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A Compensation Model Developed to Liberalize Spectrum in the 4G Era

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Abstract

Because fourth-generation (4G) mobile communications services are rooted in heterogeneous multibands, a unified management regime fails to accommodate spectral heterogeneity. This study examined an adequate regime in the 4G era that maximizes spectrum efficiency. A conjoint analysis was conducted to assert the policy preferences of Taiwan's mobile operators, including second generation (2G), third generation (3G), and wireless broadband access (WBA) operators.

The results of the conjoint analysis indicated that the WBA operators were highly supportive of spectrum usage rights, such as technology and service neutrality and secondary trading. The 3G-only operators prioritize no granted tender period after license expiration, whereas the 2G incumbents mostly emphasize refarming on their bands. Regulators are encouraged to create a differentiated spectrum management regime that tailor individual firms' needs and increase their willingness to efficiently use spectra.

First, the WBA operators should be allowed for secondary trading in their underused spectrum. Second, the 2G and 3G operators should be able to perform refarming. Finally, the recall of the 2G bands should be mandated once the 2G incumbents fail to satisfy the set efficiency criteria to avoid hoarding behaviors. Thus, the differentiated spectrum management regime could neutralize the propagation characteristics of different bands to maximize long-term use efficiency.

Keywords: spectrum management, spectrum usage rights, tender period, technology neutrality, service neutrality, secondary trading, recall, refarming, spectrum caps

1 Spectrum management for innovation

Mobile communication was developed to address consumers pursuing mobility, and has swiftly become a growing sector in telecommunications. In 2008, 65 developed countries exhibited a 100% mobile penetration rate. Additionally, the average penetration rate of mobile communications in developing countries was approximately 80% (International Communication Union (ITU), 2010). The rapid growth in mobile services highlights the demand for electromagnetic frequencies available for network access. Because a spectrum is considered a scarce input factor, allocating limited bandwidth to designated parties becomes a crucial challenge in developing mobile services.

Currently, spectrum management is being evaluated because of the launch of fourth-generation (4G) mobile communications services. Unlike the second-generation (2G) or the third-generation (3G) communication services that were deployed at the same band slots, 4G services are harbored on heterogeneous multibands such as 700 MHz, 800 MHz, 900 MHz, and 1800 MHz. The various propagation characteristics of different bands certainly influence operators' network costs and their preferences regarding the spectrum management regime. Consequently, designating a regime that can accommodate band differences and increase spectrum use efficiency in the transition to 4G technology is inevitable. Policymakers are left to question whether the unanimous framework used to govern spectrum allocation and assignment remains applicable to 4G services. In other words, they question whether the regulatory framework should be differentiated to neutralize band differences.

Although several propagation characteristics influence the value of bands that can be reflected by the bidding price at auctions, few countries have adopted auctions in assigning spectrum frequencies. Thus, optimal regulation could be an alternative to adjusting band heterogeneity. Particularly during the situation in which spectrum

resources are further concentrated by a few operators through auctions, the renovation of the spectrum management regime may be a buttress to defend competition. When various bands do not differ because of the renovated and differentiated spectrum management regime, operators can plan an integrated approach to using spectrum frequencies without being constrained by limited bandwidth in individual bands. This undoubtedly provides small service providers niches in competing against incumbents. The variety and diversity of spectrum use is thus achieved.

Taiwan underwent an auction of mobile broadband services (i.e., 4G), which contained a total of 270 MHz bandwidths in 700 MHz, 900 MHz, and 1800 MHz bands. The limited rights of secondary trading were assigned to those bands for the first time. Nevertheless, 2G, 3G, and wireless broadband services (WBA) in 2500–2690 MHz are still barred from secondary trading and full technology neutrality. Taiwan has already exercised a differentiated management regime to a certain degree. The efficacy of Taiwan's regime is worthy of study because it can elucidate the establishment of adequate spectrum management in 4G transition. This study examined Taiwan's differentiated regime and derived a regulatory framework to accommodate the various propagation characteristics of heterogeneous bands according to the operators' policy preferences obtained through a conjoint analysis.

The remainder of this paper is organized as follows: Section 2 introduces various management mechanisms of spectrum allocation and assignment in Taiwan. Section 3 discusses relevant literature concerned with spectrum management. Section 4 addresses the four policy attributes of the spectrum management regime based on literature review and in-depth interviews. Section 5 presents the estimation method and data used in conjoint analysis and presents the results of the ordinary least square regression model and a comparison of the policy preferences among the 2G, 3G-only, and WBA operators. A trajectory of spectrum management during 4G transition is

proposed in Section 5. Finally, Section 6 concludes the paper and provides a recommended direction for future research.

2 Taiwan's move to spectrum management

Since the 1990s, numerous mobile communication services have been issued by the National Communication Commission (NCC) and its predecessor, the Directorate of General Telecommunications (DGT), in Taiwan. Table 1 shows the growth of major mobile communication services, including BB Call, CT2, 2G, personal handset service (PHS), 3G, and WBA; 2G prevailed to become the dominant technology in the early 2000s until 3G took off. BB Call, CT2, and PHS once seized certain market shares, but eventually lost to mainstream mobile communication technology. Thus far, WBA has yet to attain enough customers to entail economies of scale.

[Table 1 inserted here]

The 2G services were licensed in 900 MHz and 1800 MHz bands through a beauty contest in 1996. In addition to the incumbent Chunghwa Telecom (CHT), eight licenses, including two nationwide and six regional (northern, central, and southern regions) were issued to five new entrants. The licensing period extended for 15 years and expired in 2012. The designated technology is the global system of mobile communication (GSM), and the service is limited to voice communication. The licensing fees are charged to the operators at 2% of the annual operating revenues. Three operators, CHT, Taiwan Mobile (TWM), and Far Eastone Telecom (FET), emerged after years of fierce competition and a series of mergers and acquisitions.

Considering auctions as the primary method of spectrum assignment, DGT subsequently conducted a 3G auction in 2002, in which the simultaneous

multiple-round (SMR) method was adopted. Five nationwide licenses were auctioned, spreading in 2100–2300 MHz and 800 MHz bands. The licenses are effective for the same 15 years, as with 2G, expiring in 2018. As shown in Table 2, three 2G incumbents and two entrants, Asia-Pacific Telecom (APT) and VIBO, won the licenses. The bidding price totaled NT\$48.90 billion (US\$1.65 billion). Similar to the requirement of designated technology in 2G services, the IMT-2000 technologies ratified by the International Telecommunication Union (ITU) were imposed on the 3G operators' deployment. Whereas 2G services are designated for voice communication only, 3G operators can provide either voice or nonvoice (such as data) communication services.

