Toward Designing Economic Mechanism for Spectrum Reallocation
--- A System with Compulsory Revelation of Supply Prices

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Hajime ONIKI
Institute of Economic Information Research, Inc. (Japan)
oniki@alum.mit.edu
http://www.ab.auone-net.jp/~ieir/

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I. INTRODUCTION: OBJECTIVE OF THIS STUDY

I. Introduction: Objective of This Study

To design a market mechanism (the *extended market mechanism*) for reallocating scarce spectrum resources from incumbents to qualified new users to increase the overall efficiency of spectrum use.

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II. BACKGROUND

II.A. Demand/supply of spectrum
1. 1900 – 1980

- technological progress --- slow
- expansion of spectrum frontiers
  LF → MF → HF → VHF → UHF
- wireless communication, radio, TV, military use
- spectrum demand filled by successive increases in supply
- spectrum value: low

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II.A. Demand/supply of spectrum

2. 1980 – 2010

- technological progress --- accelerated
- increased demand for spectrum
  - mobile telephony/data communication
  - wireless Internet
- demand filled by reallocating spectrum
  - reclamation of spectrum used by government & others
  - assignment by auction or c/c (as in Japan)
- spectrum value: high

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II.A. Demand/supply of spectrum

3. 2010 –

- demand explosion
  - expansion of broadband applications
- spectrum shortage and strong need for spectrum reallocation
  - U.S. NBP (National Broadband Plan), March 2010
  - repurposing and reassignment of spectrum

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II.B. Spectrum users

1. Traditional users

a. Users

- private users --- commercial/non-commercial
  - TV broadcasters, airlines, others
- public/governmental users
  - military users

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II.B. Spectrum users

1. Traditional users

b. Economic status of private users (1/2)

- frequency blocks assigned when spectrum value was low
  - license renewed repeatedly
  - low spectrum fees
- investment on equipment/structures for using spectrum
  - sunk cost (non-recoverable cost)

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II.B. Spectrum users

1. Traditional users

b. Economic status of private users (2/2)

- commercial users enjoy profits on local monopoly
  - vested interests formed on spectrum
- possible capital gains foreseen from holding up spectrum
- little incentive to yield spectrum

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II.B. Spectrum users

2. Users with spectrum via auction (1/2)

- mostly commercial users
  - mobile telephone providers, ISP's
- frequency blocks assigned with high spectrum value
- license renewals in the future:
  - guaranteed by law or
  - not guaranteed but likely

II.B. Spectrum users

2. Users with spectrum via auction (2/2)

- investment --- sunk cost
- spectrum is considered as private property

  spectrum may be sold, but

  market of spectrum not yet established

II.B. Spectrum users

3. Indirect users of spectrum

- consumers receiving services provided with spectrum

  broadcast, mobile telephony

  equipment purchased, vested interests

II.B. Spectrum users

4. Users of spectrum commons

ISM band users, WiFi users

equipment purchased, vested interests

5. Potential users

willing to pay for spectrum use

II.C. Legal and economic properties of spectrum

1. Economic property --- history

- from: free goods with abundant supply

  like air, sea water, rural land

- to: scarce goods of high value

  like drinking water, city land

II.C. Legal and economic properties of spectrum

2. Legal property --- not yet established clearly

a. Basic right

collective property of the people as a whole

private ownership prohibited in most countries

II.C. Legal and economic properties of spectrum

2. Legal property --- not yet established clearly

b. Usage rights

exclusive or shared use allowed with or without licenses

vested interests formed through repeated license renewals

II.C. Legal and economic properties of spectrum

2. Legal property --- not yet established clearly

c. De facto private ownership

given to users through auction

possible limitation from license terms

II.C. Legal and economic properties of spectrum

3. Economic property --- theory

one of space resources

like land, water space, air space

economic value depends on scarcity

example: terrestrial spectrum

utility generated by using the surface of the earth electro-magnetically

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III. ATTEMPTS TO REALLOCATE SPECTRUM

III.A. Direct command and control

1. Method

- discontinuation of license renewal/ governmental arrangement
- possible relocation of incumbents to less congested band
- compensation for moving costs

III.A. Direct command and control

2. Shortcomings

- strong opposition by incumbents

  absence of economic reasoning

  "injustice" to incumbents
- generates incentive to hold up spectrum

III.B. Secondary Markets

1. Method

- give spectrum ownership to incumbents
- give freedom of selling/leasing spectrum (at least in part)

  incentive auction (NBP)

