GEORGE MASON UNIVERSITY SCHOOL OF LAW

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06-28

GEORGE MASON UNIVERSITY LAW AND ECONOMICS RESEARCH PAPER SERIES

A WELFARE ANALYSIS OF SPECTRUM ALLOCATION POLICIES*

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April 7, 2006

Abstract

Economic analysis of spectrum allocation policies focuses on competitive bidding for wireless licenses. Auctions generating high bids, as in Germany and the UK, are identified as "successful," while those producing lower receipts, as in Switzerland and the Netherlands, are deemed "fiascoes." Yet, even full and costless extraction of license rents does not map directly to social welfare, because spectrum policies creating rents impose social costs. For example, rules favoring monopoly market structure predictably increase license values, but reduce welfare. This paper attempts to shift analytical focus to the relationship between spectrum policy (including license auctions) and efficiency in output markets. In cross-country comparisons of performance metrics in mobile telephone service markets, empirical estimates suggest that countries allocating greater bandwidth to licensed operators and achieving more competitive market structures realize demonstrable social welfare benefits. These gains generally dominate efficiencies associated with license sales. Spectrum policies and rules intended to increase auction receipts (e.g. reserve prices and subsidies for weak bidders), should be evaluated in this light.

Key words: spectrum allocation, wireless telecommunications policy, auctions, revenue extraction, mobile telephone competition, competition policy, information infrastructure

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* The authors would like to thank Robert Hahn and Ricardo Smith for valuable comments on an earlier version of this paper. Of course, remaining errors are ours.

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I. INTRODUCTION

Competitive bidding to assign wireless licenses constitutes a substantial policy advance. Following Leo Herzel (1951) and Ronald Coase (1959), auctions were advocated by numerous economists (e.g., Levin 1962), policy experts (Pool 1983), and policymakers (Fowler & Brenner 1982). Competitive bidding was finally adopted by New Zealand in 1989 (Crandall 1998), India in 1991 (Jain 2001), and the United States in 1993 (McMillan 1994). At least twenty-five other countries have instituted license auctions in recent years (Hazlett 2004).

The argument for using the "price system" to allocate wireless licenses is premised on three types of efficiencies:

a) elimination of rent dissipation associated with "comparative hearings" or "beauty contest" awards (Kwerel & Felker 1985);
b) assignment of licenses to the most productive suppliers, saving the costs of secondary market reassignments (Cramton 2002, 608);
c) generation of revenues for public use, funds which could displace activity-distorting taxes; the consensus estimate is that $0.33 in social cost is saved for every dollar not raised by taxes (Cramton 2001, 48; Klemperer 2002b, 179).[3]

A healthy literature on the implementation of auctions has emerged, focusing on the efficiency of rival bidding mechanisms.[4] Here, the revenues raised by government auctions are seen both as indicators of auction design efficiency and as appropriated surplus that increases social welfare by offsetting activity-distorting taxes. Consequently, auction success is measured by license receipts.[5] The auctions producing relatively high bids in the U.K. and Germany are widely identified as "successes," while license sales producing far lower revenues in Switzerland or the Netherlands are deemed "fiascoes."[6]

This *revenue centric* approach assumes that license assignments are independent of underlying spectrum allocations. The logic is diagrammed in Figure I.1. Policy makers allocate bandwidth for particular services in Stage 1 -- "spectrum allocation." In this, policy makers create wireless licenses, and in so doing, set forth rules that largely determine how the market will be structured and how efficiently operators will perform. This includes such policy choices as how many competitive operators to license, rules to limit or facilitate license aggregation, rules governing interconnection of networks, technology and service mandates, and the determination of which frequencies are allocated to the licenses. In Stage 2 the licensee rights created in Stage 1 are distributed

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3 Cramton (2002, 608) cites a range of 17-56 cents, relying on Ballard et al., 1985.

4 See McMillan 1994, McAfee & McMillan 1996, Cramton 1995, 2002; Moreton & Spiller 1998; Grimm et al. 2001; Wolfstetter 2001; Binmore & Klemperer 2002; Van Damme 2002; Klemperer 2002a, 2002b.

5 It is customary to adjust receipts by bandwidth allocated licenses and the population of the franchise area, such that prices are quoted in terms of "$ per MHz per pop."

6 Klemperer (2002a, 841) identifies the British auction as "successful," while rating auctions in Austria, Netherlands and Switzerland as "fiascoes." The auction in the Netherlands is rated a "miserable failure" in Binmore & Klemperer (2002, C93).

to service providers – "license assignment."[7] Ultimately, wireless services are provided by licensees to consumers, generating economic welfare in Stage 3.

FIGURE I.1: SEPARATING SPECTRUM ALLOCATION AND LICENSE AUCTIONS

Stage 1	==→	**Stage 2**	==→	**Stage 3**
Spectrum Allocation		License assignment		Retail Market
Wireless licenses created		Auction rules		Prices, outputs
Market structure rules				Tax savings

Formal economic analysis has focused on Stage 2, scrutinizing alternative bidding mechanisms. Of this approach, Paul Klemperer has written: "What really matters in auction design are the same issues that any industry regulator would recognize as key concerns: discouraging collusive, entry-deterring and predatory behavior. … By contrast, most of the extensive auction literature … is of second-order importance for *practical* auction design" (Klemperer 2002b, 169-70, emphasis in original).[8] This approach, "just good undergraduate industrial organization" (Ibid.), is suggested for auction design, which it assuredly assists. But an essential analytical conflict is left intact: auction rules that alter market structure or operator performance produce Stage 3 welfare effects, and these spillovers are not systematically accounted for.

For instance, economists often advocate improving license auctions by imposing reservation prices,[9] extending credits to "weak bidders,"[10] and restricting the number of licenses (to increase scarcity value).[11] In addition, the social discount rate is ignored in auction processes that delay productive use of frequencies for months or years.[12] Each implicates spectrum allocation rules (Stage 1), and alters final market outcomes (Stage 3). Yet, policies are evaluated on the incremental revenues they extract in license bids.[13]

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7 This theoretical separation is facilitated by the use of the term "spectrum auction," which implies that what is being sold is a natural resource, a physical commodity exogenously defined. We employ what we hope is a less confusing terminology, referring to "wireless license auctions." See discussion in Hazlett 2001, 402-407.

8 Support for this view is also supplied in Klemperer & Binmore 2002 and Klemperer 2002a.

9 See Cramton (2002), Krishna (2002) or Klemperer (2002a).

10 See Ayres & Cramton (1996), Rothkopf et al. (2003).

11 See Wolfstetter (2001), van Damme (2002), Rothkopf & Bazelon (2003).

12 Binmore & Klemperer (2002, C90) note that a three year planning phase was used to good cause in crafting the U.K. 3G auctions, without accounting for the relevant welfare trade-offs.

13 In a standard treatment, Peter Cramton (2002, 631) explicitly notes the "two steps in making spectrum available to companies." He goes on to write: "Arguably, the greatest economic gains will come from better allocation of spectrum, rather than from improved methods of assigning the spectrum. This is because current spectrum auctions already are highly efficient. In contrast spectrum allocations often are far from efficient." We agree with the conclusion, but disagree with the rationale. Even where license auctions are not in place the largest efficiency gains come from improved spectrum allocation. Our instant point, however, is that the relationship between auction (Stage 2) and allocation (Stage 1) is not properly integrated. On the analysis of spectrum allocation policy per se, see Rosston & Steinberg (1997), White (2000), Hazlett (2001), Owen & Rosston (2001), Kwerel & Williams (2002), Faulhaber & Farber (2002), Hazlett (2003), and Faulhaber (2005).

The problem is put into perspective with some simple estimates of social value. Empirical research suggests that annual consumer surplus associated with U.S. cellular telephone licenses is at least ten times as large as annual producers' surplus.[14] Policies undertaken to improve license revenues, then, focus on a small fraction of the economic value at stake.[15] Rules that increase auction bids but risk collateral damage – say, by reducing operator efficiency or market competitiveness – are not properly evaluated by reference to rent extraction alone. This is true even when revenues raised by license auctions do, ceteris paribus, increase welfare.

