DUFF & PHELPS

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Broadband Spectrum Pricing

TFI Communications Technology Conference, January 25-26, 2018, Austin, Texas

Ruben Miranda, ASA

Ongoing Series on Spectrum Pricing

- Part 1: Analysis of Auction 73 (700 MHz)

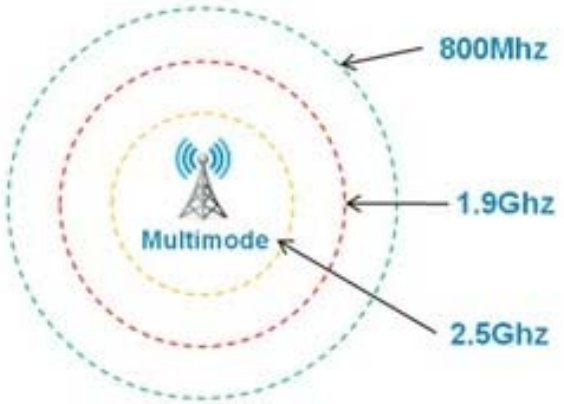
  Presented January 2014 in Austin, TX
- Part 2: Analysis of Auction 96 (1915-1920 MHz & 1995-2000 MHz, aka “H-block”)

  Presented July 2014 in Wichita, KS
- Part 3 (this one): Analysis of
  - Auction 97 (1700 MHz & 2100 MHz, aka “AWS-3”) on Jan 2015
    - » Mid-band spectrum
    - » Top bidder: AT&T
  - Auction 1002 (600 MHz, aka “Incentive”) on April 2017
    - » Low-band spectrum
    - » Top bidder: T-Mobile

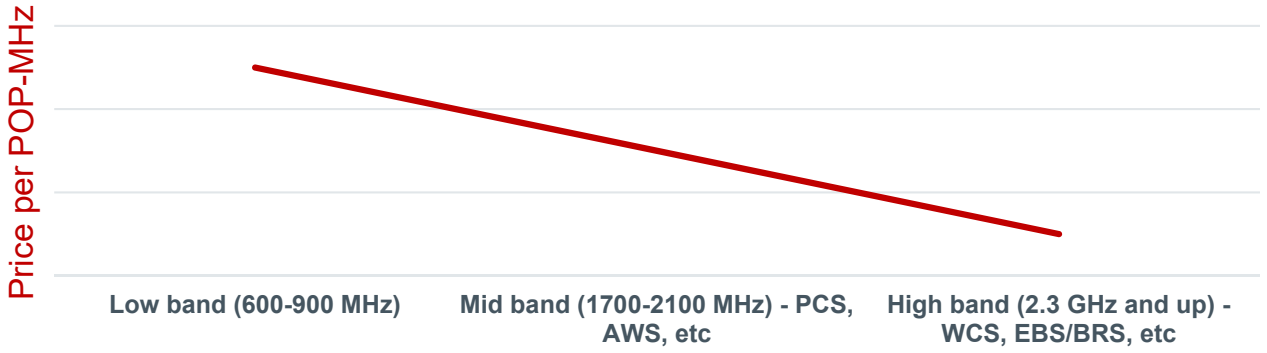
  Presented January 2018 in Austin, TX

Key Takeaways from Previous Sessions
Spectrum for Wireless Communications

- Historically, carriers relied on low-band spectrum to maximize coverage.
  - Propagation (travels farther)
  - Penetration (in-building coverage)
  - Exclusivity (no interference)

