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

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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.

II. Background

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
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
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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B. Spectrum users

1. Traditional users
   a. Users
      private users --- commercial/non-commercial
         TV broadcasters, airlines, others
      public/governmental users
         military users
   b. Economic status of private users
      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)
      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
2. Users with spectrum via auction
   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
   investment --- sunk cost
   spectrum is considered as private property
      spectrum may be sold, but
      market of spectrum not yet established
3. Indirect users of spectrum
   consumers receiving services provided with spectrum
      broadcast, mobile telephony
      equipment purchased, vested interests
4. Users of spectrum commons
   ISM band users, WiFi users
      equipment purchased, vested interests
5. Potential users
   willing to pay for spectrum use

C. Legal and economic properties of spectrum

1. Economic property --- history

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from: free goods with abundant supply
like air, sea water, rural land
to: scarce goods of high value
like drinking water, city land

2. Legal property --- not yet established clearly
   a. Basic right
      collective property of the people as a whole
      private ownership prohibited in most countries
   b. Usage rights
      exclusive or shared use allowed with or without licenses
      vested interests formed through repeated license renewals
   c. De facto private ownership
      given to users through auction
      possible limitation from license terms
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

III. Attempts to Reallocate Spectrum

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
2. Shortcomings
   strong opposition by incumbents
   absence of economic reasoning
   "injustice" to incumbents
   generates incentive to hold up spectrum

B. Secondary markets

1. Method
   give spectrum ownership to incumbents
   give freedom of selling/leasing spectrum (at least in part)
   incentive auction (NBP)

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2. Shortcomings
   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
      incomplete market and positive externalities
         high transactions cost

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
2. Shortcomings
   difficult to find appropriate rents or prices
   possible fragmentation of returned spectrum

IV. Economics of Spectrum Reallocation --- A Heuristic Approach

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
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.
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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<Figures IV.A.1,2>

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.

   <Figures IV.A.3, 4>

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

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 $C^d_j \gtreqless C^s_i$.

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.

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.

B. On designing an economic mechanism for spectrum transfer (reallocation)

1. Simplifying assumptions:

   no externalities between blocks in producing services, and hence in determining returns.

   no combinatorics in auction process.

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.

3. The objective

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

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C. On mechanism-design approach

What is mechanism-design approach?

a. Given data
   economic agents
   economic objects (goods, resources)
   preference relations
   technological possibilities

b. The "variable"
   economic system
      a set of rules for economic agents consistent with their behavior patterns
         (incentive-compatible rules)

c. Design targets
   to find a "solution" (an economic system) satisfying given conditions

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
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
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
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
   b. the Pareto principle
      no agent shall be worse off by introducing the system

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V. Proposal of Market Mechanism with Compulsory Revelation of Supply Prices

A. Basic principles (Bill of Spectrum Rights)

1. Spectrum is a property owned and controlled by the society collectively.
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.
3. The spectrum user shall declare an amount of compensation representing the value of the spectrum block to the user.
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.
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.

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
2. Payment of spectrum usage fee (R)
   $R = r\, c^s$.
   r: (annual) rate of spectrum usage fee to be determined by the government
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>
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
5. Who should be the "incumbents"?
   all users of spectrum
   private and government users
   direct, indirect, and commons users
   (→ see V.G, H)

C. Obligations of the new (potential) user

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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
2. After obtaining spectrum block(s)
   becomes an incumbent user

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)
2. Maintenance and publication of the "spectrum database"
   for each block
      definition of the block
      current user(s)
      current supply price declared
3. Providing "spectrum-dashboard" services
   block information
   statistics

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)
2. Principles for setting a fee rate
   single and uniform rate for all users
   rate may be changed over time
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
4. Regulation of supply-price setting by users

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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

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

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

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

   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

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)

   <Figure V.G.1>

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>

3. A case: transition to DTV

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

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.

<Figure V.H.1>

VI. Expected Outcomes

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>

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.

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.

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

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>

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

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$r^1 < r^2$

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

<Figure VI.A.3>

4. Supply and demand of spectrum blocks

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.

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

$\Delta Y = 0$ → spectrum used efficiently

<Figure VI.A.4>

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>

2. The case without technological progress

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).

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>

3. The case with technological progress

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.

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.