[Table 2 inserted here]

Since 2004, the Ministry of Economic Affairs (MOEA) has promoted the technology of worldwide interoperability for microwave access (WiMax) in the Two Trillion and Twin Star Development Program, hoping that Taiwan could advance in next-generation communication technology. The MOEA has requested the Executive Yuan (central government) to release 2500–2690 MHz bands so that manufacturer vendors could conduct field trials and commercialize their products. The NCC consequently announced an auction plan for six regional WBA licenses (three northern regions and three southern regions) in 2007. However, considering industrial promotion and unpredictable market risks, the NCC constrained the auction to a maximum of 10 rounds of bidding on the percentage of operating revenues paid to the government. When an auction could not be completed in the 10th round, a sealed first-price auction was implemented. The licensing period was only 6 years, extendable to another 6 years subject to the approval of the NCC. As shown in Table 3,

only one 2G incumbent, FET, won the WBA licenses; the remaining five were issued to entrants¹. Although no designated technology or services were specified for most licenses, two licenses reserved for entrants were attached to the clause of the WiMax technology (A1 and C2). However, the WBA operators managed a negligible growth in their subscriptions that resulted in only two operators, Global Mobile and Vee Time, surviving through mergers and acquisitions. As shown in Table 4, Taiwan's mobile communication services became segmented by three dominant 2G (and 3G) incumbents, two medium-sized 3G carriers, and two small WBA operators. Among all service providers, Chunghwa Telecom exhibits the highest number of subscribers, which is equivalent to 36% of the market share.

[Table 3 inserted here]

[Table 4 inserted here]

As the 2G licenses approached expiration and long-term evolution (LTE) technologies progressed, the NCC began consultations regarding future spectrum assignment and allocation in 2011. The NCC granted a 4-year tender period to the 2G services until 2016. It also assigned 700 MHz, 900 MHz, and 1800 MHz bands for 4G services. Fig. 1 illustrates the trajectory of spectrum assignment in Taiwan. Licensing 4G services marks the spectrum assignment on nonvacant and heterogeneous bands for the first time. The 4G auction was conducted from September 3, 2013 to October 29, 2013². The auction ended in the 393th round, and the final bidding price

¹ VMax was partially invested by the 3G incumbent, VIBO, and considered an affiliate to it. It was later incorporated into VIBO in 2013.

² The NCC divided 270 MHz bandwidths into 27 2×5 MHz slots and bundled them into 2×10 or 2×15 MHz license slots for auction. Although the combinatorial clock auction (CCA) is well-suited for multiband allocation, the SMR method was still selected to prevent high learning costs incurred by

accumulated to US\$4.03 billion, which was 3.7 times higher than the reserve price.

[Fig. 1 inserted here]

The 4G auction presented a contrast to the widely accepted perception that the bands below 1 GHz should have enlisted high bidding prices. By contrast, the highest bid of US\$868.6 million (eight times higher than the reserve price) went to License C5 for the 2x15 MHz vacant bands in 1800 MHz (shown in Fig. 2). The bidding prices for the three licenses in 900 MHz were only slightly higher than the reserve prices. Although 900 MHz bands are supposed to exhibit superior propagation characteristics to 1800 MHz bands, most parts of 900 MHz bands are being undertaken by the 2G incumbents until 2016. Nevertheless, the NCC has maintained an arm's-length approach to the problems of frequency clearance and switchover, which has rendered the transfer of these bands to the winners other than the incumbents complex and cumbersome. Consequently, the demand for these bands and their bidding prices have plummeted. This auction indicated that the propagation characteristics alone could not determine the demand for spectra. Rather, the regulatory constraints associated with band frequencies substantially affect operators' rights in using the bands and, therefore, their evaluation.

[Fig. 2 inserted here]

Table 5 lists the spectrum management regimes created for 2G, 3G, WBA, and 4G. The regulatory framework for 2G services is the strictest: no technology and service flexibility and no secondary trading are permitted. The spectrum usage rights

both the NCC staff and bidders.

(SURs), that is, service neutrality, were later inserted into the 3G bands because of an auction. Further deregulation on spectrum uses, such as technology and service neutrality and secondary trading, is employed for 4G bands. The NCC imposes a distinct management regime on the uses in various bands.

[Table 5 inserted here]

3 The framework of the spectrum management regime

Spectrum management has become an increasingly preponderant issue in policymaking. Spectrum management is categorized into assignment and allocation. Assignment refers to mechanisms that authorize users to access spectrum, namely auctions and secondary trading. Allocation refers to the framework governing the choice of wireless services, such as technology enabling (Minervini, 2013). As the command and control model gradually lost its appeal because of inefficiency in assigning spectrum frequencies, telecommunication scholars concentrated on discussions of various methods of spectrum assignment (Light, 2010). Market and commons are the most discussed approaches (Faulharber, 2006). Advocates of both approaches agree completely on the inefficiencies incurred by using the traditional command and control system; they nevertheless differ in the reform solutions. The market advocates contend against bureaucratic allocation mechanisms, but approve of granting licenses of exclusive use by using the market mechanism (Baumol & Robyn, 2006). By contrast, the commons advocates refuse the idea of exclusive control of spectra by using licensing (Faulharber, 2006). They desire to ensure full access to spectra whenever technology permits. Because the market regime consisting of well-defined property rights can easily accommodate commons, according to

Faulhaber, it is more substantially robust than a commons regime³. The government is then left to design a clear property rights system so that the operating rules and overall allocation rules can be established and enforced. Lundborg et al. (2012) considered that regulation may distort market competition if the restrictions on use conditions do not appropriate network costs.

3.1 Management flexibility and the spectrum usage rights

Spectrum management regimes were proposed to address the regulatory influence on spectrum values. The regimes are based on the premise that various bands exhibit different propagation characteristics, thus yielding different qualities of service and different values among spectrum frequencies (Freyens, 2009; Cave, 2010). For example, economic differences between the bands below 1 GHz and those above 1 GHz are substantial (Lundborg et al., 2012). Regulators first divide a spectrum into licensed and unlicensed bands according to their physics differences (Bykowsky et al., 2010; Cave & Webb, 2012). The licensed bands are governed by the market regime that grants firms exclusive control of spectrum through auctions, whereas the unlicensed bands are governed by the commons approach that allows full access (Bykowsky et al., 2010). Bykowsky et al. (2010) suggested an auction model (e.g., congestion pricing) among competing users to avoid harmful interferences once access to the unlicensed bands become overcrowded. This reduces the incentive that service operators may misstate their expressed value of a particular licensing regime.

Second, the regulators have explored the SURs assigned to the licensed and unlicensed bands. Usage rights are a subset of property rights that consist of four

³ Freyens (2009) argued for a triangulated approach to spectrum management. An intermediary regime, or easement regime, could be developed to complement the market and commons approaches. The easement regime regards spectrum as a club goods that excludes use by nonmembers and allows nonrivalrous use among the members (Freyens, 2009, p. 137).

elements: (1) the right to use goods or assets, (2) the right to earn income from it, (3) the right to transfer it to others, and (4) the right to the enforcement of property rights (Cave & Webb, 2012, p. 294). The SURs are thus exemplified in three dimensions: (1) full possession, (2) free disposal, and (3) transferability. Freyens (2009) identified three factors that affect the degree to which the SURs are exercised: (1) transferrable rights, (2) government intervention on interference, and (3) standards and usage flexibility. Interference is the major externality in spectrum use. The setting level of interference or entry conditions could prevent the SURs from being enforced (Cave & Webb, 2012).

