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Drafting spectrum policy in an access-price targeting perspective and exploring its embedded biological nature

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ABSTRACT

Spectrum policy is the government statement of how it guides information and communication industry growth. Since 5G commercial launch is expected in 2020, ITU has estimated the spectrum requirement is 1340 MHz–1960 MHz. However, the population ageing and the unpredictable pace of telecommunication innovation cause the spectrum demand may be overestimated. The author designs an Access-Price Targeting framework (APT) to help the Taiwan government to draft spectrum policy during 2013–2016 considering the long-term/short-term telecommunication economic activities. APT, in a long-term, estimates the spectrum demand decreases from 1070 MHz in 2013 to 1025 MHz in 2030, when the Taiwan population ages. In a short-term, APT suggests the spectrum authority should decide an explicit targeting online access-price and guide the market development by mediating spectrum supply, just like the relationship between Central Bank and its monetary policy, rather than keeping releasing spectrum and lowering online access-price. This strategy ensures the stable telecommunication industry development. The contributions of APT are (1) ensuring predictability, transparency and accountability of spectrum policy-making process to reduce economic and financial uncertainty, and (2) allowing spectrum policy to focus on guiding the development of domestic telecommunication industries and to respond to shocks from domestic and foreign telecommunication economy.

1. Introduction

Since 4G Long Term Evolution (LTE) cellular technology acquires enormous telecommunication market success, various technologies and application specifications are eager for joining the next generation (5G) telecommunication standard. The International Telecommunication Union (ITU) designed a spectrum requirement estimation model (called M2290 hereby), which suggests governments to release sufficient spectrum to accommodate the future telecommunication technology and application developments [1]. M2290 estimates that the total spectrum requirements in the year 2020 are 1340 MHz and 1960 MHz for lower user density countries and higher user density countries, respectively [1]. Many economies, such as the United Kingdom, Japan, China, GSMA and Taiwan, modify the M2290 to reflect the recent developments in their mobile telecommunication markets. These countries also treat the estimated spectrum requirement as a guideline to build their own spectrum policy and corresponding telecommunication policies [2].

Spectrum, however, is scarce natural resource, and it is allocated not only for the commercial telecommunication market, but also the science research and public safety usages. The government hardly spares telecommunication market 1340 MHz–1960 MHz simply to accommodate all 4G/5G technologies and corresponding applications. Furthermore, some governments consider their own macroeconomic policy goals and only allocate necessary spectrum resource to promote specific telecommunication technologies, guiding the development of its domestic telecommunication industry and market. For example, Indonesia designed the Indonesia System model (INS) and estimated the 5G spectrum requirement at 295 MHz in the year 2025 [3]. South Korea, Australia, and Russia also developed their own spectrum requirement estimation model, and they only require 1220 MHz, 1081 MHz, and 1065 MHz, respectively, for 4G/5G telecommunication market in the year 2020 [4,5].

To date, there are no reliable statistics and feedback on the use of the above spectrum supply targeting methods [1]. The main reason is M2290 ignores two problems surrounding policy implementation. First, from a long-term perspective, M2290 ignores the population structure of an economy that affects the spectrum demand, especially for the ageing society. The magnitude and speed of population ageing slow down telecommunication usage pattern accompanied by low economic activities, resulting in low telecommunication traffic demands. However, M2290 presumes the traffic demands of the child, adult, and old age are the same. This leads the 5G traffic demands is over-estimated in an ageing society, the government then releases too much spectrum to

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the telecommunication market, causing unnecessary low telecommunication service price level (e.g., data access price) and the following cut-throat competition in the telecommunication market.

Second, from a short-term perspective, the unpredictable pace of telecommunication innovation causes the instability of the spectrum demanding. That is, the spectrum market may randomly adjust 4G/5G spectrum demands through spectrum sharing and high spectral efficiency technologies, such as radio white space, LTE-Wi-Fi Link Aggregation (LWA), and 3D beamforming. The spectrum then becomes over-issued in a short-term, and the data access cost decreases, and earned interest rate of the telecommunication service raises. On the other hand, the telecommunication commodity market may spontaneously increase the spectrum demands through the emerging telecommunication in-band services, such as Narrow Band Internet of Things (NB-IoT) and Public Protection and Disaster Relief (PPDR). The spectrum supply, therefore, becomes short in a short-term, the data access price increases, and earned interest rate of the telecommunication service decreases.

This study, therefore, designs an Access-Price Targeting (APT) spectrum policymaking framework, which provides a theoretical foundation of spectrum policy for the Taiwan spectrum authority during 2013–2016. APT suggests the spectrum authority should directly decide an explicit target variable, i.e., data access price, and announces this target to the public, without any intermediate variable such as spectrum supply. The idea of APT is based on the macroeconomic theory that the best policy to support the long-term growth of the economy is to maintain price stability [6–10]. The spectrum authority can use a single variable to pin down expectations of telecommunication investors and subscribers about the nominal price level or about what decision the spectrum authority might make to achieve the targeting price. Therefore, the authority can own the power to make an independent and top-down spectrum policy, i.e., deciding the core telecommunication policy and then mediating the spectrum supply to guide the development of domestic telecommunication industry, instead of a button-up policy-making process, i.e., the spectrum demanding calculation of current industry development guides the spectrum supply policy-making process. APT also helps the spectrum authority operate either spectrum supply changes or interest rate changes to stabilize the access price and achieve their telecommunication policy goal, i.e., GNP growth. The telecommunication investors can also easily factor in the changes of data access price, anticipate development direction of the market, adjust their investment strategy to support long-term growth, and the market uncertainty will be therefore reduced.

APT consists of two parts. First, for a long-term, is that Adjusted User Density algorithm (AUD) calculates the effective online population and corresponding economic activities to reflects the real spectrum demand. Second, for a short-term, APT provides an Aggregate Demand and Aggregate Supply (ADAS) and Investment–Saving and Liquidity preference–Money supply (ISLM) access-pricing targeting model to analyze the macroeconomic effects of different spectrum policy alternatives. The spectrum authority can apply APT to determine the spectrum supply to keep stable price level of telecommunication service, and to support the long-term growth of the economy [6–10].

This work further applies an in-depth case study, which interviews with 10 key personnel in the government and think tanks, to evaluate APT. The case study method also explores the interoperability between stakeholders during spectrum policy-making process in a multiple-stream perspective [11]. Although some studies on spectrum policy have already been conducted, most of these have focused on technology, law, economic perspective. This study intends to investigate the government's point of view to unveil how the interoperability enactment can be achieved in drafting spectrum policy across Taiwan's public, private, and third party.

The contributions of APT are (1) establishing a single and institutional commitment which keeps the spectrum authority from falling into the time-inconsistency trap and insulates the authority from political pressure to undertake an overly expansionary spectrum policy, (2) ensuring predictability, transparency and accountability of spectrum policy-making process to reduce economic and financial uncertainty and to increase the effectiveness of spectrum policy, which are essential in a democratic society, (3) and allowing spectrum policy to focus on guiding the development of domestic telecommunication industries and to respond to shocks from the domestic and foreign telecommunication economy, rather than simply releasing spectrum to lower the online access price.

