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Spectrum Licensing, Policy Instruments and Market Entry^{*†}

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Abstract

Competition policy attempts to address the potential for market failure by encouraging competition in service markets. Often, in wireless communication service markets, national regulatory authorities seek to encourage entry via the spectrum assignment process. Instruments used include the assignment mode (auction or beauty contest), setting aside licenses and providing bidding (price and quantity) credits for potential entrants, and making more licenses (spectrum blocks) available than incumbent firms (excess licenses). The empirical analysis assesses the effectiveness of these policy instruments on encouraging entry. The econometric results show that the probability of entry is enhanced by using auction assignments and excess licenses. Furthermore, quantity, but not price, concessions encourage entry.

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1. Introduction

In granting spectrum rights to provide wireless communication services, national regulatory authorities (NRAs) often employ policy instruments to encourage mobile network operator (MNO) entry, and in doing so attempt to influence aftermarket competition.¹ For instance, some regulators set-aside licenses for potential entrant bidders,² or issue targeted bidding credits (by discounting winning bid prices or providing additional amounts of spectrum).³ Other policy instruments that are intended to encourage entry include the license assignment mode (auction or ‘beauty contest’)⁴ and making more licenses (spectrum blocks) available than incumbent firms (excess licenses)⁵ (Jehiel and Moldovanu, 2003).

The apparent justification for the policies is the presence of high wireless service market entry barriers. In particular, incumbents generally value licenses more than potential entrants because winning licenses prevents entry and restricts aftermarket competition. Also, legacy

¹ The environment in which Western European NRAs assigned spectrum to MNOs during 1999–2001 was shaped by the European Commission (1997) Directive 97/13/EC that stated new operators should be encouraged to enter markets to ensure the development of European telecommunications service markets. In particular, the UMTS Forum argued that market entry was required to stimulate competition and that optimum subscriber benefit will only be achieved when competing infrastructures provide advanced and innovative services (UMTS Forum, 1998).

² Potential entrants are firms that do not operate second-generation (2G) networks in the nation assigning spectrum. However, if NRAs want to influence aftermarket competition by setting-aside licenses they need perfect information about potential licensee valuations. This is important as the inefficiency of allocating a license to a low-value (inefficient) firm may outweigh any positive effect on social welfare due to market entry (Hoppe et al., 2006).

³ However, to assure entry, bidding credits must raise entrants’ willingness to pay above an incumbents pre-emptive willingness to pay (Hoppe et al., 2006; Gruber, 2007; Azacis and Burguet, 2008; Ansari and Munir, 2008). Recently, Cramton et al. (2011) theoretically demonstrated that the impact of bidding credits on enhancing competition is ambiguous.

⁴ Beauty contests require that MNOs submit plans or bids including spectrum-use plans. NRAs then hear proposals and award spectrum to operators. Importantly, spectrum price is only one aspect of NRA decisions. Conversely, auctions require operators to make price bids for spectrum lots. Thus, auctions are competitive, price-based mechanisms that should result in allocations to operators with the highest spectrum valuations (Cramton, 2002: 608).

⁵ For the sampled assignments, operators can only win one license. Hence, the presence of excess licenses provides potential entrants with an enhanced opportunity of winning spectrums.

infrastructure is readily leveraged to provide third-generation (3G) services.⁶ Moreover, there are substantial establishment costs on entering new markets.⁷

Surprisingly, there is an absence of empirical research indicating whether NRA policy instruments influence the probability of entry into 3G national markets. The resolution of this question is fundamentally important given industry convergence, the growth in the demand for data services and the spectrum dividend made available from the ‘switch off’ of analogue networks. Moreover, Gruber (2007) and Hazlett and Muñoz (2009) argued that the benefits from entry, including lower retail prices and improved service quality, are expected to be substantial. Most likely, this paucity of empirical analysis results from data limitations. Namely, the available data sets typically do not include information on whether potential entrants decide to bid or not.

Accordingly, the econometric analysis requires that potential entrant participation decisions be incorporated into the estimating equations, i.e., sample selection issues be addressed. This study obtains consistent parameter estimates by treating the issue as an omitted variable problem. The proxy variable is sourced from a censored entrant-to-bidder ratio regression. Additionally, ancillary instrumental variable (IV) binomial probit and Poisson regressions address endogeneity bias concerns relating to the specification of the entry probability equation. Namely, endogeneity concerns arise when regulators design assignments to encourage entry, and these instruments are arguments in the entry probability equation. Following the two-stage residual inclusion (2SRI) method, residuals calculated from those

⁶ Hoppe et al. (2006) studied the relationship between the number of 3G spectrum licenses offered and aftermarket competition (or market structure proxied by the number of active firms). They found incumbents were more willing to deter entry the greater is the potential fall in profit.

⁷ Positioning costs include infrastructure deployment; establishing administrative functions; and marketing and promotion. The extent that these expenditures are barriers to entry varies by entrant.

ancillary regressions are introduced as additional arguments in the second-stage binomial probit probability of entry equation.⁸

Using a unique dataset covering national 3G spectrum license awards, the principal research question addressed is: do regulators' licensing policy instruments promote entry? The econometric results show that the entry probability is enhanced by using auction assignments and excess licenses. Furthermore, quantity, but not price, concessions encourage entry.

2. Market Entry, Assignment Mode and License Conditions

National 3G spectrum assignment data is sourced from the DotEcon Spectrum Awards Database (2008). This resource is a global record of radio spectrum awards for mobile telephony, fixed and broadband wireless access, fixed links and digital radio licenses. DotEcon records the winning bidder, characteristics of the license and assignments (including country, frequency band, date, assignment mode, spectrum size, duration, price and whether licenses are set-aside for entrants), and relevant demographic and economic indicators.

To analyse entry, only 'contested' (by incumbents and potential entrants) license assignments are modelled.⁹ This approach provides a sample of 141 national license awards from 49 assignments for the period 1999–2008. These data are augmented with information obtained from MNO, NRA and media Web sites. In particular, whether the winning bid made is by carriers that operate national 2G networks prior to 3G spectrum assignment.