Barroso et al. (2012) conducted an empirical study modeling the impacts of the SURs on the bands of digital dividends (i.e., 700 MHz). The simulation results indicated that the spectrum that was not preallocated to a particular service maximized auction revenues. Service neutrality, as considered by Barroso et al. (2012), allows for usage flexibility that enhances spectrum efficiency and values. Zaber and Sirbu (2012) contended that spectrum management policies, such as mandating band and technology, play a substantial role in shaping 3G diffusion. Zaber and Surbu's econometric analysis confirmed that the presence of multiple technology standards can delay the launch of 3G services. Conversely, mandating a specific band for 3G services was determined to help countries produce a rapid rollout. Both studies have empirically verified the impacts of service and technology neutrality on spectrum values and mobile communication penetration.

3.2 Secondary trading

Trading is generally considered as the essence of spectrum reform. Yoon et al. (2012) emphasized that secondary trading can increase economic welfare. They also claimed that flexible use of a spectrum based on technology and service neutrality

could encourage spectrum trading (Yoon et al., 2002, p.17). Crocioni (2009) asserted that well-defined property rights can reduce externalities and increase trading efficiencies. The aspects of property rights that are relevant to trading are security and duration of tenure as well as misalignments across frequencies, which could be used for similar applications⁴. Publication of price and nonprice information, such as a vacant spectrum or white space, could further reduce transaction (information) costs in the thin market of spectrum trading.

3.3 Heterogeneous multiband allocation

Sridhar and Prasad (2011) studied the spectrum management in India and portrayed a trajectory of spectrum reform. They argued that from the command and control regime to market mechanisms, India must further undergo spectrum reform because of technological progress that makes 2G refarming and spectrum sharing unavoidable. Although several studies have highlighted technological solutions to increase spectrum efficiency (Matheson & Morris, 2012; Ballon & Delaere, 2009; Bennett, 2011⁵), they have still emphasized the importance of the regulatory environment that creates a clear trajectory for dynamic allocation of spectra (MacCarthy, 2010). Cave et al. (2007) determined that developing countries could adopt a simple regime to administer spectra because they were under less credible institutions. Crocioni (2009) suggested that trading and liberalizing all bands could generate positive externalities of big-band reform. Minervini (2013) contended that speed and sequencing are particularly critical in determining the success of spectrum

⁴ Misalignment refers to a situation in which some frequency bands are tradable and other complementary frequency bands are not.

⁵ Matheson and Morris (2012) suggested creating a licensed electrospatial region (LER) that controls the emission level no more than the designated region can increase the efficiency of spectrum management and reduce the regulatory costs. Ballon and Delaere (2009) developed a cognitive pilot channel (CPC) to enable both dynamic spectrum allocation and spectrum pooling. Bennett (2011) described dynamic spectrum access (DSA) as an alternative to property right regime, offering free reign to access all frequencies.

reform when heterogeneous bands are used. Bazelon and McHenry (2013) asserted that spectrum heterogeneity in 4G services makes hybrid management approaches compulsory.

4 Policy attributes derived

The aforementioned studies have indicated the need for rethinking spectrum management practices when using heterogeneous multibands in the 4G era. Although the network costs caused by the propagation characteristics can be adjusted by the bidding price in an auction without regulatory intervention, the spectrum policy that neutralizes propagation differences may further enhance the efficiency of spectrum uses. When various bands become technologically indifferent because of policymaking, firms can integrate spectrum uses without being constrained by limited bandwidths in individual bands.

As mentioned, operators' evaluation and demand for bands are heavily influenced by their propagation characteristics as well as the SURs assigned to them. The operators who provide substitute services from heterogeneous bands are then assumed to have distinct policy preferences regarding spectrum management regimes. This study thus investigated the essential elements of the spectrum management regime and assessed operators' preferences toward them. We conducted in-depth semistructured interviews with seven mobile operators, four experts, and two government officials from August 2012 to December 2012. Table 6 lists the issues concerned with spectrum management, such as technology neutrality, service neutrality, secondary trading, spectrum caps, licensing expiration, and recall. Table 6 documents various policy positions among the concerning parties. Based on the interview and literature findings, we identified four attributes and 11 levels that were considered most relevant in designing the spectrum management regime.

[Table 6 inserted here]

4.1 Tender period

Because spectrum licenses in most countries are periodically limited, whether to grant a tender period after the licenses have expired becomes critical in spectrum management. The United Kingdom, France, and Norway have informed operators early enough (3 to 4 years in advance) to allow them ample time to reallocate services to other bands. These countries consequently have not granted tender periods to the operators.

By contrast, Hong Kong issued tender licenses for CDMA and TDMA services after their expiration dates because no urgent demand for such inefficiently used bands were made. The Office of Telecommunication Authority allowed the operators to retain one-third of the bandwidths in 3 years. The NCC of Taiwan also granted a 4-year tender period to the 2G licenses, which are due in 2016. However, this tender period overlaps the duration of 4G licenses whose services are supposedly to be launched later next year (2014). The NCC has not yet mandated any rulemaking regarding band clearance and switchover. This attribute contains two levels: (1) no tender period granted after license expiration and (2) a tender period granted after license expiration.

4.2 The spectrum usage rights

As mentioned, the SURs include (1) transferrable rights, (2) government intervention on interference, and (3) standards and usage flexibility. We herein connoted “usage flexibility” as technology and service neutrality, and “transferrable rights” was inferred as permitted secondary trading (either de facto transfer or lease).

The three levels of this policy attribute are thus (1) technology neutrality, (2) technology and service neutrality, and (3) technology, service neutrality, and secondary trading.

4.3 Special treatments for designated entities

To prevent over-consolidation of spectrum uses, the US Federal Communication Commission (FCC) used bidding credits, set-asides, and installment payments to encourage the participation of minority groups and small businesses (Cramton, 2000, p. 3). Similarly, Japan and Canada restricted incumbents from obtaining certain slots in bidding for the same reason. For example, the Canadian incumbents could acquire only one pair of B, C, C1, and C2 slots in 700 MHz (Chou et al., 2013, pp. 54-55). During the WBA auction in Taiwan in 2007, two licenses were reserved for entrants' bidding only. Comparably, the United Kingdom and Hong Kong have otherwise reserved specific slots for incumbents to encourage them for rapid network deployment.

Nevertheless, Cramton (2000) argued against the designated entity rules because the regional small players to whom special treatments were assigned still seldom competed with nationwide operators, causing diseconomies of allocation. However, Cramton (2000) agreed that spectrum caps could effectively limit anticompetitive concentration. Cave (2010) advocated that the caps on the stock of spectra should be maintained to deter firms from hoarding a particular spectrum. In 1994, the FCC placed a cap of 45-MHz bandwidth, which a single entity could acquire, on the Commercial Mobile Radio Spectrum. The cap was raised to 55 MHz in 2001 and abolished in 2003 (Cave, 2010, p. 258).

Numerous European Union countries encourage incumbents to upgrade the technologies of their current bands to increase spectrum efficiency. Refarming could

be considered as a specific treatment for incumbents, which might place potential entrants at a disadvantageous position in competition. We herein defined the three levels of this policy attribute as (1) refarming allowed for incumbents, (2) certain slots reserved for entrants, and (3) placed spectrum caps.

4.4 Recall

The essential issue of spectrum management lies in the efficient uses of spectra. How to reduce underused spectrum after its first assignment (e.g., auction) therefore deserves policy consideration. The ideal situation would be to transfer a spectrum from underusing parties to those who may thoroughly utilize the spectrum. However, the underusing party may not be voluntarily consent to transact the spectrum in the secondary market because of concerns of hoarding and anticompetition. Policy intervention is inevitable in such a dilemma of usage inefficiency. The NRA should develop supplementary measures before the underused spectrum can be recalled.