<Figure VI.B.3>

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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

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.
<Figure VI.C.1>

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.
<Figure VI.D.1>
<Figure VI.D.2>

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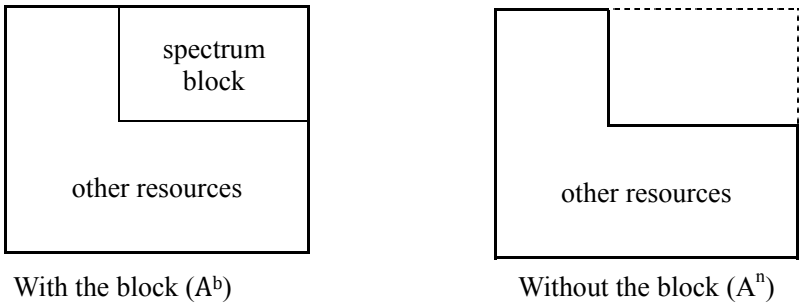

Figure IV.A.1: Business Resources of Incumbent i with and without the Block

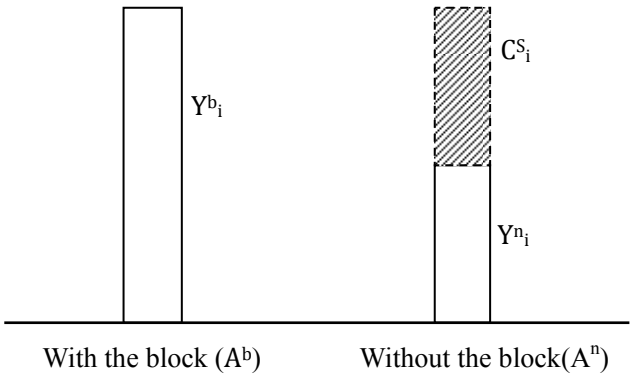

Figure IV.A.2: Returns to Incumbent i with and without the Block and the Supply Price C^S_i

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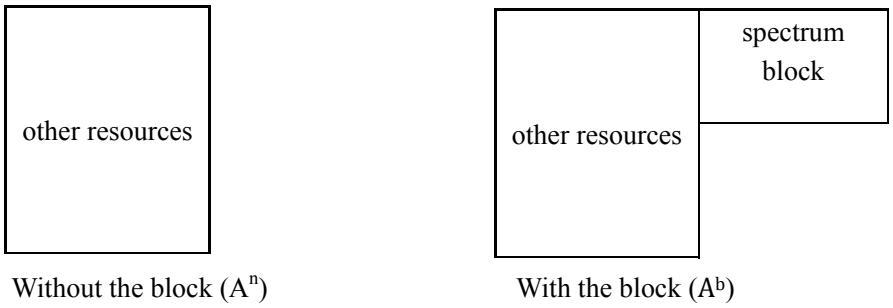

Figure IV.A.3: Business Resources of (Potential) New Users (j) without and with the Block

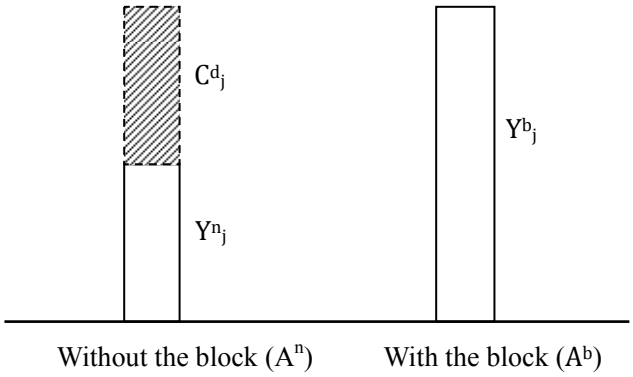

Figure IV.A.4: Returns to (Potential) New Users (j) without and with the Block
and the Demand Price C^d_j

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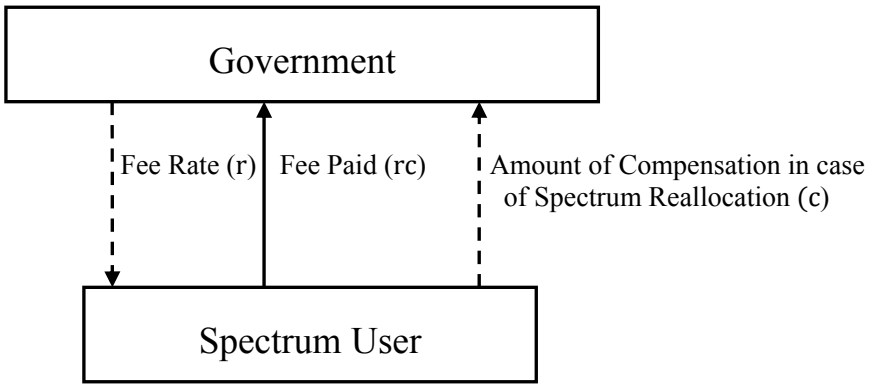

