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A compensation model developed to increase spectrum usage efficiency in the 4G era

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A Compensation model developed to increase spectrum usage efficiency in the 4G Era

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Abstract

Because fourth-generation (4G) mobile communications services are provided over reformed and heterogeneous bands for the first time, a unified spectrum management regime fails to accommodate the spectral heterogeneity. In Taiwan, we still extend the 2G incumbents' usage right on the 900MHz and the 1800 MHz frequencies until 2015; meanwhile they have been reformed for 4G uses since the late 2013. Likewise, the 2600 MHz frequencies are now considered for 4G auction in late this year (2015); nonetheless, they are currently assigned for wireless broadband access (WBA) services until 2020. This marks the telecommunications service providers' usage rights on the certain bandwidths are overlapping with each other, causing the unintended consequences of interference, hoarding, delayed deployment, and consequentially lack of spectrum usage efficiency.

This paper is written to design an institution that mitigates the problem of unintended hoarding by the incumbents so that the spectrum can be swiftly switched to

the supposedly more efficient uses. Facing the similar hoarding problem in the bandwidths of digital dividend, the US Federal Communication Commission (FCC) proposed incentive auction in hopes of compensating media broadcasters for their relinquishing the usage rights with the amount of bids paid by the winner. Even though the US Congress authorized the FCC to conduct incentive auctions in February, 2012, the FCC so far has not yet initiated once. This delay implies that incentive auction seems theoretically plausible but may not realistically feasible. Therefore, this study provides alternatives for efficient handover of spectrum usage rights.

We hypothesized 4 scenarios for the WBA operators in hoarding the 2600 MHz frequencies. One is neither upgrade to 4G technologies and nor license renewal; the second is the upgrade allowed but no license renewal; the third is no upgrade but the license renewed; and fourth is both upgrade and renewal are allowed. We then employed econometric analysis to estimate the value of 2600 MHz frequencies under different usage restrictions. The value indicates the incumbent's willingness to forgo its usage right once compensated.

Nevertheless, we observed that, even if with highest amount of compensation, the WBA incumbent may still opt to hoarding because it expects beyond-normal payoffs. Without the enforced mechanism rooted in incentive auction, the incumbent demonstrates opportunistic behavior to raise the payoffs in exchange its forgone usage of the bandwidths. We then devised an institution of the *ad hoc* clearing house guaranteed by the national regulatory authority (NRA). The NRA facilitates the transaction between the new owner and incumbent by acting as the third-party warrantee. Doing so could swiftly clear the used bandwidths and increase the efficiency of spectrum usage.

Keywords: spectrum usage rights, refarming, incentive auction, spectrum value, evaluation methods

1 Reassignment of spectrum uses

Mobile communication has swiftly become the most growing sector in telecommunications since its provision. In 2008, 65 developed countries exhibited a 100% mobile penetration rate. The average penetration rate of mobile communications in those countries is 120.6% nowadays (International Communication Union (ITU), 2015). Likewise, the per-capita subscription of mobile communications in developing countries has reached approximately 0.92 in 2015. Additionally, the number of mobile handheld devices globally was expected to surpass that of the total population worldwide (Cisco, 2013). The data flow of cloud computing has already exceeded 1,600 exabytes, 20 times greater per capita than that five years ago. This rapid growth in mobile broadband service entails tremendous demand on 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 advancing mobile services.

Scholars have long advocated for the commons approach in utilizing spectrum uses. In contrast to both the command-and-control and auction allocation regimes that assign exclusive uses on spectrum, the commons approach allow various parties to share spectrum without exclusive licenses as long as others' uses are not precluded from the interference problem and they can coordinate on such the matter. In this sense, the commons model enables a great number of users to access to such the scarce assets. Nevertheless, the current technological constraints make unlicensed and shared uses virtually impossible in certain bands. The model of dynamic access management (DAM) was then proposed to maximize spectrum usage efficiency that non-licensed parties can have access to momentarily unused slots even though they were pre-assigned exclusively to the licensed ones. The model is said to eliminate the interference concern because non-licensed parties access to the bands only when they are vacant. That is, it can

simultaneously monitor spectrum usage and coordinate various parties regarding their access to spectrum provided that spectrum dashboard is built and technological advances are permitted (Basaure et al., 2014).

Many national regulatory authorities (NRAs) instead adopted a pragmatic approach in increasing spectrum usage efficiency in that they allow for secondary trading of spectrum usage rights (SURs). No matter to whom the SURs were initially assigned, usually through auction, both parties can embark transaction on the SURs depending on their respective utilities and increase spectrum usage efficiency provided that the secondary market is constituted. The transaction is indeed conducted under the premise of zero or low transaction costs (Coase, 1965); otherwise, high transaction costs will prevent both parties from engaging in trade. Regrettably, few secondary trades on SURs have been undertaken in a decade and it is speculated that high transaction costs deter telecommunication operators or potential ones from embarking on trade even if they recognize economic and social benefits incurred by successful transaction. The FCC initiated an incentive auction that will be held in March, 2016 in hopes of encouraging terrestrial TV broadcasters to voluntarily relinquish their SURs in 500~600 MHz bands and consequently redeploying those bands for higher efficient uses. This two-sided, reverse and forward, auction supposedly abates the negotiation costs incurred to the TV broadcasters because of its information transparency and unbiased transaction platform. Nevertheless, the generic incentive auction requires NRAs' computational capabilities to complement while most of them lack such capabilities. Taking the high demand on the scarce assets of spectrum into policy consideration, it how to create a mechanism that facilitates the relinquishment of the SURs from the occupants who undervalue and utilize the assigned spectrum less efficiently become a crucial and challenging task for the NRAs.