Extending the Klemperer critique, we argue that economists must not only pay attention to market structure issues within auction design, investigations of license assignment efficiency should be nested within an analysis of wireless output markets. The fundamental issue is consumer welfare: how are service prices ultimately impacted by alternative rules? Efficient license assignments are important to these outcomes, and public revenues can generate value, as well. But where auction rules affect final users, output market welfare changes are not only implicated, they are likely to dominate.

We hasten to note that Paul Klemperer has correctly diagnosed the temptation to favor monopoly rent creation over competitive output markets. Klemperer (2002b, 185) comments on a proposal by Italian regulators (not, in fact, implemented) to eliminate a 3G[16] license (and the competitor it would empower) in order to raise auction revenues: "[T]he approach was fundamentally flawed…it is putting the cart before the horse to create an unnecessarily concentrated mobile-phone market to make an auction look good" (Ibid.).[17]

In contrast, however, Klemperer endorses the policy implemented in 3G license auctions held in Belgium and Greece in 2001. Both countries are credited with raising incremental revenue by imposing reserve prices. The result was that each country sold three wireless licenses, with a fourth unsold. Klemperer credits the authorities for producing receipts of about 45 Euros per person, counting this as a public financing efficiency. Excluded from the analysis, however, is the fact that each unsold license was

[14] Greg Rosston writes: "Hausman (1997) has estimated that the introduction of cellular created consumer surplus on the order of $30 to $50 billion per year. In Rosston (1994), I used sales of cellular systems to estimate that auction revenues for the two cellular licenses would have been $30 billion. Both of these numbers may be subject to criticism, but are used to give an idea of the magnitude of the differential between the value of licenses and consumer surplus generated. With discounting, this gives an order of magnitude more weight to the consumer surplus than to the private license values. With additional competition, the private license values should decrease more as scarcity is lessened" (Rosston 2001, 23).

[15] This focus is highlighted by Paul Milgrom's analysis of "The Profit and Surplus Contribution of an Entrant" (Milgrom 2004, p. 215). This analyzes producers' surplus only. This is reasonable in the context of auction rules that are cleanly separated from spectrum allocation, but otherwise misleading.

[16] "3G" refers to "third generation" mobile telephone services, commonly thought to encompass digital voice and high-speed data. First generation consisted of analog voice; second generation of digital voice and narrowband data.

[17] Klemperer (2002b, pp. 176 and 178) also (correctly) pronounces the Turkish auction outcome a "fiasco." In auctioning two competing licenses sequentially, regulators set the winning bid for the first license as the reservation for the second. The obvious strategy obtained: the winner of the first auction bid so high that no bidder was willing to match the reservation price for the second.

allocated approximately 35 MHz of bandwidth,[18] and that this frequency space could have been productively used by a fourth network (if a willing entrant had come forth at a license price of between zero and 45 Euros per capita[19]) or divvied up among the three (incumbent) networks to expand available bandwidth.

After calibrating an empirical model measuring the relationship between frequencies allocated to cellular service and retail prices, we find (and show below) that the welfare cost of withholding spectrum via reservation pricing easily exceeded total revenues raised in either Belgium or Greece. We offer this as one frequently-encountered example of how Stage 2 analysis invokes Stage 1 resource allocation and market structure decision-making. The problem arises when the auction analysis does not then incorporate attendant welfare effects. We offer a critique of analytical partitioning that is asymmetrically broached. This argument emerges from an empirical study that estimates the determinants of consumer welfare in spectrum allocation policy.

This analysis focuses on wireless telephone service in twenty-nine countries, of which 19 employ auctions to assign licenses. After adjusting for cross-sectional differences in demand and supply, we find that increasing the quantity of spectrum available to operators, as well as more intense competitiveness (measured by the Herfindahl-Hirschman Index), are strongly associated with lower prices. We then use the coefficient estimates from our model to perform simulations quantifying retail market effects associated with various policy changes. In general, auction rules intended to increase license rent extraction by restricting spectrum access are not welfare-enhancing. Restricting the use of spectrum inputs is a relatively expensive way to raise public funds.

This paper is organized as follows. In Section II we discuss the basic framework for evaluating spectrum policy. Section III develops a theoretical model for wireless telecommunications markets, while Section IV explores welfare implications of the model. Section V describes the empirical model, and reports regression and simulation results. Section VI then offers a conclusion.

II. FORMAL OBJECTIVES OF ALLOCATION POLICY

Focusing our analysis on the market for wireless telephone service,[20] we assume the existence of a regulator who aims to maximize social welfare.[21] We summarize this goal in the following objectives:

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[18] Sources: Greece: National Telecommunications and Post Commission, Press Release (July 13, 2001), http://www.eet.gr/eng_pages/telec/umts/Main.htm Belgium: BIPT, "Communication of the BIPT concerning the results of the auction" (March 2, 2001), http://www.umts.bipt.be/EN/PR%20English.pdf.

[19] We here exclude the possibility of a subsidy to an entrant.

[20] Not only is wireless telephony the most important market studied by economists analyzing license auctions, no rival wireless industry could be studied in such a systematic way. Note that the Handbook of Telecommunications Economics, Vol. I (2002) includes chapters on "Spectrum Auctions" (by Peter Cramton) and "Mobile Telephone" (by Jerry Hausman), but otherwise omits analysis of wireless.

[21] For critical analysis of spectrum allocation policy, see: Rosston & Steinberg 1997; White 2000; Hazlett 2001; Kwerel & Williams 2002; Owen & Rosston 2001; Faulhaber & Farber 2002; Hazlett 2003.

- Allocate spectrum to promote the most efficient delivery of wireless services;
- Select a mechanism to assign licenses that maximizes social value;
- Subject to these constraints, maximize the present value of payments to the government.

The first goal concerns decisions made before licenses are assigned; indeed, it encompasses the procedure wherein licenses are created. Here, the regulator constructs a bundle of rights to assign to private parties, and establishes rules shaping industry structure and performance, largely determining expected license rents.

A less concentrated market structure tends to increase price competition. Yet, scale and/or scope economies may exist, and dynamic (Schumpeterian) efficiencies may result when relatively efficient firms increase market share. At a general level, fixed and variable costs tend to increase when the amount of spectrum assigned to a license is reduced, as happens when additional licenses share a given allocation of bandwidth. Given these trade-offs, our hypothetical regulator designs policies intended to produce an optimal market structure.

The second goal is to assign licenses such that total welfare is maximized. As van Damme (2002) notes, this *market efficiency* is distinct from *value efficienc*y, which results where licenses go to the players who value them the most. To van Damme, "bidders are guided by shareholder value and not by consumer surplus, or total welfare. Hence, at best one can expect an auction to produce an allocation that is 'value efficient,' it need not be 'market efficient'" (Ibid., p.7). Market efficiency might, for example, be improved by auction rules discriminating against an incumbent to improve post-auction market structure (see Gilbert & Newbery 1982 for an excellent discussion of preemptive patenting, directly applicable here). This approach is distinct from a policy of subsidizing weak bidders in that the discrimination is intended to expand efficiency in the output market instead of increasing revenues.

The third goal focuses on raising revenues for public use. Our assumptions isolate this process to one of pure rent transfer. In this context, higher revenues are unambiguously preferred to lower revenues. In actual policy making, however, the assumption is a strong one.

III. A MODEL

In this section we introduce a simple valuation model which forms the basis for our empirical inquiry. Our goal is to identify the variables that should be included in an empirical welfare analysis of spectrum policy. Consider a market where N firms will be producing a homogeneous mobile telephone service, with output levels given by q_i where i identifies the firm. We assume there is no initial incumbent. Aggregate output is given by $\sum_i q_i = Q$. The market price associated with this output is defined by the inverse demand function *p(Q)*. Firm *i* has a cost function assumed to adopt the form:

$$C_i(q_i) = c(K_i, S_i)q_i \tag{III.1}$$

This implies constant marginal cost given a particular level of capital, K_i, and the amount of spectrum, S_i, allocated to the license awarded firm *i*. When quantity decisions are made, capital and spectrum are fixed and the prices paid for these resources sunk. Marginal cost is decreasing in capital and spectrum, and these two inputs are substitutes (engineering cost models indicate that for a given level of service, as the amount of spectrum [MHz] increases, capital expenditure per subscriber declines [Reed 1992, 11-12, 20-21]).