III.B. Secondary Markets
2. Shortcomings (1/2)

- oppositions to "unjustifiable" income going to incumbents
- low incentive to yield spectrum
  - vested interests on sunk cost
    investment in the past
    profits from local monopoly being enjoyed
    possible capital gains in the future

III.B. Secondary Markets
2. Shortcomings (2/2)

- incomplete market and positive externalities

high transactions cost

III.C. Usage rents and rewards by government
1. Method

- usage rents imposed to incumbents
- rewards given for returned spectrum block
- using incentive scheme, no direct enforcement

III.C. Usage rents and rewards by government
2. Shortcomings

- difficult to find appropriate rents or prices
- possible fragmentation of returned spectrum

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IV. ECONOMICS OF SPECTRUM REALLOCATION --- A HEURISTIC APPROACH

IV.A. What does the efficiency of spectrum use mean?
1. Basic concepts --- a simple framework

- spectrum blocks
- spectrum users
- returns from using (and not using) spectrum
- total net returns to the society

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IV.A. What does the efficiency of spectrum use mean?

2. Business alternatives and return to individual users

a. alternative 1 (A^b): with a spectrum block

Y^b: return with A^b.

b. alternative 2 (A^n): without a block

Y^n: return with A^n.

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IV.A. What does the efficiency of spectrum use mean?

3. Incumbents users --- state and the behavior

Y^b: the current income with A^b.

Y^n: the (maximum) income with A^n net of the cost of moving from A^b to A^n.

$Y^b > Y^n$.

(Otherwise, A^n would have been chosen.)

$C^s = Y^b - Y^n$: the minimum compensation for the incumbent to move from A^b to A^2.

C^s: the *supply price* of the spectrum block.

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Figure IV.A.1: Business Resources of Incumbent i With and Without the Block

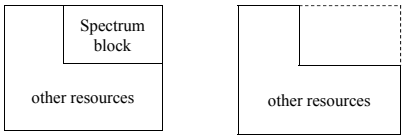

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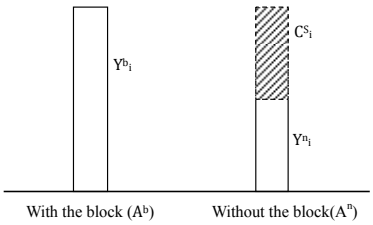
Figure IV.A.2: Returns to Incumbent i With and Without the Block and the Supply Price C^S_i



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IV.A. What does the efficiency of spectrum use mean?

4. Potential (new) users --- state and the behavior

Y^n: the current income with A^n.

Y^b: the (maximum) income with A^b net of the cost of moving from A^n to A^b.

$Y^b > Y^n$.

(Otherwise, A^b would not be chosen.)

$C^d = Y^b - Y^n$: the maximum payment for the new user to move from A^n to A^b.

C^d: the *demand price* for the spectrum block.

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Figure IV.A.3: Returns to (Potential) New Users (j) Without and With the Block and the Demand Price C^d_j

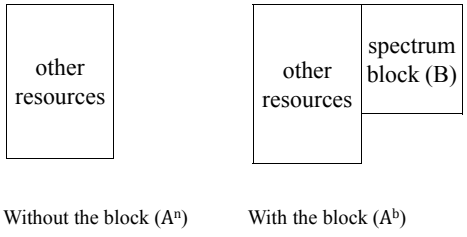

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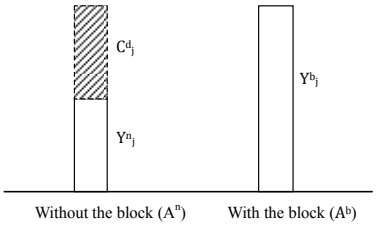
Figure IV.A.4: Business Resources of (Potential) New Users (j) Without and With the Block



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IV.A. What does the efficiency of spectrum use mean?

5. Spectrum transfer from one incumbent (i) to one new user (j):

the incumbent: C^s_i, Y^b_i, Y^n_i

the new user: C^d_j, Y^b_j, Y^n_j

the total return before the transfer:

$$Y^1 = Y^b_i + Y^n_j.$$

the total return after the transfer:

$$Y^2 = Y^n_i + Y^b_j.$$

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IV.A. What does the efficiency of spectrum use mean?

