A Brief Review and Analysis of Spectrum Auctions in Canada

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Abstract

We begin by explaining the importance of efficient spectrum allocation and reviewing Canada's recent spectrum allocation history. We then use a dataset covering more than 1,200 licenses auctioned from 2001 to 2015 that seeks to account for each auction's particular rules. Our results confirm that measures of demand such as population covered, income levels, frequency levels, bandwidth, etc. indeed drive license valuation. We also quantify the negative impact on price of setting aside particular license auctions for new entrants, suggesting that the set-aside provision constitutes an implicit subsidy for those firms.

***JEL Classification*:** D44; D45; D47; L51; O33
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I. Introduction

Spectrum is the set of radio frequencies used to communicate over airwaves. Television stations use spectrum to send over the air broadcast signals to our homes, radio stations use spectrum to send audio streams to our cars, and cellular telephones use spectrum to connect us to one another in a mobile fashion. Importantly, spectrum is finite. Since the launch of cellular phones and the proliferation of mobile communication, spectrum allocation has gained greater attention. In this paper, we focus on licenses of spectrum related to cellular services.

In October of 1982, the Canadian Department of Communications responded to the launch of cellular phones with an allocation of spectrum based on "beauty contest" principles. Applicants submitted business plans replete with the alleged social and economic benefits that would be enjoyed if they were given the spectrum. This method has fallen out of favor in most countries, as the process tends to be politicized and can prompt costly litigation if an applicant is unhappy with the result.[1] Auctions are far more transparent – once rules are set, the result is straightforward and objective. At the time, however, Canada was actually quite proud of its regulatory regime.[2] In 1986, the Department of Communications published a brochure that boasted about its unique ability to regulate spectrum: "Canada's communication system is one of the finest in the world, providing high-quality, inexpensive, and reliable services for the entire population" (Taylor, 2013). The Department went on to call Canadians "world leaders in managing and monitoring the radio frequency spectrum."

[1] For example, the losers of spectrum beauty contests in Sweden and Spain for 3G spectrum filed costly litigation (Binmore and Klemperer, 2002).

[2] It should be noted that Canada was not alone in assigning spectrum in this fashion around this time. The United States used the beauty contest until the Federal Communications Commission held its first auction in 1994. The United Kingdom held its first spectrum auction in 2000.

Canada now allocates its spectrum via transparent auctions. The U.S. held its first spectrum auction in 1994, and has spent many years refining its auction mechanism and rules to increase the efficiency of its auctions. Canada held its first auction in 1999. Since then, the regulatory body responsible for the auctions, now called Industry Canada, has held 11 separate auctions, summarized on the next page in Figure 1.

Figure 1: A Summary of Canada's Spectrum Auction History

Auction	*Frequency (in MHz)* [1]	*Year*	*Number of Bidders*	*Licenses Offered*	*Licenses Sold*	*Percent Sold*	*Total Winning Bids*
24 & 38 GHz	24250-25250; 38700-39800	1999	13	354	260	73.45%	$171.8 million
PCS - 2 GHz	1865-1910; 1945-1990	2001	7	62	52	83.87%	$1.5 billion
2300 & 3500 MHz	2305-2360; 3475-3650	2004	22	849	392	46.17%	$11.2 million
Residual 2300 & 3500 MHz	2305-2360; 3475-3650 (Residual)	2005	25	457	450	98.47%	$57.5 million
AWS-1	1670-1755; 1910-2155	2008	27	292	282	96.58%	$4.3 billion
Air-ground	849-851; 894-896	2009	3	2	2	100.00%	$2.1 million
2300 & 3500 MHz	2305-2360; 3475-3650 (Residual)	2009	9	10	10	100.00%	$124.0 thousand
700 MHz	698-756; 777-787	2014	10	98	97	98.98%	$5.3 billion
AWS-3	1755-1780; 2155-2180	2015	10	42	39	92.86%	$2.1 billion
2500-2690 MHz	2500-2690	2015	11	318	302	94.97%	$755.4 million
700 MHz & AWS-3 (residual)	Residual from 700 MHz Auction; Residual from AWS-3 Auction	2015	6	18	15	83.33%	$58.5 million

[1] Small discontinuities in frequency ranges ignored for simplicity. Frequency ranges presented are merely illustrative.
Source: DotEcon and Government of Canada

