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Commercial radio spectrum use rights in the US are traditionally assigned using licenses over large geographic areas with 10- or 15-year terms, to encourage infrastructure investment. However, such long-term licenses are difficult to reassign as more valuable uses for spectrum arise. Licenses with shorter term limits over smaller areas expedite reassignment of spectrum to innovative entrants, but provide lower incentives for long-term investment. Recent economic theory suggests that this trade-off between protecting long-term investments and enabling valuable, innovative entry can be muted by a new, more efficient "depreciating" license. A promising application is to priority access in the 3.5GHz band, where thousands of licenses are about to be auctioned. Alternatively, carefully redesigning auction rules may offer similar benefits.

Innovation and expansion in the US wireless communications network offers enormous growth potential for the US economy, enabling not just improvements to traditional services like those linked to mobile phones, but new services involving the Internet of things, self-driving cars, wireless factories and warehouses, and more. Yet harnessing the full benefits of technological progress requires well-functioning markets for spectrum rights that encourage innovation, competition and investment. In this article, we propose replacing the existing license structure with a new system of ``depreciating licenses'' that can allow markets to perform better along all these dimensions.

Existing license designs present regulators with a stark choice between encouraging entry and innovation or ensuring that licensees' complementary, long-term investments are secure. The 10- or 15-year licenses typically sold to wireless service providers with an expectation of renewal protect their large investments in the physical system infrastructure. However, they effectively give incumbents control over critical parts of the spectrum, allowing them to demand a share of returns from new uses, blocking or delaying the emergence of innovative new uses. Unlicensed spectrum or short-term licenses for small geographic areas encourage entry and innovation, but provide lower incentives for long-term investment.

Attempting to balance the benefits of long license terms for investment with the benefits of short licenses for innovative entrants, the Federal Communications Commission (FCC), which regulates the use of spectrum, has recently proposed using a 3-year license term for priority access to the 3.5GHz band. The apparent goal is to provide some protection for long-term investments while still allowing relatively quick turnover of spectrum users and uses as needs and technology change.

This goal of balance is laudable, but the FCC can do much better. As industry groups have recently highlighted in a petition to change the FCC's proposed rules, three years is not long enough to recoup some kinds of infrastructure investments in wireless networks. At the same time, the recent FCC incentive auction highlights how long renewable licenses (in that case, for TV broadcast) have sometimes delayed valuable changes, and saddled them with huge costs. For markets to work best, we need a new kind of license, carefully designed using economic theory, that provides enough protection to secure long-term investments, but not so much as to blockade new entry and preclude value-increasing innovation.

In this paper, we propose such a license: the "depreciating license" based on ideas two of us have developed in our academic work along with University of Chicago Law Professor Eric Posner. The licenses are of unlimited duration, but licensees must declare a price at which they are willing to sell their licenses and pay a license fee based on that price. The unlimited duration of these licenses provides strong protections for long-term infrastructure investments to support valuable uses, but the license terms also allow valuable innovations to emerge quickly, by taking advantage of a liquid secondary market for spectrum.

Although depreciating licenses are a theoretically ideal solution, many of the same benefits can be achieved in another way that may be more consistent with traditional FCC policy and practice: by introducing auction rules that provide a similar advantage to incumbent licensees. We explain below how this can be achieved.

Why Markets Need Smart License Design

In a hypothetical, "perfect" market, bargaining among parties would lead licenses to migrate to their economically most efficient uses at every point in time, regardless of how they are initially designed. The work of Ronald Coase is often misinterpreted as suggesting something similar might happen in actual practice. Yet Coase rejected this interpretation of his own work. Economic theory, empirical analysis and common sense all clearly suggest this conclusion is false: the rules governing transfers of rights can affect economic efficiency.

There are several potentially important problems with traditional systems of spectrum licensing. One is that some licensees might hoard spectrum that they do not plan to use. They could do this either to block entry by competitors or to "tax" or pre-empt future innovators who may need spectrum access. A second problem, familiar from land reallocation, is that one or a small number of holdouts may try to extort high payments for cooperating in large-scale reassignment. These problems were illustrated dramatically by the time, effort and cost required to reallocate spectrum used for over-the-air television broadcast to more valuable uses. Some such spectrum was recently reallocated by the FCC's incentive auction, and the success of that effort teaches another important lesson: market performance can depend deeply on license design. In legislation enacted in 2012, the government decided that TV

broadcasters that chose not to sell their broadcast rights could nevertheless be required to shift to a different broadcast channel, greatly reducing the holdout problem.