The author was the spectrum policy staff during 2013–2016 in the Office of Science and Technology (OST), which is a task force of the Taiwan Executive House and helps the government coordinate nationwide science and technology policies [12]. The author in advance coordinated the Executive House and spectrum authority to organize and draft the first version of Taiwan Spectrum Supply Plan in 2015 [13]. As the author has pre-existing relationships with Taiwanese officials and deep engagements in spectrum policy making, this study analyzes the first-hand data regarding the spectrum policymaking in Executive House during 2013～2016, being a unique piece of work to feature in-depth interviews with staffs and major officials who headed the entire spectrum policymaking in Taiwan during 2013～2016.

This paper is organized as follows: Section 2 describes the M2290 in detail. Section 3 provides the details of APT. Section 4 demonstrates the research method and Section 5 applies APT to exam Taiwan spectrum policy as a case study. Finally, Section 6 describes findings and conclusions.

2. Related works: ITU-R M2290

In light of the 4G/5G development, ITU-R publishes M2290 to estimate spectrum requirements for terrestrial IMT (International Mobile Telecommunications) in the year 2020 [1]. M2290 is a spectrum supply targeting method which calculates the spectrum requirement of telecommunication market and suggests the government to re-farm the spectrum allocation and fulfill the requirement of 4G/5G market. M2290 consists of nine steps which are grouping into four phases, as shown in Fig. 1.

The first phase is collecting market data including the radio and service environments. The radio environment are the parameters of macro/micro/pico cell, hot spot, and different radio access technologies (RATGs). The service environment are the service types (e.g., super-high multimedia high multimedia, medium multimedia, low rate data and low multimedia, and very low rate data), and traffic classes (e.g., conversational, streaming, interactive, and background) based on different service usage patterns (e.g., home, office, and public area) and

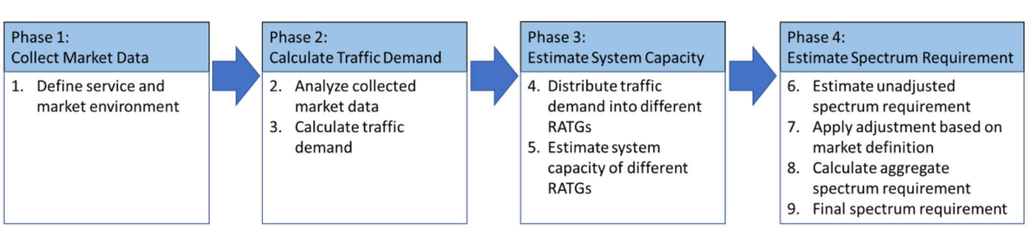


Fig. 1. M2290 flowchart.

telecommunication densities (e.g., dense urban, suburban, and rural).

The second phase is calculating traffic demand consists of two steps: (1) analyzing the collected market data and transforming to market attribute settings, such as user density, session arrival rate per user, average session duration, mean service bit rate, and mobility ratios; (2) calculating the traffic demand (bps) based on the market attribute settings.

The third phase is estimating the system capacity consists of three steps: (1) distributing traffic demands of each service category to each available RATG; (2) to estimate the required system capacity (bps/cell) to support the forecasted traffic demand in different RATGs in different telecommunication densities.

The fourth phase is estimating the spectrum requirement consists of three steps: (1) calculating the raw spectrum requirements (Hz) of different system capacity requirements (bps/cell) using spectral efficiency values (bps/Hz/cell); (2) adjusting the raw spectrum requirements based on the minimum amount of spectrum allocation for each RATG/ISP and the number of overlapping network deployments; (3) summarizing the overall spectrum requirement.

M2290 estimates that the total spectrum requirements in the year 2020 to be 1340 MHz and 1960 MHz for lower user density countries and higher user density countries, respectively [1]. Many countries/economies, such as United Kingdom, Japan, China, Indonesia, South Korea, Australia, Russia, GSMA and Taiwan, modify the methodology utilized in or extended from M2290 to reflect the recent developments in their mobile telecommunication markets [2–5].

The traffic demand estimation step of M2290 is used to calculate the traffic demand by the market data, such as the parameters of user density (U) and so on. However, M2290 presumes the traffic demands of child, adult, and old age are the same, ignoring the diverse internet usage patterns of different age groups [1]. When population ages, the ageing societies decreases the economic activities and telecommunication traffic demand [14,15]. This leads the 5G traffic demands calculated by M2290 is over-estimated, and the government then releases too much spectrum to the telecommunication market, causing unnecessary lower telecommunication service price level (e.g., data access fee) and the following cut-throat competition in telecommunication market.

3. Proposed framework

This study designs an access-price targeting (APT) spectrum policy making framework. APT consists of (1) Adjusted User Density Algorithm (AUD), and (2) Aggregate Demand and Aggregate Supply (ADAS) and Investment–Saving and Liquidity preference–Money supply (ISLM) model in an online access-price targeting perspective. AUD calculates the effective online population as the user density to reflects the real traffic demand of the corresponding population structure. ADAS/ISLM access-price targeting model to analysis the macroeconomic effectiveness of different spectrum policies on national-wide economic indicators and on investigators' decision. The followings subsection demonstrates the details of APT.

3.1. Adjusted user density algorithm

The main idea of AUD is that the user density should be the weighted average population based on the cell phone access time of each age population group. As the line 1–2 shown in Fig. 2(a), AUD first chooses the median age (A^m) of the population which is not skewed so much by extremely large or small age groups, and then calculate the online access weight (W_i) of each age i. Then, as shown in line 3–4 of Fig. 2, AUD calculates the weighted average population as the effective online population $N^{y'}$, and it calculates the effective online population ratio R^y as a parameter to adjust the user density. Finally, the adjusted user density $U^{y'}$ is acquired by R^y and U^y in line 5 of AUD. Fig. 2(b) demonstrates the flowchart that AUD cooperated with M2290.

Furthermore, the inputs of AUD, which are (1) the average cell phone access time for each age and the current population in the current year, (2) the targeted population in the year y, and (3) the User Density U_y estimated in the year y, can be collected from the open data of government statistics and market investigation.

Input:
- The current average cell phone access time (T_i) of each age i and population N^c
- The targeted population N^y in the year y
- The User Density U^y for a scenario in the year y

Output:
- The adjusted User Density $U^{y'}$ for a scenario in the year y

Algorithm:
1. Find the median age (A^m) of N^c, and the corresponding average cell phone access time (T^m)
2. Calculate the weight of cell phone access time $W_i = T_i / T^m$ for each age i
3. Calculate the effective online population in the targeted year y by $N^{y'} = \sum_i N_i^y \times W_i$
4. Calculate the effective online population ratio $R^y = N^{y'}/N^c$
5. Get the adjusted User Density $U^{y'} = U^y \times R^y$ in the year y

3.2. ADAS/ISLM access-price targeting model

ADAS and ISLM model are macroeconomic models that explain price level, interest rate and GNP through the relationship of aggregate demand and aggregate supply as shown in Fig. 3.

This study applies ADAS to evaluate the effectiveness of various policies on two national-wide economic indicators: Gross National Product (GNP) and the Implicit Price Deflator (called IPD or price hereby) [6–10]. GNP is the market value of all the goods and services produced in an economy, and IPD is a measure of the level of prices of goods and services in an economy. As shown in the bottom of Fig. 3, ADAS consists of a downward-sloping AD (aggregate demand) curve and an upward-sloping AS (aggregate supply curve) in the price and GNP. AS curve is the amount of goods and services in the telecommunication market available for buyers at all possible price levels. AD curve is the amount of goods and services in the economy that will be purchased at all possible price levels. The intersection of AD and AS curves indicates an equilibrium price level. That is, the AD and AS curves intersect when the quantity of telecommunication service demanded equals the quantity of telecommunication service supplied.