6. Outcome from the transfer

the (net) increase of total return: ΔY

$$\Delta Y = Y^2 - Y^1$$
$$= (Y^n_i + Y^b_j) - (Y^b_i + Y^n_j)$$
$$= (Y^b_j - Y^n_j) - (Y^b_i - Y^n_i)$$
$$= C^d_j - C^s_i.$$

$\Delta Y \gtreqless 0$ if and only if $C^d_j \gtreqless C^s_i$.

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IV.A. What does the efficiency of spectrum use mean?

7. Criterion for reallocation:

the total return $Y = Y^1 + Y^2$ increases

if and only if $\Delta Y > 0$.

ΔY: the social surplus of reallocation.

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IV.A. What does the efficiency of spectrum use mean?

8. A scheme for "share auction."

$C^d_j = C^s_i + \Delta Y$: the auction price paid by the winning new user (j).

C^s_i: the share for the incumbent (i).

ΔY: the share for the government.

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IV.B. Obligations of the incumbent user

1. Simplifying assumptions:

- no externalities between blocks in producing services, and hence in determining returns.
- no combinatorics in auction process.

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IV.B. Obligations of the incumbent user

2. Information on C^s_i and C^d_j.

C^d_j: may be revealed by auction.

C^s_i: may not be revealed by auction or by conventional means.

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IV.B. Obligations of the incumbent user

3. The objective

to design a mechanism for having incumbents reveal C^s_i.

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IV.C. Obligations of the new (potential) user

1. On mechanism-design approach

What is mechanism-design approach?

a. Given data

- economic agents
- economic objects (goods, resources)
- preference relations
- technological possibilities

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IV.C. Obligations of the new (potential) user

1. On mechanism-design approach

b. The "variable"

- economic system

  a set of rules for economic agents

  consistent with their behavior patterns

  (incentive-compatible rules)

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IV.C. Obligations of the new (potential) user

1. On mechanism-design approach

c. Design targets

to find a "solution" (an economic system) satisfying given conditions

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IV.D. Application of mechanism-design approach to spectrum reallocation

1. Given data

- agents: spectrum users seeking maximum profits/satisfactions
- objects: spectrum blocks
- technology: production function with spectrum
- initial state: current assignment of spectrum blocks to users

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IV.D. Application of mechanism-design approach to spectrum reallocation

2. The variable

a set of incentive-compatible activity rules for agents

agents:

- traditional users
- users with auctioned spectrum
- public/governmental users
- commons users
- indirect users
- new (potential) users

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IV.D. Application of mechanism-design approach to spectrum reallocation

3. The target of the system:

to increase (or to maximize) the total revenue (Y) earned on spectrum blocks.

i.e.,

to increase (or to maximize) the overall efficiency of using the spectrum blocks

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IV.D. Application of mechanism-design approach to spectrum reallocation

4. Conditions to be satisfied by the system:

a. the market-mechanism principle

no direct control of the behavior of agents by government

give freedom of choice within a given set of rules

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IV.D. Application of mechanism-design approach to spectrum reallocation

4. Conditions to be satisfied by the system:

b. the Pareto principle

no agent shall be worse off by introducing the system

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--- A System with Compulsory Revelation of Supply Prices

V. PROPOSAL OF MARKET MECHANISM WITH COMPULSORY REVELATION OF SUPPLY PRICES

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V.A. Basic principles (Bill of Spectrum Rights)

1. Spectrum is a property owned and controlled by the society collectively.

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V.A. Basic principles (Bill of Spectrum Rights)

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

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V.A. Basic principles (Bill of Spectrum Rights)

3. The spectrum user shall declare an amount of compensation representing the value of the spectrum block to the user.

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V.A. Basic principles (Bill of Spectrum Rights)

4. The spectrum user shall yield the right of using the spectrum block when requested with a compensation equal to or exceeding the amount declared.

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V.A. Basic principles (Bill of Spectrum Rights)

5. The spectrum user shall pay a usage fee to the government; the fee shall be equal to the product of the amount of compensation declared by the user and the fee-rate to be determined by government.

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V.B. Obligations of the incumbent user
1. Revelation of a supply price (c^s) of each block being used

c^s: the least amount of compensation for which the incumbent agrees to yield the right of using the spectrum

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V.B. Obligations of the incumbent user
2. Payment of spectrum usage fee (R)

$R = r\, c^s$.