License assignments are mostly made by auction or administrative tender (beauty contest). In auctions operator's 'simply' price-bid for spectrum. Conversely, beauty contests require operators bid for spectrum via multiple-dimension plans that include intended use of the spectrum, network coverage and aftermarket service pricing. Table 1 shows that 29 national

⁸ Importantly, the approach is applicable to a wide range of selection problems where data availability is limited.

⁹ Infrequently, regulators attempted to encourage entry by setting aside licenses for potential entrants. That is, incumbents cannot bid. Accordingly, the licenses are not included in the sample for estimation.

assignments are by beauty contest, while 20 are by auction. These data also indicate that, the entrant-license ratio is statistically equivalent for both auction and beauty contest assignment modes.

Table 1. Entry by Assignment Mode

Assignment Mode	Number	Entrant-License Ratio	
		Mean	Std. Dev.
Auction	20	0.30	0.36
Beauty Contest	29	0.25	0.35
Total	49	0.27	0.35

Note: The mean entrant-license ratios by assignment mode are not significantly different from zero.

Importantly, the environment within which licenses are offered is affected by NRA positions on entry. However, NRA positions on market entry are usually unobservable. Further, the use of assignment mode only imperfectly suggests any regulatory bias towards market entry. That is, it is possible that NRAs could more easily encourage entry via beauty contests, rather than trusting to the vagaries of auctions (where incumbents have incentives to outbid potential entrants in auctions). Alternatively, incumbents are probably more likely to be successful in politically-oriented lobbying processes than are potential entrants: Since incumbents have more to lose than entrants have to gain, incumbents are willing to spend more.¹⁰

In addition to assignment mode, NRAs might attempt to encourage entry by: making available more licenses than incumbent operators (excess licenses), setting aside licenses for potential entrants, and offering potential entrant-only concessions. Such concessions include targeted bidding credits, viz., licenses that contain more spectrum when awarded to an entrant and price discounts. Both instruments lower an entrant's average spectrum price per megahertz.

Table 2 lists the number of excess licenses and new entrants. Of 49 national assignments, in 25 cases excess licenses equal the number of entrants. For the remaining assignments, either

¹⁰ The authors are grateful to the Editor for clarification on this point.

the number of excess licenses is greater than new entrants (9 cases); or new entrants ‘out bid’ incumbents (15 cases).

Table 2. Excess Licenses and New Entrants, 1999–2008

Country	Year	Excess Licenses	New Entrants
Finland	1999	0	0
Austria	2000	2	2
Germany	2000	2	2
Italy	2000	0	0
Japan	2000	0	0
Korea Republic	2000	0	0
Netherlands	2000	0	0
Norway	2000	1	1
Poland	2000	2	0
Portugal	2000	1	1
Spain	2000	1	1
Sweden	2000	1	2
Switzerland	2000	1	1
UK	2000	0	0
Belgium	2001	0	0
Czech Republic	2001	1	0
Denmark	2001	0	1
France	2001	1	0
Greece	2001	0	0
Israel	2001	1	0
Liechtenstein	2002	2	0
New Zealand	2001	1	2
Singapore	2001	0	0
Slovenia	2001	1	0
France	2002	1	0
Ireland	2002	0	1
Latvia	2002	0	0
Luxembourg	2002	1	1
Malaysia	2002	0	0
Slovak Republic	2002	0	0
Taiwan	2002	1	2
Estonia	2003	1	0
Luxembourg	2003	0	1
Croatia	2004	0	1
Hungary	2004	1	0
Romania	2004	0	0
Bulgaria	2005	0	0
Denmark	2005	0	1
Latvia	2005	0	1
Poland	2005	1	1
Egypt	2006	0	1
Georgia	2006	0	2
Indonesia	2006	0	1
Malaysia	2006	1	1
Philippines	2006	1	1
Slovenia	2006	0	1
Ireland	2007	0	1
Russia	2007	0	0
Slovenia	2008	0	1
Total		26	31

Note: Set-aside license assignments are omitted.

Table 3 indicates potential entrants receive price or quantity concessions in only 6 (of 49) assignments. However, for these assignments only Greece failed to award a new entrant license.¹¹ Additionally, Table 4 lists set-aside licenses by World Bank national income classification. Setting aside licenses occurs only rarely (8 of 149 licenses), and only in High Income countries. As only contested (by incumbents and potential entrants) license awards are econometrically modelled, the set-aside licenses are omitted from the sample. However, for the contested license sample, awarding set-aside licenses reduces the competition (pool of potential entrant bidders) for licenses. Thus, the variable SETASIDE is included as an argument in the probability of entry equation.¹²

Table 3. Potential Entrant Concessions, 1999–2008

Country	Year	Assignment Mode	Concession
Italy	2000	Auction	Spectrum
UK	2000	Auction	Spectrum, Price
Greece	2001	Auction	Spectrum
Israel	2001	Auction	Price
Ireland	2002	Beauty Contest	Spectrum, Price
Slovak Republic	2002	Beauty Contest	Spectrum

Note: (a) Spectrum indicates that additional spectrum is awarded to new entrants, while price indicates the spectrum is discounted to new entrants; (b) The Irish awarded potential entrants with additional price points. *Source:* Börgers and Dustmann (2003), Analysys (2007), DotEcon Spectrum Awards Database (2008).

Table 4. Set-aside Licenses and New Entry by National Income, 1999–2008

Income Classification	License Awards	Set-aside Licenses		New Entrants	
		Number	%	Number	%
High	116	8	7	30	26
Upper-Middle	22	0	0	4	18
Lower-Middle	11	0	0	5	45
Total	149	8	5	39	25

Note: (a) World Bank income classification; (b) base percentage awarded licenses (number) by income; (c) Belgium had a set-aside license, however, ultimately it was awarded to the state-owned incumbent, Belgacom. Klemperer (2002) argued this was due to potential entrant perception about incumbent dominance.