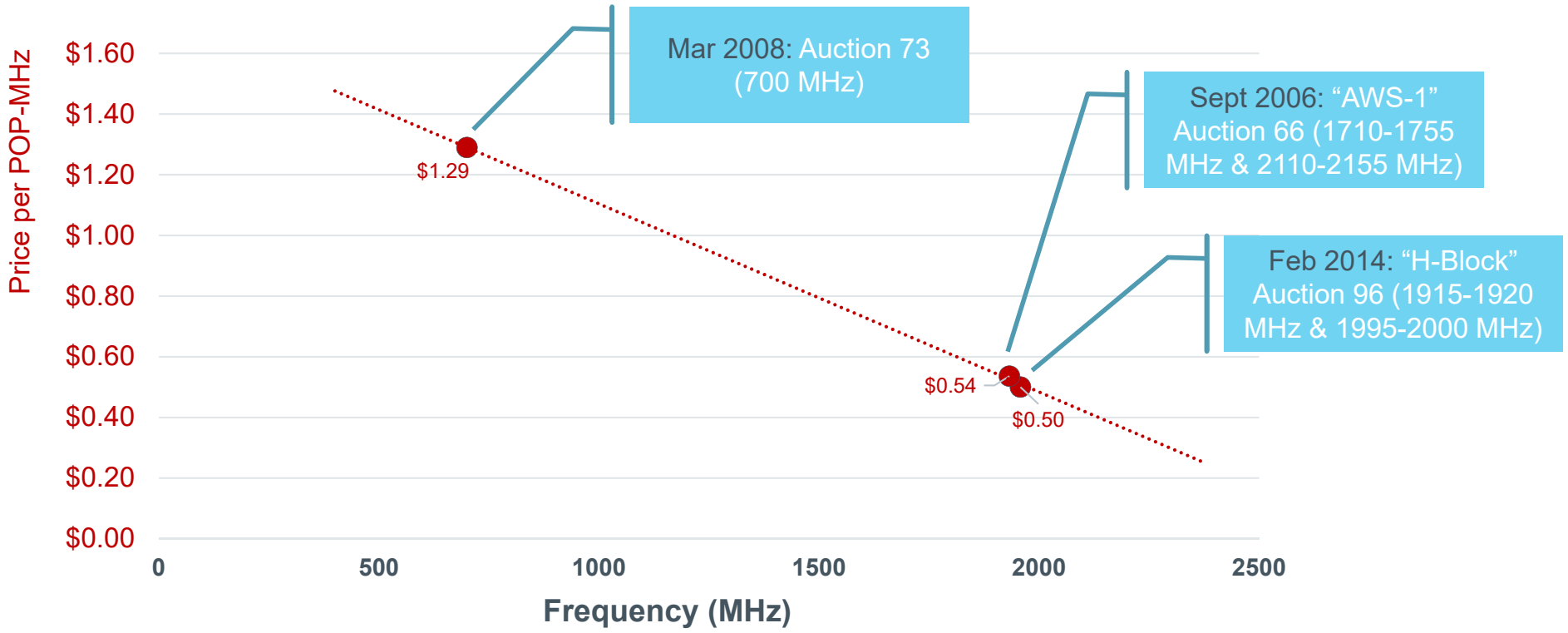


- Because of this emphasis on coverage, it would follow that, *all things being equal*, spectrum's intrinsic value was historically worth more at low frequencies, and less at high frequencies.



Key Takeaways from Previous Sessions (continued)

- This anecdotal relationship between bandwidth and intrinsic value was supported by the previous auctions reviewed:



Key Questions Not Addressed

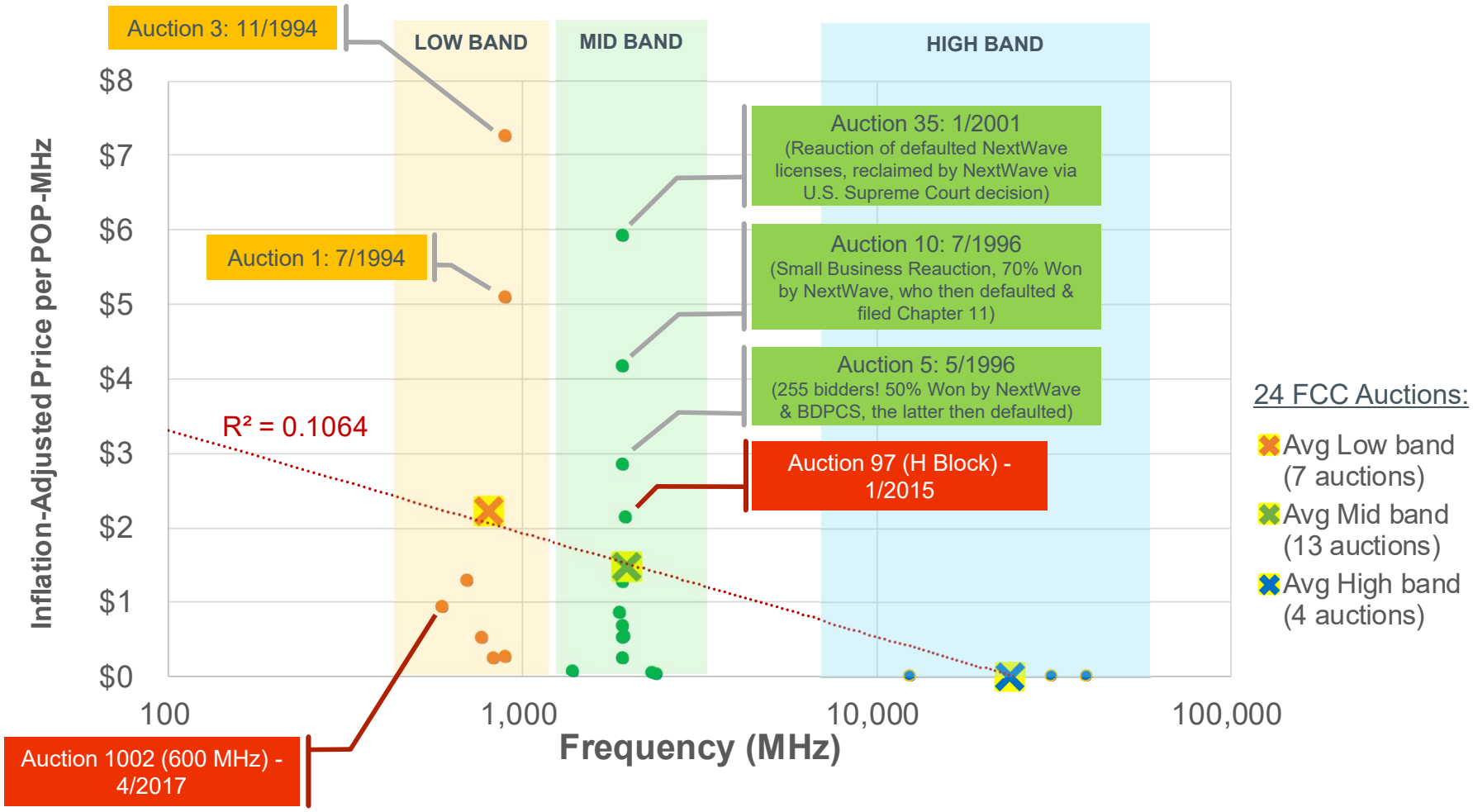
- What about older auctions? Over 80 prior to 2014
- And the newer auctions, Auction 97 (Jan 2015) and Auction 1002 (Apr 2017)?
- Aggregated results from auction data with focus on large auctions > $100 MM

Auction #	Name	Date	Frequency	Qualified Bidders	W/A Bandwidth	$ / POP-MHz	Inflation Adjusted Price per POP-MHz
1	Nationwide Narrowband (PCS)	7/29/1994	900	29	0.08	$3.010	$5.073
3	Regional Narrowband (PCS)	11/8/1994	900	28	0.08	$4.301	$7.250
4	Broadband PCS A and B Block	3/13/1995	1,898	30	30.00	$0.518	$0.850
5	Broadband PCS C Block	5/6/1996	1,943	255	30.00	$1.772	$2.838
6	Multipoint/Multichannel Distribution Services	3/28/1996	2,415	155	78.00	$0.012	$0.019
7	900 MHz Specialized Mobile Radio Service	4/15/1996	900	128	0.25	$0.168	$0.269
8	Direct Broadcast Satellite 110 Degrees (DBS)	1/25/1996	12,450	3	672.00	$0.004	$0.006
10	Broadband PCS C Block Reauction	7/16/1996	1,943	32	30.00	$2.590	$4.148
11	Broadband PCS D, E, & F Block	1/14/1997	1,928	153	10.00	$0.332	$0.515
15	Digital Audio Radio Service (DARS)	4/2/1997	2,333	4	12.50	$0.025	$0.039
17	Local Multipoint Distribution System (LMDS)	3/25/1998	31,150	139	650.00	$0.002	$0.003
22	C, D, E, and F Block Broadband PCS	4/15/1999	1,943	67	23.56	$0.161	$0.242
30	39GHz	5/8/2000	39,300	35	100.00	$0.001	$0.002
33	Upper 700 MHz Guard Bands	9/21/2000	770	15	3.00	$0.353	$0.516
34	800 MHz SMR General Category Service	9/1/2000	830	26	1.25	$0.171	$0.249
35	C and F Block Broadband PCS	1/26/2001	1,938	87	10.13	$4.184	$5.912
53	Multichannel Video Distribution & Data Service	1/27/2004	12,450	14	500.00	$0.002	$0.003
58	Broadband PCS	2/15/2005	1,943	35	10.10	$0.980	$1.265
66	Advanced Wireless Services (AWS-1)	9/18/2006	1,933	168	14.98	$0.536	$0.669
69	1.4 GHz Bands	3/8/2007	1,400	9	2.67	$0.054	$0.066
73	700 MHz Band	3/18/2008	700	214	14.00	$1.098	$1.284
96	H Block	2/27/2014	1,958	23	10.00	$0.500	$0.527
97	Advanced Wireless Services (AWS-3)	1/29/2015	1,968	70	10.83	$2.035	$2.128
1002	Incentive Auction (600 MHz)	4/13/2017	600	62	10.00	$0.909	$0.925