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

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V.B. Obligations of the incumbent user

3. Incumbents

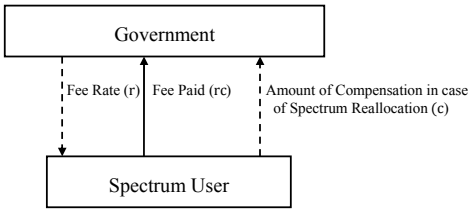
may continue using the block

if there is no offer $> c^s$

must give up using the block

if there is an offer $\geqq c^s$

Figure V.B.1: Supply Price Revealed by a Spectrum User



V.B. Obligations of the incumbent user

4. Determination of c^s by incumbents:

incumbents wish to declare

a high c^s for continuing the use of the block

a low c^s for saving payment R

tradeoff to incumbents

"holding up" of spectrum will be costly

V.B. Obligations of the incumbent user

5. Who should be the "incumbents"?

all users of spectrum

private and government users

direct, indirect, and commons users

(→ see V.G, H)

V.C. Obligations of the new (potential) user

1. Before obtaining spectrum block(s)

must publish a demand price c^d for the block

may participate auction of the block

if $c^d > c^s$

may obtain spectrum

if no competition

V.C. Obligations of the new (potential) user

2. After obtaining spectrum block(s)

becomes an incumbent user

V.D. Role of government (1/3): Organization and control of spectrum resources

1. Determination of spectrum bands and blocks

- objective of spectrum use
- technical specifications
- formation of spectrum blocks

  with respect to frequencies and areas

  regulation of block division and integration by users

(mostly unchanged from the current practices)

V.D. Role of government (1/3): Organization and control of spectrum resources

2. Maintenance and publication of the "spectrum database"

- for each block

  - definition of the block

  - current user(s)

  - current supply price declared

V.D. Role of government (1/3): Organization and control of spectrum resources

3. Providing "spectrum-dashboard" services

- block information
- statistics

V.E. Role of government (2/3): Determination of spectrum-fee rate

1. Functions of the fee rate (r)

- to control the speed of spectrum reallocation

  the speed increases (decreases) as r is raised (lowered)

  (similar to the function of the discount rate of a central bank to the credit size of the macro economy)

V.E. Role of government (2/3): Determination of spectrum-fee rate

2. Principles for setting a fee rate

- single and uniform rate for all users
- rate may be changed over time

V.E. Role of government (2/3): Determination of spectrum-fee rate

3. Strategies of setting fee rates at the time of system implementation for reallocation

- initial rate: r = 0
- then increases r slowly
- long-run target for r:

  to be determined by trials and errors

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V.E. Role of government (2/3): Determination of spectrum-fee rate

4. Regulation of supply-price setting by users

- to prevent holding up and speculations by users

  c^s may be lowered as desired

  c^s may not be raised beyond a government-set percentage for a year

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V.F. Role of government (3/3): Reallocation of spectrum

1. Determination of spectrum-transfer tax rates

- incumbents selling spectrum must pay transfer tax

  - high rate on traditional users with spectrum assigned without spectrum price

  - low rate on other users

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V.F. Role of government (3/3): Reallocation of spectrum

2. Reallocation mode (1/2): full control by the government

- initiate a proceeding by specifying bands/blocks to be reallocated
- conduct auction for potential users
- if auction ends with a winning bid $c^d > c^s$, then execute reallocation
  trade surplus goes to government
- else cancel proceeding

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V.F. Role of government (3/3): Reallocation of spectrum

3. Reallocation mode (2/2): market transactions with government control

- allow free transfer of spectrum by users under government-preset conditions
  specify bands/blocks tradable
  specify transfer-tax rates strategically

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V.F. Role of government (3/3): Reallocation of spectrum

3. Reallocation mode (2/2): market transactions with government control

- trade surplus (after tax) goes to new users

note: (trade surplus) = (the highest price a new user is willing to pay, the demand price) – (the supply price, declared and fixed by incumbent in this case) = ΔY

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V.G. Secondary (indirect) users of spectrum

1. Commons users:

primary user: government administrator

secondary users: general users (the public)

c: the sum of all compensations declared by the secondary users

R: may be collected at the time the device for using the block is purchased
(payment may be made together with that of insurance fees for breakage)