¹¹ Also, Greece was the only country not to have made available excess licenses.

¹² The anticipated sign of the coefficient is negative.

Next, the relationship between new entry and excess licenses is explored via the joint probabilities reported in Table 5. The table shows that new entrants win licenses when no excess licenses are available in 9% of cases, compared to 13% when excess licenses are available. Table 6 reports the conditional probability of entry with excess licenses available at 0.25. Further, the probability that there is entry when there are no excess licenses is 0.18. Thus, market entry occurs when incumbent numbers equal or exceed available licenses, also the presence of excess licenses does not ensure entry. For assignment mode, Table 7 shows the entry probability is marginally higher for auctions.

Table 5. Joint Probability

Event	Probability
Prob(Entry \cap Excess Licenses Available)	0.13
Prob(Entry \cap No Excess Licenses Available)	0.09
Prob(No Entry \cap Excess Licenses Available)	0.40
Prob(No Entry \cap No Excess Licenses Available)	0.38
Total	1.00

Table 6. Probability of Entry Conditional on Excess License Availability

Event	Probability
Prob(Entry Excess Licenses Available)	0.25
Prob(Entry No Excess Licenses Available)	0.18

Table 7. Probability of Entry Conditional on Assignment Process

Event	Probability
Prob(Entry Auction Assignment)	0.23
Prob(Entry Beauty Contest Assignment)	0.21

3. Econometric Method

The baseline entry probability model is:

$$\Pr(\text{Entry} = 1) = F(\varphi_0 + \varphi_1 \text{Instruments} + \varphi_2 \text{Attributes} + \varphi_3 \text{Market Conditions} + \text{error}) \quad (1)$$

where $\Pr(\text{Entry} = 1)$ is the probability that potential entrants win licenses. Instruments is a vector of regulator-determined spectrum policy instruments, Attributes is a vector of spectrum package attributes, and Market Conditions contains a vector of national economic and mobile market condition variables.

To incorporate potential entrant participation decisions into the estimating equations, i.e., address sample selection issues, requires that potential selection bias is treated as an omitted variable problem. Furthermore, endogeneity concerns arise when regulators design assignments to encourage entry. These endogeneity bias concerns are addressed by including residuals from several instrumental variable (IV) regressions as additional arguments in (1). The methods used to address these concerns are detailed below.

Following Greene (2008: 884), the simplest selection (incidental truncation) equation is:

$$z_i^* = \mathbf{w}_i' \boldsymbol{\delta} + u_i, \quad u_i : N[0,1] \quad (2)$$

with the equation of primary interest given by:

$$y_i = \mathbf{x}_i' \boldsymbol{\beta} + \varepsilon_i, \quad \varepsilon_i : N[0,1] \quad (3)$$

where y_i is observed only if $z_i^* > 0$. The standard result is that with u_i and ε_i distributed bivariate normal with zero means and correlation ρ ,

$$\begin{aligned}
E(y_i | z_i^* > 0) &= E(y_i | u_i > -\mathbf{w}_i' \boldsymbol{\delta}) \\
&= \mathbf{x}_i' \boldsymbol{\beta} + \beta_k \lambda_i(\alpha_{ii})
\end{aligned} \tag{4}$$

where $\alpha_{ii} = -\mathbf{w}_i' \boldsymbol{\delta}$ and $\lambda_i(\alpha_{ii}) = \phi(-\mathbf{w}_i' \boldsymbol{\delta} / \sigma_u) / \Phi(-\mathbf{w}_i' \boldsymbol{\delta} / \sigma_u)$. Clearly, least squares regression produces inconsistent estimates of $\boldsymbol{\beta}$ when the independent variable λ is omitted.

That is, consistent parameter estimates of the sample selection model require estimation by maximum likelihood or Heckman (1979) two-step estimation procedure (see Greene: 888).¹³ However, neither approach is feasible as the current sample does not contain data on the selection mechanism variable, i.e., whether potential entrants decide to bid or not. Potential entrants initially must assess their willingness to apply for spectrum and then, whether to submit bids. If potential entrants perceive a disadvantage relative to incumbents, they might not bid, or they may form consortia with incumbents. Both types of behaviour were observed in spectrum assignments (Jehiel and Moldovanu, 2003: 286).

The approach adopted is to replace the independent variable λ with a proxy sourced from a censored (Tobit) regression explaining the entrant-to-bidder ratio (BIDRATIO). The Tobit model explicitly recognises the sequential decision process of bidders. That is, an increased BIDRATIO residual enhances the probability of entry.¹⁴ Including \hat{e}_i (the BIDRATIO residual) on the right-hand side of (3) controls for any endogeneity arising from sample selection.¹⁵

¹³ Further, the model is generalized for the case when the selection variable is not observed. In this case the selection mechanism is specified as a probability model to account for the latent selection variable. Another generalization is to allow nonlinear specification of the primary equation (see Greene 1992, 2006; and Terza 1995, 1998 for examples of the approach).

¹⁴ An increase in the entrant-to-bidder ratio error should be positively associated with gaining entry in the spectrum contest. The residual is a proxy for unobserved private information. Thus, including the omitted self-selection residual controls for and tests for the significance of private information in explaining ex post outcomes. The authors thank the editor for this insight.

¹⁵ The proxy for the selection mechanism is: $s_i^* = \mathbf{w}_i' \boldsymbol{\delta} + e_i$, $s_i = 0 (s_i^* \leq 0)$, $s_i = s_i^* (s_i^* > 0)$, $e_i : N[0,1]$ where the probability that y_i is observed increases with the value of s_i^* .