The assumption of Cournot competition[22] leads to a pricing rule defined by:

$$p(Q) = c(K_i, S_i)\left[1 + \frac{s_i}{\varepsilon(Q)}\right]^{-1} \tag{III.2}$$

where $s_i = \frac{q_i}{Q}$ and $\varepsilon(Q) = \left[\frac{dp}{dQ}\frac{Q}{p}\right]^{-1}$.

Regulators allocate bandwidth across competitive licenses. The spectrum allotted to a given license can be written as: $S_i = \phi_i S$, $0 < \phi_i \leq 1$. Thus we can write:

$$p(Q) = c(K, \phi_i S)\left[1 + \frac{s_i}{\varepsilon(Q)}\right]^{-1} \qquad i = 1 \ldots N$$

Some algebraic manipulation yields:

$$p(Q) = \left[1 + \frac{HHI}{\varepsilon(Q)}\right]^{-1} \sum_{i=1}^{N} s_i\, c(K, \phi_i S) \tag{III.3}$$

When spectrum allotments are equal across competitive licenses,[23] we get:

$$p(Q) = \left[1 + \frac{HHI}{\varepsilon(Q)}\right]^{-1} c\left(K, \frac{S}{N}\right) \tag{III.4}$$

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[22] See Varian (1992, 290).

[23] Given that bandwidth allotments determine costs, equal allotments imply equal market shares.

We interpret the equilibrium equation (III.3) as one where the market price depends on the elasticity of demand $\varepsilon(Q)$, the level of investment (K), the amount of allocated spectrum (S), and the Herfindahl-Hirschman Index (HHI).

When licenses are assigned by auction, the winning bidder i will offer an amount B such that:

$$B_i \leq PV = \frac{\pi_i}{r} \qquad \text{(III.5)}$$

where,

B_i = dollar amount bid by firm i,
π_i = expected net income per period for firm i should a license be acquired,[24]
r = discount rate.

In other words, the maximum bid for a license is determined by the profits the resulting business opportunity is anticipated to yield. For simplicity, we characterize the profit stream as constant and perpetual. Discounted present value constitutes an upper bound on the bid. In general, we can write:

$$B_i = \frac{\alpha_i \, \pi_i}{r}, \qquad \text{(III.6)}$$

where α_i satisfies $0 \leq \alpha_i \leq 1$, denoting the degree to which the auctioneer extracts license rents. Auction form, interdependent valuations, and the existence of different types of bidders (with asymmetric valuations) impact α_i.[25] Equation (III.6) also permits us to see how spectrum policies that create rents affect bids. Rules regulating technology, defining services or business models, setting the number of licenses, or prescribing interconnection rights impact π_i. In traditional auction models the vector of valuations (equivalent to a vector of π_i) is exogenous. On the other hand, the auction rules affect α_i. Thus a higher value for α_i implies more efficient rent extraction.

Given constant marginal costs, expected net income is given by:

$$\pi_i = \left[p(Q) - c(K, \phi_i S)\right] q_i - rK \qquad \text{(III.7)}$$

By substitution, and assuming ex ante net income is positive,[26] we obtain:

[24] When B_i is revealed, capital costs are yet to be sunk and are incorporated into the profit function.
[25] Using standard auction theory we could construct a ranking of revenues for the different auction formats depending on the informational structure assumed (see Krishna 2001). However, the theory assumes that the number of players is independent of the auction format. More importantly, the result is not a social ranking, given the difference between market efficiency and value efficiency.
[26] Otherwise, the firm exits the auction.

$$B_i = \alpha_i \left[\frac{(p(Q) - c(K, \phi_i S))q_i}{r} - K \right] \tag{III.8}$$

Assuming identical firms under Cournot competition, as in (III.4), implies:

$$B_i = \alpha_i \left[\frac{p(Q)\, HHI\, q_i}{-\varepsilon(Q)\, r} - K \right] = \alpha_i \left[\frac{p(Q)\, Q\ HHI^2}{-\varepsilon(Q)\, r} - K \right] \tag{III.9}$$

Equation (III.9) implies that bids depend partly on spectrum allocation policy. A given level of expected market revenues, $p(Q)Q$, is consistent with distinct winning bids. In general, different market structures (*HHI*) generate different bids. The effect of auction design is entirely captured by α_i. This is because the number of licenses, and the subsequent number of market competitors, has been fixed in the spectrum allocation that precedes (and creates) the license auction.

IV. WELFARE IMPLICATIONS

We now turn to the question of how social welfare is affected when some exogenous variables are modified. Defining $U(Q) = \int_0^Q p(x)dx$, it can be shown that the output at a symmetric Cournot equilibrium with constant marginal costs solves:[27]

$$\underset{Q}{Max}\, W(Q) = \frac{1}{N}[p(Q) - c]Q + \frac{(N-1)}{N}[U(Q) - cQ] \tag{IV.1}$$

This expression represents the weighted sum of producers' surplus and total surplus.[28] At one extreme, when $N=1$, Cournot competition implies the monopoly solution, where profits are maximized and market output is Q_M. On the other hand, when N goes to infinity, the Cournot solution converges to perfect competition (Q_c), where $Q_c>Q_M$ obtains. In between, i.e., when $Q_M<Q<Q_c$, ex post social welfare under Cournot competition[29] is increasing in the level of product Q. Moreover, the level of Q under Cournot competition is always in the range $Q_M<Q<Q_c$ and it is increasing in N.

To illustrate welfare effects of changes in the variables, we establish an inverse demand function. We assume demand for wireless telephony to be a function of the price

[27] See Varian (1992, 291).
[28] These expressions do not include sunk costs. As bygones, they do not affect the solution in (IV.1).
[29] Ex post means that we are ignoring sunk costs.

of wireless service (p), income level (Y), and the price of alternative telephone services (F).[30] We posit a constant elasticity of demand function for wireless telephony such that:

$$Q = \lambda Y^{\delta} F^{\rho} p^{\varepsilon} \tag{IV.2}$$

Calling Q^* the optimal solution in (IV.1), and incorporating the demand function defined in (IV.2), yields:

$$W(Q^*) = \frac{1}{N}[p(Q^*) - c]Q^* + \frac{(N-1)}{N}[U(Q^*) - cQ^*]$$

where:

$$Q^* = \frac{\lambda Y^{\delta} F^{\rho}}{c^{-\varepsilon}} \left[1 + \frac{HHI}{\varepsilon}\right]^{-\varepsilon} \tag{IV.3}$$

$$p(Q^*) = \frac{c}{\left[1 + \frac{HHI}{\varepsilon}\right]}$$

Note that when $HHI=1$ ($HHI=0$), the solution for the monopoly (competitive) case arises.

Given that $Q_M < Q^* < Q_c$, we know that social welfare is increasing in Q^*. From (IV.3) we anticipate welfare to be increasing in income (Y) (i.e., we expect $\delta > 0$), decreasing in marginal cost (c), and decreasing in market concentration (HHI) ($\varepsilon < 0$).

Social welfare under Cournot competition can be summarized by:

$$SW(Q^*) = U(Q^*) - cQ^* - NK \tag{IV.4}$$

As modeled, SW does not depend on α, the degree of rent extraction in the auction.[31] Rather, it strongly depends on the final market structure measured by the *HHI.* On the other hand, winning auction bids strongly (positively) depend both on α and the Herfindahl index (see eq. [III.9]). Consequently, the observation of high bids cannot be directly interpreted as welfare enhancing because such receipts could result from high concentration in the output market, which may decrease social welfare, rather than from a high value of α_i, which is neutral in terms of social welfare.[32]

Both *HHI* and α are heavily influenced by regulatory design. A high value for α is obtained when the auction mechanism selected prevents collusion, entry-deterring and

[30] Fixed and mobile telephony services are not necessarily substitutes, so the sign of ρ is ambiguous.

[31] Note that we are studying this market in a partial equilibrium analysis. The public finance social benefits of license auctions stem from the opportunity to reduce distortions in other markets. Analytically, those benefits (from reduced distortions) are accounted for separately.

[32] Higher values of α_i could positively impact welfare if achieved in a non-distorting way. In the empirical section we return to this issue.

predatory behavior. On the other hand, regulatory decisions over the number of licenses and spectrum allocation, as well as rules governing services, business models, and technologies will heavily influence market structure. Marginal costs (in the previous model) are a function of sunk investments in spectrum and capital, where $c = c(K, \phi_i S)$ is assumed to be decreasing in the amount of allocated spectrum and the level of capital investment.