This paper is written to study the institutions that mitigate the negotiation costs

incurred to the occupants of less efficiently-used spectrum so as to attain their relinquishing of the SURs. We contend for two kinds of transaction costs associated with the negotiation: information regarding spectrum valuation and trust not to engage in opportunist behaviors. As Taiwan is undergoing an auction on 2500~2600 MHz bands part of which are hoarded by wireless broadband access (WBA) providers, the handover of the WBAs' SURs to potential winners afterwards could exemplify the effectiveness of the institutions in safeguarding negotiation. In this paper, we will reckon the value of 2500~2600 MHz bands in Taiwan to increase information transparency during negotiation. We also contrive an institutional design that renders WBA providers enough trust so as to increase their willingness to relinquish the SURs.

The remainder of this paper is organized as follows: Section 2 discusses the literature concerned with spectrum management approaches, SURs, and the methods of spectrum valuation. Section 3 addresses the problems of ill-defined SURs incurred by spectrum reassignment for the auction on mobile broadband service licenses in Taiwan since 2013. Section 4 displays the WBA providers' decision tree regarding the relinquishment of their SURs. It continues to estimate the spectrum value at each given decision node based on the hybrid approach of benchmark criteria and business case development. The WBAs' preferences toward negotiation outcomes are then revealed via this spectrum valuation and their negotiation strategies are predicated. Section 5 discusses the institutional stalemate that prevents the WBA providers from participating in negotiation. It then analyzes the institution design that propels the WBAs to negotiate. Finally, Section 6 concludes the paper and provides a recommended direction for future research.

2 Literature review

2.1 spectrum management approaches: market vs commons

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 Faulharber, it is more substantially robust than a commons regime¹. 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.

¹ 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).

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.

2.2 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 applications². Publication of price and nonprice information, such as a vacant

² Misalignment refers to a situation in which some frequency bands are tradable and other complementary frequency bands are not.

spectrum or white space, could further reduce transaction (information) costs in the thin market of spectrum trading.

2.3 spectrum usage rights (SURs)

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 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.

The Coase Theorem lays a theoretical underpinning for developing the spectrum management mechanism. Coase contended that economic exchange can be undertaken as long as property rights are clearly defined and the costs of transaction are low (Basaure et al., 2014). Cave and Webb (2012) applied the concept “usage rights” proposed by Lueck and Miceli (2007) to the discussion of spectrum transferability because the holding of it is not a complete property right³. Having SURs assigned to its holders, they are able to transfer part or all of the rights to others so that the efficiency of using spectrum could increase. Recognizing that the interference problem caused by the spectrum holders may hinder the efficiency of using spectrum, Cave and Webb particularly asserted the usefulness of the SURs in resolving the problem because the holders have lower transaction costs in negotiating the terms and conditions of the non-interference level with full knowledge of the respective SURs.

Also based on the two premises of clearly defined SURs and low transaction costs, Basaure et al. (2014) proposed the “dynamic spectrum management” (DSM) that attains higher efficiency in using spectrum. Currently interference management is either too restrictive in an exclusive regime of spectrum uses or too relaxed in a commons regime. Neither regime could achieve usage efficiency since the exclusive one deters the holders from negotiation while the commons one entails too high negotiation costs. The DSM with cognitive technologies dynamically detects spare bandwidths (not yet in use) and allows for simultaneous transactions of those bandwidths to the one most in need at every moment and location. It then significantly mitigates the transaction costs of various users in negotiating the uses of

³ Lueck and Miceli (2007) defined usage rights are a subset of property rights, which consist of four elements: the right to use the good or asset; the right to earn income from it; the right to transfer it to others; and the right to enforcement of property rights.

spectrum⁴, avoiding the interference problem because of spectrum shortage and reaching the optimal assignment of spectrum.

Brasaure et al. also recognized that different propagation characteristics entailed by heterogeneous frequency slots calls for the reassignment of spectrum. The DSM could then attain such the goal. Nevertheless, SURs must be redefined to a limited sense before the DSM can be constituted in the regulatory regime because many premium frequencies are withheld by incumbents in most countries. In response to a growing demand on spectrum, it how to release the preoccupied but underused frequencies from the incumbents becomes a timely critical issue.

2.4 incentive auction

The US Federal Communication Commission (FCC) has long considered the utilization of 500~600 MHz bands which are currently seized by terrestrial TV broadcasters⁵ (FCC, 2012). Milgrom and his teammates contracted by the FCC designed a double-sided auction, namely incentive auction, that enables the broadcasters to relinquish their SURs with monetary compensation for their forgone benefits and clearing costs (Milgrom et al., 2012). Fig. 1 illustrates the broadcasters' decision tree regarding whether or not to go off-air.

⁴ Braasure *et al* (2014) pinpointed that the costs in negotiating the uses of a specific band in a given time include information cots, coordination costs, measurement of output, and spectrum specificity.

⁵ Unlike the SURs assigned to the mobile communication licenses that are valid only for a period of time, the transmission rights of terrestrial TV broadcasters are unofficially recognized as permanent.