The method follows from Terza et al. (2008) that compared the performance of methods to treat endogeneity, viz., two-stage predictor substitution (2SPS) and 2SRI. 2SPS is the extension to nonlinear models of linear two-stage least squares estimation. In 2SRI, second-stage estimation includes first-stage residuals as additional regressors. Within a generic nonlinear framework, Terza et al. demonstrated that 2SRI is consistent, while 2SPS is not.¹⁶

Next, bias arising from the inclusion of potentially endogenous variables on the right-hand side of (3) is addressed. In (3), the vector \mathbf{x} includes both exogenous variables (\mathbf{x}_0) and potentially endogenous variables (\mathbf{x}_E). This situation occurs when NRAs design assignments to encourage entry. In particular, NRAs specify both the assignment mode (auction / beauty contest), and license availability conditions (excess licenses / set-aside licenses) and entrant-only (spectrum price and quantity) concessions.

The presence (or absence) of such conditions define a set of variables. To address any endogeneity bias introduced into the principal (probability of entry) equation by including these arguments, IV estimation is applied to the binomial probit model,¹⁷

$$x_{E_i}^* = \mathbf{z}_i' \boldsymbol{\lambda} + v_i, \quad x_{E_i} = 1 (x_{E_i}^* > 0), v_i : N[0,1] \quad (5)$$

where \mathbf{z} contains both instrumental variables and exogenous variables. The instrumental variables are specified to be strongly correlated with the endogenous variable, but are independent of the structural equation. Endogeneity bias in (2) is controlled for by the inclusion of the \hat{v}_i on the right-hand side (Terza et al. 2008).

The estimating equation that describes the probability that potential entrants win licenses is,

¹⁶ Terza et al. (2008: 534) asserted that the 2SRI method is first proposed by Hausman (1978) in a linear model context. Consistent 2SRI methods for specific nonlinear models were developed by Blundell and Smith (1989, 1993), Newey (1987), Rivers and Vuong (1998), and Smith and Blundell (1986).

¹⁷ The following discussion concerns the binomial probit specification. However, isomorphic econometric procedures apply to the Poisson specification.

$$y_i^* = \mathbf{x}_i' \boldsymbol{\beta} + \gamma_i \hat{e}_i + \hat{\mathbf{v}}_i' \boldsymbol{\rho} + \varepsilon_i, \quad y_i = 1 (y_i^* > 0), \varepsilon_i : N[0,1] \quad (6)$$

where

$$\text{Prob}(y_i = 1 | \mathbf{X}) = \int_{-\infty}^{\mathbf{X}'\boldsymbol{\beta}} \phi(t) dt = \Phi(\mathbf{X}'\boldsymbol{\beta}) \quad (7)$$

and Φ denotes the standard normal distribution, with $\mathbf{x}_O, \mathbf{x}_E, \hat{e}, \hat{\mathbf{v}} \in \mathbf{X}$. Acceptance of the Null that $\rho_i = 0$ indicates that variable i is not a source of endogeneity bias.

The simulated maximum likelihood estimator is asymptotically consistent as the number of observations and draws approach infinity.¹⁸ Within this framework the variances of the disturbances are normalised to unity. Additionally, standard errors are corrected for sample clustering.¹⁹ That is, these data are partitioned into 49 (annual national assignments) mutually exclusive and exhaustive clusters. The corrected asymptotic covariance matrix is:

$$\text{Est. Asy. Var} [\hat{\boldsymbol{\beta}}] = \mathbf{V} \left(\frac{G}{G-1} \right) \left[\sum_{i=1}^G \left(\sum_{j=1}^{n_i} \mathbf{g}_{ij} \right) \left(\sum_{i=1}^{n_i} \mathbf{g}_{ij} \right)' \right] \mathbf{V} \quad (8)$$

where \mathbf{V} is the estimated asymptotic covariance matrix ignoring the clustering and \mathbf{g}_{ij} is the first-derivative matrix of the log-likelihood function for assignment i parameters in the cluster j .

Greene (2008) constructs marginal effects as the coefficient vector multiplied by the density function:

¹⁸ Cappellari and Jenkins (2003) argued that if the number of draws is greater than the square root of the sample size the parameter estimates will be robust to different initial seed values.

¹⁹ The cluster estimator corrects estimated standard errors for panel data type effects that are present, but omitted from the model. A Lagrange multiplier test is initially used to detect heteroskedasticity (see Greene, 2007). The Null hypothesis of homoskedasticity is rejected for all models. Yatchew and Griliches (1984) found that maximum likelihood estimators for binary choice models were inconsistent and the covariance matrix inappropriate under conditions of heteroskedasticity. Greene (2008) noted this test will likely detect other forms of misspecification when present, e.g., unmeasured heterogeneity, omitted variables, nonlinearity or an error in the distributional assumption (Greene, 2008: 780). Given this, it is best to use robust corrections.

$$\frac{\partial E[y_i|\mathbf{X}]}{\partial \mathbf{X}} = \frac{dF(\mathbf{X}'\boldsymbol{\beta})}{d(\mathbf{X}'\boldsymbol{\beta})}\boldsymbol{\beta} = \phi(\mathbf{X}'\boldsymbol{\beta})\boldsymbol{\beta}. \quad (9)$$

The marginal effects for dummy variable d are:

$$E[y|\mathbf{X}, d=1] - E[y|\mathbf{X}, d=0]. \quad (10)$$

4. Variables and Estimation

The dependent variables are defined and summary statistics provided in Table 8. The binomial probit model is intended to provide estimates of the impact of NRA policy instruments on the probability of entry. However, potential entrants must first decide whether to contest for licenses. The decision sequence and the available data raise a sample selection issue. To obtain consistent parameter values an ancillary selection equation is required. The censored BIDRATIO equation provides a residual (omitted variable proxy) for inclusion as an argument in the probability of entry equation.