Auctions are employed in an effort to allocate spectrum most efficiently to firms. Absent liquidity constraints, the firm that is willing to spend the most for spectrum expects to gain the most economically. However, Industry Canada has modified the framework of auctions to accomplish specific policy objectives. For example, in an effort to increase competition in the telecommunications industry, the government of Canada has exercised exclusionary auction rules. Some licenses have been "set aside" for new entrants, and spectrum aggregation limits have restricted large firms' growth.[3] As late as the 2004 auction of 2300 & 3500 MHz, regulators "found no compelling argument to demonstrate that a set-aside of spectrum for new entrants would significantly advance new service offerings, nor serve the public interest" (Industry Canada, 2003). But in the 2008 AWS auction, Industry Canada found that "market conditions are such that establishing [set-aside] measures for the auction for AWS spectrum licenses to sustain and enhance competition is warranted" (Industry Canada, 2007). It is not clear that these rules have accomplished their intended effects. Public Mobile, one new entrant that won set-aside spectrum, was promptly acquired by TELUS, a large firm, for about five times the amount spent by Public Mobile in the spectrum auction (Masse and Beaudry, 2016).

It is also worth noting that Canada is not alone in its use of such set-asides. The United States' Federal Communications Commission (FCC) also offers set-aside auctions, bidding credits (making a small firm's bid worth more in the auction than the actual amount of the bid), and even previously offered installment payments to firms that it designates as small bidders. These have similarly resulted in several cases of readily identifiable problems, such as defaults, fraudulent claims of small bidder status, quick resales to larger firms, etc. (see Kwerel and Rosston, 2000; Cramton, 2001; Connolly, Sa, Roark, Zaman and Trivedi, 2017; Connolly, Zrenner, and Nnoromele, 2017).

[3] "New entrants" have been defined as "entit[ies], including affiliates and associated entities, which hold less than 10 percent of the national wireless subscriber market share, or 20% or more of wireless subscriber market share in the province of the relevant license area" (Industry Canada, 2014).

Theory demonstrates that such rules will influence license valuation and winning bid prices for multiple possible reasons. First, empirical evidence suggests that offering bid credits increases the total number of bidders (Connolly, Zrenner, and Nnoromele, 2017). This increases competition for licenses and results in higher prices.[4] Second, the combination of bid credits and the possibility of resale of licenses to larger firms could result in “bid shading,” depressing final winning bid values by failing to bid up to a license’s valuation (Loertscher and Marx, 2015). Large bidders know they can buy the license on the resale market from a small bidder with a bid credit. As such, the large bidder will shade their bid to hide their true value, only to end up buying the license from the resale market for a lower amount in order to maximize surplus. This results in a lower winning bid. Third, despite rules expressly prohibiting collusion, there is evidence of collusive behavior in U.S. FCC auctions (see Appendix I). This behavior would influence the value of the final winning bid, as firms could agree to not compete with each other for certain licenses. To the best of our knowledge, however, this possibility has not yet been investigated for Canada’s auctions.

Finally, smaller firms in set-aside auctions may fail to bid up to a license’s intrinsic valuation because of liquidity constraints, a lack of sufficient technical knowledge, or a lack of existing infrastructure or scale. In this paper, we seek to isolate and quantify the impact of setting aside spectrum on spectrum auction prices in Canada. We also study the effects of income, population, and frequency data. These findings could have implications for Canadian spectrum policy, and spectrum policy in general. If setting aside spectrum for new entrants leads to a lower price in the auction, then that lower price amounts to an implicit subsidy for the small firm that should be justified to Canadian taxpayers. It also implies that a scarce resource is being allocated to less efficient firms, thereby reducing social welfare all else equal.

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[4] It is worth noting, however, that use of a bid credit causes an expected *decrease* in the value of the final winning bid, according to their results.

II. Literature Review

Regulators have implemented a variety of different spectrum auction systems and rules in an effort to accomplish specific spectrum allocation goals. Glass and Rhodes (1999) argue that a simultaneous multiple round (SMR) spectrum auction system would provide the proper balance between market forces and social policy considerations. According to Industry Canada, "In a simultaneous multiple round auction, multiple licenses are open for bidding at the same time and bidding remains open on all licenses as long as acceptable bids are placed on any of the licenses. Bidding occurs in a sequence of rounds. The results of each round are announced to the bidders prior to the start of the next round. The auction is run by computer with on-line bidding." Glass and Rhodes further propose the utilization of a hybrid system whereby prospective bidders must first pass an initial screening to be eligible for the auction. Canada used this kind of SMR auction framework for its first five auctions (1999-2008). Since then, Canada has experimented with two other frameworks: a combinatorial clock auction (CCA) in 2014 and 2015 and a sealed-bid combinatorial auction for multiple auctions in 2009 and 2015.