Figure V.B.1: Supply Price Revealed by a Spectrum User

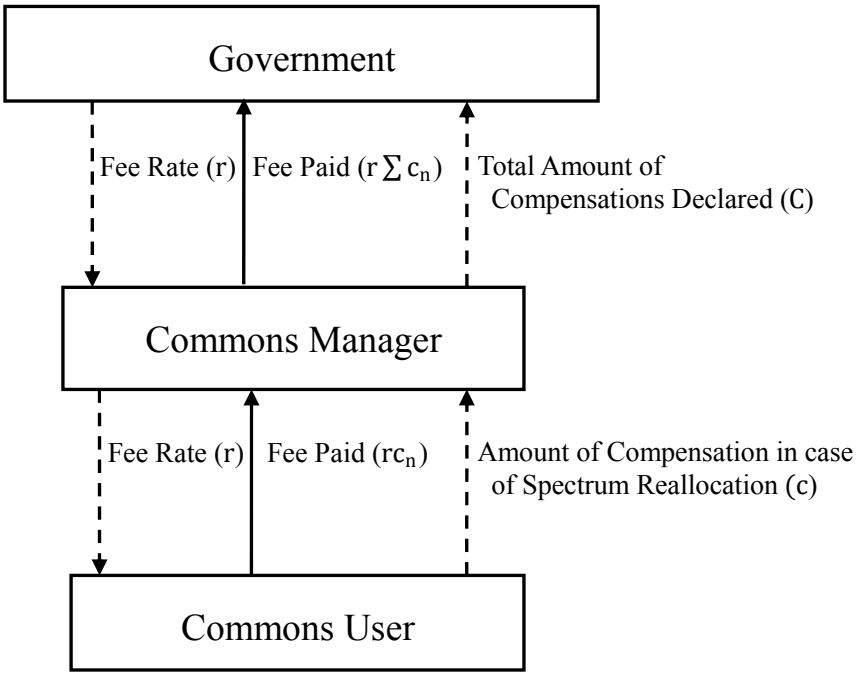

Figure V.G.1: Supply Price Revealed by Commons Users

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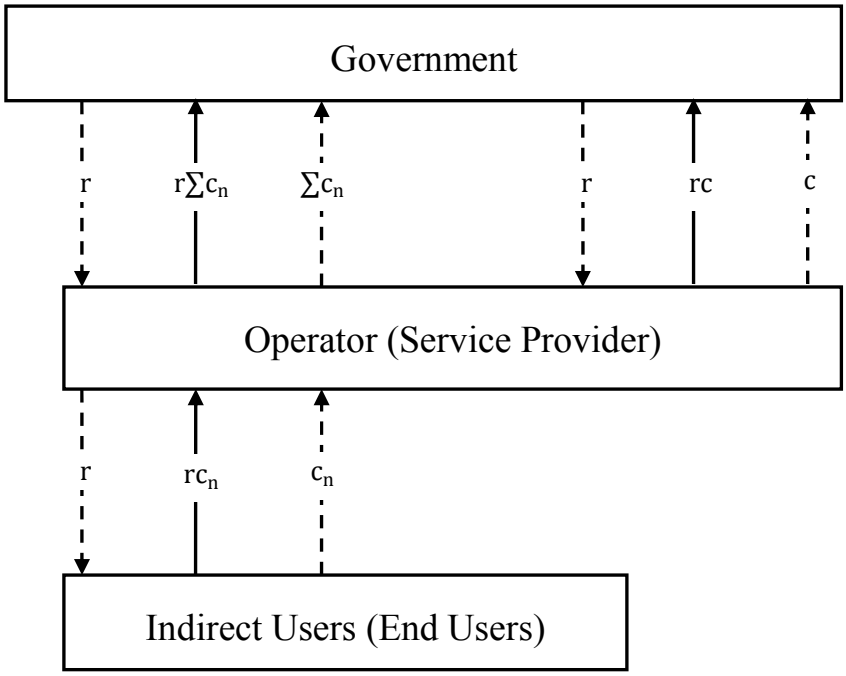