Furthermore, the empirical analysis also recognises that entry decisions are in part based on policy instruments. Under such circumstances policy-instrument variables are potentially endogenous, i.e., not independent from the disturbances of the entry probability function. Accordingly, a binomial probit IV equation for AUCTION is estimated on exogenous and instrumental variables. Similarly, separate Poisson IV equations are estimated for EXCESS and SETASIDE. Residuals generated from these equations are included as regressors in the probability of entry equation to treat the endogeneity problem. Ancillary regressions are also run for PCONC and SCONC however, the coefficients for the residuals in the probability of entry equation are insignificant indicating that the variables are not a source of endogeneity bias.

Table 8. Dependent Variable Summary Statistics, 1999–2008

Variable	Definition	Mean	S. Dev.	Min.	Max.
Entry equation					
ENTRANT	= 1, if license assigned to a potential entrant; = 0, otherwise	0.22	0.42	0	1
Selection equation					
BIDRATIO	= Number of entrant bidders / number of contestants	0.33	0.26	0	1
IV equations					
AUCTION	= 1, if license assigned via an auction; = 0, otherwise	0.49	0.50	0	1
EXCESS	= Available licenses minus incumbents	0.66	0.73	0	2
SETASIDE	= Number of licenses set-aside for potential entrants only	0.13	0.39	0	2

Table 9 provides explanatory variable definitions. Also reported therein are the mean, standard deviation, minimum and maximum sample values. NRAs control the assignment mode. While beauty contests provide NRAs with an opportunity to influence who wins licenses through the performance criteria, it is widely considered that entry is more common under auction assignments.²⁰ Furthermore, excess and set-aside licenses are intended to incentivise potential entrants to bid. A variable indicating the number of set-aside licenses within an assignment should be negatively related to the (contested license) entry probability. Furthermore, spectrum price and quantity concessions are intended to increase the probability of new entry.

NRAs also specify the operator's required aftermarket network coverage (COVER), the license duration (DURATION), and financial obligations (FEE, INITIAL and RESERVE) via license conditions. In particular, COVER is the percentage of the national population to be served, while TIME indicates the maximum period by which this coverage is required.

²⁰ Auctions can promote market entry by imposing allocation limits on individual firms or by specifying particular auction designs to achieve particular allocation outcomes (e.g., single or several licenses). Hoppe et al. (2006) argued that excessive supply capacity weakens pressure for competitive bidding, while reducing supply raises the prospect of new market entry (under specific cost conditions, tacit collusion is more difficult for incumbents). McAfee (1998) also indicated that excessive capacity supply undermined viable businesses.

Annual license fees (FEE) are specified either as fixed amount or by percentage of operator revenue. INITIAL is the headline price that winning bidders must pay for licenses.²¹

Importantly, the (generally-applicable) spectrum package attributes and national economic condition variables affect the ‘attractiveness’ of the environment within which the licenses are situated. Ideally, ‘attractive’ licenses are of longer duration, with less onerous deployment and financial obligations. Furthermore, high densities lower network deployment costs, whereas high incomes translate to greater mobile service revenues. Finally, monopolistic domestic markets are more appealing as they imply greater price-cost margins.

Das Varma and Lopomo (2010: 451), when examining non-cooperative entry deterrence in 3G license auctions, argued that incumbent firms have an incentive to deter new firm entry to preserve market power. The incentive arises as entry causes aggregate industry profit falls through more intense aftermarket competition. Conversely, deterrence incentives are weaker when the potential foregone profit is ‘low’ (i.e., the environment is ‘unattractive’). Thus incumbents are less likely to participate, increasing the likelihood of new entry. That is, new entry mostly occurs for licenses situated in unattractive environments. Table 10 supports this view, with new entrants winning, on average, licenses with short durations and situated in less densely populated areas.

²¹ In auction assignments COVER, TIME, FEE, INITIAL and RESERVE are usually specified by NRAs, and MNOs price bid based on these predetermined conditions. However, beauty contests require multiple-dimension bids based on spectrum price and some (or all) of the spectrum assignment elements (viz., COVER, TIME, FEE, INITIAL and RESERVE). Usually, regulators provide guidelines to potential bidders via supporting documents.

Table 9. Explanatory Variable Summary Statistics, 1999–2008

Variable	Definition	Mean	S. Dev.	Min.	Max.
Assignment mode					
AUCTION	= 1, if license assignment is via auction; = 0, otherwise	0.49	0.50	0	1
License availability					
EXCESS	= Available licenses minus incumbents	0.66	0.73	0	2
Entry incentives					
PCONC	= 1, if potential entrants receive price concession; = 0, otherwise	0.04	0.20	0	1
SCONC	= 1, if potential entrants receive quantity concession; = 0, otherwise	0.08	0.27	0	1
Spectrum package attributes					
COVER	= Population to be covered (fraction)	0.46	0.36	0	1
DURATION	= License term (years)	16.91	4.08	5	30
FEE	= Annual fee (\$US / 100 MHz / million population)	0.16	0.45	0	2.12
INITIAL	= Upfront fee (\$US million / MHz / million population)	0.56	1.04	0	5.58
RESERVE	= Minimum allowable bid price (US\$ million)	183	580	0	4294
SERVICE	= (1 – COVER) * TIME	1.20	1.26	0	4.90
TIME	= Years to achieve network population coverage	3.45	2.68	0	12
National economic and mobile market conditions					
DENSITY	= National population / square kilometre	303	966	8	6746
INCOME	= GDP per capita (\$US)	18406	12701	1159	64404
MCOMP	= Inverse one plus number of facilities-based operators	0.23	0.05	0.17	0.33
SETASIDE	= Number of licenses set-aside for potential entrants only	0.13	0.39	0	2
TIME ₂₀₀₀	= 1, if assignment process held in 2000; = 0, otherwise	0.38	0.49	0	1
TIME ₂₀₀₁	= 1, if assignment process held in 2001; = 0, otherwise	0.19	0.39	0	1
TIME ₂₀₀₅	= 1, if assignment process held in 2005; = 0, otherwise	0.04	0.20	0	1
Instrumental variables					
IREG	= 1, if regulator is independent; = 0, otherwise	0.59	0.49	0	1
BFREE	= Business freedom index	72.07	10.44	39.80	100
INCUMBENT	= Number of 2G facilities-based mobile operators	3.23	0.89	2	5
EARLY	= 1, if 2000-2002 European assignment; = 0, otherwise	0.53	0.50	0	1
IREGBFREE	= IREG * BFREE	43.30	37.03	0	100
IREGINCUM	= IREG * INCUMBENT	1.87	1.71	0	5
EARLDEN	= EARLY * DENSITY	83.35	114.41	0	469

Note: High SERVICE values indicate more time or lower coverage, or both. IREG is sourced from *Global Competition Review* (GCR). GCR identified telecommunication regulators as independent when decisions will not be controlled or directed by government, nor influenced by operators. BFREE is the ability to start, operate and close businesses (Heritage Foundation, 2012). High BFREE index values suggest greater business freedom.