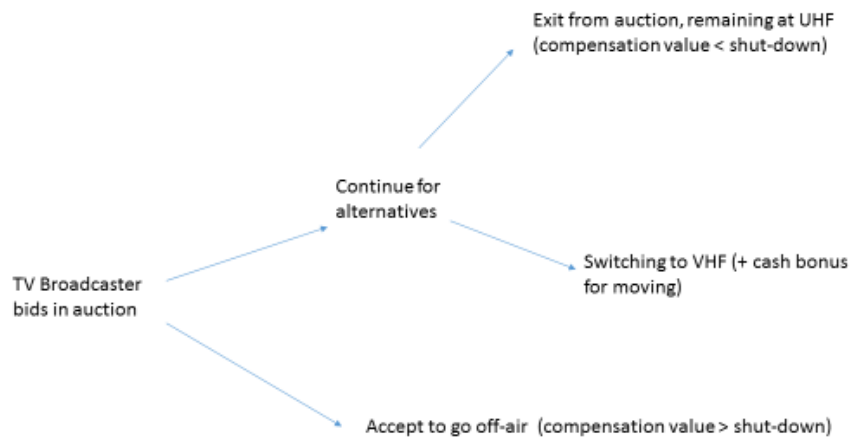


Fig. 1 TV broadcasters' decision tree

The incentive auction highlights three major features: 1. Licenses are generic; 2. The design is clock auction; 3. Intra-round bidding is used to avoid a tremendous price increase during bidding (Milgrom et al., 2012:4-5). The auction begins with the reverse one in which the regulatory agency set an initial price that is the maximum value paid to the TV broadcasts should they relinquish their SURs. The broadcasters can then choose either to accept the offer or to stay for alternatives (i.e., moving to VHF bands or remaining at the original UHF bands). The price offered to the broadcasters continues to fall during the interim rounds until no more excess supply of UHF bands (i.e., the relinquishment of the SURs) from them (FCC, 2015). The regulatory agency, on the other hand, can simultaneously or sequentially conduct a forward clock auction that it announces the initial minimum price to telecommunication operators and they specify the quantity to purchase. The bidding price likewise continue to rise during the interim rounds until there is no excess demand on UHF bands (FCC, 2014).

Indeed, it successfully implementing the incentive auction requires the regulatory

agency the computational capability (Milgrom et al., 2012:4). The regulatory agency has to dynamically utilize the price and quantity information revealed by both the broadcasters and telecommunication operators to meet the excess supply with the excess demand. Otherwise, the regulatory agency with weak computational power may not be able to close auction by failing to hit the clearing target. Regrettably the national regulatory authorities in most countries at this moment lack of knowledge and expertise to conduct the incentive auction. Even in the US, the FCC postponed the incentive auction until March 2016. There is not an empirical case tested yet at this moment although it sounds theoretically operable. In addition, the incentive auction may be unnecessary when the underused bands are sparse and they are withheld by only a very few occupants. In this case, there is no excess supply at the opening bid round. The opportunity costs of operating the incentive auction might be even greater than those of direct negotiation with the occupants.

The question follows is what are the costs of directly negotiating with the occupants? Two kinds of transaction costs are involved: assessment of spectrum value and trust⁶. As far as trust is concerned, the occupant may be less willing to participate in negotiation if the consequences of relinquishing the SURs it anticipates are at odds. For example, the FCC previously stipulated that winners of AWS band licenses could “self relocate” eligible existing users by incurring the costs themselves, and then getting some of these costs reimbursed by the FCC. However, this process did not go as smoothly as planned (Bazelon & McHenry, 2013:). The case evidences that, although the secondary trade increases the efficiency in using spectrum, no such a deal could be attained when there is no mutual trust in between.

⁶ In its adoption of the Incentive Auction Bidding Procedures Public Notice (FCC, 2015), FCC detailed the methods to calculate the opening bid price in the reverse auction. Doing so will create more transparency about the incentive auction and increase their willingness to participate in the auction. This action entails the costs of assessing spectrum value as well.

2.5 spectrum value

Bazon and McHenry (2013) asserted that “spectrum value derives from its use in deploying wireless services, that is, the present value of the future profits that can be earned through using it.” They categorized three approaches of appraising spectrum value: market comparable analysis, discounted cash flow analysis, and econometric analysis. It is imperative to notice that each approach leaves some valuable information unused when employed in isolation. They advocated a hybrid choice of the approaches that yields a more precise estimate. They also pinpointed the variables impacting spectrum value such as sea level differences and changes, band specific differences and changes, and geographic differences in spectrum value.

Ofcom (2009) proposed administrative incentive pricing (AIP) to be set to reflect the opportunity costs of spectrum denied to other uses and users, rather than just the costs of managing the spectrum. Poort and Kerste (2014) contended that setting license renewal or extension fees based on opportunity costs usually involves either the development of business cases for other uses, or a benchmark of spectrum prices from auctions or secondary market transactions in other countries. Poort and Kerste continued to explain that the business case approach has the advantage that it is generally applicable. Disadvantages are that it is administratively burdensome and sensitive to assumptions about the costs and revenues of network operators and their strategies toward spectrum uses and network investment (2014⁷). To contrast, basing renewal fees on a benchmark is possible if recent market outcomes from other countries are available⁷. Poort and Kerste then presented a combination of

⁷ The benchmark approach can be as burdensome and controversial as well, since it requires taking due account of a host of country-specific difference, such as population size and density, geography, GDP level, market structure, rollout obligations, spectrum availability in other bands, ant etc. (Poort & Kerste, 2014⁷).

business case valuation and benchmarking for setting the extension fees. These are corrected for non-linear effects caused by discounting and the growth of revenues over the license period, on the basis of a simplified business case and a generally applicable calculation. Two main features consist of their valuation: first, prices corresponding with the licenses to be extended are derived from the auction outcomes. Second, because the license periods of the extension and the auctioned licenses differ, the relative value addition of the extension period for the new license is derived by using a model for the development of a given operator's EBITDA over time. They assumed that the methodology presented in the paper administratively less burdensome and less assumption sensitive.