First, the NRA should establish a dashboard that records designated entities, their technological choices, and service provisions (Cave et al., 2007). Second, the NRA should construct efficiency indicators and assess spectrum uses accordingly. The NRA can promulgate the recall mandates after the efficiency of spectrum uses is evaluated. Japan already enforces the recall mandates and offers compensation if an underused spectrum is identified. Taiwan has not yet initiated any recall mandates. We defined three levels of this policy attribute to include (1) voluntary recall including compensation, (2) no recall enforced, and (3) recall enforced when failing to meet the efficiency criteria.

5 The dissipated preferences among the operators

We performed a conjoint analysis after identifying the policy attributes and levels.

Although conjoint analysis has generally been applied to marketing research to assess consumers' preferences, it is, in a broader sense, a type of trade-off analysis tool used for a systematic assessment of decisions (Tseng et al., 2013). Conjoint analysis is thus appropriate for econometrically analyzing the policy preferences of the operators among heterogeneous multibands.

5.1 Data and method

We included all 10 mobile operators in Taiwan as our survey respondents. They were three 2G/3G incumbents, CHT, TWM, and FET, two 3G-only operators, VIBO and APT, and five WBA operators, First International Telecom, Global Mobile Corp, Tatung Infocomm, VMax, and Vee Time. The survey was conducted from August 2012 to December 2012.

The objective of conjoint analysis is to assess the number of attributes that are most influential on a respondent's choice or decision making. The analysis involves asking survey respondents to rank or rate product stimuli that are created from a combination of levels from all or some of the constituent attributes (Green & Srinivasan, 1978). We determined the part-worth function model to be adequate in this study, because it calculates additive utility scores (i.e., the relative importance of a particular attribute) (Poortinga et al., 2003, p. 55).

5.2 Policy profiles

The full factorial design required 54 ($=2 \times 3 \times 3 \times 3$) policy profiles to be generated for the respondents' evaluation. However, evaluating all 54 profiles is time-consuming and overwhelming for respondents, thus decreasing their evaluation accuracy. The

fractional factorial design⁶ was adopted instead. (F.1) was used to calculate the minimal number of profiles required for the respondents' ranking.

$$3 \times (k - m + 1) \tag{F.1}$$

where m is the number of attributes and k is the number of levels.

Only 24 ($=3 \times (11 - 4 + 1)$) hypothetical profiles are required in the fractional factorial design. We used an orthogonal design to create the policy profiles based on the premise that each profile is sufficiently similar to other profiles as close substitutes, but dissimilar enough to be distinguished. Thus, the orthogonal design could miss the least information and maintain estimation efficacy (Claret et al., 2012, p. 261). To save the respondents' time, we further employed conjoint value analysis (CVA) software by Sawtooth Co. to create 12 sets of pairwise comparisons on the policy profiles. A sample of the questionnaire is shown in Fig. 5. A 9-point-Likert scale employed in the pairwise comparison represented the relative preference of the respondents between the two profiles.

[Fig. 5 inserted here]

5.3 Empirical results

Table 6 shows the weights of attributes obtained from performing the ordinary least square (OLS) regression on the ranking data that we collected. The R-squared of Column A (i.e., all the operators) is 0.94, suggesting a robust and unbiased estimation. The operators ranked the attribute SURs as the top priority (33.40), followed by the

⁶ Fractional factorial designs are experimental designs consisting of a carefully chosen subset (fraction) of a full factorial design. The subset is selected to expose information on the most critical features of the problem being studied (Green & Srinivasan, 1978).

designated entity rules (32.33), recall (19.66), and tender period (14.61). The weights of the SURs and designated entity rules proved that they were nearly equally preferred by the operators.

[Table 6 inserted here]

Cluster analysis is often conducted to determine the existence of consumer segments exhibiting similar preferences (Claret et al., 2012, p. 261). We performed an agglomerative hierarchical cluster analysis that defines the final number of clusters and still achieves an acceptable level of heterogeneity between the clusters (Hair et al., 1998). Table 7 shows the results of the agglomerative hierarchical cluster analysis. The value of the convergence coefficient increased from 8.51 to 14.00 as the number of clusters changed from 3 to 4. This was the highest increase in the coefficient value among all of the groupings, indicating a distinct heterogeneity between the three groups of operators. The results also confirmed that the three distinct groups were WBA, 3G-only, and 2G/3G operators. In other words, the disparate preferences of the three groups of operators were due to the various propagation characteristics embedded in the bands.

[Table 7 inserted here]

Columns B, C, and D of Table 6 show the policy preferences of the three groups of operators. First, the WBA operators emphasized the SURs (42.36) the most, followed by recall (23.48), the tender period (17.93), and designated entity rules (16.24). Second, the 3G-only operators preferred the tender period (47.40) to the designated entity rules (24.81), SURs (15.84), and recall (11.96). Finally, the 2G/3G

incumbents ranked the designated entity rules (46.34) the highest, followed by the SURs (24.36), recall (19.82), and tender period (9.48). Thus, the WBA operators prioritized the SURs, whereas the 3G-only operators preferred the tender period, and the 2G/3G incumbents desired the designated entity rules.

Table 8 lists the utility values of each level within the policy attributes. Estimated on the zero-centered difference, a positive value suggests a respondent's inclination toward such a choice. By contrast, a negative value suggests a respondent's disinclination toward such a choice. The higher (lower) the positive (negative) value is, the more approved (disapproved) the policy choice by the mobile operators.

The results listed in Column E in Table 8 indicate that the operators collectively preferred the policy choices of (1) no tender period granted, (2) technology and service neutrality and secondary trading, (3) incumbent refarming, and (4) recall enforced when the criteria were set. Consistent results were obtained by comparing the utility values among Columns F, G, and H for each policy level. The high utility value of the 3G-only operators expressed their strong interests without the tender period being granted. The stakeholder analysis also confirmed that the other two groups of operators were indifferent about this attribute because of their small utility values. The net utility value of "no tender period granted" was positive ($90.14 - 8.90 + 94.79 + 4.25$) so that the operators could converge on this policy choice.

[Table 8 inserted here]

Second, the WBA operators decidedly supported the SURs that grant operators flexibility in managing their bands and the right to transfer the bands, whereas the other operators opposed them. Conversely, the WBA operators vehemently disapproved of the SURs containing only technology neutrality, whereas others

modestly advocated such flexibility. The strong policy preferences of the WBA operators determinedly influenced the collective decision making. The net utility value of the policy level “technology, service neutrality, and secondary trading” was 70.89 (=99.56+(-12.64)+(-16.03)), higher than that of “technology neutrality” (15.61= -69.89+37.80+48.50) and of “technology and service neutrality” (-87.49= -29.67+(-25.35)+(-32.46)). Consequently, the operators consented to the level of management flexibility and secondary trading.