Table 10. License Environment and New Entry

Variable	New Entrant	Incumbent	<i>t</i> statistic	Desired Value
Spectrum package attributes				
COVER	0.48	0.46	0.27	Low
DURATION	15.8	17.2	1.97**	High
FEE	0.22	0.14	0.77	Low
INITIAL	0.42	0.60	0.92	Low
TIME	3.06	3.56	1.03	High
National economic and mobile market conditions				
DENSITY	142	348	1.96**	High
INCOME	21,554	17,520	1.24	High
MCOMP	0.24	0.23	0.71	High

Note: ** significant at 5%.

Table 11 shows the specification of the entry, selection and IV equations, and a priori coefficient sign expectations. The probability of entry equation includes measures of the set of potentially endogenous policy instruments (AUCTION, EXCESS, PCONC, SCONC), generally-applicable spectrum package attributes (COVER, DURATION, FEE, INTITAL, TIME), national economic and mobile market conditions (DENSITY, INCOME, MCOMP, SETASIDE,²² TIME₂₀₀₁); and residuals that correct for sample selection (RESID_{BIDRATIO}) and endogeneity (RESID_{AUCTION}, RESID_{EXCESS}, RESID_{SETASIDE}) bias.

The BIDRATIO selection equation addresses the unobserved decision of whether a potential entrant contests an assignment. High BIDRATIO residual values should be positively correlated with more potential entrants contesting assignments. This selection equation is explained by information that informs potential entrant participation decisions. This information includes spectrum package attributes, and national economic and mobile market conditions. Additionally, a negative sign is expected for the TIME₂₀₀₁ coefficient for the 2001

²² As the control variable SETASIDE is determined by the regulator it is also potentially endogenous.

dot-com bubble (Klemperer, 2002), while the $TIME_{2005}$ dummy recognises that in 2005 assigning countries provided very strong entry incentives. In particular, Poland had just liberalised, while Bulgaria attempted to reduce incumbent dominance. Finally, Denmark and Latvia held second assignments when incumbents already had been awarded licenses.

Furthermore, the IV AUCTION equation is regressed on the composite market-orientation and business freedom environment (IREGBFREE) index, and population density (DENSITY). IREGBFREE is an interaction variable that has high values for an independent regulator in more liberal business environments. Similarly, EXCESS is regressed on interaction (IREGINCUM) and population density variables. IREGINCUM has high values when there is an independent regulator with many incumbent operators (i.e., more market-orientated and competitive environment). Finally, SETASIDE is assumed positively correlated with IREG, BFREE, INCUMBENT*ITALY and EARDEN* $TIME_{2000}$. The variables INCUMBENT*ITALY and EARLDEN* $TIME_{2000}$ characterise the Italian environment, which provided the only instance where multiple licenses were set-aside.

Finally, negative correlations are expected for the joint presence of price and quantity concessions (PCONC*SCONC), and the time dummy variables. As concessions (open bidding, but with an advantage) and set-aside (selective bidding) mechanisms are philosophically opposed methods to encourage entry, a negative PCONC*SCONC coefficient is expected.

Table 11. Entry, Selection, and IV Equation Specifications

Variable	Entry	Selection	Instrumental Variable		
	ENTRANT	BIDRATIO	AUCTION	EXCESS	SETASIDE
Assignment mode					
AUCTION	+				
License availability					
EXCESS	+				
Entry incentives					
PCONC	+				
SCONC	+				
Spectrum package attributes					
COVER	+				
DURATION	–	–			
FEE	+	+			
INITIAL	+				
RESERVE		–			
SERVICE		–			
TIME	–				
National economic and mobile market conditions					
DENSITY	–	–	+	+	
INCOME	+	+			
MCOMP	+	+			
SETASIDE	–				
TIME ₂₀₀₁	–	–			–
TIME ₂₀₀₅		+			
Instrumental variables					
IREG					+
BFREE					+
IREGBFREE			+		
IREGINCUM				–	
TIME ₂₀₀₀					–
PCONC*SCONC					–
INCUMBENT*ITALY					+
EARLDEN*TIME ₂₀₀₀					+
Estimated residuals					
RESID _{BIDRATIO}	+				
RESID _{AUCTION}	–				
RESID _{EXCESS}	–				
RESID _{SETASIDE}	–				

5. Estimation Results

Table 12 reports the censored regression estimates for the BIDRATIO sample selection equation. Estimation is by maximum likelihood procedures as outlined by Greene (2008: 871–875). Further, the likelihood test rejects the Null that the explanatory variables do not impact on the ratio. Additionally, the DECOMP based fit measure is reported. These results suggest that spectrum package attributes (DURATION, RESERVE and SERVICE) and national economic and market conditions (DENSITY and INCOME, and the dummy variables TIME₂₀₀₁ and TIME₂₀₀₅) are particularly important for explaining the willingness of potential entrants to bid for spectrum.