3 The local context for spectrum reassignment

3.1 The spectrum assignment for mobile broadband services in 2013

As the 2G licenses approached expiration and long-term evolution (LTE) technologies progressed, the NCC began consultations regarding spectrum reassignment and reallocation in 2011. The NCC granted a 4-year tender period to the 2G services until 2016. Department of Transportation that is responsible spectrum planning then reassigned 900 MHz, and 1800 MHz bands for mobile broadband (4G) usages, in addition to 700 MHz bands. Licensing mobile broadband services marks the spectrum assignment on nonvacant and heterogeneous bands for the first time. The spectrum frequencies put on for auction are 45 MHz*2 in 700 MHz bands, 30 MHz*2 in 900 MHz bands, and 60 MHz*2 in 1800 MHz bands, totaling 135 MHz*2 bandwidths (shown in Fig. 2) and the auction was conducted from September 3, 2013 to October 29, 2013⁸. It ended in the 393rd round, and the

⁸ 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 selected due to concern of high learning costs incurred by

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

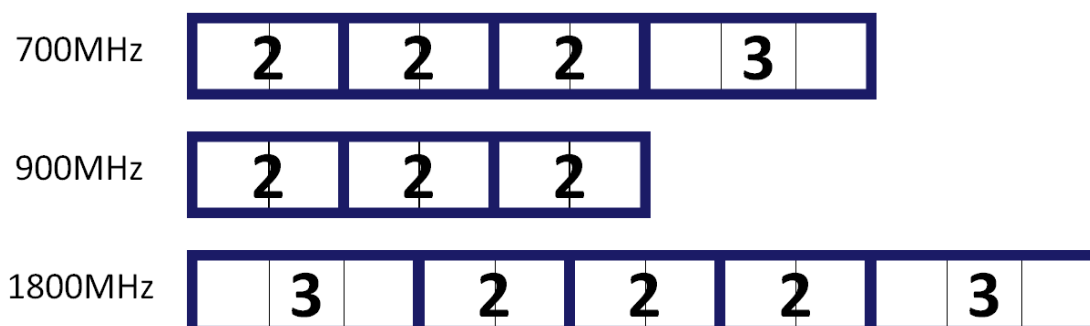


Figure 2. The reallocation of spectrum

The auction outcome 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 15 MHz*2 vacant bands in 1800 MHz (shown in Fig. 3). The bidding prices for the slots in both 700 MHz and 900 MHz were only slightly higher than the reserve prices. Although speculation on the bidders' strategies is never verified, it is widely believed that the spectrum value of the 900 MHz bands decrease due to the fact the most parts are being undertaken by the 2G incumbents until 2016 and the NCC has maintained an arm's-length approach to switchover. The potential winners' opportunity costs of using the 900 MHz bands enormously rise since the negotiation with the incumbents to clear such bandwidths presumably complex and cumbersome. Consequently, the demand for these bands and their bidding prices have plummeted. As for the 700 MHz bands, the smartphones, especially iPhones, that support such the band usage at the moment of auction were not available that reduces the bidders' valuation of those frequencies.

both the NCC staff and bidders.

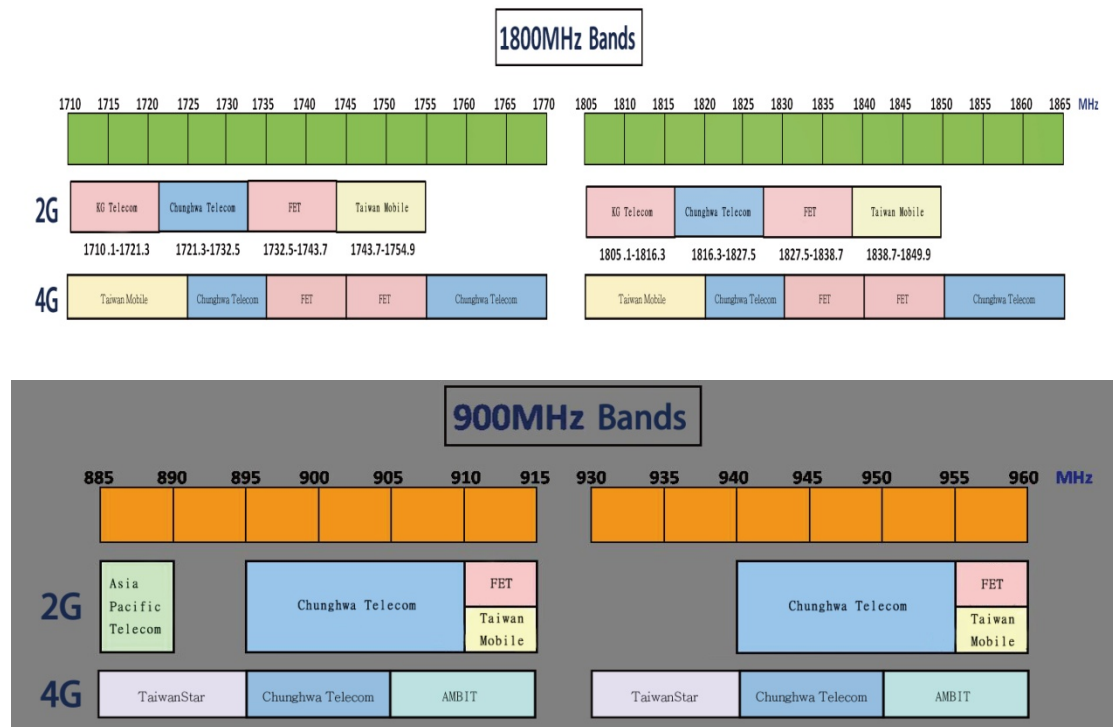


Fig. 3 The auction of mobile broadband licenses in 2013

Moreover, two problems regarding conflicting USRs emerged after the auction. The second and the third largest 2G operators, Taiwan Mobile and FarEasTone, are said to “mistakenly” bid over each other’s original slots (C1 & C4 shown in Fig. 3). Lacking of mutual trust, both desperately pursued the NCC to facilitate the exchange. Nevertheless, the NCC’s arm’s-length approach kept the stalemate hardly reconcilable. FarEasTone in order to redeploy its C3 slot for 4G service cleared and handed the C1 slot back to the NCC, while Taiwan Mobile failed to do so and continued its uses on the C4 slot⁹. FarEasTone constrained by limited bandwidths in the C3 slot then filed an injunction petition against Taiwan Mobile’s uses of the C1 slot, accusing that Taiwan Mobile breached the mutually-signed switchover agreement. Taiwan Mobile in return filed another injunction to be exempt from