Industry Canada used the CCA framework for the 700 MHz (2014) and 2500-2690 MHz (2015) auctions.[5] In the Licensing Framework for the 700 MHz (2014) Auction, Industry Canada explains the way a CCA works and why that format was chosen: "The CCA format was proposed for the 700 MHz auction, as it utilizes package bids, eliminating the risk that bidders win some but not all of the licenses needed for their business case, known as exposure risk. This auction format reduces complexity for bidders in that they can bid on the entire packages of licenses in an all-or-

[5] The CCA is a complicated auction framework. There are two stages: the allocation stage (when the number of licenses that a bidder wins and the base price to be paid by each winning bidder is determined) and the assignment stage (which assigns specific frequencies to winners of generic licenses). In the allocation stage, there are two sets of rounds. The clock rounds allow for price discovery. Firms are only able to bid on one package of licenses in each clock round. The supplemental round offers an opportunity for bidders to improve bids from the clock rounds and/or submit new bids on different packages. Read more here: https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10583.html

nothing basis rather than trying to put together a package comprised of individual licenses" (Industry Canada, 2013).[6] Cramton (2013) argues for the benefits of a CCA, claiming that it "allows alternative technologies that require the spectrum to be organized in different ways to compete in a technology-neutral auction."

However, Canada opted for the sealed-bid framework for the Air-Ground (2009), Residual 2300 and 3500 MHz (2009), AWS-3 (2015), and Residual 700 MHz & AWS-3 (2015) auctions. In a sealed-bid second-price auction, applicants submit their bids in a sealed envelope for whichever licenses they wish to acquire. The bids are then ranked and licenses are awarded. Winners pay the amount of the second-highest bid.[7] The Air-ground (2009), Residual 2300 & 3500 MHz (2009), and Residual 700 MHz & AWS-3 (2015) auctions are unique. They offered only 2, 10, and 18 licenses, respectively, which renders more complicated auction formats like the SMR or CCA unnecessary. Industry Canada acknowledged this rationale in the Licensing Framework for the Residual 700 MHz & AWS-3 (2015) Auction: "Although both CCA and SMR formats provide stakeholders with the benefit of price discovery through the multiple rounds, these formats are more complex and time consuming. Given the proposal to offer a limited number of licenses in this auction process, Industry Canada is of the view that the use of a sealed-bid auction format would be optimal" (Industry Canada, 2015). In the AWS-3 (2015) Auction, Industry Canada argued that because one block was set aside for new entrants and the two open blocks

[6] Fox and Bajari (2013) investigated United States auctions of a particular spectrum type and found that geographic complementarities between licenses accounted for a significant portion of a package's value to firms. Ausbel, Cramton, McAfee, and McMillan (1997) also find evidence for geographic complementarities in PCS spectrum. Prices were higher when the highest-losing bidder held adjacent licenses. The existence of these geographic complementarities provides theoretical justification for encouraging package bidding of licenses rather than individual license bidding in order to maximize efficiency.

[7] Winners may also pay the reserve price set by Canada, in the event the winner is the only bidder. If there is a tie, tied bidders must submit a second bid in order to break the tie. This process continues until there is no longer a tie.

allowed for package bidding, "a simplified auction [i.e. a sealed-bid auction] [could] be held for this spectrum" (Industry Canada, 2014).