We may now evaluate the effect of spectrum policy. Suppose that the regulatory authority decides to increase bandwidth allocated to each license by an equal increment, keeping constant the number of licenses and leaving the auction mechanism unchanged. This action decreases marginal cost. Recalling Equation (IV.3), it is clear that Q^* increases and P^* decreases, leading *SW* to rise. However, spectrum and capital are substitutes and, when bids are made, capital is not yet sunk. Accordingly, if larger spectrum bands are allotted licenses, capital requirements of prospective network operators (i.e., bidders in the auction) decline. Less investment is necessary to achieve the same marginal cost. This effect also increases welfare.

The effect on bids is less clear. From equation (IV.3) it is seen that price declines and quantity increases in response to an expanded spectrum allocation, yet the effect over the first term in the brackets in equation (III.9) ($p(Q)Q$) is ambiguous. Lower capital requirements tend to increase license bids. Engineering studies suggest that for relatively narrow bandwidth licenses, the substitution effect between capital and spectrum is strong. The effect diminishes at higher levels of bandwidth. It is then plausible that bids, as a function of spectrum, exhibit an inverted U shape.[33] Nevertheless, increased spectrum allotments are always social welfare improving.[34]

Increasing N also produces ambiguous results. Expanding the number of firms operating in the market , ceteris paribus, intensifies retail competition. Yet, offsetting factors obtain. First, the spectrum allocated to each license decreases, raising marginal costs. Second, the number of new networks built increases, raising capital costs.[35] Third, the greater competitiveness in the market implies lower retail prices, which reduces expected profits. With respect to welfare, the price reductions are unambiguously efficient, but the increase in the number of firms is not. An increase in marginal and capital costs offsets, to some degree, the welfare gains achieved from enhanced competitiveness. The optimal number of licenses balances these trade-offs.

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[33] Some empirical evidence on this effect has been found in Hazlett 2004.

[34] This does not say that more bandwidth should always be allocated to a particular service, which incurs opportunity costs in alternative markets.

[35] In reality, investment costs are not always additive. Firms may share towers, transport facilities, switches, or other physical infrastructure. Accordingly, the cost of capital can be approximated by a function $K(N)$, so the total cost would be $N^*K(N)$. Although this may change the optimal number of licenses, it does not alter the qualitative analysis.

V. ESTIMATION AND PREDICTIONS OF THE MODEL

V.1. ESTIMATION OF THE MODEL

The empirical implementation of our model is based on the estimation of a system formed by a log-log version of equation (III.3) (the Mark Up equation) and a log-log demand function (eq. (IV.2)). Both include nonlinear terms. The benchmark system is given by:

$$\begin{aligned}\ln(RPM_{it}) = {} & \alpha_0 + \alpha_1 \ln(Q_{it}) + \alpha_2 \left[\ln(Q_{it})\right]^2 + \alpha_3 \ln(HHI_{it}) + \alpha_4 \left[\ln(HHI_{it})\right]^2 \\ & + \alpha_5 \ln(Spectrum_{it}) + \alpha_6 \left[\ln(Spectrum_{it})\right]^2 + \alpha_7 \ln(Density_{it}) \\ & + \alpha_8 \left[\ln(Density_{it})\right]^2 + \alpha_9 \, Auction_{it} + \alpha_{10} \, Notcpp_{it} + \varepsilon_{it}\end{aligned} \tag{V.1}$$

$$\begin{aligned}\ln(RPM_{it}) = {} & \beta_0 + \beta_1 \ln(Q_{it}) + \beta_2 \left[\ln(Q_{it})\right]^2 + \beta_3 \ln(agdppc_{it}) + \beta_4 \left[\ln(agdppc_{it})\right]^2 \\ & + \beta_5 \ln(Fixprice_{it}) + \beta_6 \left[\ln(Fixprice_{it})\right]^2 + \beta_7 \, Notcpp_{it} + \varepsilon_{it}\end{aligned} \tag{V.2}$$

where *i* denotes the country and *t* the period. Variables are as follows:

RPM	Revenue per minute in US$ for mobile voice services, a proxy for price.
Q	Output, measured as total minutes of use per month (totmin). Units are in millions.
HHI	Herfindahl-Hirschman Index in the market (0 to 10,000).
Spectrum	Aggregate bandwidth available for mobile phone service by all operators in the market. Measured in MHz.
Density	A proxy for capital investment. Measured as mean inhabitants per square kilometer.
Auction	Dummy variable = 1 if wireless licenses awarded via auction; 0 elsewise.
Notcpp	Dummy variable = 1 if the market *not* using *calling party pays* rule.
Agdppc	Adjusted (by PPP) Gross Domestic Product per capita in US$.
Fixprice	Mean price of 3-minute call in US$ using fixed network (peak period).

(V.1) and (V.2) represent a system of equations in the endogenous variables ln(RPM) and ln(totmin). Given that we have a sample of countries, and data reported quarterly, we decided to run fixed effects models to control for factors specific to the countries, such as institutional differences. Unfortunately, the dummy variables *Auction* and *Notcpp* do not vary for the countries in the period under analysis, so they were excluded because of collinearity with the fixed effects. On the other hand, the variable *Fixprice* took the value zero in several countries (e.g., USA). To control for this truncation effect we introduced a dummy variable *dumfix,* which takes the value of unity if the fixed line price is zero, and is otherwise equal to zero. In lieu of *Fixprice,* then, we include the variables *dumfix* and (1-*dumfix*)**ln*(*Fixprice*) as regressors. Given that *dumfix* did not change, within countries, during the period under analysis, it was absorbed in the fixed effects and the second variable was renamed *Aln*(*Fixprice*).

To avoid a system bias caused by the endogeneity of the output, we moved to a 2SLS approach to estimate the model.[36] Output (which is *ln*(*totmin*)) was first regressed against all the independent variables and then predicted values were used to perform the estimation of the structural equations. Finally, the traditional identification problem is easily solved here because we meet the order conditions for identification.[37]

Accordingly, the system of equations is transformed to:

$$\begin{aligned}\ln(RPM_{it}) = {} & \alpha_{0i} + \alpha_1 \ln(Q_{it}) + \alpha_2 [\ln(Q_{it})]^2 + \alpha_3 \ln(HHI_{it}) + \alpha_4 [\ln(HHI_{it})]^2 \\ & + \alpha_5 \ln(Spectrum_{it}) + \alpha_6 [\ln(Spectrum_{it})]^2 + \alpha_7 \ln(Density_{it}) \\ & + \alpha_8 [\ln(Density_{it})]^2 \end{aligned} \qquad \text{(V.3)}$$

$$\begin{aligned}\ln(RPM_{it}) = {} & \beta_{0i} + \beta_1 \ln(Q_{it}) + \beta_2 [\ln(Q_{it})]^2 + \beta_3 \ln(agdppc_{it}) + \beta_4 [\ln(agdppc_{it})]^2 \\ & + \beta_5 A\ln(Fixprice_{it}) + \beta_6 [A\ln(Fixprice_{it})]^2 \end{aligned} \qquad \text{(V.4)}$$

Data are quarterly from 1999-I through 2003-II for wireless telephone markets in 29 countries provided by Merrill Lynch (2003). A detailed description of the sample is given in Appendix 1. Summary statistics are displayed in Table V.1.

[36] Ignoring this endogeneity problem leads to inconsistent estimators.
[37] That is to say, the number of exogenous variables which are excluded from equations (V.3) or (V.4) below is higher than the number of right hand side endogenous variables in each equation.