Design of Priority Access Licenses for the 3.5GHz Band

The 3.5GHz band, currently used for naval and other military radars, along with certain satellite earth stations, is soon to be shared with other uses. The FCC has mandated the use of a "Spectrum Access System" in the 3.5GHz band, which acts like a traffic signal for wireless transmissions, allowing higher-priority uses to preempt lower-priority uses. Access rights to this band are to be divided into three tiers. The highest priority would belong to the incumbent military uses, and upon request these users would be able to block any other user. The lowest priority tier, called General Authorized Access (GAA), would be for unlicensed uses. Any device satisfying use-sharing protocols can operate using GAA at no cost, but must yield when higher priority uses are present. There would also be a middle priority tier: the holders of a "priority access license" (PAL) would have higher priority than unlicensed users when the band is too congested to serve all comers.

The frequency at 3.5GHz is well-suited to a variety of uses, and the heterogeneity of uses has led to controversy over the design of PALs. A central issue of contention has been the choice of license term limits. Short license terms with no expectation of renewal facilitate flexible reassignment of spectrum licenses. Parties with new uses would have frequent opportunities to compete for short-term licenses in efficient auctions, rather than in a secondary market burdened by the spectrum hoarding and holdout problems. On the other hand, with short term limits, licensees who have invested in developing large areas run the risk of losing future license auctions, leaving their investments stranded or diminished. By providing greater security for the network investments needed to use spectrum efficiently, longer term limits promote these investments.

Related to term limits is the question of whether licenses can be renewed. In the past, spectrum licenses have had ten-year or fifteen-year terms with the expectation that they could be renewed upon expiration. Licenses with a strong expectation of renewal provide good incentives for investments to maintain and upgrade networks. Whatever the term, if there is no expectation of renewal, a license eventually becomes a lame duck, with little time left in its term. The 3.5GHz proposal allows parties to acquire up to two consecutive three-year licenses when PALs are initially assigned, but provides no assurances for renewal thereafter; as a result, PAL holders cannot capture the full return on investments that can enhance the value of the spectrum band beyond a six-year horizon.

Another contentious issue is the geographic scope of licenses. Licenses covering small geographic areas facilitate localized use of spectrum. For example, the owner of a factory or warehouse might purchase a PAL for the area around its facility, leaving nearby areas available for licensing by others. The proposal for 3.5GHz defines licenses for each of the more than

74,000 census tracts in the US, which would allow entrants to purchase licenses for highly localized uses. With so many potential uses, users and licenses, some have expressed concern about the feasibility of an auction that is both flexible enough to efficiently assign licenses and simple enough to attract robust participation. Geographic granularity also poses a challenge for parties who prefer to aggregate PALs covering larger geographic areas; a mobile carrier might argue that its customers want consistent wireless coverage throughout its service area. Even without larger area licenses, consistent coverage can be provided by using the unlicensed part of the band and purchasing PALs where the band is most congested.

Ideally, instead of designing licenses to support any one specific paradigm, licenses should be flexible enough to accommodate alternative usage patterns, and the market should reassign spectrum licenses to more valuable uses, both to correct initial assignment mistakes and to adapt to technology as it evolves over time. Recent work in economic theory suggests an innovative license design which takes a large step towards this goal.

Depreciating Licenses

We propose to assign priority access rights for the 3.5GHz band using "depreciating licenses," sold on a depreciating license exchange (DLE). The DLE is a decentralized trading exchange that allows spectrum reassignment to occur at any time, minimizing holdout and hoarding problems. Depreciating licenses are characterized by some fixed annual depreciation rate – we suggest approximately 10% – and are initially sold to interested parties in a one-time auction.