On the other hand, this study adopts ISLM to predict the investors' decision of the money they intent to invest and the interest rates they expect to receive [6–10]. Two intersecting curves are placed in ISLM model, as shown in the top of Fig. 3. The downward-sloping IS (investment saving) curve represents all combinations of earned interest rate (called rate hereby) and GNP that will keep the telecommunication market in equilibrium, given that total private investment equals total saving. The upward-sloping LM (Liquidity preference–Money supply) curve shows the combinations of earned interest rate and GNP for which the money market is in equilibrium. Equilibrium in money market means the demand of money equals the supply of money. The money demand includes transaction demand and asset demand, where the former is the willingness to hold money for everyday living, and the later means the desire to have money for investment other than those necessary for living. The money supply is a policy tool that the government leverages commercial banks to loan money for the market in accordance the national-wide policy direction.

Many technology/market changes can shift the AD/AS and IS/LM curves. For example, the improvement of 4G/5G technology shifts the AS and IS rightward because it increases the productivity, resulting in firms producing more output with the same amount of resources and increasing aggregate supply. As shown in Fig. 3, the AS and IS curves move rightward because of 4G/5G technology, the original equilibrium point A then moves to B in ADAS and ISLM model, and therefore the earned interest rate decrease (from R_A to R_B), telecommunication

Input:

- The current average cell phone access time (T_i) of each age i and population N^c
- The targeted population N^y in the year y
- The User Density U^y for a scenario in the year y

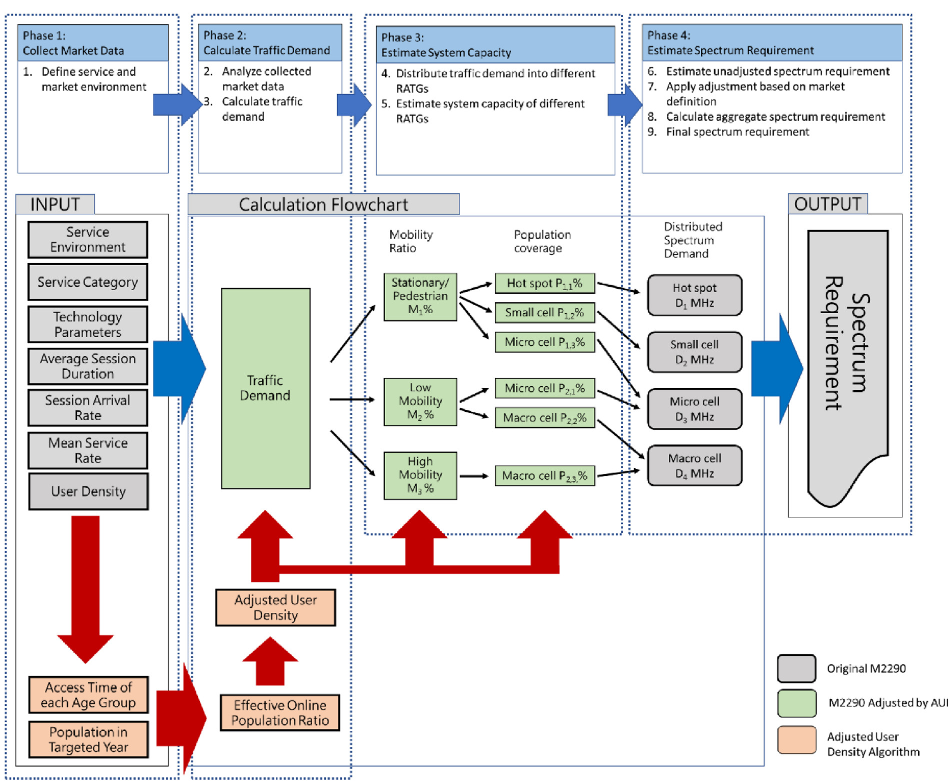
Output:

- The adjusted User Density $U^{y'}$ for a scenario in the year y

Algorithm:

1. Find the median age (A^m) of N^c, and the corresponding average cell phone access time (T^m)
2. Calculate the weight of cell phone access time $W_i = T_i / T^m$ for each age i
3. Calculate the effective online population in the targeted year y by $N^{y'} = \sum_i N_i^y \times W_i$
4. Calculate the effective online population ratio $R^y = N^{y'} / N^c$
5. Get the adjusted User Density $U^{y'} = U^y \times R^y$ in the year y

(a) Adjusted User Density Algorithm



(b) Adjusted User Density Flowchart

Fig. 2. Adjusted user density algorithm and flowchart.

service price decreases (from P_A to P_B), and GNP in telecommunication sector increases (from Y_A to Y_B). On the other hand, when new applications emerge, such as 4KTV or new online gaming, the aggregate demand of telecommunication service rises and AD/LM curves move rightward. As shown in Fig. 3, the equilibrium point B then moves to C in ADAS and ISLM model, and therefore the earned interest rate

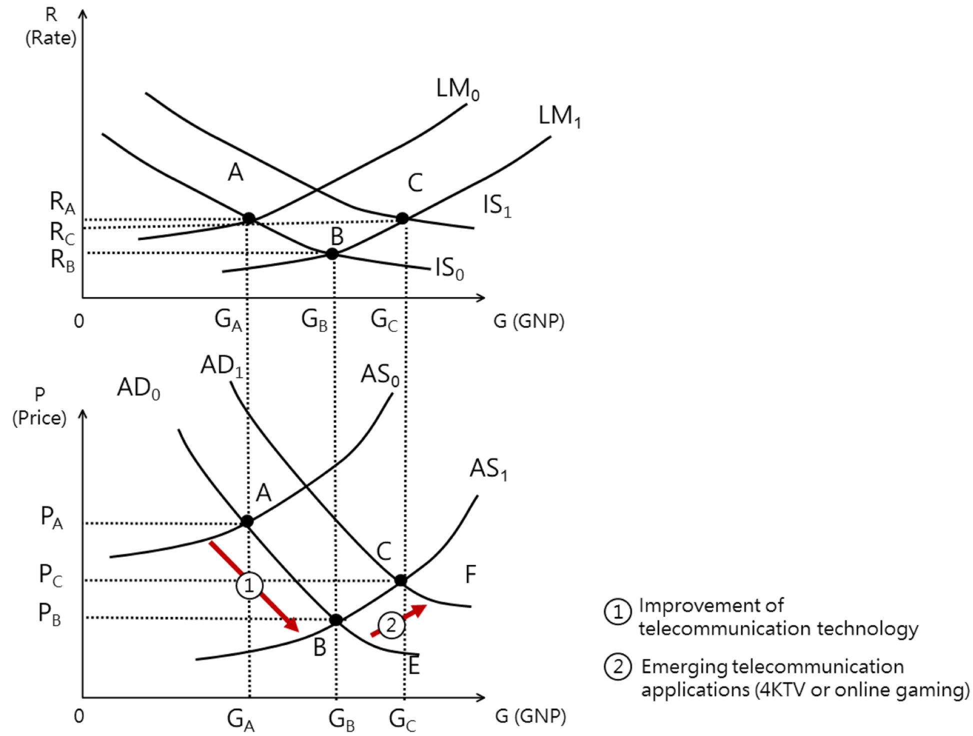


Fig. 3. ISLM/ADAS analysis model.

increases (from R_B to R_C), telecommunication service price increase (from P_B to P_C), and GNP in telecommunication sector increases (from Y_B to Y_C).