TABLE V.1: DESCRIPTIVE STATISTICS

Variable	Obs	Mean	Std. Dev.	Min	Max
totmin (mil./Month)	488	2788.72	8057.09	70.89	78338.39
RPM (US$)	470	0.21	0.08	0.07	0.62
HHI (1-10000)	522	3900.69	1058.25	1648	6458
spectrum (MHz)	522	179.46	97.63	36.4	530
density (hab./sq. kms.)	522	536.42	1633.80	2.46	6832.46
auction (0-1)	522	0.66	0.48	0	1
notcpp (0-1)	522	0.14	0.35	0	1
agdppc (US$/year)	522	21627.75	8616.87	4953	38278
fixprice (US$)	504	0.10	0.05	0	0.193548

In the estimation of the system formed by the equations (V.3) and (V.4) we detected a period serial correlation problem in each equation. In order to remedy this, we assumed a structure for the correlation of residuals in a given country for different periods, keeping the assumption that residuals of different countries were uncorrelated. That is:

$$E(\varepsilon_{it}\varepsilon_{js}) = \begin{cases} \sigma_{ts} & \text{if } i = j \\ 0 & \text{if } i \neq j \end{cases}$$

Under this assumption the serial correlation problem was solved. The variance-covariance matrix of residuals was estimated from the sample, resulting in a 3SLS model.

The selected model was tested against the totally pooled model using a traditional F test in both equations. The statistics were 50.58 and 46.96 for the Mark Up and Demand equations, respectively. Both of them were well above the critical value, at 1% of confidence, which is approximately 1.72 in both cases.

The two columns in Table V.2 display the final results achieved from estimating the system of equations V.3 and V.4. Some squared terms were dropped from the reported specification because they were not significant at conventional levels. This was the case for Ldensity2 in the Mark Up equation and Ltotminhat2 in both equations. The insignificance of Ltotminhat2 in the Demand equation implies constant price elasticity. If the price elasticity of demand is constant, the theoretical Mark Up equation III.3 predicts that price should not depend on total minutes,[38] consistent with an insignificant coefficient estimate for Ltotminhat in the Mark Up equation.

[38] This is because the theoretical Mark Up equation only depends on the quantity proxy through the elasticity of demand; with constant elasticity, we expect quantity proxies to be insignificant.

While the purpose of this exercise is not to measure the price elasticity of demand, we note that the model's estimate is the inverse of the coefficient -0.867165, which is around -1.15. This is consistent with other estimates reported in the literature.[39] In addition, the estimated demand function exhibits a willingness to pay positively related to the adjusted GDP per capita, although at a decreasing rate. The willingness to pay is also increasing in the price of a call using the fixed network (peak period), revealing a substitution effect between fixed and mobile services.

The mark up equation results suggest that the equilibrium price in the market increases with the Herfindahl-Hirschman Index, but decreases with the amount of spectrum allocated to mobile services. These results are statistically significant, and are consistent with economic theory. It is expected that more competitive markets feature lower service prices, while expanded availability of radio spectrum lowers both fixed costs and variable operating expenses. Lower fixed costs encourage entry, increasing competitiveness (accounted for by *HHI*), while increased bandwidth reduces the opportunity cost of a given phone call, leading directly to lower prices. Finally, prices are decreasing in density, suggesting scale economies in the density dimension.

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[39] Ingraham and Sidak (2004) have estimated that the elasticity of demand in US for wireless services is between -1.12 and -1.29.

TABLE V.2: LOG-LOG RESULTS. DEPENDENT VARIABLE = LN(RPM).
ALL ESTIMATIONS USE A FIXED EFFECTS MODEL.

	The Mark up equation V.3	The Demand equation V.4
Ltotminhat	0.109621	-0.867165*
	(1.54)	(-11.85)
LHHI	6.561295*	
	(2.69)	
LHHI2	-0.352471**	
	(-2.41)	
Lspectrum	-0.391080**	
	(-2.33)	
Lspectrum2	0.031232***	
	(1.87)	
Ldensity	-7.175110*	
	(-6.44)	
Lagdppc		8.347920**
		(2.48)
Lagdppc2		-0.284226***
		(-1.62)
aLfixprice		4.838753*
		(4.61)
aLfixprice2		0.972481*
		(4.16)
CONSTANT	-0.500565	-45.34805*
	(-0.05)	(-2.77)
No.Observations	451	451
R-Square	0.8188	0.8237
DW	1.99	2.0032

3SLS estimation in Panel Data adjusted by serial correlation. Values of t-statistics in parentheses: *, **, *** refer to 99%, 95%, and 90% confidence levels, respectively. Fixed effects not reported.

V.2. THE ROLE OF SPECTRUM POLICY

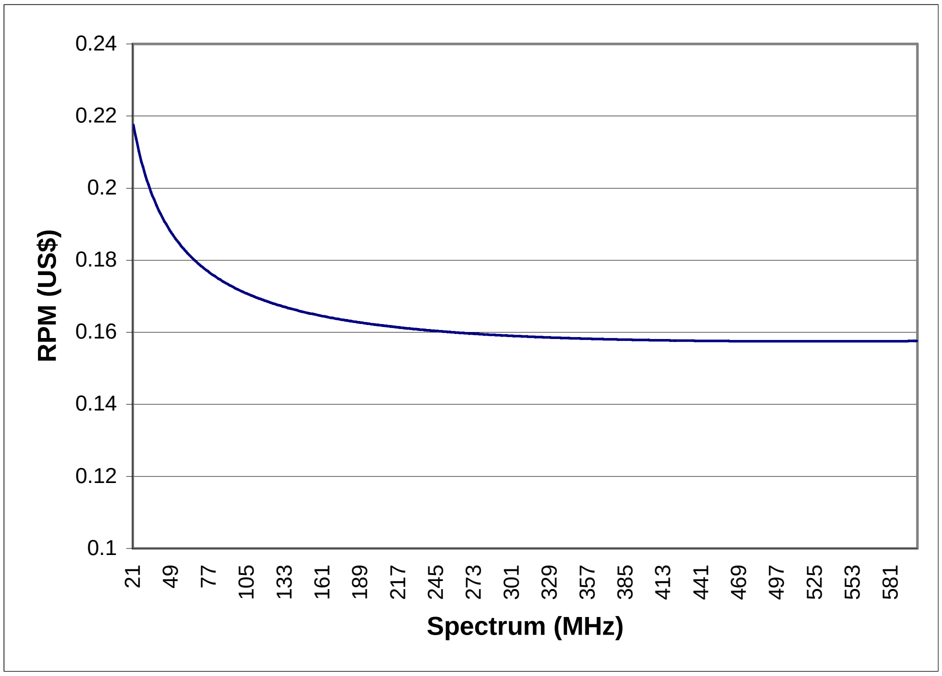
The coefficients of greatest interest in the Mark Up equation are those for LHHI, LHHI2, Lspectrum and Lspectrum2, which measure effects of variables directly affected by spectrum policy makers. Here simulate hypothetical policy changes to project the impact on prices and welfare in the mobile phone market.

Price Effect

These simulations were performed using the model reported in Table V.2. We fixed all the other exogenous variables at their mean values, and then varied the quantity of spectrum (in MHz) allotted to the mobile telephony sector. The estimated parameters derived in the previous sub-section are then used to predict the effect on price and output, permitting social welfare changes to be calculated.

Figure V.1 displays results. Price is decreasing in the amount of allocated spectrum, with the rate of decrease declining. Retail prices are reduced because marginal costs are lower with more abundant inputs. Recall from Table V.1 that the mean spectrum allocation in our sample is about 180 MHz, with a range of 36 MHz to 530 MHz.

FIGURE V.1: PRICE AS A FUNCTION OF SPECTRUM ALLOCATION



It is important to note that to obtain Figure V.1 we had to select the mean value for fixed effects. To observe the direct effect of an increased spectrum allocation for mobile telephony in a particular country, the fixed effects associated with that country will produce a function different from that displayed in Figure V.1.

Welfare Effect

We may now evaluate changes in social welfare when additional spectrum is allocated for use with simulations using the model calibrated in Table V.2. We adopt a "country like" scenario to estimate the impact on consumer and producer surplus related to a policy that exogenously increases the spectrum allocated to the market in 20, 80, 140 and 200 MHz increments. We assume that the bandwidth increments are assigned to mobile phone operators.