Depreciating licenses can be described in several equivalent ways. From one perspective, the depreciating license is a perpetual license that carries an annual license fee equal to 10% of its "value," as declared by the licensee. What disciplines the declared value is that it doubles as an offer: the licensee must be prepared to sell her license to any party who is willing to pay the declared value. From a second perspective, the licensee is granted a depreciating stake in a perpetual license, with 10% of the right reverting annually to the FCC. To continue to use the license, the incumbent licensee purchase the missing 10% each year at a price of X, which the incumbent licensee herself determines. However, when she declares X, she commits to sell her license to any buyer during the next year at a price of 10X, which becomes an upper bound on the licensee's "ask price" for that year. These rules create a tension – a licensee can pay a reduced license fee by declaring a lower value X, but must then be willing to sell the license for the corresponding lower price. If a licensee tries to hoard spectrum by claiming a high value, she must pay a high license fee every year. The balance of these effects encourages the incumbent licensee to quote a price X that is roughly equal to 10% of her actual value.

Operating such a system would require creating an exchange platform on which licenses can be bought and sold. The platform would include a searchable database listing the prices for the licenses for each area . This exchange format would replace the usually illiquid and

haphazard secondary market for spectrum licenses with a much more liquid market, like one for commodities or stocks. All licenses would be available for purchase at posted ask prices at any point in time, allowing purchasers to access all licenses and buy the lowest priced ones. There could be posted bid prices as well. Licensees who make significant unrecoverable investments in spectrum can choose to post higher ask prices, paying somewhat higher license fees to protect the value of their investments. Their licenses will be sold only if buyers arrive with sufficiently high values to want to purchase despite the high ask prices and the associated high annual license fee. If such a buyer does appear, the licensee is paid her ask price (10X), allowing her to recover much of the value of her investments. Furthermore, because the license is effectively renewed annually, it never becomes a lame duck, so the same protection applies to new investments made to renew or upgrade any networking infrastructure.

The DLE is self-regulating, promoting license reassignment in a manner that is responsive to changes in the competitive and technological environment surrounding spectrum use, without requiring new legislation or discretionary government interventions, like "incentive auctions" or eminent domain. A licensee who finds the fees too high or wishes to sell her license can do that at any time, either immediately by announcing a new ask price lower than the highest bid price in the register, or by gradually lowering her ask price and paying reduced license fees until a willing buyer appears. New entrants likewise can either purchase spectrum instantly at the prevailing ask prices, or submit bids and wait until an ask price drops below their willingness to pay for spectrum use. Moreover, even if technological innovations require the FCC to redesign licenses, for example changing the permitted uses in the band, it could rely on the prevailing ask prices to assess the economic values and possibly to make its purchases.

Depreciating licenses would be straightforward to administer; the only infrastructure required is a standard market platform like eBay or Airbnb, which is responsible for collecting and cataloging bid and ask prices from potential buyers and current licensees, collecting license fees, and facilitating license transfer when bid prices exceed ask prices. As in any traditional example, a license is transferred when a buyer and seller in any market post compatible bid and ask prices. A bidder that requires coverage of a larger area could see the relevant prices and buy all the relevant licenses at the same time. Once the exchange infrastructure is in place, this system could be significantly easier and less costly for both the operator and the participants than the current system of periodic auctions.

Practical Alternatives

This infrastructure, however, is different from what is currently implemented using well-established FCC authorities, so it is interesting to examine how a similar economic outcome might be promoted with smaller changes to the existing FCC infrastructure and auction rules. As in the exchange design, depreciating licenses with some fixed annual depreciation rate could be initially sold in a one-time auction. Thereafter, instead of the continuous license reassignment of the DLE, licenses could be reassigned in auctions that take place, for example, once every

three years. To make these reassignment auctions approximate the DLE outcomes, current licensees would be given a substantial advantage over new buyers. For example, if auctions are held every three years and the goal is to mimic a depreciation rate of 10%, then an incumbent licensee who loses an auction for her own license is paid 70% of the final auction price, as compensation for relinquishing her remaining stake in the license. This compensation might be awarded in cash or, more consistent with existing FCC practice, in transferable credits that can be used to purchase other licenses. Similarly, incumbent licensees who win auctions would pay only 30% of the auction price, the rest being covered by bidding credits.