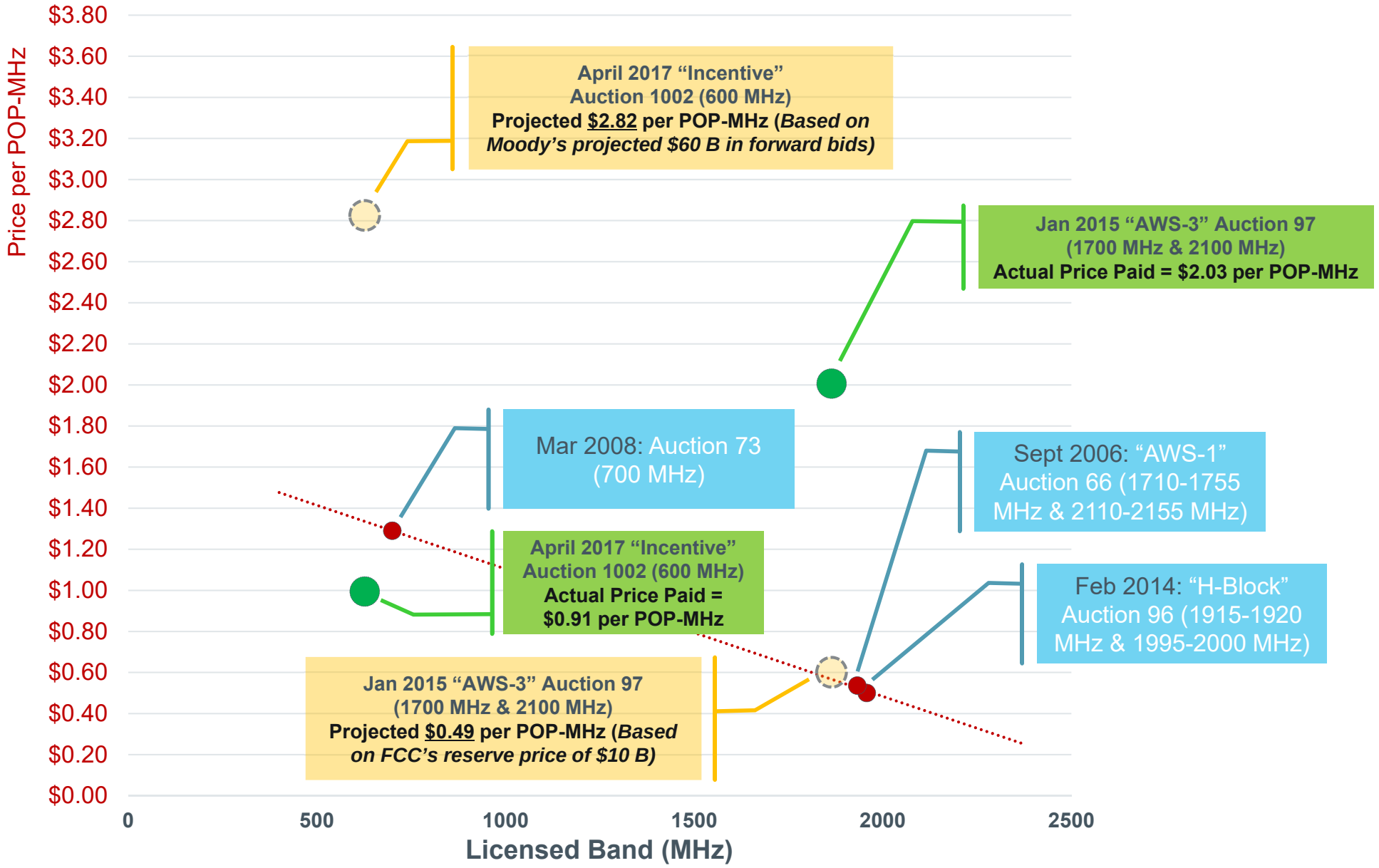
Analysis of FCC Spectrum Auctions, 1994-2017

Net Winning Bids Greater than $100 MM

(24 Auctions)



Projected Prices for Auction 97 & 1002 vs. Actual



What's Happening Here?