Expanded spectrum availability tends to cause industry concentration to decline. Take the U.S. case. The cellular telephone market was originally a duopoly, with 50 MHz of allocated spectrum split equally between licensees. Then, personal communication licenses were auctioned in 1995 and 1997; the PCS licenses were, in aggregate, allocated 120 MHz. The additional bandwidth facilitated entry; by 2000, there were six competing national networks.[40]

In order to incorporate this relationship in the simulations, we could estimate the *HHI*-Spectrum elasticity directly from our sample. This, however, would under-estimate the effects due to the use of fixed effects in the model and the multi-year lags involved in the HHI-Spectrum relationship. During the sample period, for example, U.S. HHI fell as new networks expanded using PCS licenses awarded years before. The U.S. did not award any additional mobile phone licenses during the 1999I-2003II sample period. Conversely, several countries awarded 3G licenses during 2000 and 2001, yet new 3G deployments became operational, with limited exceptions, starting in 2004.[41] The impact of network launches on HHI then would be expected to take additional years.

To estimate the effect of additional spectrum allocations on market concentration, we follow the approach taken by U.S. regulators in evaluating competitive market structure in wireless phone service. Establishing a "spectrum cap" to regulate PCS license auctions in the 1990s, the U.S. Federal Communications Commission measured

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[40] One of the national networks, Nextel, utilized approximately 15 MHz allocated to Specialized Mobile Radio licenses. This constitutes a reinforcing example of new spectrum allocations yielding additional competition. On the formation of Nextel (nee Fleet Call) using SMR licenses, see Hazlett (2001). Conversely, the 120 MHz allocated to PCS licenses was not fully available to mobile carriers until 2005. That was when a dispute over so-called PCS C-block licenses, allocated 30 MHz, was resolved. See Roy Mark**, "**FCC Opens NextWave Spectrum Auction," *Internet News* (Jan. 26, 2005).

[41] There were 61 3G networks launched by Dec. 2004. The first two began in Japan in October 2001 and December 2002. The next twelve were launched in 2003. 3G/UMTS Commercial Deployments, http://www.umts-forum.org/servlet/dycon/ztumts/umts/Live/en/umts/Resources_Deployment_index (visited Nov. 5, 2005).

HHIs under alternative scenarios, using the bandwidth allocated to competitors' licenses as proxies for market share. If, for instance, four licenses were awarded, each with equal bandwidth allocated to it, HHI was estimated to equal 2500. In fact, a spectrum cap of 45 MHz was eventually set. Given total availability of about 180 MHz, this rule relied on the intuition that greater license aggregation would result in market concentration levels exceeding an HHI = 2500.[42] The spectrum cap has since been relaxed, in favor of standard antitrust rules. It is not the policy which we here rely on, but the underlying economic analysis.

It allows us to infer *HHI-Spectrum* elasticity. Taking those 13 countries in our sample that auctioned 3G licenses during the period under study, and so increased the spectrum available to mobile phone carriers, we track the decrease in HHI that would result under simplifying assumption that licenses are allocated equal bandwidth. Hence, when a country with four licensed operators awards additional licenses, and five competitive networks result, the change in HHI is calculated as -500 (2500 ➔ 2000). The commensurate increase in spectrum allocation permits estimation of an *HHI-Spectrum* elasticity. For instance, during the sample period, the Australian allocation was observed to increase from about 126 MHz to 230 MHz, while mobile networks rose from four to five. Given our method, this implies an *HHI-Spectrum* elasticity of -0.24.

The range of calculated elasticities is (0, -0.52), with Austria featuring the highest and the Czech Republic the lowest (with an additional 110 MHz, the Czech market hosted three operators before and after 3G license auctions). The average across the countries equals -0.28; if Australia and New Zealand are omitted, the mean rises to -0.30. These two countries have distinctly liberal policy regimes that have permitted relatively large quantities of spectrum to be utilized (particularly New Zealand, which increases its mobile spectrum from 90 MHz to 530 MHz, about 175 MHz above the next highest). Hence, we assume a *HHI-Spectrum* elasticity = -0.3.

We then modify the *HHI* according to an assumed Spectrum increase. The simulation proceeds as follows.

1. Initial values are assumed for the exogenous variables, creating "country like" scenarios. Using our model's parameter estimates, the instrument is calculated; the mark-up equation then yields the expected *RPM* in the benchmark case.

2. An increase in Spectrum is assumed, say 80 MHz. The corresponding *HHI* is obtained through the *HHI*-Spectrum elasticity, and the Mark Up equation is used to predict the new *RPM*. From the percentage change in *RPM* and the demand elasticity at the initial level of output (total minutes), we then estimate the change in output.

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[42] Federal Communications Commission, *In the Matter of Amendment of Parts 20 and 24 of the Commission's Rules – Broadband PCS Competitive Bidding and the Commercial Mobile Radio Service Spectrum Cap, Report & Order*, WT Docket No. 96-59 (June 24, 1996), Appendix A.

3. Given changes in prices and outputs we calculate the expected change in Consumer Surplus and Producer Surplus (per month).[43] We estimate net present values, assuming flows as perpetuities and a net annual discount rate of 5%.[44]

TABLE V.3: SIMULATION SCENARIO FOR A COUNTRY LIKE THE UK

	units	**start**	**end**
totmin	mil./month	4574	implied
HHI	0-10000	2566	implied
spectrum	MHz	201	341
density	hab./sq(km)	241	241
dumfix	0-1	0	0
agdppc	US$	24797	24797
fixprice	US$	0.18	0.18
Ebitda	fraction	0.19	0.19

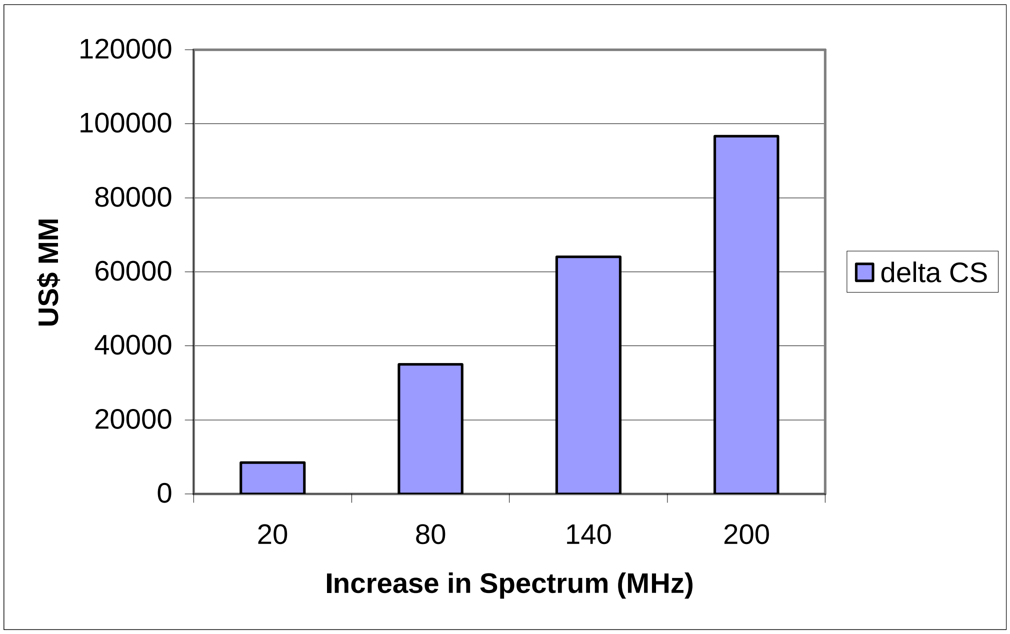
Table V.3 and Figure V.2 display results for a simulation approximating conditions found in a country like the U.K. in the first quarter of 2000 when "The Biggest Auction Ever"[45] was held. Licenses allocated 140 MHz of spectrum are assumed to be auctioned in our simulation. British 3G licenses, also allocated an aggregate of 140 MHz, sold for approximately $34 billion; applying the $0.33-per-dollar public financing bonus implies social gains of about $11.3 billion. Our simulation suggests, in comparison, that about $64 billion in consumer surplus gains were realized from the 140 MHz of radio spectrum being made available to operators. This increase in surplus dominates the benefits associated with tax efficiency. This outcome is illuminating precisely because the British 3G auctions are widely considered to be the most successful example of license rent extraction.

[43] To transform incremental revenues into producers' surplus we use the EBITDA index reported by Merrill Lynch (2003). Only operating profits are included as incremental surplus.

[44] This can be thought of as a real social discount rate. Since growth is expected for many years in wireless phone markets, it is not implausible that even if the (gross) discount rate is ten percent, that a net discount rate of 5% (reflecting anticipated growth of five percent) would be appropriate.