Third, the 2G/3G incumbents particularly favored refarming in their bands, yielding a high net utility value of this policy level at 140.80 (=9.54+32.34+98.92). Similarly, their forceful disapproval of the “spectrum caps” policy level yielded a negative utility value of -55.76 (=10.06+20.62+(-86.44)), even though the other two operators approved of it. The policy choice then converged at the level of “incumbent refarming.” Finally, the results in Table 8 indicate that none of the operators thoroughly considered the recall policy. The intensity of the operators approving or disapproving of the levels is thus moderate. Because the net utility value of the policy level “recall enforced when the criteria were set” (53.43=15.64+0.62+37.17) is greater than that of “voluntary recall with compensation” (-33.88= -38.48+(-0.33)+4.94) and of “no recall enforced” (-19.55 =22.84+(-0.29)+(-42.11)), the policy equilibrium was reached at “recall enforced.”

The total utility value of the mobile operators in a given group could be calculated using (F.2).

$$U(X) = \sum_{i=1}^m \sum_{j=1}^{k_i} U_{ij} X_{ij} + \varepsilon \quad (F.2)$$

Where $U(X)$ is the utility function of group X

m : number of attributes

k_i : number of levels of attribute i
 U_{ij} : utility value of level j of attribute i
 X_{ij} : 1 if level j of attribute i presents, otherwise = 0
 ε : intercept

Table 9 shows the utility values of the three groups of operators for the combination of the specified policy levels. The package of spectrum management contains no granted tender period, maximal management flexibility, secondary trading that includes de facto transfer and lease, refarming in incumbents' bands, or underused frequencies recalled when the efficiency criteria are set. The utility value of the WBA operators was 115.86, ranked eighth among 54 profiles. Similarly, the utility value of the 3G-only operators was 115.12, ranked seventh, and that of the 2G/3G incumbents was 124.31, ranked fifth. These figures suggest that this compromised spectrum management regime was not favorable to any group. Conversely, the total utility values could be maximized if every group of operators could choose their most desirable combination of policy levels.

To maximize the WBA operators' utility, for example, the package of the spectrum management regime should contain a granted tender period, technology and service neutrality, secondary trading, spectrum caps, and no enforced recall (Fig. 6).

[Fig. 6 inserted here]

The utility value is thus

$$\begin{aligned}
 U(X_{WBA}) = & (-8.89555) \times 0 + (8.89555) \times 1 + (-69.8857) \times 0 + (- \\
 & 29.6711) \times 0 + (99.55674) \times 1 + (9.54081) \times 0 + (-19.6031) \times 0 + (10.06225) \times 1 + (- \\
 & 38.4859) \times 0 + (22.84214) \times 1 + (15.64374) \times 0 = 141.35668
 \end{aligned}$$

The remaining two groups of operators otherwise exhibit completely different policy

preferences. They desire the package containing no granted tender period, technology neutrality, incumbent refarming, or enforced recall when the criteria are set (Fig. 6).

The utility value of 3G-only operators on this package is

$$U(X_{3G})=(94.7926)\times 1+(-94.7926)\times 0+(37.99518)\times 1+(-25.3521)\times 0+(-12.643)\times 0+(32.34387)\times 1+(-52.9624)\times 0+(20.61851)\times 0+(-0.33132)\times 0+(-0.29108)\times 0+(0.6224)\times 1=165.75405$$

And that of the 2G/3G operators is

$$U(X_{2G})=(4.25196)\times 1+(-4.25196)\times 0+(48.49666)\times 1+(-32.4663)\times 0+(-16.0304)\times 0+(98.92278)\times 1+(-12.4786)\times 0+(-86.4442)\times 0+(4.93932)\times 0+(-42.1075)\times 0+(37.16821)\times 1=188.83961$$

The results of our analysis indicated that the total utility values could be maximized when differentiated spectrum management regimes were applied to the mobile operators. We are left to question whether the spectrum management regimes should be differentiated.

5.4 Differentiated management practices

Table 9 shows a unified spectrum management regime; however, it was structured on operators' second best choices that did not entail the highest total utility values. This second-best outcome lies in the premise of the same regulatory treatments on all operators without discrimination. Nevertheless, a differentiated or asymmetric regulatory framework subject to operators' respective preferences could increase their utilities and spectrum use efficiency. The regulatory differentiation is not without evidence in telecommunication history. The interconnection requirement applied only to the dominant carrier is an asymmetric regulation. It is promulgated to deter the dominant carrier from anticompetition. Unbundling local loops further enforces the incumbent to allow for competitors' access to its last-mile infrastructure.

The network neutrality rules promulgated by the US FCC apply only to the wireline operators, whereas wireless operators are exempt.

As mentioned, different bands entail different propagation characteristics that alter operators' policy preferences. A regulatory environment embedded with operators' incentives could induce their efficient spectrum uses. Alternatively, such a regulatory environment could neutralize the propagation differences of the band frequencies so that the operators could be indifferent about band selection. This would assuredly increase the overall spectrum usage efficiency in the long-term because the operators could be dehurled from the limited bandwidths in individual bands. A differentiated spectrum management regime could then be legitimized by its effectiveness to promote usage efficiency. We propose a differentiated management regime suitable for spectrum heterogeneity.

First, the results shown in Column F in Table 8 indicate that the WBA operators exceedingly approve of secondary trading and strongly disapprove of technology neutrality only. Because the WBA operators had yet to make profits by providing services to a few customers (Table 4), secondary trading offered them an opportunity to compensate for the deployment and operation costs. Merely managing band frequencies at the WBA operators' disposal could not meet their requirements. Rather, they desired a flexible framework of spectrum management in which they could use spare bands more efficiently by transfer or lease. For regulators, the spectrum efficiency could be increased by allowing the transfer or leasing of spare bandwidths. Secondary trading should consequently be mandated in 2500–2690 MHz bands.

Second, the 3G-only operators particularly requested no granted tender period after licenses expire, exhibiting a utility value of 94.79. Conversely, they resiliently opposed the idea of a tender period, exhibiting a negative value -94.79 (Column G in Table 8). The operators should intuitively be better off when the tender period is

granted to their 3G services. Nevertheless, they shared the concern during interviews that the tender period granted to the 2G licenses overlaps the duration of 4G licenses. The overlapping period provides the 2G incumbents with competitive advantages to hoard band frequencies easily, and creates hurdles for other operators from obtaining such bands. The hoarding behavior of the 2G incumbents further threatens the 3G-only operators' competitive advantages. In addition, the 3G-only operators must deploy more base stations than the 2G incumbents because of the propagation characteristics in 2100–2300 MHz bands. Additional base stations mean higher deployment costs. Consequently, the 3G-only operators prioritize no granted tender period.

However, a 4-year tender period was still granted to the 2G services, complicating the allocation of 4G bands and greatly reducing the demand for those frequencies (as shown in 4G auctions). The policy options left to the 3G-only operators are technology neutrality (exhibiting the second highest utility value) and refarming (exhibiting the third highest utility value) in 2100–2300 MHz bands. Thus, the operators should be allowed to refarm their bands during the license period (till 2017) once innovative technologies are available. Spectral efficiency can be increased by their refarming.

Third, the 2G/3G incumbents prefer refarming at a utility value of 98.92. The negative value of –86.44 refers to their strong disapproval of enacted spectrum caps (Column H in Table 8). Their interviews suggested that they intend to retain 900 MHz and 1800 MHz bands in provision of 4G services. They can thereby refarm these bands to increase their competitive advantages. Nevertheless, the 2G incumbents' refarming creates disadvantages for other operators in competition. Several constraints must be placed on the 2G/3G incumbents to prevent unfair competition caused by their refarming.