In respond to the technology/market change and maintain stable data access fee, as shown in Fig. 4, the spectrum authority can target the online access price (as the point P_T and R_T shown in Fig. 4) as a single, time-consistent and institutional commitment, and periodically announces P_T to demonstrate the predictability, transparency, accountability commitment of a spectrum policy which are essential in a democratic society. That is, the authority applies the ADAS/ISLM model to observe how the market shock or technology change shifts the ADAS and ISLM curves. If the online access price goes awry from P_T or the corresponding earned interest rate goes awry from R_T, the authority can operate different policy tools to shift back the curves and maintain the data access fee close to P_T.

For example, when the telecommunication economy is over-heated, which means the aggregate supply is higher than the aggregated demand, the AS curve moves rightward, causing that the online access price is lower than P_T and the earned interest rates is lower than R_T. The authority may try to cool-down the market by shrinking the spectrum supply or by regulating the financial activities in telecommunication market, resulting in the ASLM curve moves leftward to P_T and R_T, respectively. On the other hand, once the telecommunication economy is under recession, which means the aggregate demand is lower than the aggregated supply, the AD curve moves leftward, causing that the online access price is higher than P_T and the earned interest rates is higher than R_T. The authority would attempt to stimulate the market by pursuing expansionary fiscal policy, such as increasing spending on public telecommunication infrastructure or reducing taxing, leading that the AD/IS curve move rightward to P_T and R_T, respectively.

Therefore, the investors can apply the proposed ISLM/ADAS Access-Price Targeting Model to modify their investment strategy and maximize their long-term profit. That is, the investors first observe the online access price or the corresponding earned interest rate goes awry from P_T or R_T, responsively, and then predict what policy the spectrum authority might choose to guide the online access price back to the targeting value.

4. Research method

Technological advancements in 4G and upcoming 5G gives birth to the Internet of Thing (IoT), which provides more direct integration of the physical world into the telecommunication-based platform, resulting in improved scale, effectiveness and efficiency of economic benefit for our society. This leads that spectrum resource is no longer as carriers for documents, but as the medium of exchange for intelligence between different industry sectors in the virtual world, tightening credit and capital gains of most industry sectors. This leads that spectrum policy becomes multifaceted and complex, and we cannot return to the past and then replicate the spectrum policy to understand the nature of the policy-making processes considering spectrum demand and supply in the ageing society. This study, therefore, employs the case study approach with in-depth interviews because of its effectiveness to explore innovative thinking on evolving stakeholders' cognition and actions on spectrum policy making [16].

Taiwan spectrum policy during 2013–2016 is selected as the case, due to that Taiwan is capable to roll out its own spectrum policy and one of the major ageing society in the world. Data are abstracted from first-hand data, internal meeting minutes, government official website, and intensive interviews of 10 key-people. All interviews are conducted with a minimum of 60 minutes for each session between July-December 2017. Interviewees are prominent stakeholders for drafting spectrum policy in Executive House, competent authorities, major think tanks, and scholars. Three key government officials are interviewed twice; two of them is major staffs for the national spectrum policy in the Executive House. Two interviewees from competent authorities supervise all spectrum policy during 2013–2016. Three key interviewees are from the think tanks to help the Executive House and competent authorities for spectrum policy drafting and cross-organizational coordination. Two scholars are experts who dedicate to 4G/5G telecommunication technology developing and spectrum management.

Data analysis is based on the grounded theory which consists of three coding steps to explore insights in the underlying phenomenon of the spectrum policy making [17]. The first step is open coding which transforms the interview data with open-mindedness to pseudo-

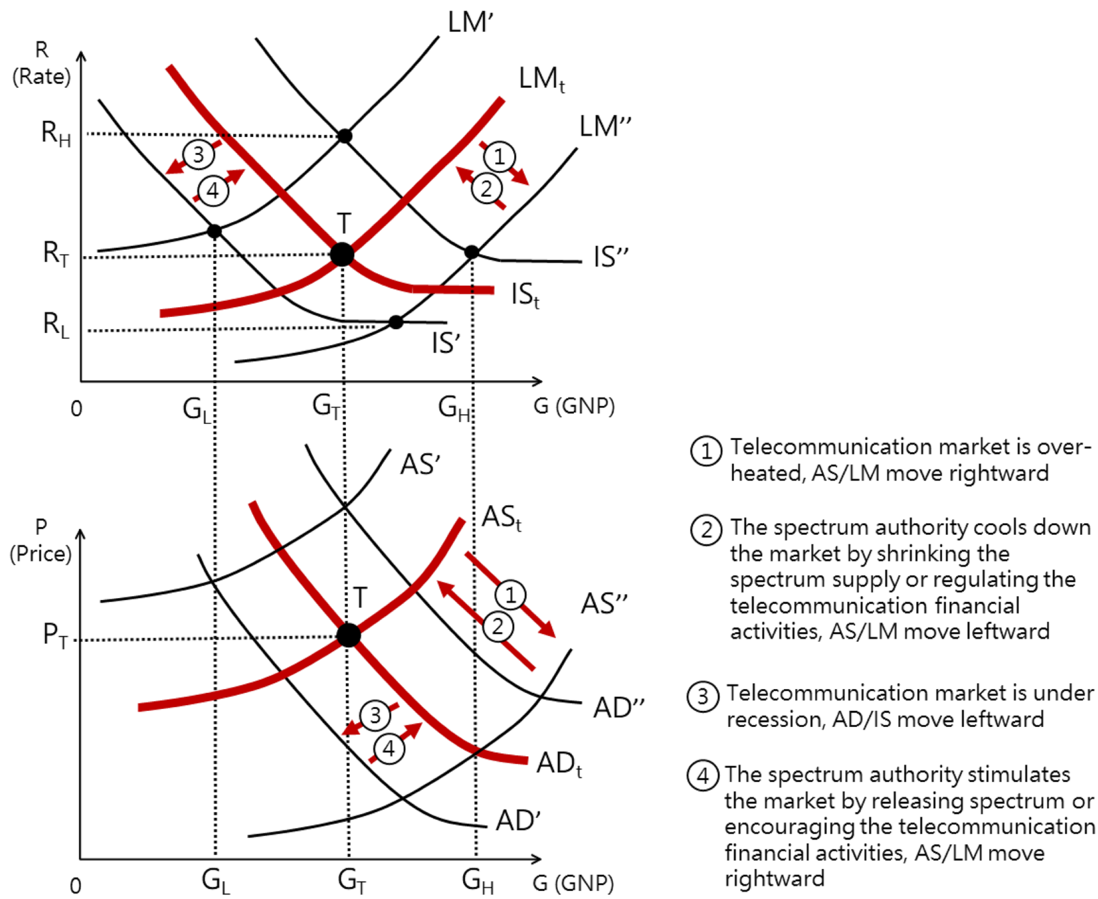


Fig. 4. ISLM/ADAS access-price targeting analysis.

construct. Cross-check between the collected open data from government official site and the pseudo-constructs are also applied. Second, the axial coding is to select a core construct and link this core construct to all pseudo constructs from the interview data. This step is an iterative and intensive process of induction and deduction to ensure reliability and validity of the interview data and the abstracted concept. The final step is selective coding to build a theoretical framework that connects all pseudo constructs to explain the basic decision-making structure of the spectrum policy in the ageing society.