[45] As Ken Binmore and Paul Klemperer referenced it in the title of their 2002 article.

FIGURE V.2: EFFECT ON CONSUMER SURPLUS OF INCREASES IN SPECTRUM ALLOCATION (IN A COUNTRY LIKE UK)



Alternatively, consider the U.S. market for wireless telephony. Using parameters obtained in our cross-country pricing model, we simulate an increase of 60 MHz in spectrum allocated for mobile telephony. This is associated with a decline in retail prices of about 13.51 percent. A price drop of this magnitude is, in turn, associated with an increase in consumer surplus of about $18.3 billion annually.

Given marginal license valuations of about $480 million per nationwide MHz,[46] the capitalized value of nationwide licenses allocated 60 MHz (even under the strong assumption that marginal valuations do not decline over the incremental increase) is about $29 billion.[47] If the public finance dividend applies, the tax efficiency gain of approximately $10 billion is projected to be only *one-half* of the *annual* gains associated with increased output. A delay of six months swamps the public financing bonus altogether.

Reservation Prices in Belgium and Greece

Of Belgian and Greek auctions held in 2001, Klemperer (2002a, 840) writes: "Both countries held auctions for four licenses – and in each case attracted only the three incumbents, who therefore obtained licenses at the reserve prices which yielded about 45 Euros per capita in each case. It is very hard to argue plausibly that an auction deterred

[46] In 2004, the FCC valued a nationwide 10 MHz PCS license at $4.8 billion (FCC 2004).
[47] Accounting for declining marginal valuations reduces this estimate, for licenses allocated 60 MHz in the generally desirable 700 MHz band, to between $20 billion and $24 billion (Bazelon 2005).

much entry when a license goes unsold, and there is also no obvious reason to criticise the reserve prices that these governments chose."

Our model helps analyze these arguments. Reserve prices do help to increase auction receipts, but the incremental revenue is not without social cost. The spectrum allocated to unsold licenses reduces operator efficiency and, perhaps, market competitiveness. While the latter implies that network entry would have occurred if the license were priced below the reserve level, the former does not. In this example, if each incumbent's license were allocated 1/3 the bandwidth allocated the fourth, lower marginal and capital costs would have resulted.

Figure V.3 shows the effect of withholding a license by the use of reservation prices in Belgium and Greece. In our simulations we assume either

(1) an entrant, at license price = 0, builds a fourth network; or
(2) no rival enters, but spectrum allocated the 4th license is utilized by incumbents.

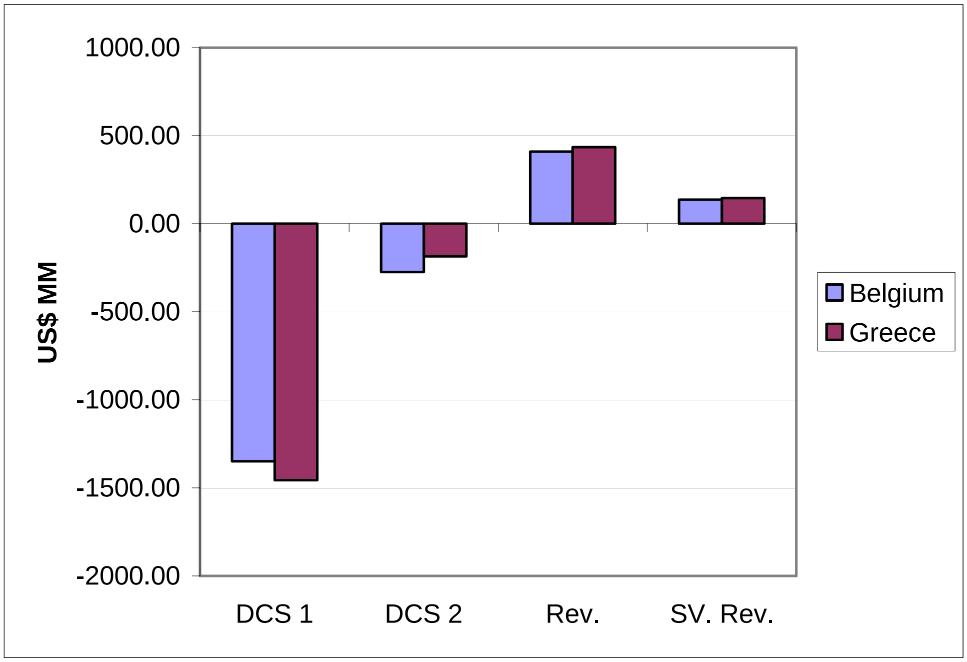
The change in consumer surplus estimated under the 1st (new entrant) scenario is "DCS1"; the estimated change in consumer surplus under the 2nd (spectrum reallocation) scenario is "DCS2." These changes, negative given that spectrum is being withheld by the reserve price policy, are compared to the positive welfare effects associated with auction revenues. Here we attribute all receipts to the reserve price policy, which generates government revenues of "Rev.", and assume that one-third of such revenues constitute social savings, identified as "S.V. Rev.".

Simulation Summary

	units	Belgium	Greece
Auction date		2001/Q1	2001/Q3
extra license	(MHz)	35.4	35
change in price scenario 1	(%)	-4.00%	-3.36%
change in MOU scenario 1	(%)	4.62%	3.87%
change in price scenario 2	(%)	-0.83%	-0.43%
change in MOU scenario 2	(%)	0.96%	0.50%
change in CS scenario 1	US$ MM	-1348.98	-1456.97
change in CS scenario 2	US$ MM	-275.08	-184.71
total rev. in auction	US$ MM	408.92	434.96
social value of rev.	US$ MM	136.31	144.99

According to the simulation performed with the model estimated above, the spectrum withholding losses are greater when it is assumed that a new entrant would materialize at reserve = 0 (i.e., DCS1>DCS2 for both the Belgian and Greek markets). This implies, not surprisingly, that the spectrum is used most efficiently by an entrant (abstracting from the cost of capital). The comparison of interest is between either DCS estimate and SV Rev. Focusing on DCS1, social losses from the reserve policy are about eleven times the magnitude of expected public financing gains in Belgium and Greece. This implies that *giving away* the licenses to facilitate competition between four rivals would have produced an order of magnitude more social welfare than restricting entry via the reserve policy.

FIGURE V.3: WELFARE EFFECT OF WITHHOLDING A LICENSE IN BELGIUM AND GREECE



Under the assumption that no new network would have been induced to enter at a license price of zero, welfare gains (DCS2) from spectrum redistribution among the incumbents also exceed those available from the reserve policy. The magnitude of this difference is not large, owing in part to the conservative assumptions made with respect to the spectrum-competition relationship.[48] However, the policies are not incompatible. Reserve prices could be utilized in an auction where spectrum allocated to unsold licenses is reallocated for the use of license winners.[49] Auction rules result, in this instance, in the unproductive withholding of both licenses and spectrum. The reserve policy gives economists ample reason for criticism.[50]

[48] It is conservative both in the assumption that no new entrant will emerge at a license price of zero, and with respect to the *HHI-Spectrum* elasticity used in the simulation model.

[49] This might, or might not, raise license bids, as the productive effects of the higher bandwidth to a particular license winner (raising value) would be at least partly offset by the increased bandwidth available to rivals (lowering value). See Hazlett (2004).

[50] Even under DCS2 the social losses are higher than social gains associated to the revenues at the auction in both countries. The magnitudes, however, are small. This is a consequence of the extremely conservative assumption on the HHI-Spectrum elasticity.

Subsidizing Weak Bidders in U.S. PCS Auctions

Finally, consider the personal communications service (PCS) C-block auctions that concluded in May 1996. U.S. regulators extended bidding credits to small businesses and rural telephone companies, extending qualified (that is, weak) bidders below-market interest rates on ten-year loans. The PCS licenses were allocated 30 MHz of nationwide radio spectrum.

Bidding for licenses was intense; C-block winners committed to paying more than twice the price paid by winners of similar A and B licenses the year previous, after netting out credits and subsidies (Hazlett & Boliek 1999). Yet, service was not provided; in fact, bids generally went uncollected. The great majority of licensees soon declared bankruptcy, effectively or explicitly defaulting on long-term obligations to the federal government. A lengthy legal battle then ensued to determine ownership of the licenses.[51] Through 2004, allocated spectrum – nearly one-sixth the total bandwidth allocated to mobile phone service -- went largely unused.