Beside the framework of the auction itself, many auctions have employed various rules to accomplish specific objectives, which has prompted review of those rules' unintended consequences. Dippon (2009) examines AWS auctions in the U.S. and Canada, arguing that set-aside obligations in Canadian auction design result in a premium in the non-set aside Canadian licenses offered in the same auction.[8] In fact, Dippon finds that the AWS-1 (2008) auction revenue exceeded the average expected revenue by approximately 138%. Historically, however, Canadian licenses have sold for *less* than comparable U.S. licenses (when price is divided by amount of MHz and population covered). Dippon argues that this discrepancy in the AWS-1 (2008) auction occurred for two reasons. First, Dippon reveals that the set-aside provision in the Canadian AWS auction resulted in "fake bidding:" firms participating in set-aside auctions were allowed to place bids on unrestricted spectrum (spectrum that was not set aside) without the intention of buying, allowing them to raise prices for incumbents.[9] Thus, incumbents bidding for unrestricted spectrum were forced to bid greater and greater amounts to compete with these false bids. Second, set-asides decrease the total supply of spectrum available to incumbents, resulting in a higher price for unrestricted licenses. In fact, the AWS-1 (2008) auction examined by Dippon set aside 44% of the available spectrum in the auction. According to Dippon, there was "no precedent" for setting aside so much spectrum for smaller firms, as the amounts set aside are "typically restricted to a small percentage of the available spectrum."

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[8] Premium is calculated over comparable non-set aside licenses in the U.S.

[9] The auction allowed new entrants the ability to rescind their bids on unrestricted spectrum if an incumbent did not outbid them.

These two consequences result in an implicit tax on the incumbents and a misallocation of spectrum away from firms who may value it the highest, thus corrupting the auction's efficiency. Dippon argues that the set-aside provision and the consequentially higher prices on unrestricted spectrum could actually *decrease* competition in the industry. The distortion could drive some larger firms out of particular markets, or compel incumbent firms to acquire smaller firms for the spectrum they acquired in set-aside blocks. Such an outcome is inefficient. First, there are considerable transactions costs to these acquisitions – considerably higher than the transactions costs present in the original auction. Second, licenses are not allowed to be re-sold for a given time period. For example, in the AWS-1 (2008) Auction, "Licenses acquired through the set-aside may not be transferred or leased to, divided among, or exchanged with companies that do not meet the criteria of a new entrant, for a period of 5 years from the date of issuance" (Industry Canada 2007). Smaller firms that paid for spectrum with the expectation of selling the company rather than using the spectrum may allow it to lie fallow, imposing significant social costs. We intend to quantify the marginal impact of set-aside spectrum on the price of the set-aside licenses' winning bids. Our paper does not investigate the effects of set-aside spectrum on other licenses in the auction or attempt to quantify the impact of set-aside provisions on social welfare.

Researchers, though, have begun to assess these impacts. Hyndman and Permeter (2015) investigate the same auction that Dippon analyzed, the AWS-1 (2008) auction. They employ concepts introduced by Fox and Bajari (2013) to estimate firms' profit functions, accounting for geographic complementarities between licenses, and find that removing the set-aside rule would have avoided a $400-500 million efficiency loss.[10] The authors point out that the gains to consumers could have been even larger. With so much spectrum set aside for smaller firms and

[10] For this calculation, Hyndman and Permeter assume that there is no new entry and incumbents' pre-existing market share is largely unchanged.

therefore less spectrum available to larger firms, it was more difficult for larger firms to achieve geographic complementarities, which would improve efficiency.

These results have motivated this study of the impact of the set-aside rule on all of Canada's spectrum auctions relating to cellular services, rather than focusing narrowly on just one. We also provide evidence for the positive effect of conventional demand drivers (such as income and population covered) in Canadian auctions. Auctions related to cellular services in the United States have been analyzed extensively (Connolly, Sa, et. al, 2017), but we were unable to find comparable studies for Canadian auctions. To that end, we hope to contribute our results.

III. Empirical Approach

To tease out the marginal effect of certain characteristics on the value of the final winning bid, we construct a model that considers a variety of potential factors that influence the final value of the winning bid, which is used as the dependent variable:

$$\begin{aligned} lnP_i = \ & \alpha + \beta ln(Median\ Income_i) + \gamma ln(Population\ Covered_i) \\ & + \delta ln(Amount\ of\ Spectrum\ Granted\ By\ License_i) + \varepsilon ln(Duration_i) \\ & + \theta ln(Spectral\ Efficiency_i) + \mu ln(Amount\ Offered\ in\ Auction_i) \\ & + \pi ln(Number\ of\ Bidders_i) + \rho(SetAside\ Binary_i) \\ & + \sigma(After2008 \times Frequency\ Above\ 2GHz_i) + \tau(Frequency\ Above\ 2GHz_i) \\ & + \epsilon_i \end{aligned}$$

We expect that telecommunications companies are willing to pay more (i.e. the value of the winning bid will be higher) as conventional demand drivers like income and population covered increase. Population density should also be a factor that influences the winning bid price, but we were unable to accurately identify the area of the landmass covered by each license. We therefore leave that for further research.

