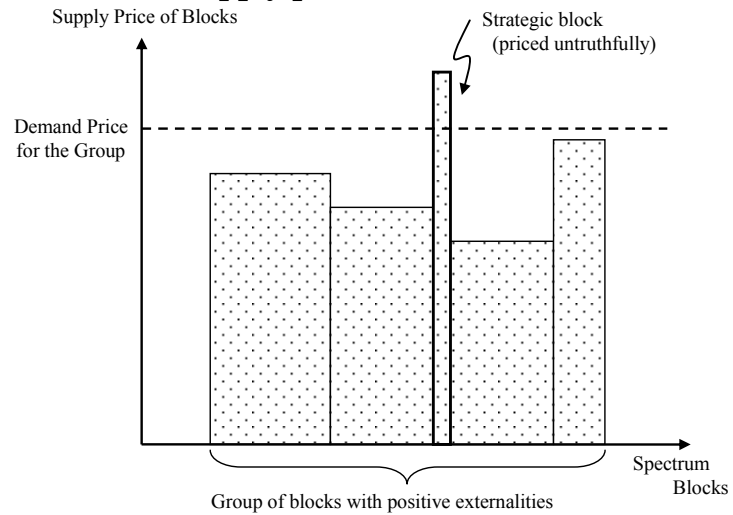**Figure 19: Example of truthful supply prices**

Supply Price of Blocks

Demand Price
for the Group

Truthful
Supply Prices

Spectrum
Blocks

Group of blocks with positive externalities

Figure 20: Example of truthful and untruthful supply prices

Supply Price of Blocks

Strategic block (priced untruthfully)

Demand Price for the Group

Group of blocks with positive externalities

Spectrum Blocks

VII. Preventing speculation with EMM(2/2)

regulation:

impose a penalty on a steep increase in C

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VIII. TRANSITION FROM
THE CURRENT SYSTEM TO EMM

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**VIII. Transition from the current system
to EMM** (1/2)

gradual transition is recommended

no "big bang"

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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

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