Table 12. BIDRATIO Censored Regression Maximum Likelihood Estimates

Category	Variable	Coefficient	Standard Error	<i>t</i> statistic	Marginal Effect
	Constant	0.60924***	0.19630	3.10	
Spectrum package attributes					
	DURATION	−0.01735**	0.00649	−2.67	−0.01411
	FEE	−0.01282	0.05617	−0.23	−0.01043
	RESERVE	−0.00013**	0.00006	−2.16	−0.00011
	SERVICE	−0.04743**	0.02114	−2.24	−0.03858
National economic and mobile market conditions					
	DENSITY	−0.00034*	0.00019	−1.84	−0.00028
	INCOME	0.000005***	0.000002	2.95	0.000004
	MCOMP	0.15294	0.62102	0.25	0.12439
	TIME ₂₀₀₁	−0.22850***	0.07400	−3.09	−0.18584
	TIME ₂₀₀₅	0.31723***	0.11925	2.66	0.25800
Disturbance standard deviation					
	Sigma	0.27402***	0.02006	13.66	
	Number of observations		141		
	DECOMP based fit measure		0.364		
	Log likelihood		−42.258		

Note: *significant at 10%; ** significant at 5%; *** significant at 1%.

Next, Table 13 reports estimation results from the ancillary IV regressions for the potentially endogenous variables. In particular, AUCTION and EXCESS are both positively correlated with population density. AUCTION is positively associated with the market-orientation and

business freedom composite index (IREGBFREE), whilst EXCESS is negatively correlated with the interaction (IREGINCUM) term. Finally, SETASIDE is negatively correlated with PCONC*SCONC, and positively correlated with interaction terms INCUMBENT*ITALY and EARLDEN*TIME₂₀₀₀.

Table 13. Instrumental Variable Maximum Likelihood Estimates

Dependent Variable	Variable	Coefficient	Standard Error	t statistic
AUCTION (Binomial Probit model)				
	Constant	-1.03104**	0.48154	-2.14
	DENSITY	0.00321**	0.00161	1.99
	IREGBFREE	0.01077*	0.00630	1.71
	Number of observations		141	
	McFadden Pseudo R ²		0.157	
	Log likelihood		-82.376	
	Restricted log likelihood		-97.702	
EXCESS (Poisson model)				
	Constant	-0.18122	0.20860	-0.87
	DENSITY	0.00009*	0.00005	1.71
	IREGINCUM	-0.16095***	0.03732	-4.31
	Number of observations		141	
	McFadden Pseudo R ²		0.024	
	Log likelihood		-142.79	
	Restricted log likelihood		-146.26	
SETASIDE (Poisson model)				
	Constant	-4.75507	5.67725	-0.84
	IREG	0.54849	1.62402	0.34
	BFREE	0.02909	0.07071	0.41
	TIME ₂₀₀₀	-1.03225	0.72917	-1.42
	TIME ₂₀₀₁	-0.28917	1.46241	-0.20
	PCONC*SCONC	-97.7173***	1.01619	-96.16
	INCUMBENT*ITALY	1.05166***	0.08409	12.51
	EARLDEN*TIME ₂₀₀₀	0.00378***	0.00123	3.07
	Number of observations		141	
	McFadden Pseudo R ²		0.245	
	Log likelihood		-43.139	
	Restricted log likelihood		-57.130	

Note: * significant at 10%; ** significant at 5%, *** significant at 10%. ITALY = 1, if the spectrum assignment is in Italy; = 0, otherwise.

The equation of primary interest is the second-stage binomial probit ENTRANT model. Estimation is by maximum likelihood procedures as outlined by Greene (2008: 777–793), with the results reported in Table 14. The first-stage BIDRATIO residual ($RESID_{BIDRATIO}$) is added to the ENTRANT equation. Importantly, the model specification is supported by a statistically significant $RESID_{BIDRATIO}$ coefficient. That is, a higher probability of participation error is expected to be positively related to the entry probability thus the coefficient estimate conforms to expectations.

Furthermore, the IV equation endogeneity residuals, $RESID_{AUCTION}$, $RESID_{EXCESS}$ and $RESID_{SETASIDE}$, are also included as arguments in the probability of entry equation. Importantly, all three estimated coefficients are statistically significant indicating the variables AUCTION, EXCESS and SETASIDE are endogenous in the restricted specification.²³

Additionally, the likelihood test rejects the Null that the set of explanatory variables do not impact on the entry probability. Furthermore, the errors are homoscedastic. Finally, the model tracks the data well with 75% of the observations correctly predicted, while McFadden's sample pseudo R^2 is 32%.

Distinct patterns emerge from the results contained in Table 14. First, national economic and mobile market condition variables that are significant in explaining the probability of entry are DENSITY (with partial effect -0.00088), INCOME (0.00001), SETASIDE (-1.54763) and $TIME_{2001}$ (-0.17987). The setting aside of licenses enables only potential entrants to bid. Thus, the policy instrument reduces the pool of potential entrant bidders for contested licenses, thus the probability of a potential entrant winning a contested license is diminished. The estimated SETASIDE coefficient reports the anticipated negative sign.

²³ The Appendix Table reports results from the restricted binomial probit model estimation.

Second, for variables that describe the generally-applicable (to both incumbents and potential entrants) spectrum package attributes: the required network coverage (COVER = 0.43387) and annual fee (FEE = 0.13991) estimated coefficients are positive; whilst the estimated coefficients for duration (DURATION = -0.01850) and the time to complete network coverage (TIME = -0.07909) are negative. Whilst these signs initially appear counterintuitive, this is not the case. Indeed, they reflect the observation (see Section 4) that new entrants typically win licenses situated in relatively unattractive environments, e.g., shorter license duration (DURATION) and in less densely populated areas (DENSITY). This suggests that it is more difficult for potential entrants to overcome incumbent advantage when the license environment is favourable (see Das Varma and Lopomo, 2010).

The main study interest is in the estimated coefficients of licensing policy instruments intended to enhance the probability of entry, viz., assignment mode (AUCTION), license availability (EXCESS), and entry incentive (PCONC and SCONC) variables. Not surprisingly, auction spectrum assignments increase the entry probability (AUCTION = 0.34517). Furthermore, allotting more licenses than the number of incumbent 2G operators (EXCESS = 0.87522) also increases the entry probability.