We also expect these companies would positively value greater amounts of spectrum granted by a particular license (in terms of more MHz), as well as greater amounts of time to use that spectrum (i.e. longer durations). We predict that as these factors increase, the natural log of the winning bid will also increase. We also expect that a greater number of bidders increases competition and demand for the license, resulting in higher winning bids.

We include a dummy for different frequencies provided by licenses because different frequencies are used for different purposes, influencing valuation. Importantly, we must point out that although we were interested in analyzing all licenses related to cellular services, our dataset only covers licenses of at least 1 GHz. Therefore, there are only two frequency buckets we analyze: 1-2 GHz and 2+ GHz. We use a dummy for 2+ GHz to capture the effect of different frequency ranges on the value of the winning bid. We hope that future research may be able to include data on auctions of spectrum with a frequency of less than 1 GHz.

The amount of new spectrum being offered in an auction will determine the supply available to bidders. We expect that increasing the amount of spectrum made available in the auction will have a negative effect on the value of the winning bid, because increased supply should lower price (all else equal). We also consider spectral efficiency and technological progress, such as the introduction of Multiple-Input Multiple-Output (MIMO) stations that occurred early in 2009. This technology increases spectral efficiency, but can only be used at higher frequencies (Connolly, Sa, et. al, 2017; Kerans et. al, 2011). Higher frequency spectrum auctioned after the introduction of this technology should carry a higher valuation, so we interact a post-2008 dummy with a dummy that captures auctions of spectrum with frequency greater than 2 GHz.

We employ both OLS and Tobit regression methodologies in order to analyze the effects of these different factors. While the OLS regression is a more straightforward statistical process, we employ a Tobit model as well, following the example of Connolly, Sa, et al. (2017). This model was employed in their paper because of reserve prices imposed by auctioneers that serve as the minimum amount that must be bid in order to win the license. These reserve prices can result in censoring of data (if the regulator sets a reserve price higher than the highest valuation, no one bids and wins the license, even if it is highly valued). We expect that our data will not suffer very much from this problem because Industry Canada has auctioned off licenses in residual auctions when those licenses did not sell in earlier auctions. In these residual auctions, reserve prices eventually collapse to 0. We therefore still use a Tobit model because our dependent variable is constrained by 0 (i.e. all winning bids must be non-zero), but the results should be substantially similar to the OLS model's results. We use OLS for our baseline regression and compare to a Tobit model for that same baseline, but use Tobit for the regressions that follow because it is a more consistent estimator for our data.

IV. Data

As part of Professor Michelle Connolly's Spectrum Lab at Duke University, we obtained proprietary data from DotEcon on Canada's spectrum allocation from 1999 to 2009. The dataset covers 1,445 sold licenses. From this dataset, we gather the following:

- Total number of bidders in the auction
- Amount of spectrum available in the auction
- License name and region
- Auction format

- Population covered by the license
- Amount paid by the winning bidder
- Whether particular licenses in an auction were set aside

There have been four spectrum auctions conducted by Industry Canada after the 2009 auction of residual spectrum in the 2300 and 3500 MHz bands, which is the last auction provided by DotEcon. We added the following data to the overall dataset from the AWS-3 (2015) auction to match our prior data:

- Total number of bidders in the auction
- Amount of spectrum available in the auction
- License name and region
- Auction format
- Population covered by the license
- Amount paid by the winning bidder
- Whether particular licenses were set aside

We were unable to get reliable data on the amount paid by winning bidders in the other three auctions that have been conducted since the conclusion of the DotEcon dataset because disaggregated license-specific data has not been made available by Industry Canada. We are therefore unable to include those auctions in the regression analysis. We are also not including the 24 & 38 GHz (1999) Auction and the Air-ground (2009) Auction to remove auctions that are not related to cellular services. 24 & 38 GHz spectrum is not designated for cellular services.[11]

[11] This spectrum is mostly used for "high-speed Internet, video teleconferencing, wireless local loop, electronic commerce applications" (Industry Canada)." Read more here: http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01834.html

The Air-ground (2009) Auction only offered two licenses, both to be used for communication with aircraft. Figure 2 presents a summary of the auctions we analyze in our regressions.