⁹ Article 44 of “Regulations for Administration of Mobile Broadband Businesses” requires the winner of certain slot(s) to hand back the original slot(s) used for 2G service in the same given band before it can deploy 4G service in such the slots. The article was promulgated to ensure fair use of 4G bands that prevents the 2G incumbents from on one hand deploying 4G service while on the other hand maintaining 2G service in their original slots that are already reassigned to the rivals.

abiding by the aforementioned one.

The second problem lies in the interference of numerous microphone users and TV programmers transmitting signals wirelessly with Taiwan Mobile in the A4 slot that was previously assigned to microphone uses. Likewise, the NCC kept an arm's-length approach despite Taiwan Mobile and TV programmers' complaints.

3.2 The reassignment of 2500~2600 MHz bands for mobile broadband services

The Ministry of Economic Affairs (MOEA) of Taiwan sided with Intel 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 licenses for wireless broadband access (WBA) service in 2007. However, considering unpredictable market risks and industrial development, 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. The six winners are First International Telecom, Global Mobile Co., Vmax, FarEasTone, Tatung Telecom, and Vee Time and five of those are entrants except for FarEasTone¹⁰. Unfortunately, the WBA operators managed a negligible growth in their subscriptions since their launching of service. While Vee Time was denied of license extension due to the insufficient deployment of network infrastructure, the

¹⁰ VMax was partially invested by the 3G incumbent, VIBO, and considered an affiliate to it. It was later incorporated into VIBO in 2013.

rest three WBA operators, including FarEasTone, voluntarily relinquished their SURs and returned the assigned bands back to the NCC in 2014. In this case, Global Mobile is the only survivor. As Department of Transportation reallocated 2600 MHz bands for mobile broadband service, the auction on them is scheduled to conduct by the end of 2015. It is imperative to notice that the potential winner of the bands Global Mobile currently uses can partially claim its SURs until Global Mobile's license expires in 2020. That is, the SURs attached to the F2 slot are incomplete (shown in Fig. 4).

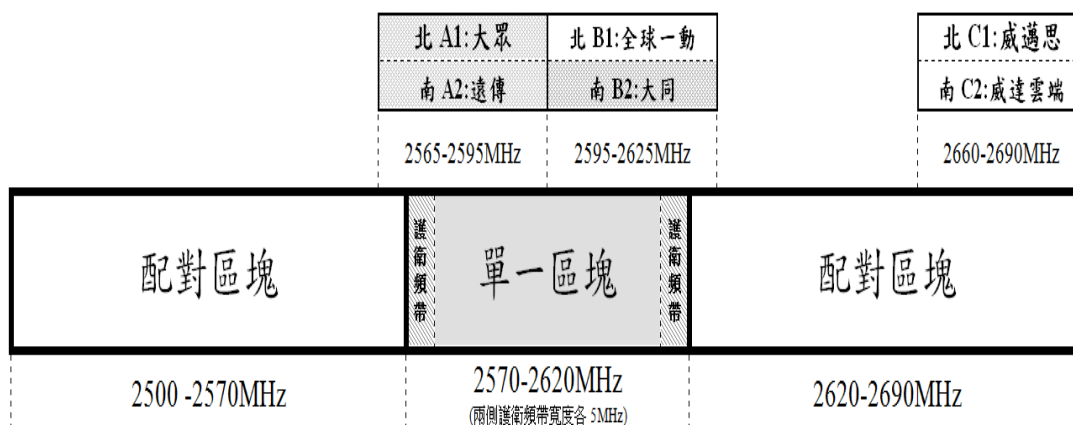


Fig. 4 The current assignment of 2600 MHz bands

It is highly anticipated that the ill-defined SURs will significantly decrease the bidders' valuation on the spectrum in avoidance of enormous transaction costs of negotiating with the occupant for its handover. The past experience demonstrates that private negotiation of spectrum handover can hardly be accomplished when the regulatory authority keeps an arm's-length approach. Especially constrained by the payment obligation that stipulates the winner to pay the winning bid in the full amount immediately after the auction is closed, the potential winner will suffer from financial losses should it bear uncertainty in acquiring vacant bands. The rational

choice left for potential bidders is to reduce the bidding price for such the nonvacant bands.

Nevertheless, the economic efficiency of spectrum incurred by 4G operation is estimated higher than that of the WBA uses. The social welfare could then be improved provided that the F4 slot can be swiftly redeployed for 4G uses. The regulatory intervention to facilitate the switchover seems plausible when the costs of intervention are smaller than the social benefits incurred by 4G uses. As discussed previously that valuation of the remaining SURs and trust are the major opportunity costs occurred to the transaction parties, the regulatory authority could mitigate such the transaction costs by estimating the spectrum value and by building a trustworthy mechanism for the parties to engage in transaction. The first of next two sections will explore the methods of spectrum valuation and calculate the remaining six-year value of 2600 MHz bands. And the second one will discuss the institutional design of a trustworthy transaction mechanism.

4. The valuation of 2600 MHz bands

In this section, we describe the structure of choices of a WBA operator by a decision tree, identify what the available options are, and evaluate the consequences of each option by the cash flow method.