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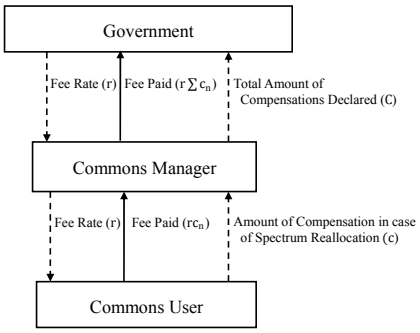
Figure V.G.1: Supply Price Revealed by Commons Users



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V.G. Secondary (indirect) users of spectrum

2. Subscribers to service using spectrum:

ex.: mobile-phone users

wireless Internet users

primary user: providers, broadcasters

secondary users: subscribers, "users"

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

R: may be collected by primary user from secondary users

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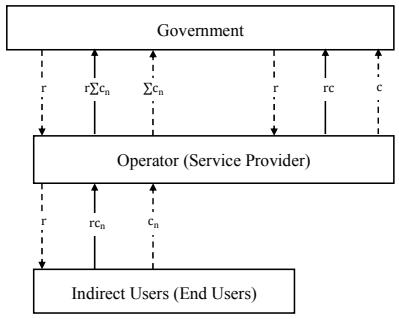
Figure V.G.2: Supply Price Revealed by a Service Provider and End Users



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V.G. Secondary (indirect) users of spectrum

3. A case: transition to DTV

would have been a case of reallocation of commons blocks under this system

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V.H. Introduction of reallocation as a forward trading, forward supply price

specify timing of reallocation

ex.: reallocation x years after the current year

x = 1,3,5 and 10 years

c, r to be specified for each x.

the system is applied for each x.

actual reallocation will be done in the year x

both incumbent and potential users will be benefited.

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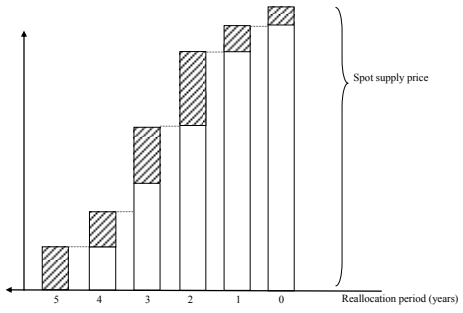
Figure V.H.1: Supply Prices in Forward Trading of Spectrum



Note : A shaded area denotes the increase in the supply price when the period of trade execution is shortened by 1 year.

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VI. EXPECTED OUTCOMES

VI.A. Expected behavior of incumbents
1. Definitions

$c^s = y^b - y^n$: (truthful) supply price of block b

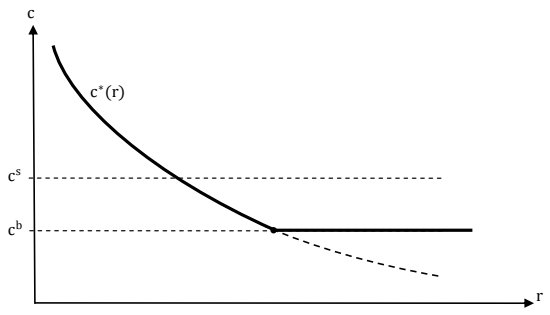
r: annual rate of spectrum usage fee

c: revealed supply price of block b

$c^* = c^*(r)$: supply price maximizing the expected revenue

c^b: the level of supply price where the probability of block b being transferred to potential users is one.

Figure VI.A.1: Supply Price Maximizing the Expected Revenue of the Incumbent



VI.A. Expected behavior of incumbents
2. Determination of $c = c^*(r)$ by an individual incumbent

$c^*(r)$: decreases as r increases.

$c^*(r)$ may not be equal to c^s.

$c^*(r) \geqq c^b$, for all r.

VI.A. Expected behavior of incumbents
3. Supply prices of incumbents

Case: no. of incumbent users = 5. in one area.

$c_i^*(r)$: revealed supply price of incumbent i.

β_i: the size of spectrum block held by i.

$i = 1, 2, ..., 5$.