Figure 2: Auctions that Remain in the Dataset

Auction	*Use*	*Year*	*Frequency (in MHz)* [1]	*Total Licenses Sold*	*Auction Mechanism*
PCS - 2 GHz	Personal Communication Services	2001	1865-1910; 1945-1990	52	SMR
2300 & 3500 MHz	2300 MHz: Wireless Communication Services; 3500 MHz: Fixed Wireless Access	2004	2305-2360; 3475-3650	392	SMR
Residual 2300 & 3500 MHz Auction	2300 MHz: Wireless Communication Services; 3500 MHz: Fixed Wireless Access	2005	2305-2360; 3475-3650 (Residual)	450	SMR
AWS-1	Advanced Wireless Services	2008	1670-1755; 1910-2155	282	SMR
2300 & 3500 MHz	2300 MHz: Wireless Communication Services; 3500 MHz: Fixed Wireless Access	2009	2305-2360; 3475-3650 (Residual)	10	Sealed-Bid
AWS-3	Advanced Wireless Services	2015	1755-1780; 2155-2180	39	Sealed-Bid

[1] As in Figure 1, small discontinuities in frequency ranges are ignored.
Source: DotEcon and Government of Canada

To this dataset, we added median income data from CANSIM, Statistics Canada's key socioeconomic database, via the University of Toronto's CHASS Data Centre. This dataset provides median household income for 10 provinces as well as 20 select census metropolitan areas in constant 2011 dollars.[12] We matched all the locations to the corresponding province, then searched through for the metropolitan areas provided in the dataset and matched up wherever

[12] Licenses that covered Yukon, Northwest Territories, and/or Nunavut were assigned income from "all other non-selected areas," as the median income data of these regions were not elsewhere recorded in the dataset.

possible.[13] We also add spectrum efficiency data by considering two potential measures of spectral efficiency: maximum link spectral efficiency and system spectral efficiency. As telecommunication technologies improve over time, the effective usage of spectrum increases. Given that the change in spectral efficiency should affect spectrum values, it is necessary to control for the evolution of this variable. Maximum link spectral efficiency is given by dividing net bitrate by bandwidth, where bitrate is the speed of data transmission. System spectral efficiency is given by maximum link spectral efficiency divided by the number of cellular towers, or other required buildings or technology. We choose to use system spectral efficiency, since it takes into account the fact that different types of technology require different levels of infrastructure. Finally, we add a dummy variable to capture all auctions conducted in 2009 or later, accounting for the introduction of MIMO technology, and interact that dummy with high-frequency spectrum.

We convert both the amount paid by the winning bidder and the median income data to USD by using the spot exchange rate (according to the Bank of England) on the date of the auction. To put the amount paid by the winning bidder in constant 2016 USD, we multiplied that amount by the ratio of the CPI of the month of auction to the CPI as of November 1, 2016 (according to the Bureau of Labor Statistics).[14] For median income, which was already in constant 2011 dollars, we used the ratio of the CPI of January 2011 to the CPI of November 2016 to convert that data into constant 2016 figures.

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[13] Some licenses cover both Nova Scotia and Prince Edward Island. To these licenses, we assigned the median income from Nova Scotia because the population of Nova Scotia is approximately seven times that of Prince Edward Island, as of the 2011 Census

[14] We convert into real USD for better comparability with other analyses in Dr. Connolly's Spectrum Lab, which primarily focuses on United States auctions.

V. Results & Comparison

Our results are shown in Figure 3.