Finally, with regard to the concessions offered by regulators, the only significant estimated coefficient is for SCONC (= 0.15836), albeit at the 10% level. This outcome may be because potential entrants consider the measures insufficient in magnitude or ineffective because of the mode of implementation. Further study is required to determine whether the concessions approach should be modified or abandoned.

Table 14. ENTRANT Binomial Probit Regression Maximum Likelihood Estimates

Category	Variable	Coefficient	Standard Error	<i>t</i> statistic	Marginal Effect
	Constant	-2.19286*	1.26113	-1.74	
Assignment mode					
	AUCTION	2.04876***	0.45330	4.52	0.34517
License availability					
	EXCESS	4.33404**	2.00584	2.16	0.87522
Entry incentives					
	PCONC	-0.99038	0.61997	-1.60	-0.14820
	SCONC	0.70183*	0.39461	1.78	0.15836
Spectrum package attributes					
	COVER	2.14850***	0.73708	2.91	0.43387
	DURATION	-0.9159**	0.03834	-2.39	-0.01850
	FEE	0.69283**	0.32017	2.16	0.13991
	INITIAL	0.21421	0.15300	1.40	0.04326
	TIME	-0.39165***	0.11561	-3.39	-0.07909
National economic and mobile market conditions					
	DENSITY	-0.00434***	0.00118	-3.69	-0.00088
	INCOME	0.00003**	0.00001	2.43	0.00001
	MCOMP	-4.32746	3.86153	-1.12	-0.87389
	SETASIDE	-7.66379**	3.83446	-2.00	-1.54763
	TIME ₂₀₀₁	-1.14042***	0.30574	-3.73	-0.17987
Sample selection residual					
	RESID _{BIDRATIO}	1.96849***	0.39685	4.96	0.39752
Endogeneity residuals					
	RESID _{AUCTION}	-0.69084**	0.32429	-2.13	-0.13951
	RESID _{EXCESS}	-4.53871**	1.94433	-2.33	-0.91655
	RESID _{SETASIDE}	-7.18988*	4.05489	-1.77	-1.45192
	Number of observations		141		
	McFadden Pseudo R^2		0.316		
	Log likelihood		-50.765		
	Restricted log likelihood		-74.269		

Note: * significant at 10%; ** significant at 5%; *** significant at 1%.

Finally, Table 15 reports elasticity estimates for the policy instruments. The elasticity values (at the sample means) are inelastic, with the exception of EXCESS (2.626). The elastic value for EXCESS suggests that allotting ‘additional’ licenses to encourage entry (increase the probability of entry) is largely successful. Finally, using an auction to assign spectrum and providing quantity-based concessions also increases the entry probability. However, for the latter instrument this impact is relatively slight.

Table 15. NRA Policy Instrument Elasticity Estimates

Category	Variable	Elasticity
Assignment mode	AUCTION	0.768
License availability	EXCESS	2.626
Entry incentives	PCONC	-0.029
	SCONC	0.056

Note: Bold indicates coefficient is statistically significant.

6. Conclusions

It is widely accepted that regulators design spectrum assignments in an attempt to influence aftermarket competition via new entry. Accordingly, the fundamental question addressed is: are regulatory policy instruments effective in promoting entry? This focus is important as it has not been previously empirically tested.

Regulator policy instruments include: the assignment mode (auction or beauty contest), making more licenses (spectrum blocks) than incumbent firms available, and by providing targeted bidding credits (through discounted winning bid prices or providing additional spectrum) to successful potential entrants. Not surprisingly, auction spectrum assignments, and allotting excess licenses increase the probability of entry. However, quantity concessions only have a slight impact.

Clearly, the assignment design recommendations that emerge are that regulators might only have limited policy instruments to influence aftermarket composition. Of particular importance is the ineffectiveness of price concessions. However, an empirical question remains as to whether the price concessions approach should be modified or abandoned.

7. References

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Appendix

The Appendix Table reports the results from restricted binomial probit model estimation, viz., with coefficients of selectivity and endogeneity arguments set to zero. The restricted equation results are clearly inferior to those reported in Table 14. In particular, while the estimated coefficient signs accord with expectations, the coefficients for excess licenses (EXCESS), quantity concessions (SCONC), population density (DENSITY), and national income (INCOME) are insignificant.

Appendix Table. Restricted ENTRANT Binomial Probit Regression Estimates

Category	Variable	Coefficient	Standard Error	<i>t</i> statistic	Marginal Effect
	Constant	0.19079	1.24507		
Assignment mode					
	AUCTION	0.97092*	0.50143	1.94	0.22407
License availability					
	EXCESS	0.09506	0.09566	0.99	0.02274
Entry incentives					
	PCONC	−0.37553	0.24816	−1.51	−0.08083
	SCONC	0.21552	0.65946	0.33	0.05410
Spectrum package attributes					
	COVER	0.92277***	0.15577	5.92	0.22073
	DURATION	−0.06043**	0.02500	−2.42	−0.01446
	FEE	0.34770***	0.05538	6.28	0.08317
	INITIAL	−0.03378	0.05766	−0.59	−0.00808
	TIME	−0.20425**	0.08996	−2.27	−0.04886
National economic conditions					
	DENSITY	−0.00128	0.00179	−0.71	−0.00031
	INCOME	0.00002	0.00002	1.05	0.00001
	MCOMP	−1.00788	4.08791	0.25	−0.24109
	SETASIDE	−14.0360***	0.33130	−42.37	−0.24402
	TIME ₂₀₀₁	−0.90464***	0.15933	−5.68	−0.17768
	Number of observations		141		
	McFadden Pseudo R^2		0.190		
	Log likelihood		−60.162		
	Restricted log likelihood		−74.269		

Note: * significant at 10%; ** significant at 5%; *** significant at 1%.