The results shown in Column H of Table 8 indicate that the 2G/3G incumbents, exhibiting the third highest utility value of 37.17, approved of enforced recall when the efficiency criteria were set. Although the 2G/3G incumbents are authorized to refarm their bands, the efficiency criteria should be mandated to deter them from hoarding bands. Such criteria could include the subscription number of 2G services retained per MHz. If the 2G incumbents fail to switch their 2G customers to advanced technologies and the subscription number remains at a high level, the 2G bands would be recalled. Alternatively, regulators could raise the frequency fees proportionately to the remaining number of 2G subscribers that the incumbents serve. The higher the number of 2G subscribers is, the higher the fees are. The costs of hoarding 900 or 1800 MHz bands would increase if the incumbents continually provide 2G services. The recall enforcement and the negative monetary incentive should compel the 2G incumbents to upgrade the services as early as possible.

The trajectory of spectrum management during the 4G transition is illustrated in Fig. 7. First, full technology and service neutrality and secondary trading should be permitted in 2500–2690 MHz bands. Second, refarming should be allowed in 900 MHz, 1800 MHz, and 2100–2300 MHz bands. Finally, the efficiency criteria should be established for 900 MHz and 1800 MHz bands when they are continually used for 2G service provision. Those bands would be recalled if the subscription number is sufficiently high.

[Fig. 7 inserted here]

The NCC approves of technology and service neutrality and secondary trading in 4G bands, but not refarming or the set efficiency criteria. The NCC neither permits secondary trading in the WBA bands nor allows refarming in 3G bands. The current

spectrum management regime in Taiwan entirely contradicts the operators' policy preferences that are influenced by the propagation characteristics of the bands they occupy. Because the regime fails to neutralize the band differences, the spectrum efficiency could not be maximized.

6 Conclusion

The results of this study indicate that a differentiated spectrum regime is inevitable in managing the 4G bands. Although various regulations have been applied to 2G, 3G, WBA, and 4G bands in Taiwan, inappropriate incentives were embedded in each management mechanism so that the spectrum efficiency could not be maximized. The regulators should prudently analyze the propagation characteristics of various bands and the policy preferences of the operators holding the bands. The regulators can then promulgate different rules on different bands according to the propagation characteristics and the policy preferences induced. Because the 4G auction has been completed, research can be conducted to evaluate the policy preferences of the entrants to assess the efficacy of a management regime in 700 MHz bands. The propagation characteristics of other bands, such as 600 MHz, could also be studied to draft an appropriate and differentiated management regime that suits the requirements for commercial use in the future.

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Table 1. The numbers of mobile communication services in Taiwan, unit: thousand

Year (date)	BB call	2G	Low-powered wireless		3G	WBA
			CT2	PHS		
2013 (06.30)	0	5,241	0	747	23,528	133
2012	575	5,999	0	774	22,677	137
2011	912	7,185	0	817	20,860	133
2010	1,095	8,189	0	917	18,734	48
2009	1,121	9,773	0	1,374	15,811	
2008	1,137	12,661	0	1,459	11,292	
2007	1,050	15,907	15	1,465	6,915	
2006	1,070	18,464	15	1,336	3,429	
2005	1,095	19,876	978			
2004	1,336	21,528	788			
2003	1,415	25,090	634			
2002	1,598	23,905	521			
2001	1,756	21,633	211			
2000	2,813	17,874	44			
1999	3,873	11,541	67			
1998	4,261	4,727	31			

Source: NCC website

(http://www.ncc.gov.tw/chinese/news.aspx?site_content_sn=2017&is_history=0)

Table 2. The auction price of 3G licenses in Taiwan, unit: NT\$ billion

License	Operator	Bandwidth	Final bidding price
A	FET	2×15 MHz + 5 MHz	10.17
B	VIBO	2×10 MHz + 5 MHz	7.70
C	TWM	2×15 MHz + 5 MHz	10.28
D	CHT	2×15 MHz + 5 MHz	10.18
E	APT	2×20 MHz	10.57

Source: DGT

Table 3. WBA licensees and their bidding percentages of revenues

license	Operator	The bidding percentages of revenues
A1: North region, 30MHz	First International Telecom*	12.89%
A2: South region, 30MHz	FET	4.18%
B1: North region, 30MHz	Global Mobile Corp.	6.19%
B2: South region, 30MHz	Tatung Infocomm*	7.25%
C1: North region, 30MHz	VMax (VIBO)	5.2%
C2: South region, 30MHz	Vee Time	8.69%

Note: * merged by Vee Time in 2013

Source: NCC (2007/07)

Table 4. The numbers of mobile subscription in Taiwan, unit: thousand

Year (date)	CHT	TWM	FET	VIBO	APT	WBA operators in total
2013 (6.30)	10,421	7,106	6,998	1,735	2,510	133
2012	10,269	7,012	6,864	1,670	2,860	137

Source: NCC website

(http://www.ncc.gov.tw/chinese/news.aspx?site_content_sn=2016&is_history=0)

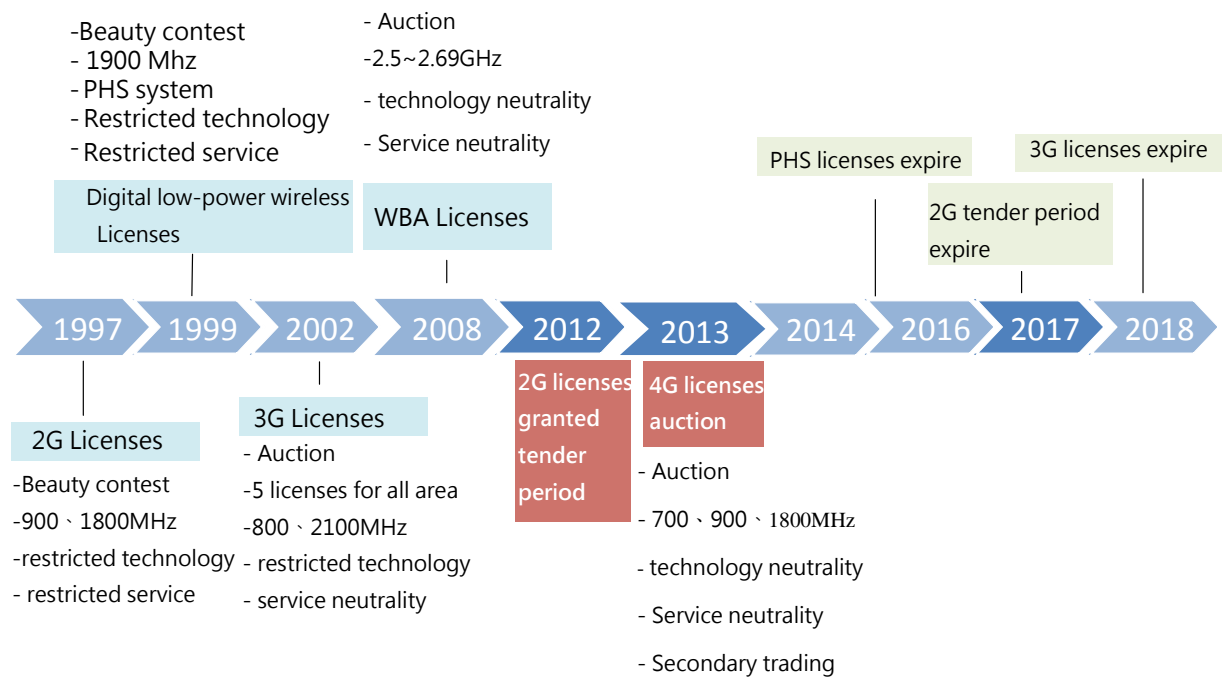


Fig. 1. Spectrum licensing in Taiwan

Source: (Chou et al., 2013, p. 4)