The auction implementation of depreciating licenses forgoes the continuous decentralization and simplicity benefits of the DLE, and fails to provide continuous information about license values. It also navigates the trade-off between flexibility and stability more poorly than the DLE: at the same depreciation rate, periodic auctions lead to slower license turnover without giving better investment incentives. It might therefore be desirable to have a higher annual depreciation rate than the 10% we suggest for licenses traded on the DLE.

Despite these drawbacks, the auction proposal nonetheless promotes relatively easy and frequent reassignment while securing complementary investment. Given that the awarding of bidding credits to incumbents is already common, the most significant difference between depreciating license auctions and the FCC's current auction system is that some of these credits are transferable or refundable if the incumbent loses.

Other Considerations

The use of depreciating licenses or the related auction-based system resolve and simplify many of the issues associated with license design. First, the issue of renewal expectations does not arise, as licenses have indefinite lengths. In effect, the licensee renews her license continually at a market-determined price. In that respect, our auction implementation of depreciating licenses is closely related to proposals suggesting that licensees should be allowed to renew licenses by paying a fee based on the license's initial auction price. However, rather than using the *initial* auction price to set the renewal fee, our system requires licensees to pay a fraction of the *current* auction price at the time of renewal. This accounts for the possibility that unforeseen valuable uses of spectrum may emerge, or that, conversely, there will be few such uses, in which case the licensee can pay less to renew. In short, these designs adapt to market conditions, rather than getting stuck with obsolete prices from past auctions.

The combination of depreciating licenses and unlicensed access (GAA) tremendously simplifies auction design. Indeed, the main reason for the relatively complex auctions traditionally used for spectrum licenses is that some licenses may be substitutes or complements. For some bidders in FCC auctions, licenses were complements: these bidders may have wanted to acquire licenses only if they could fully cover a large area. With unlicensed uses to fill in the gap plus the possibility of acquiring more PALs on the DLE, the strongest complementarities are largely eliminated. For other bidders, licenses may be substitutes: a

small new entrant might wish to establish a service in one or two cities, picking among them depending on the price. For such an entrant, substitution in the auction is amply replaced by the posted prices of the DLE. Thus, with depreciating licenses, there is little need to adapt auctions to accommodate substitutes and complements. Even a simple simultaneous sealed-bid auction, or a simultaneous ascending auction with no switching, can be easily run for very many licenses, and is manageable for even relatively inexperienced bidders. The same auction solutions could apply with the alternative triennial auction.

The FCC could also manage the tradeoff between licensed and unlicensed spectrum use by setting reserve prices for depreciating PALs through its own bids. For example, by bidding X, Y and Z for three licenses with X<Y<Z, the FCC effectively sets the low reserve price X if just one PAL is purchased with the other two open for additional GAA use, a medium reserve price Y in case two are purchased and just one is left for additional GAA use, and a high reserve price Z if all three are purchased. In this way, reserve prices increase as more PALs are sold, reflecting the increasing social cost of excluding more spectrum from unlicensed use. Such bids would also provide some insurance to a licensee, as at any time she could sell her license to the FCC at the reserve price, in which case her PAL is converted to additional spectrum for GAA use.

Finally, the DLE design also offers an exciting possibility for the determination of geographic license areas: incumbent licensees might be given permission to decide those areas themselves. They could combine several licenses that were previously fragmented and post a value only for the combination, or a buyer could purchase a large geographical license and carve it up. Allowing for the market rather than license designers to determine the appropriate geographical scope of licenses is a potentially important advantage of a DLE.

Conclusion

We have here focused on the 3.5GHz band because of its immediate policy relevance. But depreciating licenses appear to have wider promise for public asset leases in which costly investments in developing the resource must be balanced against the flexibility to allow innovative new methods. For example, conflicts over the use of public lands (for grazing, farming, mining, etc.) have been an important theme of American history. Each use requires investment, but the best use of lands has changed frequently and the control of past licensees has often blocked innovative new uses. Every application raises its own special issues, but the depreciating license approach for this band provides another chance for the FCC to bring innovative market-based solutions to an important policy problem.

Readings

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