4.1 WBA operator's decision tree

When considering the decision to transition from WiMAX to other, more advanced technology, the WBA operator is subject to the discretion of government regulation. In particular, it is constrained by the government's decision as to whether to allow license extension and whether to make it contingent on a technological upgrade. Given the exogenous mandates issued by the government

(NCC in this case), the decision path of the WBA operator can be depicted as in Fig. 5.

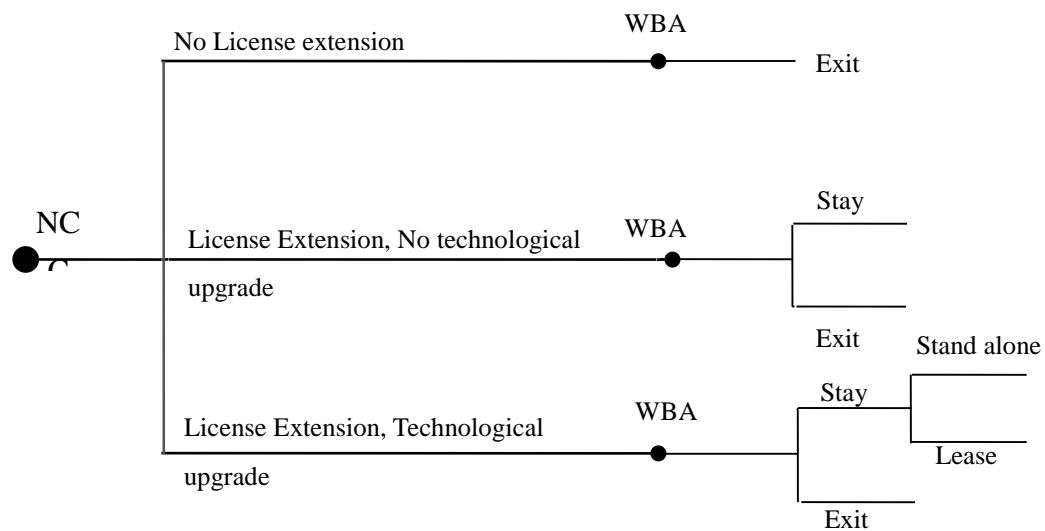


Fig. 5 The Decision Tree of WBA operator

In the decision tree there are three mutually exclusive mandates from the government: not allow license extension, allow license extension and require no technological upgrade, and allow license extension and require a technological upgrade. When the government decides not to allow a license extension, the WBA operator can only go out of business at the expiration date of the current license. If the government decides to allow for a license renewal, either requiring a technological upgrade or not, the WBA operator has two options, stay or exit. The decision to exit then implies that the choice to stay can generate no more than scrap value. When the government allows a license extension and requires no upgrade (to avoid loss to current subscribers), the WBA has to decide whether it can attract additional subscribers and generate a positive profit stream during the new contract period while operating with its almost-obsolete technology. When the

government allows a license extension but requires a technological upgrade, the WBA operator has to decide if the capital costs of installing the sufficient number of base stations required by the upgrade can generate a high enough profit stream to cover the expense. Relevant considerations are the oligopolistic nature of the market, the first mover advantage due to direct network effects and the presence of numerous incumbents. Besides stand-alone operation, we also add “lease” as an option to the WBA operator. To enhance the usage efficiency, leasing the vacant spectrum to the incumbent is an alternative available in the US or UK¹¹. Although currently this arrangement is not feasible in Taiwan, we are interested to know what this option worth compare to the other alternatives.

4.2 Value estimation

To evaluate the consequence of the decision tree, we specify the WBA operator as the WiMAX operator named Global Mobil Corporation (henceforth GMC). As described in 4.1, the expected return of the spectrum relies on the NCC’s decision toward license extension, technological upgrade, and if allowing to lease the spectrum to other operators. Therefore, we can summarize the decision tree depicted in Fig. 5 to four mutually exclusive scenarios, as presented in in Table 1, and they are scenario I: no license extension, scenario II: no license extension, and no technological upgrade, scenario III: license extension, technological upgrade, and operation stand-alone, and scenario IV: license extension, technological upgrade, however allowing to lease. The appraisal method of the value of each scenario is similar to the cash flow method summarized by Prasad (2014). In the following, we provide details about the method

¹¹ In this case, two leasing arrangements are possible: first, de facto lease, in which the eligibility of lessee requires permission from the government. Second, de jure lease, the lessor get to decide whom he lease the spectrum to. Since, in this incident, we are interested in exploring possible value of leasing, and thus we take leasing arrangement as de jure lease, and keep government regulation aside.

adapted to the practical data and the results of computation, which are summarized in Table 1:

Table 1: Possible scenarios of GMC's operation

| | No License Extension | License Extension | |
|--------------------------|----------------------|------------------------------|-----------------------|
| No Technological Upgrade | Scenario I | Scenario II | |
| Technological Upgrade | | Scenario III: Stand Alone | Scenario IV: Lease |

Scenario I: No License Extension

Under this scenario, GMC can only provide the original service (WBA) within the remaining duration of the initial license, which means its expected profit should be the present value of the expected profit of the operation from the current time to the expiration date of the license. Since GMC is not a listed company, we cannot access to its income statement. However, fortunately, we have income statement for another WBA, Vee Teleco which is a listed company, and thus income statements are available. Vee Teleco has quit its WBA service in Aug 2015, and the income statement of the second quarter of 2015 shows a net loss of 250 million NTD (about 8.3 million USD), and thus we use 500 million NTD to approximate GMC's net loss in 2015. It should be noted that Vee Teleco's service covers southern part of Taiwan, and GMC's service covers northern part¹² of Taiwan. Since Taiwan's size of population in the north is higher than that of in the south, we expect the rough net loss for GMC is an upper bound.