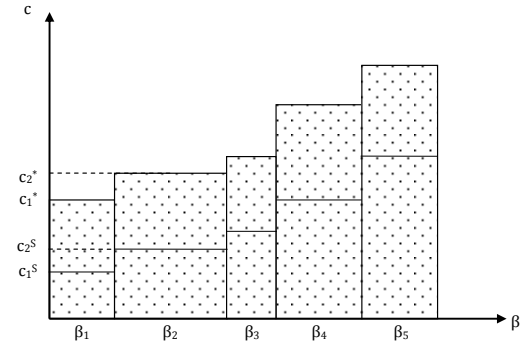
VI.A. Expected behavior of incumbents
3. Supply prices of incumbents

a. supply schedule for a given r.

assumption:

$$c_1^*(r) \leqq c_2^*(r) \leqq c_3^*(r) \leqq c_4^*(r) \leqq c_5^*(r).$$

Figure VI.A.2: The Revealed Supply Schedule of Spectrum Blocks of 5 Incumbents



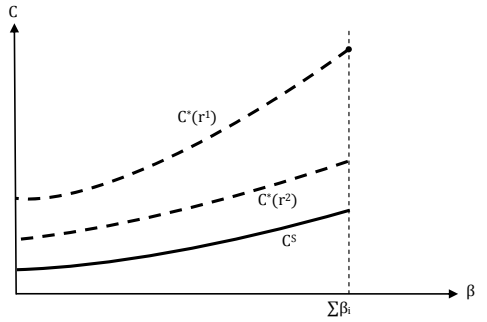
VI.A. Expected behavior of incumbents
3. Supply prices of incumbents

b. supply schedules for r^1 and r^2.

$r^1 < r^2$

the industry supply schedule $c^*(r)$ is shifted downward as r increases.

Figure VI.A.3: Revealed and Truthful Supply Schedules for r^1 and r^2 ($r^1 < r^2$)



VI.A. Expected behavior of incumbents
4. Supply and demand of spectrum blocks (1/2)

C^D: the demand schedule for spectrum blocks.

C^S: the truthful supply schedule (does not depend on r.)

$C^*(r)$: the revealed (false) supply schedule

$\beta^*(r)$: the size of spectrum blocks transferred with given r

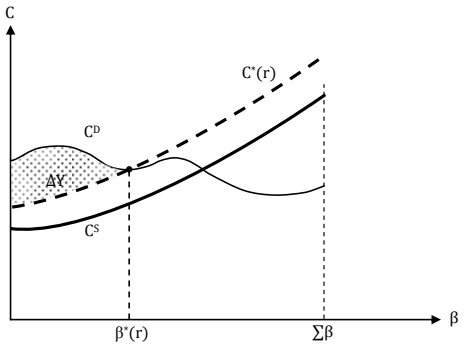
→ increase in the efficiency of spectrum use.

VI.A. Expected behavior of incumbents
4. Supply and demand of spectrum blocks (2/2)

ΔY: the social surplus arising from the transfer $\beta^*(r)$.

$\Delta Y = 0$ → spectrum used efficiently

Figure VI.A.4: Transfer of Spectrum Blocks for Given r



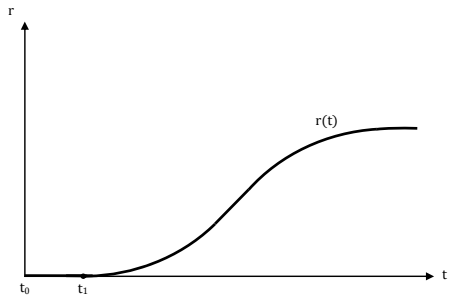
VI.B. Expected outcomes for the industry

1. Time path of fee rate r(t).

t_0: the time of introducing the system.

r(t): time path of fee rate $r = r(t)$ to be chosen strategically by the government via trials and errors.

Figure VI.B.1: An Example of Free-rate Path r(t)



VI.B. Expected outcomes for the industry

2. The case without technological progress (1/2)

Y^*: the maximum level of Y for the given technology.

Y(r): the path of Y for given r(t).

Y(0): the path Y for $r(t)=0, t > 0$.

the case of conventional market mechanism (secondary market).

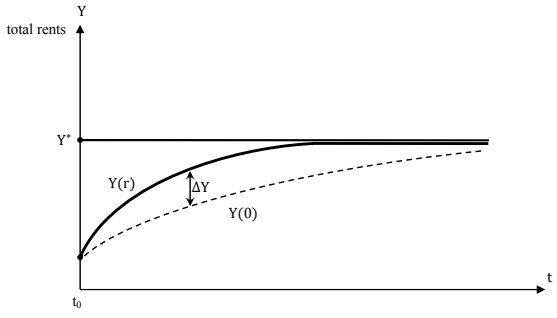
VI.B. Expected outcomes for the industry

2. The case without technological progress (2/2)

ΔY: the social surplus from introducing the system

the path Y(t) of total returns will approach to the maximum level Y^*.