Figure 3: Regression Results

	Dependent variable:			
	Natural Log of Winning Bid			
	OLS	*Tobit*	*Tobit*	*Tobit*
	(1)	(2)	(3)	(4)
Set-Aside	-1.096***	-1.096***	-1.074***	-0.928***
	(0.114)	(0.114)	(0.116)	(0.130)
ln(Median Income of Population Covered)	2.381***	2.381***	2.053***	2.661***
	(0.230)	(0.229)	(0.228)	(0.254)
ln(Population Covered)	1.337***	1.337***	1.373***	1.431***
	(0.024)	(0.024)	(0.024)	(0.027)
ln(Amount of Spectrum Granted by License)	0.877***	0.877***	0.852***	0.332***
	(0.089)	(0.088)	(0.090)	(0.096)
ln(Duration of License)	3.718***	3.718***		
	(0.537)	(0.534)		
ln(Efficiency Per Site)	0.957***	0.957***	1.098***	0.470***
	(0.066)	(0.066)	(0.064)	(0.060)
ln(Amount of Spectrum Offered in Auction)	-1.331***	-1.331***	-1.179***	-1.149***
	(0.067)	(0.067)	(0.064)	(0.073)
ln(Number of Bidders in the Auction)	-0.115	-0.115	-0.263	2.233***
	(0.216)	(0.215)	(0.218)	(0.190)
After 2009 x Frequency Above 2GHz	-7.310***	-7.310***	-5.621***	
	(0.393)	(0.391)	(0.312)	
Frequency Above 2GHz	2.177***	2.177***	2.122***	0.183
	(0.231)	(0.230)	(0.235)	(0.235)
Constant	-31.107***	-31.107***	-20.151***	-32.383***
	(2.898)	(2.885)	(2.466)	(2.668)
Observations	1,212	1,212	1,212	1,212
R^2	0.933			
Adjusted R^2	0.932			
Log Likelihood		-1,574.84	-1,598.59	-1,742.07
Residual Std. Error	0.891 (df = 1201)			
F Statistic	1,665.159*** (df = 10; 1201)			
Wald Test		16,804.100*** (df = 10)	16,111.690*** (df = 9)	12,459.460*** (df = 8)
Note:	*p<0.1; **p<0.05; ***p<0.01			

In Regressions 1 and 2 we find, as predicted, that conventional drivers of demand (income, population covered, amount of spectrum granted by the license, duration of the license) all drive up the price of the license. Notably, the results suggest that the number of bidders has no statistically significant impact on the value of the final winning bid. The total amount of spectrum offered in the auction lowers the price of spectrum, which matches our intuition that this represents a new, increased supply of spectrum. We also find that setting aside licenses results in an expected decrease in the value of the winning bid of those licenses, lending empirical support to the claim that set-asides constitute a subsidy for new entrants. Importantly, we find that the coefficients of each variable and their respective statistical significances are almost the same in the OLS model and the Tobit model, confirming our expectations.

It is also important to note that the interaction term that accounts for the MIMO technological innovation in 2009 was effectively equal to a dummy variable for a sealed-bid auction framework. That is, the only auctions in our dataset that did not employ an SMR framework – the 2300 & 3500 MHz (2009) Auction and the AWS-3 (2015) Auction – occurred on or after 2009, and both auctioned off high frequency spectrum. Therefore, this variable also captures the effect of using a sealed-bid framework rather than an SMR framework. We believe this might be the reason why the effect is negative rather than positive, as we predicted. We hope future research will be able to isolate the impacts of different auction frameworks.

In Regression 3, we drop license duration because ~98% of the observations in the dataset had a duration of 10 years. We therefore worried that it would not capture the effects of license duration but instead communicate other information about the ~2% of licenses with different durations. Again, we find that conventional demand drivers increase the price of spectrum while the set-aside provision lowers the price.

Regression 4 drops the interaction term that accounts for the MIMO technological innovation in 2009 that applies to high frequency spectrum. We still find the same results as in the other regressions.

VI. Conclusion

Canada auctions off spectrum, but not necessarily to the highest bidder. Canada has employed exclusionary set-aside provisions to create auction markets for small firms at the expense of large firms, arguing that this policy will increase competition and therefore improve telecommunications services for Canadians.

The results of this paper suggest empirically that the taxpayers of Canada are paying to support new entrants in the telecommunications space. In our view, Canada ought to justify this taxation by showing that (1) the set-aside provision does indeed increase competition in the telecommunications industry and (2) that this increased competition is actually net beneficial for the Canadian people. The existence of more firms in a market does not necessarily mean more quality at a lower price. Investigating this justification further is outside the scope of this paper.

VII. Appendix

I. Collusion in the United States' FCC Spectrum Auctions

Open and simultaneous auctions could facilitate potential collusion between bidders (Cramton, 2000). Since bidders can observe one another's bids, they have full information to coordinate a collusive agreement. For instance, until recently, bidders could engage in "code bidding" in the United States – attaching market numbers in the trailing digits of their bids to inform another bidder to withdraw. Alternatively, a bidder could bump a rival from a license and immediately withdraw its bid to show the rival that it is not interested in that license. This behavior acts as a warning to the rival that it could raise the price on that market as a punishment for rival bidding in another market.

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