5. Results and discussion

We choose Taiwan as the case study to validate our proposed spectrum demand estimation framework APT, since Taiwan government periodically collects comprehensive telecommunication market data, and releases them with corresponding spectrum policy to the public. This work further explores the interoperability between stakeholders during spectrum policy-making process in a multiple-stream perspective [11]. The spectrum demand estimation result of APT is described in Section 5.1. The case analysis of Taiwan spectrum policy during 2013–2016 are provided in Section 5.2.

5.1. Spectrum demand estimation result by APT

Tables 1 and 2 demonstrate the inputs of APT including (1) the average mobile phone access time (T_i) of each age i and (2) the population data from 2013–2030. The market and technical parameters follow the settings of Ministry of Transportation and Communications in Taiwan [2].

The Mobile phone access time of each age group in Taiwan is collected by National Development Council in Taiwan [18]. Table 1 shows that the mobile phone access time dramatically decreases when people aged from 30 years old. The mobile phone access time is set to zero for the age group 1–11 because it is presumed that the child should only use the mobile phone through Wi-Fi under parental guidance.

Table 1
Mobile phone access time for each age group in Taiwan.

Age group	1–11	12–19	20–29	30–39	40–49	50–59	60 ~
Mobile phone access time in minute	0	204	281	203	202	134	93

The population data is collected by National Development Council in Taiwan as shown in Table 2 [19]. Table 2 also demonstrate that Taiwan is becoming an ageing society because the population will decrease from 2020, and the median age and the population above 60 years old increases from 2013.

The spectrum requirement estimated by M2290 and APT are shown in Table 3. APT considers that Taiwan is becoming an ageing society in which the economic activities decrease and therefore the effective online population decrease. Therefore, the spectrum requirement estimated by APT decrease from 1070 MHz in 2013 to 1025 MHz in 2030 despite the total population is slight increased from 2013 to 2020. On the other hand, the spectrum requirement estimated by M2290 is in direct ratio to the population.

5.2. Validation of APT

It is difficult to validate APT in a straightway, because we cannot return to the past and then replicate the spectrum policy. But the economic data can be applied as the indirect evidence to support APT. That

Table 2
Taiwan population structure between 2015–2030.

Year	Population	Median Age	1–11	12–19	20–29	30–39	40–49	50–59	60 ~
2013	23,373,517	38	2,500,859	2,402,694	3,252,033	3,938,272	3,671,985	3,539,321	4,068,353
2015	23,492,074	39	2,457,079	2,230,536	3,190,390	3,926,998	3,620,156	3,608,663	4,458,252
2017	23,571,227	40	2,437,779	2,012,166	3,223,754	3,732,974	3,680,233	3,634,503	4,849,818
2020*	23,653,294	41	2,404,592	1,769,805	3,100,665	3,491,958	3,777,388	3,638,609	5,470,277
2025*	23,586,431	45	2,252,839	1,615,753	2,652,500	3,208,943	3,879,182	3,504,495	6,472,719
2030*	23,294,396	48	1,948,503	1,679,294	2,135,103	3,120,026	3,453,186	3,662,775	7,295,509

Table 3
Spectrum requirement.

Year	Spectrum Requirement by M2290 (MHz)	Spectrum Requirement by APT (MHz)
2013	1538	1,070
2015	1539	1,068
2017	1545	1,065
2020*	1546	1,058
2025*	1545	1,043
2030*	1537	1,025

is, APT estimates that the spectrum requirement decreases from 1070 MHz in 2013 to 1025 MHz in 2030, and this means the AD/IS curves may move leftward, leading that the Implicit Price Deflator (IPD) and earned interest rates may decrease, as the arrow 2 shown in Fig. 5.

Table 4 demonstrates that the macroeconomic data collected by Taiwan government matches the analysis result of arrow 2 in Fig. 5. That is, the IPD of telecommunication continuously decreases from 2013 to 2017; the negative value of Operating Income Growth Rates (OIGR) and Operating Revenue Growth Rates (ORGR) of the three biggest ISPs in Taiwan demonstrates that the earned interest rates also continuously drop from 2013 to 2017.

On the other hand, the GNP of telecommunication industry increases in 2014 and 2016 due to the increasing spectrum supply by the spectrum authority in Taiwan [13], but it decreases in 2015. These results also match analysis of arrow 1 and 2 in Fig. 5.

It should be noted that, the diminishing marginal utility will occur if the authority overissues spectrum to stimulate the telecommunication market. This means that the decrease in the marginal (incremental) output of GNP as the increase in spectrum supply. Once the spectrum supply exceeds the spectrum demand especially in ageing society, according to the ADAS/ISLM model as show in Fig. 6, GNP of telecommunication market will not increase and the earned interest rate will be too low to decrease. This may trigger liquidity trap that the low interest rate affects investors concerning the current financial state of telecommunication market, resulting in selling bonds that is harmful to the telecommunication economy.

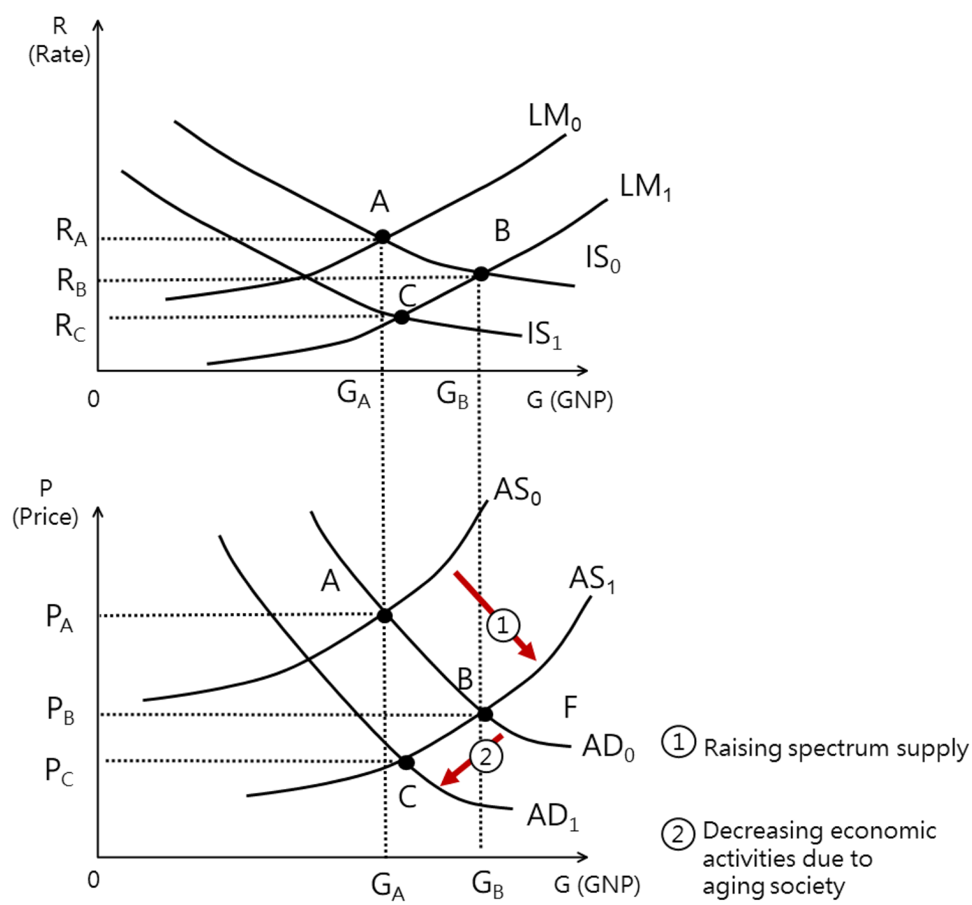


Fig. 5. ADAS/ISLM analysis model for Taiwan spectrum policy during 2012 ~ 2017.