Figure VI.B.2: Expected Increase in the Total Returns Y(t) from Spectrum Blocks (no technical progress)



VI.B. Expected outcomes for the industry

3. The case with technological progress (1/2)

Y^{**}: the path of maximum level of Y with given technological progress for the case of instantaneous and costless adjustments (the moving target).

Y^*: the path of maximum level of Y attainable in the long run with delayed and costly adjustments.

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VI.B. Expected outcomes for the industry

3. The case with technological progress (2/2)

Y(r): the path of Y for given r(t).

the path will chase the optimal path Y^{**},

a moving target.

Y(0): the path Y for $r(t)=0, t>0$.

the case of conventional market mechanism.

ΔY: the social surplus from introducing the system.

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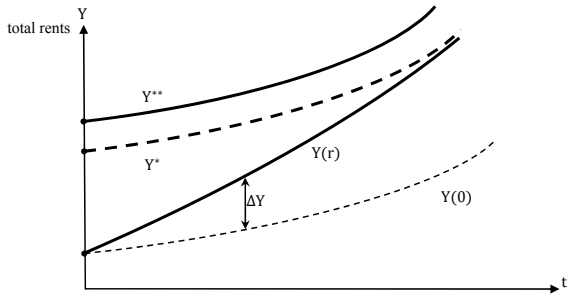
Figure VI.B.3: Expected Increase in the Total Returns Y(t) from Spectrum Blocks (with technical progress)



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VI.B. Expected outcomes for the industry

4. Transition from the current state to the long-run path

- gradual transition is recommended

  no "big bang"
- strategic choice of r(t):
- set r(t) at a level close to zero initially
- increase r gradually thereafter

  possibly with trials and errors

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VI.C. Relation of introducing the system to the current spectrum fee

apply exemption to the fee from the new system (EMM) from the currently paid fees, replacing in effect gradually the current fees with the new one.

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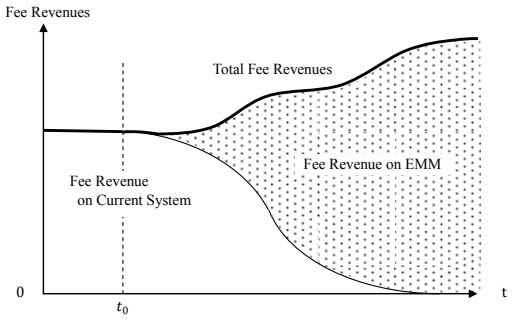
Figure VI.C.1: Expected Change of Spectrum-fee Revenues



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VI.D. Preventing speculation

speculation is possible on a strategically positioned block with respect to externalities regulation: impose a penalty on a steep increase in revealed supply prices.

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Figure VI.D.1: Example of Truthful Supply Prices

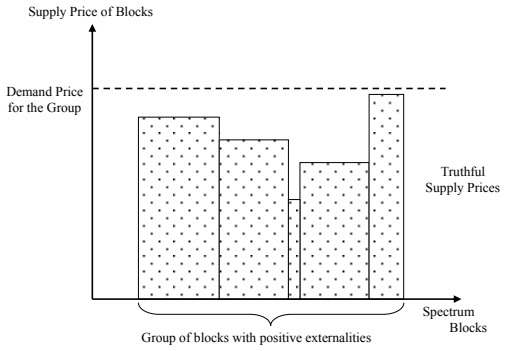

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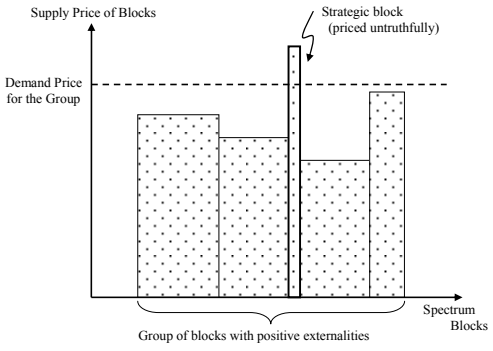
Figure VI.D.2: Examples of Truthful and Untruthful Supply Prices



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