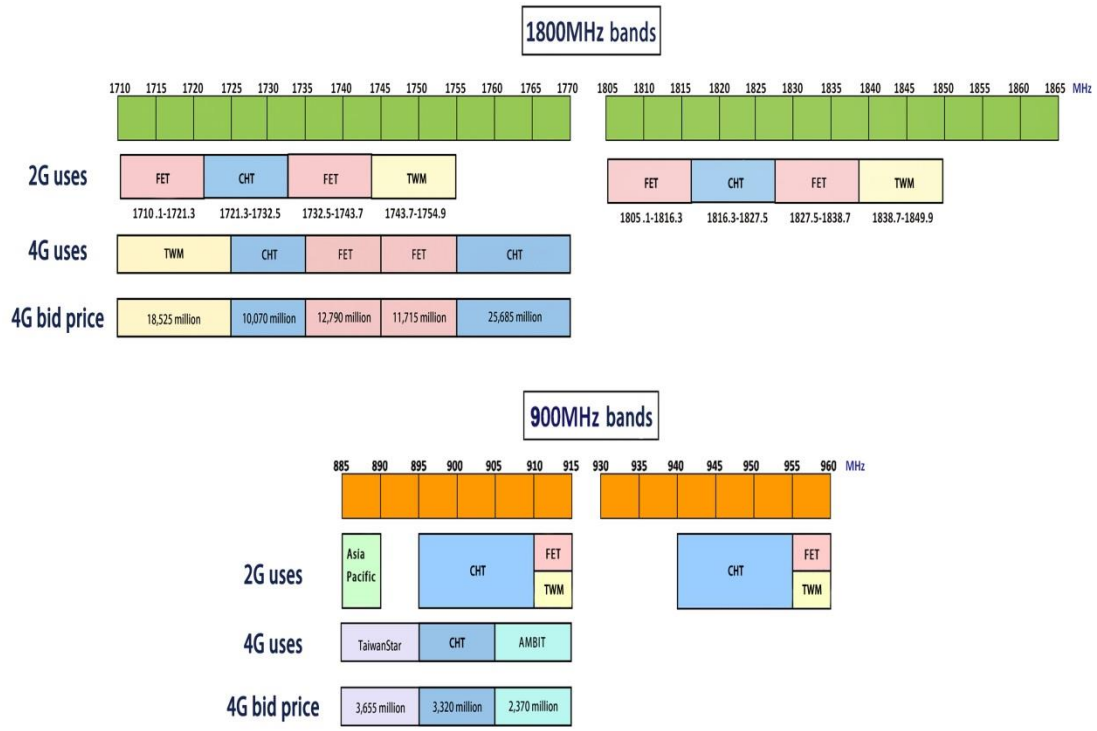


Fig. 2. Current spectrum assignments in 900 MHz and 1800 MHz
 Source: NCC (2013)

Table 5. The management regime of mobile communication services in Taiwan

License	2G	3G	WBA	4G
Band	900/1800 MHz	2100~2300 MHz	2500~2690 MHz	700/ 900/ 1800 MHz
Year licensed	1997	2002	2007	2013
License duration	15 years	15 years	6 (+ 6) years	17 years
Number of licenses issues	2 nationwide, 6 regional	5 nationwide	6 regional	12 spectrum slots awarded
Assignment method	Beauty contest	Auction	Auction	Auction
License fee	2 % of operating revenues	Bidding price	Bidding percentages of operating revenues	Bidding price
Usage flexibility	Not permitted	Service neutrality	(partially) Technology & service neutrality	Technology & service neutrality
Secondary trading	No	No	No	Yes

Table 6. Spectrum policy positions of various parties

topic	Summary of interviews
Licensing duration	<ol style="list-style-type: none"> 1. 25 years 2. 15 years
Flexible management	<ol style="list-style-type: none"> 1. technological neutrality 2. technological and service neutrality
Spectrum cap	<ol style="list-style-type: none"> 1. no caps; 2. caps for below 1 GHz bands; 3. 10 MHz for 900 MHz bands; 20 MHz for 1800 MHz bands; 4. mutually-exclusive uses on 700 MHz and 900 MHz bands
WBA services	<ol style="list-style-type: none"> 1. Approving of technology upgrades; 2. Disapproving of technology upgrades
Entrant rules	<ol style="list-style-type: none"> 1. no <i>ad hoc</i> reservation for entrants; 2. no preferences
Secondary trading	<ol style="list-style-type: none"> 1. approving; 2. hardly implementable in practice; 3. concerned with hoarding;
recall	<ol style="list-style-type: none"> 1. costs compensated by government; 2. recall enforced when failing to meet the set criteria; 3. voluntary recall
License expiration	<ol style="list-style-type: none"> 1. tender periods granted to neither 900MHz nor 3G bands; 2. tender periods granted to 2G bands, but not applicable to 3G bands; 3. all frequency bands recalled before relicensing; 4. tender periods granted to WBA bands when meeting the deployment requirements
refarming	<ol style="list-style-type: none"> 1. theoretically practicable; 2. approving;