Our empirical model can be used to estimate the cost of this loss of bandwidth in the wireless telephone market. If additional licenses for cellular service had been allowed to utilize another 30 MHz of radio spectrum, consumer surplus (excluding supply-side effects) over the eight year period, 1996-2003, would have increased by an estimated $31.2 billion (using 2004 dollars). See Table V.3. This dominates any plausible public financing gains from tinkering with auction design. In fact, aggregate revenues collected for all U.S. wireless licenses, 1994-2002, amounted to just $14 billion.[52]

The term "fiasco" has been applied to auction regimes that generate relatively low bids, but we see the FCC bidding preferences as more deserving of the term. Ironically, these preferences serve the economics literature as a *paradigmatic example* of how to intensify bidding by subsidizing weak bidders. Social costs of favoring less efficient providers are seen to be dominated by public financing gains from revenue extraction: "partially subsidizing disadvantaged bidders, generally, more than compensates for the cost of the subsidy due to increased aggressiveness by first-line bidders" (Rothkopf et al., 2003, 82). This conclusion follows from an analysis that is "complementary to Ayres and Cramton (1996)," which found "that a subsidy policy can sometimes materially benefit the bidtaker" (Rothkopf et al., 2003, 72). Specifically, Ayres and Cramton found that 1994 FCC bidding credits generated net revenues. But the overwhelming loss of welfare associated with the 1996 PCS bidding credits does not enter the policy analysis. While the government's credit policies proved faulty,[53] the salient fact for welfare analysis of

[51] The federal government effectively lost this battle. Bankrupt parties succeeded in both retaining rights to their FCC licenses and in reducing the obligations owed the federal government. In mid-2004, a negotiated settlement was finally achieved with the largest C Block licensee, Nextwave. In January and February 2005, an FCC auction reassigned C Block licenses returned to the FCC for debt satisfaction.

[52] The Budget for Fiscal Year 2003, Appendix, Federal Communications Commission, Status of Direct Loans, 1122.

[53] FCC Chairman Michael Powell believes that, as reported in the trade press: "the FCC learned its lesson from the NextWave/C-block debacle and will no longer auction off licenses using installment payments."

spectrum allocation policy is that any rule favoring less efficient providers entails expected costs.[54]

TABLE V. 3: WELFARE COSTS OF WEAK BIDDER SUBSIDIES IN U.S. PCS AUCTIONS

year	delta CS (US$ MM)	inflation rate	Adjusted delta CS (US$ MM, 2004)
1996	670.8	2.9	809.3
1997	1037.5	2.3	1216.4
1998	1376.5	1.5	1577.5
1999	2104.4	2.2	2322.6
2000	3291.1	3.4	3636.0
2001	5188.0	2.8	5543.3
2002	7171.9	1.6	7454.2
2003	8439.8	2.3	8634.0
		Total	31193.2

VI. CONCLUSION

> *Policy errors are also less likely when expertise is not too narrowly focused in one subdiscipline – for example, auction designers should remember their industrial economics and political economy (at least) in addition to pure auction theory* (*Klemperer 2004, p. 147*)

Auctions are generally superior to alternative rights-assignment mechanisms such as beauty contests or lotteries.[55] Wireless license auctions appear to assign licenses to the most efficient network operators, and to have limited rent dissipation associated with more arbitrary assignment methods. Yet, auction rules that focus on revenue extraction may conflict with the goal of maximizing social welfare.

Heather Forsgren Weaver, RCR WIRELESS NEWS, *NextWave Must Shed Most of Its Spectrum Under FCC Settlement* (April 20, 2004).

[54] Ayres and Cramton (1996, 11) discuss the possibility that licensees will default on long-term debt obligations, but dismiss its empirical significance: "If a designated bidder defaulted, the government could easily foreclose and resell the licenses, but their resale value would be uncertain."

[55] Prior to competitive bidding for FCC licenses being authorized in the United States, auctions constituted a controversial policy reform. One of the authors of this paper participated in the policy debate, writing in favor of auctions (Hazlett, *Making Money Out of the Air,* NY TIMES [Dec. 2, 1987]; Hazlett, *Dial 'G' for Giveaway*, BARRON'S [June 4, 1990]).

Formal economic analysis, which can rigorously define relevant trade-offs for policy makers, has tended to obscure regulatory choices. While revenue gains from enhanced competitive bidding are registered as leading directly to increase efficiency in offsetting activity-distorting taxes, the costs of such policies are often ignored. This is seen in frequent proposals recommending the use of reserve prices and bidding credits for inefficient wireless providers, as well as in the omission of time value when comparing alternative policy regimes.

Using a panel dataset involving 29 countries and quarterly data from January 1999 to June 2003, we identify primary determinants of social welfare in mobile telephony markets. We find that the amount of allocated spectrum and the degree of market competitiveness appear to be important variables. Each is heavily influenced by government regulation. Policies that increase competition[56] and permit the wireless service markets to operate more efficiently empirically dominate social gains from license rent extraction.

This calls into question the focus on wireless license revenues found in the economic literature. The standard analysis points to the "embarrassingly low revenue in the Netherlands," for example, as indicating a fiasco in public policy (Wolfstetter 2001, 6; citing Klemperer 2000). It might also be noted that the Dutch have succeeded in making 355 MHz available for wireless phone operators – more than any other EU country. Alternatively, U.S. regulators have made (counting generously) just 189 MHz of bandwidth available for mobile phone operators (Kwerel & Williams 2002), an outcome that merits little academic attention despite the "fiasco" it produces in lost productivity.

[56] This includes liberal allocations making radio spectrum abundantly available for productive deployment, as well as other rules allowing competitors to operate efficiently. One important set of issues not investigated in our model pertains to technology mandates. Competition between competing wireless telephone standards (as in the United States) is thought by some to have produced better technology (e.g., CDMA) and more intense rivalry. Others see the harmonization policy of the EU as a successful technology mandate. See Gandal et al., 2003.

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Appendix 1: Mobile Voice Market Database

Our main source of information was:

"Global Wireless Matrix 2Q03: Quarterly Update on Global Wireless Industry Metrics," Merrill Lynch Global Securities Research & Economics Group, Global Fundamental Equity Research Department. This includes quarterly data for the wireless market in 46 countries, fourth quarter 1998 through second quarter 2003. All data were obtained from this source except the following:

Spectrum, Auction: The main source is each country's telecommunications regulator and Communications Ministry. The Economist Intelligence Unit ViewsWire database, the European Commission and the European Radio Communications Office are secondary sources.

AGDPPC (Adjusted by PPP GDP per capita): International Monetary Fund (IMF), World Economic Outlook (WEO) Database. April 2003.

Density: It was constructed as population/area, where population is from Merrill Lynch and area is from the World Bank's World Development Indicators 2003.

Fixprice: It was taken from the International Telecommunications Union's World Telecommunications Indicators 2002 database.

Our sample is comprised of all observations in the Merrill Lynch database for which we have data for all the relevant variables from the first quarter in 1999 through the second quarter in 2003. (While Merrill Lynch data begin in fourth quarter 1998, the data listed in that quarter are very incomplete.) Our sample included the following 29 countries:

Argentina
Australia
Austria
Belgium
Brazil
Canada
Chile
Colombia
Czech
Denmark
Finland
France
Germany
Greece
Hong Kong
Hungary
Ireland
Italy
Mexico
Netherlands
New Zealand
Norway
Portugal
Singapore
Spain
Sweden
United Kingdom
United States
Venezuela

Of the 46 countries in the Merrill Lynch database, many could not be used due to missing data (for variables not included in the ML database). The most difficult data to identify included *Spectrum* and *Fixprice*. To enable the inclusion of additional country data, *Fixprice* was adjusted in the following countries:

- Canada: The reported values are zero from 1991 to 1994; thereafter it is not reported. We used an assumed value of “0” after 1994.

- Sweden: The value increases monotonically until 1999; it is not reported thereafter. We used the variable with missing values (i.e., data from Sweden was not included in regressions using *Fixprice*).