Table 4
The economic effects of releasing spectrum during 2012–2017. [13,20].

Year	Releasing New Spectrum	GNP of telecom. (Million NTD)	AGR of GNP (%)	Implicit Price Deflator	AGR of IPD (%)	ISP Chunghwa Telecom (%)		Taiwan Mobile (%)		FarEasTone (%)	
						OIGR	ORGR	OIGR	ORGR	OIGR	ORGR
2013	0	382,649	–	87.58	–	−1.31	−3.06	−2.02	−2.71	−0.65	−3.20
2014	270MHz	383,047	1.33	84.27	−3.78	−4.69	−6.75	−4.58	−7.46	−4.36	−11.32
2015	0	385,178	−0.76	78.32	−7.06	−3.24	−5.56	−2.10	−4.15	−3.53	−8.50
2016	190MHz	388,993	0.99	74.42	−4.98	−2.00	−5.85	−2.23	−3.65	−2.30	−7.06
2017	0	No Data	No Data	No Data	No Data	−3.56	−5.70	−3.73	−5.95	−5.04	−8.10

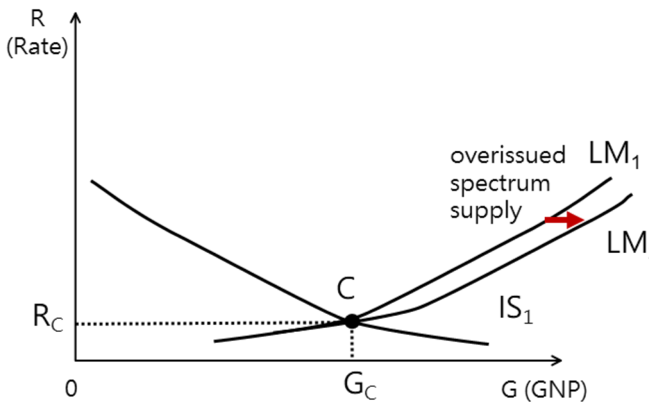


Fig. 6. Liquidity trap may occur when spectrum is overissued.

5.3. Discussion: case study of taiwan spectrum policy during 2013～2016

In this subsection, this study attempts to explore how the government applies the APT to drafting spectrum policy in ageing society, especially in Executive House and National Council, rather than ministerial level or commercial strategy making.

Based on the interviews, internal meeting minutes and policy drafts during the spectrum policymaking during 2013–2016, minds of different stakeholders jump around different parts of the conventional linear decision-making process (Fig. 7) in the process of forging a spectrum policy. As the description of interviewees in Executive House:

> *In practice, the governors, staffs, scholars and advisors have different education and social backgrounds. In order to meet consensus, their minds jump randomly from decision phase back to explore and collect alternatives, then to adjust problem definition, finally back to decision phase, in what seems a very untidy process and which in no way resembles a simple linear problem-solving process to make a policy statement.*

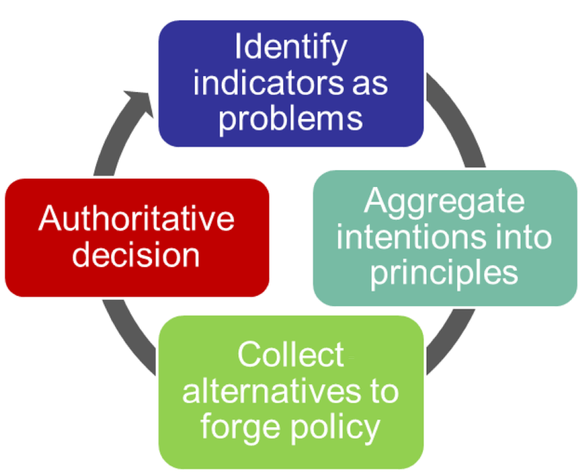


Fig. 7. Conventional stage-based process.

That is, after APT estimates the spectrum demand as the theoretical foundation for spectrum policymaking, the spectrum policy entrepreneurs are then well-informed and fully understand. Even so, from the multiple-stream perspective [11], they must jump around to seek and bring the 'streams' together, i.e., problem stream, solution stream, and political stream, to form a wave. And they watch and ensure the public sector, private sector, and third sector spontaneously follow and catch the wave – as 'surfers waiting for the big wave'– instead of directly executing policy and asking people to comply with [11]. Therefore, this case study finds that the policy-making process in Taiwan is more like a process of biological evolution, as the argument of John Kingdon that policy-making process resembles a process of biological natural selection [11]. Fig. 8 shows the Biological Evolution based Policymaking process (BEP) summarized by this case study, and it demonstrates several characteristics embedded in BEP.

First, a policy draft requires ideas to survive and grow, just like an organism needs nutrients to construct, maintain, and reproduce itself. As similar to that nutrients come from everywhere and cycle in the environment, ideas come from anywhere rather than one single actor's brainchild or an explicit source. The bottom of Fig. 8 demonstrates that, as described in [11], ideas float in the "primordial soup" around communities of researchers, government and congressman staffs. They are amended, combined, and drafted via speeches and discussion in response to the government/market requirement; they are also decomposed from the outcomes of the current live-policy and recycles by another policy. Furthermore, there is no win-win spectrum policy, since one economic sector rises may cause another fall. Therefore, it would be difficult to determine that one spectrum policy was more important than another spectrum policy, any effort to estimate the outcomes of or to defend the success of a policy, from a long-term view, is futile, unless for politic reasons. As one respondent summarized this phenomenon:

> *Governors and congressman do not have time to build new policy in a flash of insight. They always borrow ideas existed in somewhere else. Ideas to build a policy may come from anywhere, even from a failure policy or catastrophe accident. The only possible way to guarantee the quality of any spectrum policy is to keep the idea growth in sufficient volume (amount of ideas), velocity (speed of idea cycling), and variety (range of idea types and sources).*

Second, just like proteins, carbohydrates, and nucleic acids compose the three major macromolecules essential for all known forms of life, a policy is drafted by three types of ideas, which are condition, alternative, and intention, to demonstrate what problem the government wants to solve by what solution under which suitable political aura. Condition means the indicators (the status of something) or crises (eye-catching event), such as the GDP and economic crisis, respectively. An alternative is the accumulation of knowledge, theory, technology, and perspectives to change certain conditions. Intention implies the desire, such as national mood, election results, or changes of administration, to pursue one of fair ISPs competition, internet censorship, and net neutrality. Once some conditions come to the attention and are identified as a problem, an alternative is advocated as a solution, and intentions