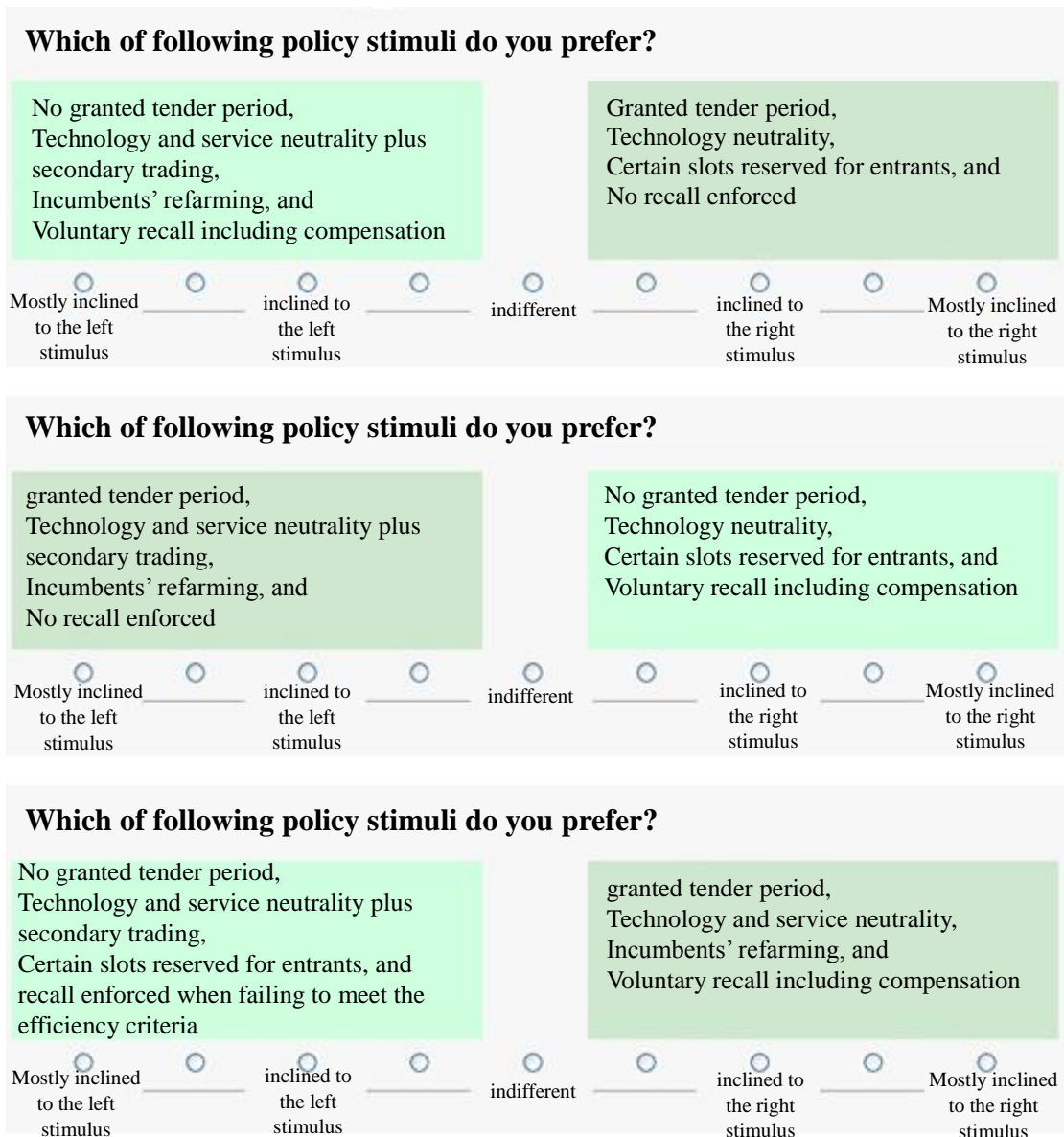


Fig. 3. A sample of CVA questionnaire

Table 7. The weights and ranking of policy attributes in spectrum management

Policy attribute	[A] All		[B] WBA operators		[C] 3G only operators		[D] 2G/3G operators	
	weights	rank	weights	rank	weights	rank	weights	rank
Tender period	14.60638	4	17.92603	3	47.39630	1	9.47516	4
SURs	33.40261	1	42.36060	1	15.83683	3	24.36417	2
Entity rules	32.33477	2	16.23697	4	24.81027	2	46.34173	1
Recall	19.65623	3	23.47641	2	11.95659	4	19.81894	3
R-Squared	0.93920		0.98622		0.94286		0.96605	

Table 8. Convergence of clustering process

cluster	Convergence coefficient	Increased value of the coefficient	Percentage of the increase
1	6.116	1.37	18.27%
2	7.483	1.03	12.10%
3	8.514	5.48	39.17%
4	13.996	1.33	8.70%
5	15.329	3.04	16.53%
6	18.365	4.05	18.07%
7	22.416	2.47	9.94%

Table 9. The utility values of the policy levels

Attribute	Level	utility value			
		[E] All	[F] WBA operators	[G] 3G only operators	[H] 2G/3G operators
Tender period	1.1 No tender period granted	5.40608	-8.89555	94.7926	4.25196
	1.2 Tender period granted	-5.40608	8.89555	-94.7926	-4.25196
SURs	2.1 Technology neutrality	5.07907	-69.8857	37.99518	48.49666
	2.2 Technology & service neutrality	-39.7205	-29.6711	-25.3521	-32.4663
	2.3 Technology & service neutrality plus secondary trading	34.6414	99.55674	-12.643	-16.0304
Entity rules	3.1 Incumbent refarming	52.93415	9.54081	32.34387	98.92278
	3.2 Licenses reserved for entrants	-35.7132	-19.6031	-52.9624	-12.4786
	3.3 Spectrum caps	-17.2209	10.06225	20.61851	-86.4442
Recall	4.1 Voluntary recall with compensation	-12.5459	-38.4859	-0.33132	4.93932
	4.2 No recall enforced	-3.58273	22.84214	-0.29108	-42.1075
	4.3 Recall enforced when the criteria were set	16.12865	15.64374	0.6224	37.16821

Table 10. The uniformed policy levels entailed

Cluster	WBA operators	3G only operators	2G/3G operators
Utility value	115.8457	115.1158	124.3126
Rank	8 th	7 th	5 th
Policy attribute	Tender period	No tender period granted	
	SURs	Technology & service neutrality plus secondary trading	
	Entity rules	Incumbent refarming	
	recall	Recall enforced when the criteria were set	

WBA operators		2G 、 3G operators
Tender period granted	Tender Period	No tender period granted
Technology and service neutrality plus secondary trading	SURs	Technology neutrality
Spectrum caps	Designated entity rule	Incumbent refarming
No recall enforced	Recall	Recall enforced when the criteria were set

Fig. 4. The differential spectrum management regimes

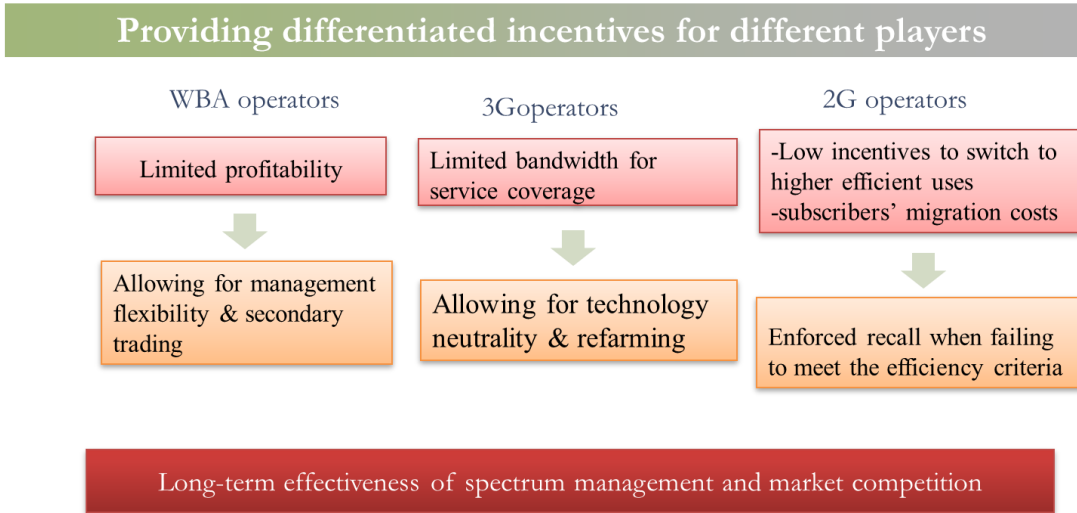


Fig. 5. The trajectory of spectrum management in 4G transition