Figure V.G.2: Supply Prices Revealed by a Service Provider and End Users

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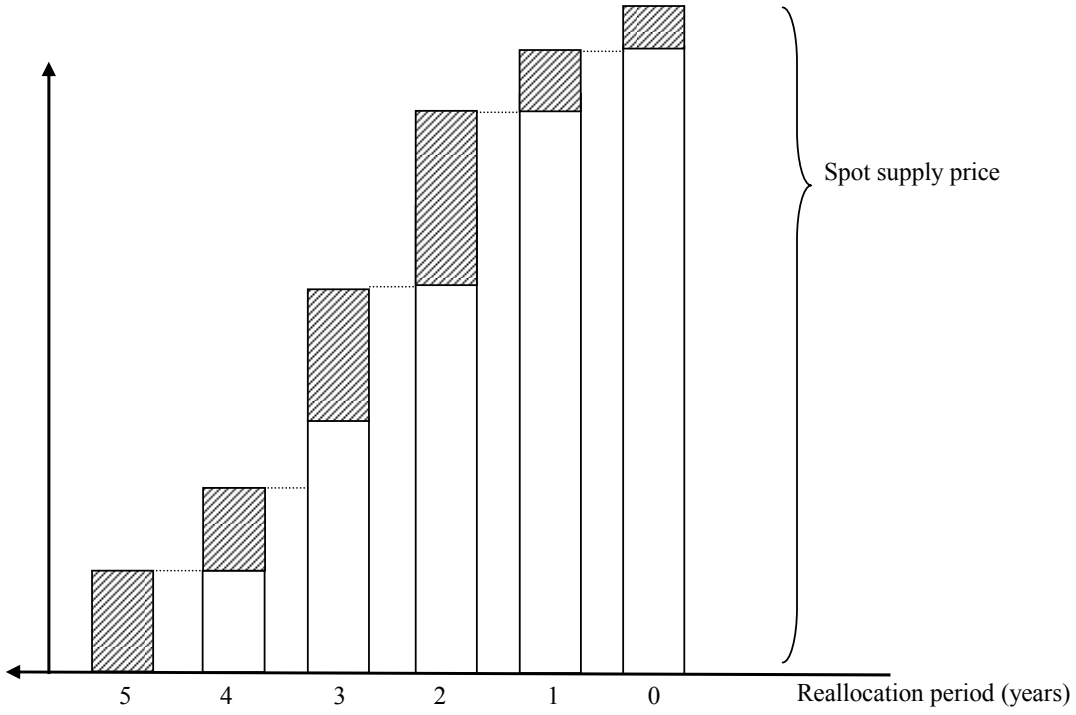

Note : A shaded area denotes the increase in the supply price when the period of trade execution is shortened by 1 year.

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

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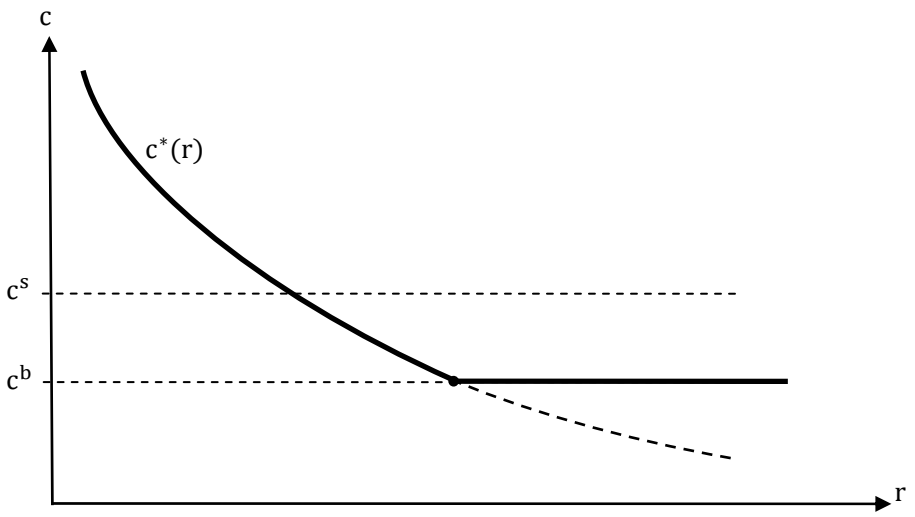