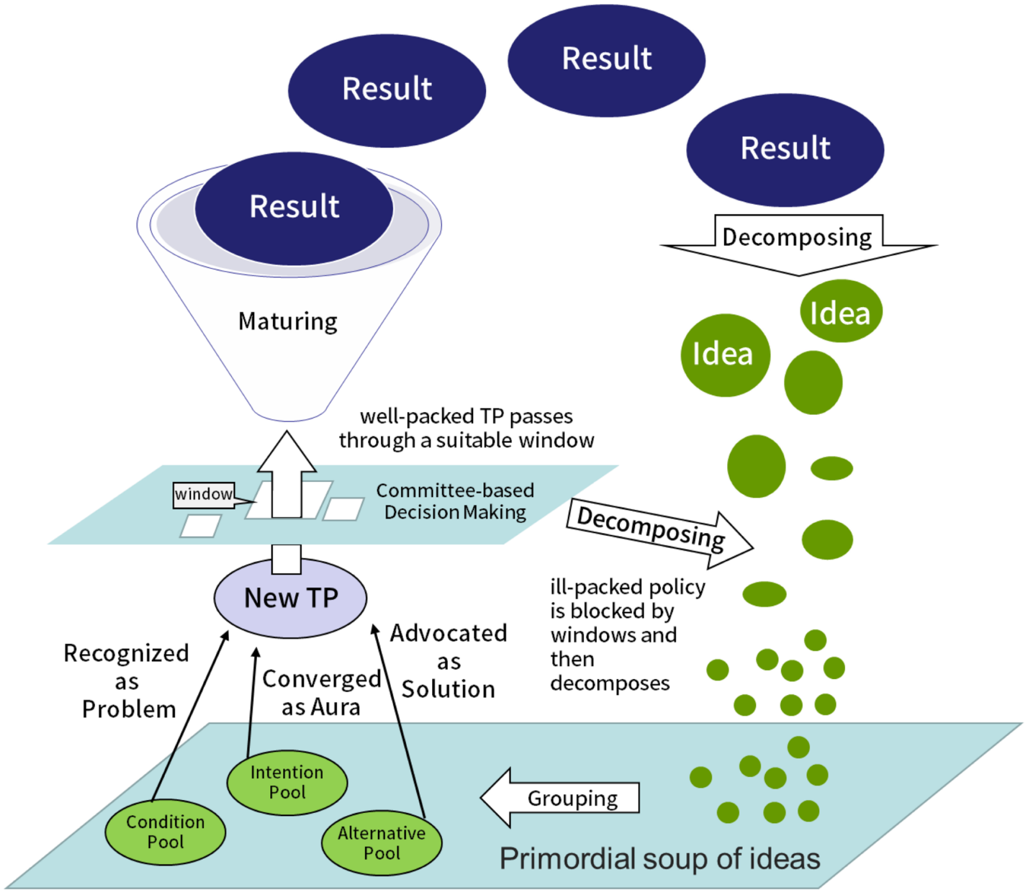


Fig. 8. BEP framework.

are converged as aura, the policymaker will pack them and draft a policy, which is presented in the left-bottom of Fig. 8.

Third, the process to draft a policy is just like the way to assemble a jigsaw puzzle. Several respondents of the government and congressman staffs described the similar way of drafting policy:

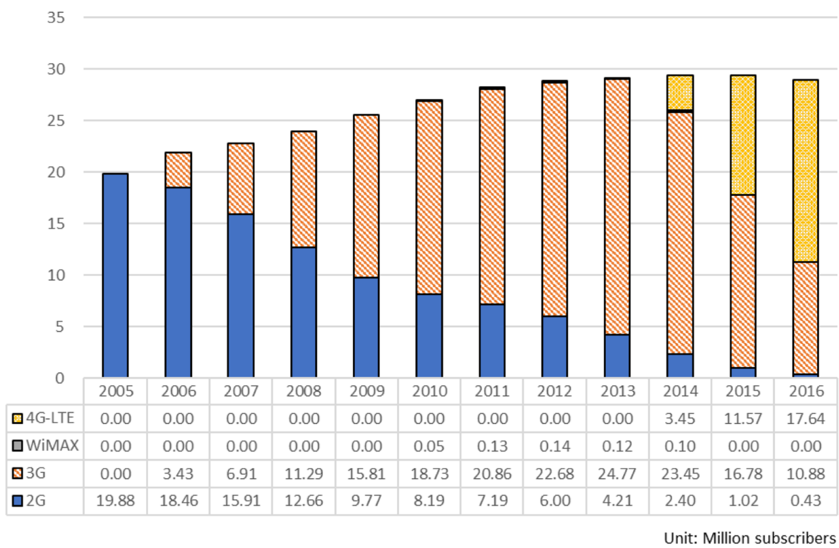
> *As the first thing before starting any jigsaw is to sort pieces by color or shape, you have to sort ideas into of pools of condition, alternative, and intention before drafting a policy. Then you just pick one piece from one pool, pick another one from another pool, make sure if they fit each other, and repeat this process after time is up to propose a policy. The outcome of a policy depends on what size of jigsaw you assemble in a limited time period, and the characteristics of a policy are affected by the sequence of assembling the pieces.*

As described above, different sequences of assembling the pieces into a policy would demonstrate different biological evolution trait, even the combination of pieces for policies are the same. For example, if the first piece of policy is from an alternative pool, this policy would trigger disruptive selection. That is, at first, a new telecommunication "species" (industry) will emerge and evolve, then the new and original industries divided the related stakeholders within a nation into two distinct groups, and the two industries finally formed a symbiosis relationship.

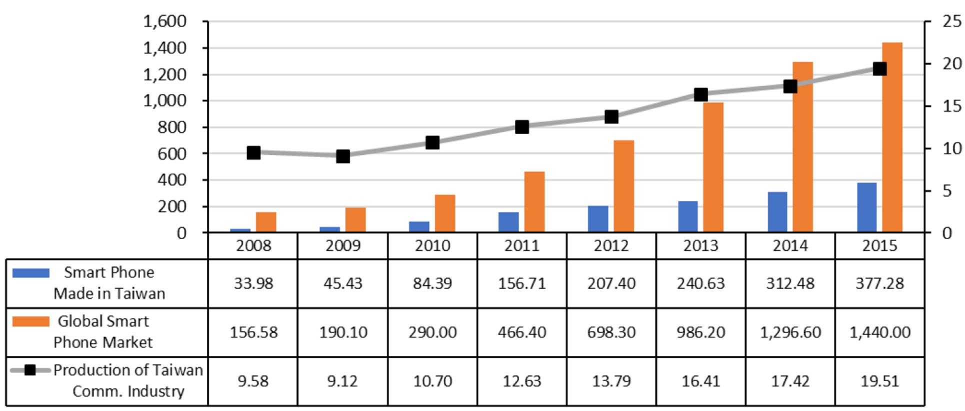
Fourth, a drafted policy can become a policy only when it adapts inertias of societies, just like natural selection: a life can survive only when it follows the traits that the natural environment confers a reproduction advantage. There are three inertias embedded in Taiwan societies including technocrat, anti-malpractice, and nationalism. Technocracy is a system of governance where decision makers are the unelected experts (also called technocrats), intending to solve societal problems through technology-focused solutions instead of the mindsets of economists or bureaucrats. Anti-malpractice is to address the various forms of negligence or incompetence on the part of a professional, especially in financing activities. Nationalism means people seek national identity and ideology for its culture or ethnicity that holds that group together in a geographical region. In addition, Taiwan bureaucrats apply committee-based deliberation process to make sure a draft policy fits inertia, where a committee is assembled by stakeholders of relevant expertise from different societies. One of the respondents eloquently stated the point:

> *No body leads anybody else to make a drafted policy to be a policy, but natural selection does. There may be real people labeled as the originator of a policy, but in reality, no one started the original behavior. The key is that people including experts are exposed to the same information due to the communications network permeating everywhere, resulting in unconnected individuals create seemingly concerted efforts to think and behave similarly. So, bureaucrats do not evaluate a policy through "classical scientific way" but observe the "data sample", which is called committee with members "sampling" from the society, to estimate upcoming natural selection of the whole environment regarding this policy. Otherwise, the bureaucrats must pay tremendous prices to convince the public, even though they have deeper and unique insights of a policy than anyone.*