¹² The northern part of Taiwan includes Taipei city, new Taipei city, Keelung city, Yilan county, Taoyuan county, Hsinchu county, Miaoli county, and Lianjiang county, and the remaining administrative districts are regarded as the southern part of Taiwan.

Scenario II: License Extension, No Technological Upgrade

Under this scenario, the NCC allows license extension however requires no technological upgrade, which force GMC to provide the same service to its current and potential customer, so we use the estimated value of profit in Scenario I to appraise the present value of the profit for the license extension. The extended period of license is 6 years, and we use Taiwan's five major banks' announced committed average lending interest for new capital expenditure in June of 104 as the discount rate, which is 0.022, and the present value of net revenue for GMC for this scenario is a loss of 3.28 billion NTD (about 110 million USD). Since WiMAX is an almost-obsolete technology and can only provide part of service of the 4G technology, we expect the customer base will decrease overtime. Inasmuch as demand will decrease overtime we expect the GMC will not invest more in capital, and thus it is not certain our imputation is can be seen as an lower bound.

Scenario III: License Extension, Technological Upgrade, Stand Alone

To evaluate the net revenue of this scenario, we assumed the implementation of technological upgrade is to transform WiMax to the technology belonging to LTE group such TD-LTE, and thus GMC will become a new entrant to the market with 5 incumbents, including Chunghwa Telecom (CHT), Taiwan mobile, and Far EasTone, Asian Pacific Corporation (APC), and Taiwan Star Telecom (TST). To be qualified for license extension and required technological upgrade, GMC must commit a sunk cost of installing a minimum amount of base station, which, according to a credible news report, should amounts to 2.0 billion NTD (about 66 million USD) for building 2,000 base

stations¹³. To become an eligible competitor, GMC should install more stations which will be considered in the capital investment revealed in the financial report described below.

The yearly net revenue of GMC is calculated as:

$$\text{NetRevenue}_t = R_t - C_t,$$

where the imputation of revenues and costs of year t , R_t and C_t respectively is formulated by

$$R_t = \text{ARPU} * 4\text{G users} * \text{Ratio of Length of Spectrum} * \text{Adjustment Index} \quad (1)$$

and

$$C_t = \text{Capital Investment} + \text{Operating Cost} \quad (2)$$

As the result of data constraint, the average revenue per unit in equation (1) has considered number of users across 2G to 4G service which is published by investor conference of each incumbent of 4G in June 2014 (citation). Number of 4G users is computed by incumbents announced number of total users (citation) reduced by NCC's announcement of 2-3G users (citation). The ratio of length of spectrum is to use the length of spectrum available to GMC (30 MHz) divided by incumbent's length of spectrum¹⁴ to avoid overestimate of the number of 4G users for the GMC. Another adjustment necessary is to use the adjustment index, which is to consider the fact that the performance of 4G-LTE advanced networks will be different in different spectrum bands. By Haider et al (2011)¹⁵, we transform the spectrum size of GMC (30 MHz) by the difference of its location of spectrum band (2.6GHz) from that of other 4G

¹³ <http://www.chinatimes.com/newspapers/20150428000045-260202>

¹⁴ The ratio of length of spectrum is 30/35, 30/35, 30/30, and 30/25 for CHT, TMB, FET, and APC respectively. Because we do not have relevant data, including ARPU and number of 4G users for TST, we are not able to estimate GMC's revenue and costs based on TST's operation.

¹⁵ Haider, F., Hepsaydir, E., & Binucci, N. (2011, June). Performance analysis of LTE-advanced networks in different spectrum bands. In *Wireless Advanced (WiAd)*, 2011 (pp. 230-234). IEEE.

providers. For example, the adjustment index is 0.8 for CHT, which means a size of 30 MHz located in 2.6 GHz is only worth 24 MHz in the 1.8 GHz in which CHT's service located in, and the index are 0.7 for TMB, 0.7 for FET, and 0.5 for APT.

In equation (2), the cost of capital investment is the amount of physical capital expense from statement of cash flow and the operating costs is the operating expenses in the income statement adjusted by multiplying to a ratio of revenue from mobile phone service to total revenue. This adjustment is justified by the fact that the mobile phone service is usually only a part (although it may be the major one) of each incumbent's business practice.

Since we do not have the data of 2015, and we do not have enough information to estimate the growth rate of net revenue for each incumbent, especially because the new entrant will have an unneglectable impact to the price and market share. We use the average net revenue of 2007-2014, and assume it constant over the time to praise the present value of GMC's stand-alone operation in the 4G service. The imputation shows that, if GMC operate like the current incumbent, with same relevant demand and cost estimator, the range of present value of its net revenue is between APC's 5.63 billion NTD (roughly about 188 million USD), to FET's 140.484 billion NTD (roughly about 4.68 billion USD)¹⁶.

Scenario IV: License Extension, Technological Upgrade, Lease

In this scenario, we assume government allows GMC to lease its spectrum to the incumbents of 4G. Because an incumbent may use GMC's spectrum as a lessee, which, to the incumbents, is more different from the [clean spectrum, acquired through an auction with a higher winning bid](#), than those occupied spectrum (the right to use the

¹⁶ The corresponding values for CHT and TMB, respectively, are 46.0 billion NTD (about 1.5 billion USD), and 107.18 billion NTD (about 3.6 billion USD)

spectrum from the owner of previous auction will only expire for a few years hereafter) , acquired with a lower winning bid. Thence, we use the occupied spectrum to assess the rent of lease.