Figure VI.A.1: Supply Price Maximizing the Expected Revenue of the Incumbent

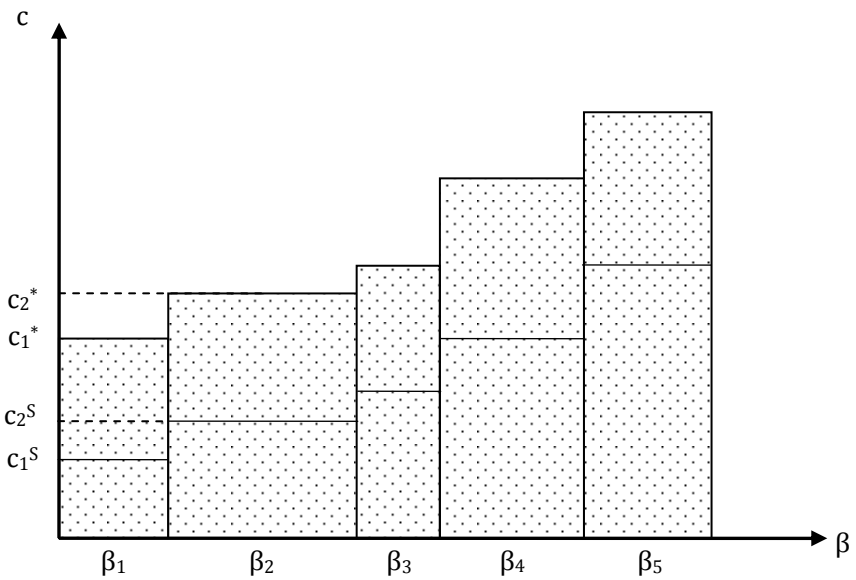

Figure VI.A.2: The Revealed Supply Schedule of Spectrum Blocks of 5 Incumbents

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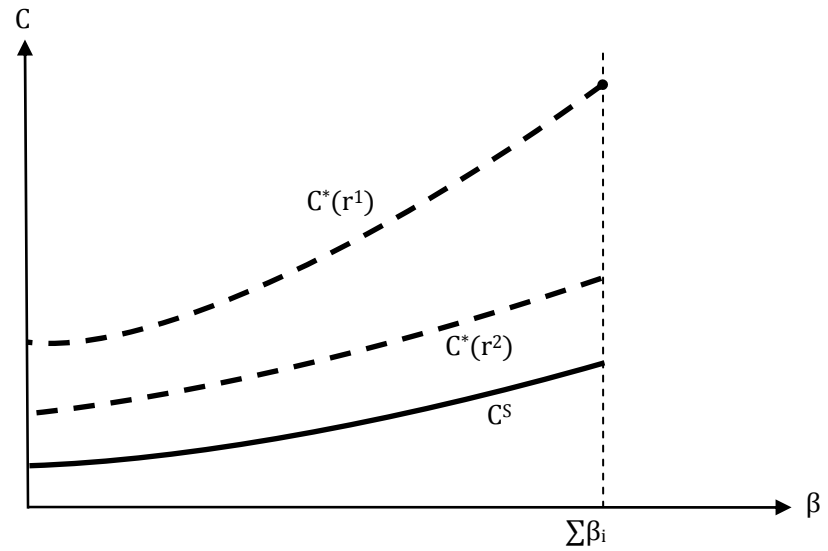

Figure V.A.3: Revealed and Truthful Supply Schedules for r^1 and r^2 ($r^1 < r^2$)