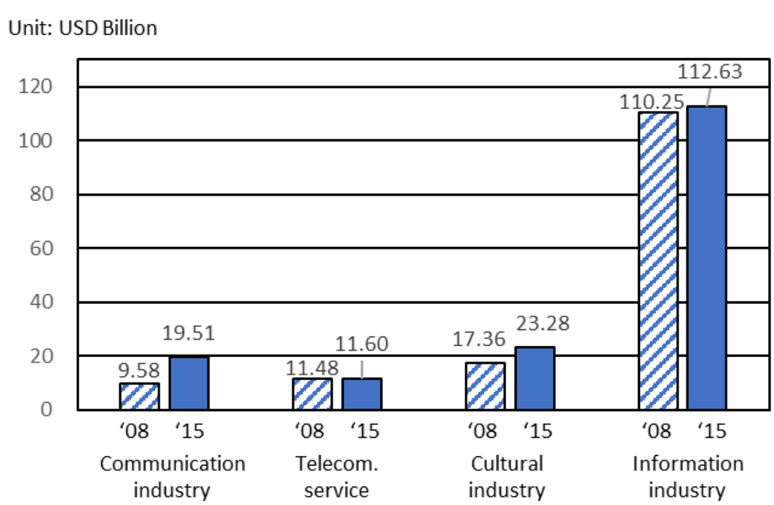
As a result, Fig. 9(a) demonstrates the spectrum policy during 2013–2016 shifted the telecommunication development from 2G/3G to 4G LTE successfully by mediating bandwidth supply, leading that 2G/3G subscribers are migrating to 4G-LTE. This strategy also boosted the development of Taiwan domestic communication industry as shown in Fig. 9(b), causing the rising of bandwidth supply and decreasing transmission fee, as shown in Table 5. Furthermore, this can suggest a cause of the raising of cultural industry production and economic



(a) The subscribers of 2G/3G/WiMAX/LTE between 2005~2016



(b) Production of Smart Phone in Taiwan



(c) Production of telecommunication related industries

Fig. 9. The outcomes of spectrum policy during 2013–2016 [21].

sectors sales through the network, paving the foundation of future data economic development, as shown in Fig. 9(c). However, the stagnation of telecommunication service and information industry during 2013–2016 might partially due to low peering fee and over expanded bandwidth supply. That is, the server side of the Internet always requires peering fee as low as possible to strengthen its unfair market

Table 5
The bandwidth supply during 2013–2016 [21].

	2012	2016
Downlink transmission rate	1.98 Mbps	49.96 Mbps
Uplink transmission rate	0.32 Mbps	19.39 Mbps
Flat rate	23.75 USD	21.84375 USD

competition, as the member of respondent said:

> *A richly funded content provider definitely needs low peering fee, such as Google, Youtube, or Netflex, who owns a performance advantage over smaller competitors by high performance servers and high quality bandwidth resources. This kind of content providers is depleting the limited network resource and crowding out the novel but weak content providers, causing the stagnated development of telecommunication service and information industry. A dynamic spectrum supplying system to mediating the peering fee is needed to macroeconomically balance the innovation and the economic effectiveness between telecommunication related industries.*

On the other hand, raising bandwidth supply conventionally does reduce transmission cost per data unit, stimulating additional demand for capital investment and novel telecommunication services. However, the overissued spectrum supply might occur once service already has sufficient bandwidth to transmit data. In this case, as the government continuously increases the base of bandwidth supply, such as the short interval between 4G spectrum auctions, ISPs and corporations foresee high data transmission rate has no effect on the real economy and simply choose to hold cash in hand without any advanced investment. All respondents described the phenomena of liquidity trap of overissued spectrum supply:

> *The political appointees, under the pressure from the policy goal of macroeconomic growth, release too much spectrum and too many charters for telecommunication and media industry. The ageing society does not need the overissued spectrum supply. First, ageing people like us roughly need about* 2 Mbps *network bandwidth in most telecommunication scenarios, and, otherwise, ISPs should offload the traffic to WiFi. Second, the domestic content providers in relatively small society,* i.e., *Taiwan, cannot generate enough content to fill up* 100 Mbps *bandwidth, causing more importation of foreign content and deficits of domestic cultural industry, from a macroeconomic perspective. This phenomenon may be treated as a new kind of trade deficit especially in content industry.*

In addition, is there any guideline that the spectrum policy could follow and how to link the spectrum demand estimation to the policy making? Most respondents expressed the same concern and suggestion:

> *There are three times of spectrum releasing for* 4G *and following* 5G. *The timing of the first spectrum releasing was slightly late, comparing to other countries. Therefore, operators demonstrated their enthusiasm, and the bid for spectrum auction was 2.3 times higher than expectations. The operators' passion then cooled down because of* ***the law of diminishing marginal utility*** *in the second time and third time of spectrum releasing. Part of the spectrum was surprisingly failed to auction out in the third time of spectrum releasing. The reason might be that the administrative officers followed the philosophy of Keynesian economics and tried to expend spectrum supply to stimulate employment and economic development. However, the telecommunication market does not need so much spectrum. The market only wants the government ensures predictability, transparency and accountability of spectrum policy to reduce economic and financial uncertainty. The government therefore should keep the online access-price stable to pin down expectations of telecommunication investors/subscribers about the nominal price level and about what decision the spectrum authority might make to achieve the targeting price, rather than simply releasing the spectrum and lowering the online access-price. In other words, the playbook of spectrum authority might be better to describe how to dynamically mediate the spectrum supply to target the online access-price, to guide the development of domestic telecommunication industries, and to respond to shocks from domestic and foreign telecommunication economy, just like the relationship between the central bank and its monetary policy.*

6. Conclusions

The spectrum policymaking framework APT considers the magnitude and speed of ageing population structure on spectrum demand and calculate the spectrum demand in different age group. The estimated spectrum demand drops from 1070 MHz in 2013 to 1025 MHz in 2030, comparing to that calculated by M2290 are 1538 MHz in 2013 and 1537 MHz in 2030. APT, on the other hand, provides an ADAS/ISLM Access-Price Targeting Model to evaluate the impacts on spectrum demand, the telecommunication market, and macroeconomics in a short term.

It is difficult to validate APT in a straightway, but the economic data can be applied as the indirect evidence to support APT. The economic data published by the Taiwan government demonstrated that (1) the telecommunication price level and earned interest rate decreases, when the population ages between 2013–2017; (2) the GNP decreases when population ages; (3) the GNP increases when the spectrum authority releases more spectrum to stimulate the telecommunication market in ageing society. Further, the ADAS/ISLM model argues that the diminishing marginal utility will occur and then cause liquidity trap if the spectrum authority overissues spectrum to the telecommunication market. This leads that investors will sell bonds of telecommunication service providers that is harmful to the telecommunication economy.

This study also conducted a case study to validate APT and explores the Biological Evolution based Policymaking process (BEP). The case study demonstrates that how the staffs of Office of Science and Technology (OST) in Taiwan Executive House shape spectrum policy based on APT and BEP during 2013 ~ 2016. The case study furthermore suggests that the playbook of spectrum authority might be better to describe how to dynamically mediate the spectrum supply to target the online access-price, to guide the development of domestic telecommunication industries, and to respond to shocks from domestic and foreign telecommunication economy, just like the relationship between the central bank and its monetary policy.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.csi.2018.11.003.

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