Because most occupied spectrum are located in 700 and 900 MHz, and thus adjustment index, as explained in Scenario III, is needed to adapted to GMC's band location, and their spectrum size are exclusively 10 MHz, and thus ratio of length of spectrum should be 30/10. Subsequently, we can use the following formulate for imputation of rents:

$$r_t = \frac{\sum_i (\text{Winning Bid}_i * \text{Ratio of Length of Spectrum}_i * \text{Adjustment Index}_i * 6/17)}{I}$$

in which I is the total number of occupied spectrum band, and 6/17 is the ratio of new license period to the permitted periods of 4G license. r_t is thus the average adjusted winning bids of the occupied spectrum, which is 2.43 billion NTD (about 81 million USD).

Table 2 The Appraisal Formula and imputation of Present Value for different Scenarios

| | Formula | Present Value |
|--------------|---|-------------------------|
| Scenario I | Net revenue of 2015 | -500 million NTD |
| Scenario II | Net revenue of 2015*(1+ $\sum_{t=1}^6 \frac{1}{(1+r)^t}$) | -3.28 billion of NTD |
| Scenario III | Net revenue of 2015 – cost for technological upgrade + $\sum_{t=1}^6 \frac{\text{NetRevenue}_t}{(1+r)^t}$ | 5.63-140.48 billion NTD |
| Scenario IV | Net revenue of 2015+Rent | 2.43 billion NTD |

5 The institutional design of trust and enforcement

Incentive auction is thought as an ideal solution to efficiently switching the underutilized bandwidths for better uses. Nevertheless, it entails uncertainty for TV broadcasters as they have tremendous learning costs in determining their bidding

strategies. In its public notice announced in August, 2015, the FCC modified the procedures of the reverse auction that the opening bid prices will be calculated and announced by the FCC prior to the TV broadcasters' registration to participate in the auction. The broadcasters should have ample time to decide whether or not to participate in the auction. Once the broadcaster has completed an application, it must commit to its preferred initial bid option. "That commitment will bind the broadcaster to relinquishing its spectrum usage rights at the opening price applicable to its preferred option. If, in the auction itself, the price offered to the broadcaster drops, the broadcaster is no longer bound to relinquish its spectrum unless it elects to remain in the auction at the lower price (FCC, 2015)." In response to TV broadcasters' concerns that the original proposal is burdensome and could limit their willingness of participation, the FCC decided to make bidding information available to bidders before the auction and to revise the auction procedures to limit the changes the broadcasters are affected (FCC, 2015). Consequently, the uncertainty associated with reserve auction is greatly reduced for the TV broadcasters. The commitment they made also helps deter themselves from engaging in opportunist behaviors that they may forgo the relinquishment should they anticipate a higher bidding price in forward auction.

The FCC's modification highlights the importance to constitute a set of institutions (i.e., rules) that the bidders abide by to undertake trading. The question we are left with is what set of institutions should be created to enforce negotiation when there are few occupants and incentive auction is not necessarily adopted. As the compensation value to relinquish the SURs (shown in the previous section) is known to the occupants, institutions must be set to deter them from engaging in opportunist behaviors, that is, forgoing the negotiation. Alternatively, the institutions are set to enforce them to voluntarily relinquish their SURs. We consider the entrusted account

often set up in purchasing real estates as an enforceable mechanism of transaction. When both parties signed a contract of purchase, bank representatives and real-estate brokers act as an impartial third-party to ensure that the buyer transfers the down-payment into the account and the seller has relinquish her property right. The impartial third-party acts to increase trust of the both parties on transaction and to reduce the costs of conveyance. The transaction is therefore facilitated.

Likewise, the NRA could act as an impartial third-party that guarantees the undertaking of transaction so that potential bidders have willingness to participate in forward auction. In addition, the NRA can enforce the undertaking provided it notices the opportunist behaviors of the occupants. We recommend that the NRA firstly signs a mutual consent with the occupants should they decide to accept the compensation price that NRA announced before the forward auction. The consent specifies the conditions under which the occupant commits itself to relinquishing the SURs at that given compensation price. The conditions, for example, may include the maximum time period that the occupants can retain their SURs, the band-clearing schedule tied with the percentage of the full payment deposited into the account, the standards and procedures of band-clearing, and etc. The occupants are authorized to collect the entire payment only after they fully implemented band-clearing as designated.

6 conclusion

Because of customers' needs being connected wirelessly and technological advances of cloud computing, the demand on spectrum is increasingly high. The current spectrum assignment and allocation plan in most countries cannot match such the high demand so that we encounter the problem of scarce spectrum. It therefore becomes one of crucial tasks for the NRAs in regulating the industry as how to effectively relinquish

underused bandwidths from the occupants and switch to the higher efficient uses. Under the current technological constraints, the commons approach, equivalently dynamic and seamless access to temporarily vacant spectrum, is not yet a feasible option. Alternatively, secondary trading is neither much adopted even if the NRAs permit it.

We constituted a case study in examining the institutional stalemates that deter the occupants of underused bands from undertaking the transaction, that is, relinquishing their SURs. We pinpointed two kinds of transaction costs associated with spectrum trading: information costs of spectrum evaluation and trust/enforcement costs to execute the transaction. To mitigate the information costs, we contended that spectrum value should be reckoned and announced by government. The value of the occupants' remaining SURs was thus estimated in this paper based on the cash flow method summarized by Prasad (2014). To foster the occupants' trust, we designated an institutional design of the entrusted account held by the NRA.

The FCC proposed to conduct incentive auction so that TV broadcasters may voluntarily relinquish their SURs. Nevertheless, it modified methods and procedures to curtail the broadcasters' uncertainty regarding the reverse auction. The modification indeed exemplifies the transaction difficulties involved in the original proposal. This paper presents a policy alternative to incentive auction that highlights the mitigation of transaction costs. Our approach is especially applicable to those countries where only a few occupants of underused bands remain in the market. Because incentive auction requires the NRA's computational capabilities, direct negotiation save its high administration costs of conducting incentive auction.

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