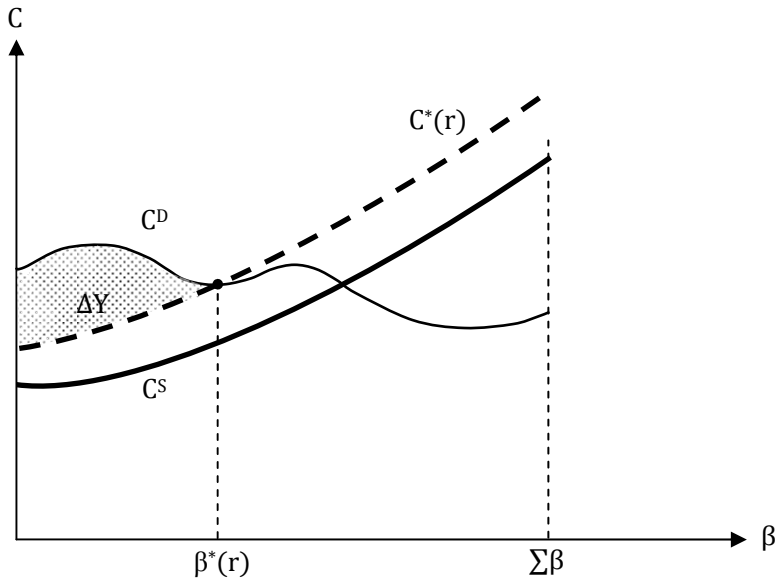

Figure VI.A.4: Transfer of Spectrum Blocks for given r

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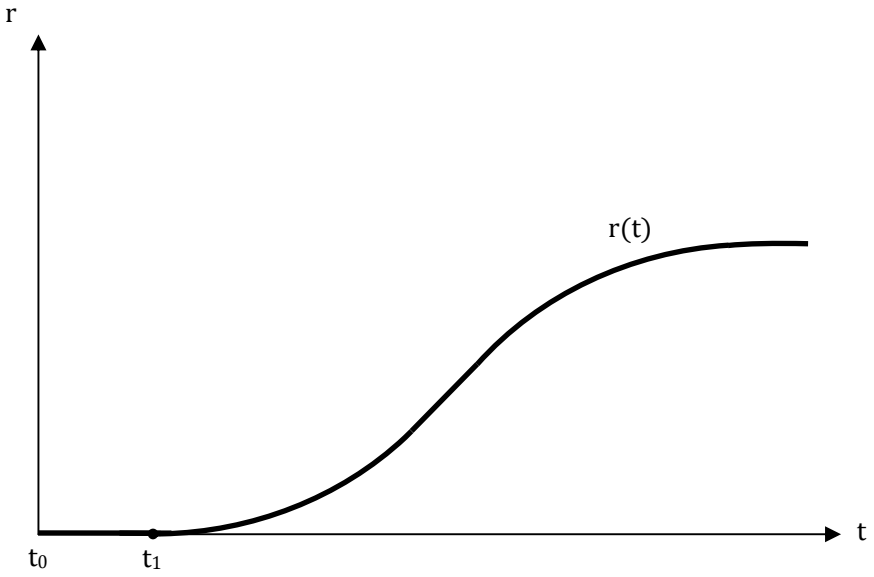

Figure VI.B.1: An Example of Free-rate Path r(t)

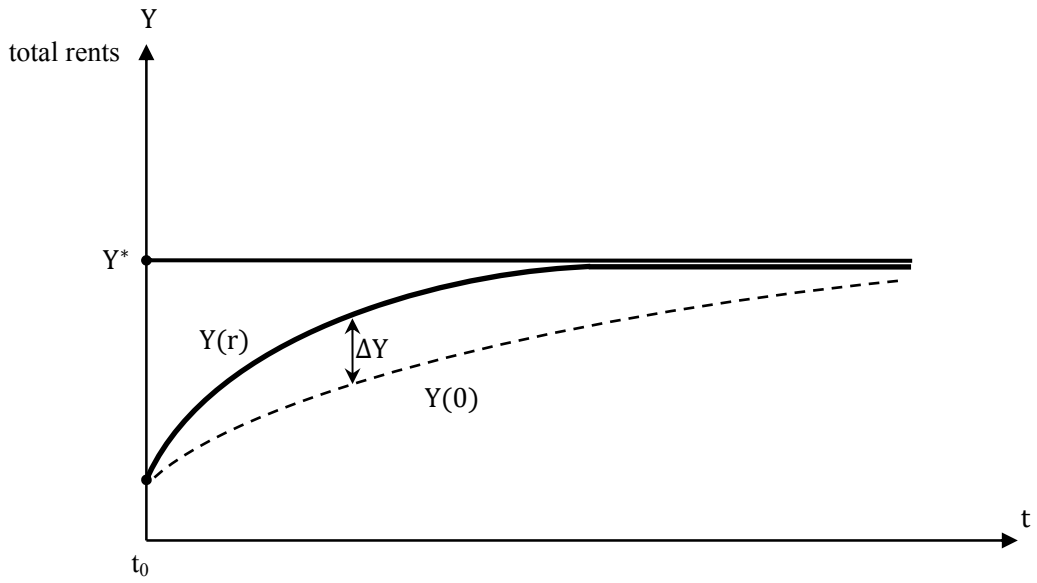

Fig.VI.B.2: Expected Increase in the Total Returns Y(t) from Spectrum Blocks (no technical progress)

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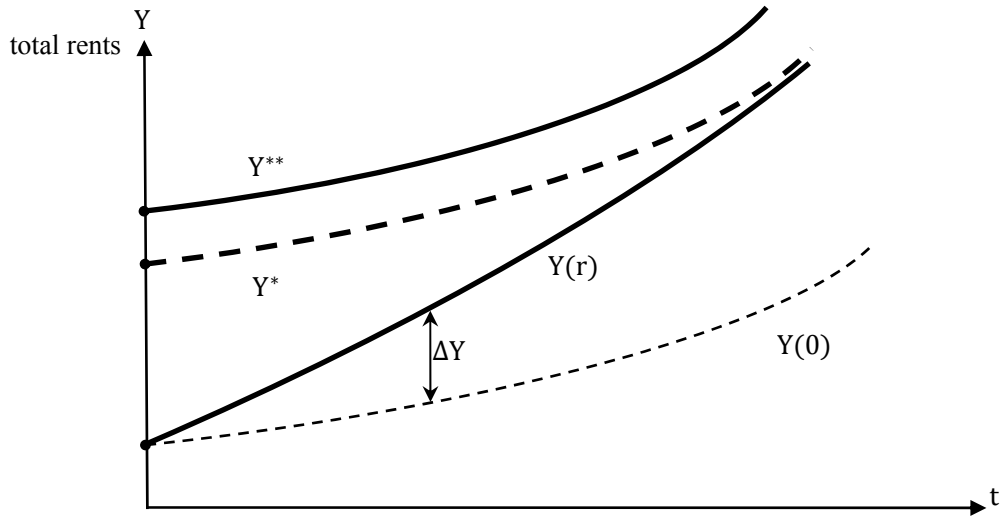

Fig.VI.B.3: Expected Increase in the Total Returns Y(t) from Spectrum Blocks (with technical progress)

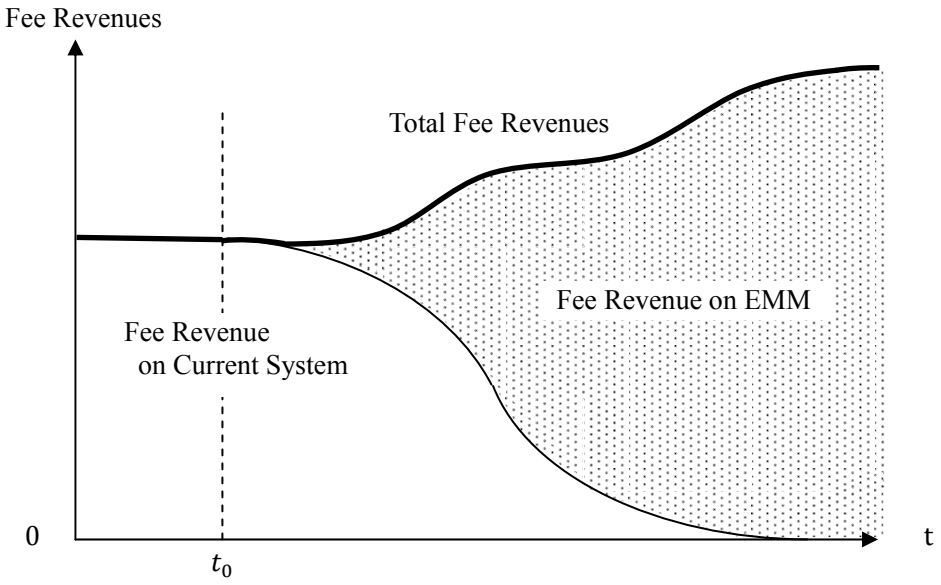

Figure VI.C.1: Expected Change of Spectrum-fee Revenues

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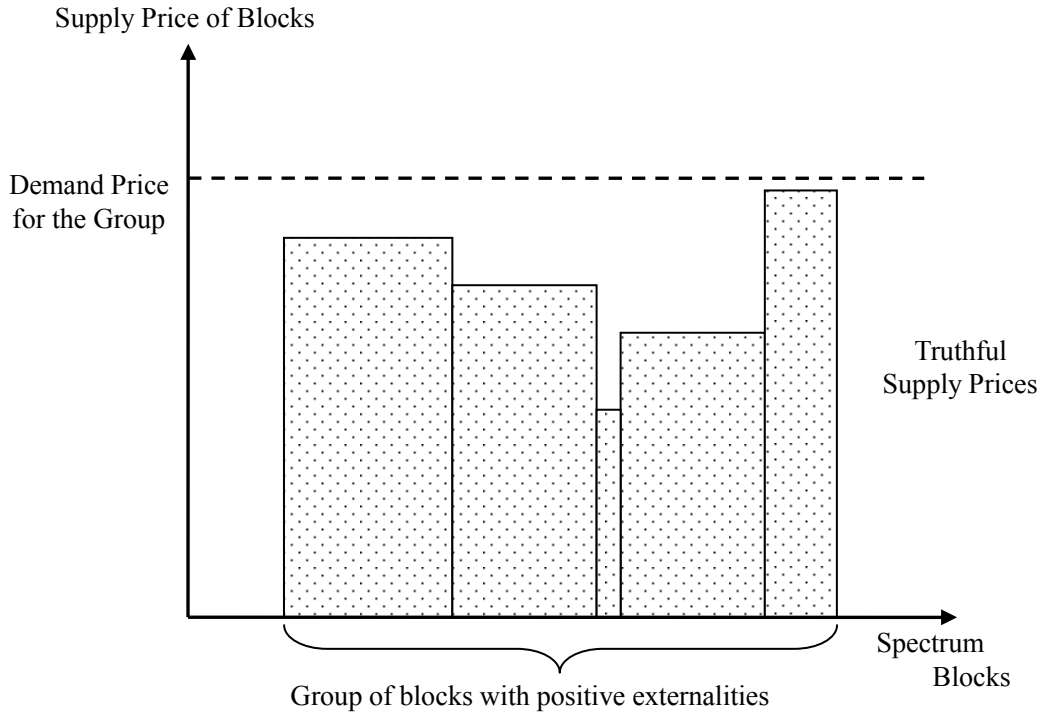

Figure VI.D.1: Example of Truthful Supply Prices

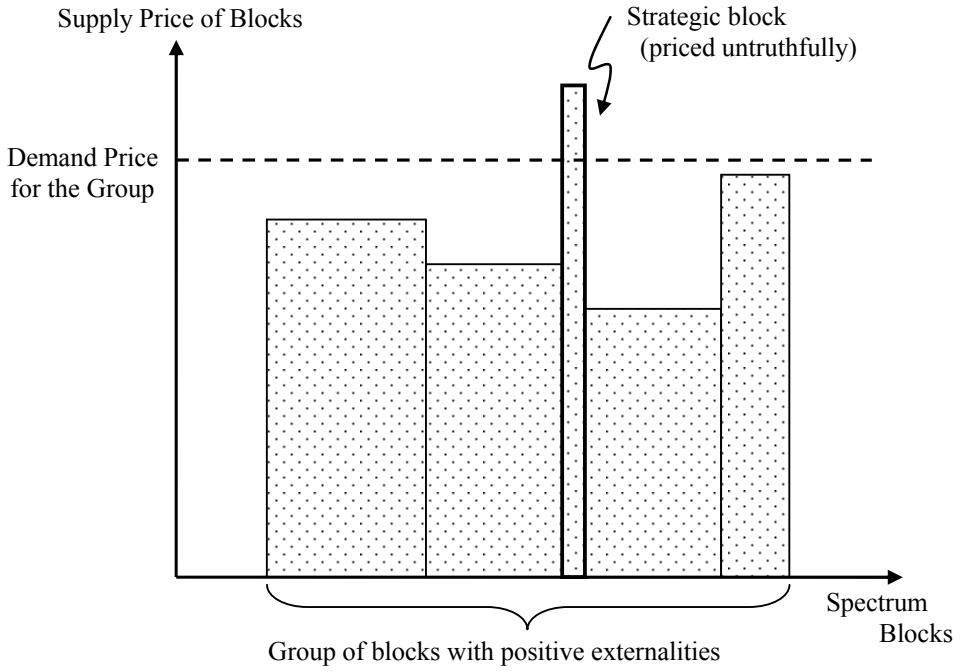

Figure VI.D.2: Examples of Truthful and Untruthful Supply Prices

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