- Each auction appears to stand alone.
  - Different incumbents and participants (pioneers, dumb money).
  - Different rules (small business only, convoluted incentive auction process).
  - Customer attitude and adoption of wireless.
  - Evolving effectiveness and usage of bands shifting towards capacity.
- Auctions 97 and 1002 may be a wake-up call for the industry.
  - Mid-band value being realized for its coverage characteristics and good reuse for capacity.
  - Low-band helps for coverage but as cells densify for capacity's sake, propagation containment is problematic.
  - In hindsight, a lot of people missed the memo before the 600 MHz auction.
    - » Moody's $60 B projection
    - » FCC Chairman Tom Wheeler promised a "spectrum extravaganza"

Auctions 66/73/96 vs Auctions 97/1002

- Two different worlds of low-band and mid-band value.
- BUT...how can we be certain frequency is driving these pricing adjustments?
- There are other historic drivers of $ per POP-MHz at local level:
  - Strong demographics (age, income, density, etc.)
  - Band characteristics for simplified and headache-free deployment
- Ran a regression on recent winning bids for individual licenses:
  - "Before" → Auctions 66 and 73 [1] → 2,165 licenses
  - "After" → Auctions 97 and 1002 → 4,292 licenses
- Variables:
  - Income, Age, and Density
    - » Obtained from Census data
    - » Market Percentiles (Between 0 – 100%)
  - Paired? Low-band or Mid-band? Bandwidth?

[1] – Auction 69 excluded due to low number of qualified bidders (9); Auction 96 excluded due to DISH's negotiated reserve bid negating all local auction bids.

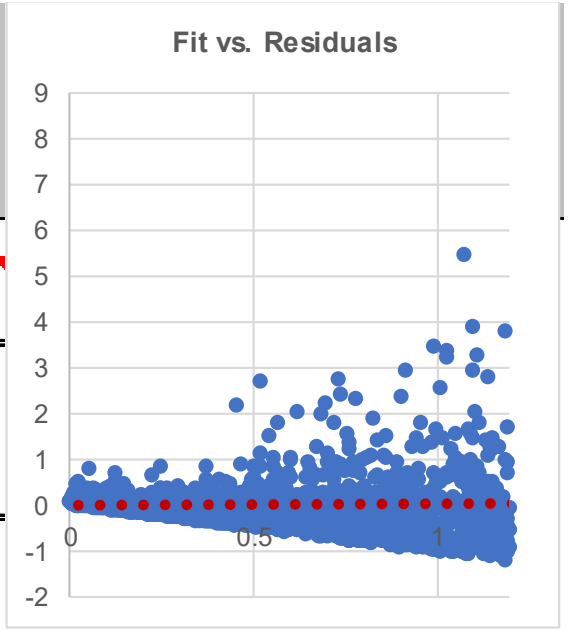
Regression Results – “Before”

StatTools Report

Analysis: Stepwise Regression of FCC Spectrum Auctions 66 and 73
Performed By: Miranda, Ruben
Date: Friday, January 19, 2018
Updating: Static
Variable: $ per POP-MHz

Stepwise Regression for $ per POP-MHz Summary	Multiple R	R-Square	Adjusted R-square	Std. Err. of Estimate	Rows Ignored
	0.6811	0.4638	0.4626	0.724673317	0

ANOVA Table	Degrees of Freedom	Sum of Squares	Mean of Squares	F	p-Value
Explained	5	981.3395894	196.2679179	373.7358628	< 0.0001
Unexplained	2160	1134.327061	0.525151417		



Regression Table	Coefficient	Standard Error	t-Value	p-Value	Confidence Interval 95% Lower	Confidence Interval 95% Upper	Multicollinearity Checking VIF	Multicollinearity Checking R-Square
Constant	0	NA	NA	NA	NA	NA		
MedianIncomePercentile	0.55326803	0.059055987	9.368534122	< 0.0001	0.4374555	0.669080536	5.716598722	0.825070807
isMidBand	-0.7591466	0.03261684	-23.27468399	< 0.0001	-0.8231103	-0.695182972	2.191929026	0.543780849
paired	0.48502238	0.047268071	10.26109944	< 0.0001	0.3923267	0.577718038	8.475016555	0.88200613
DensityFactorPercentile	0.44732563	0.055226078	8.099898705	< 0.0001	0.3390238	0.555627444	5.43457733	0.81599305
MedianAgePercentile	-0.3547104	0.060607236	-5.852608353	< 0.0001	-0.473565	-0.235855816	3.080526446	0.675380161

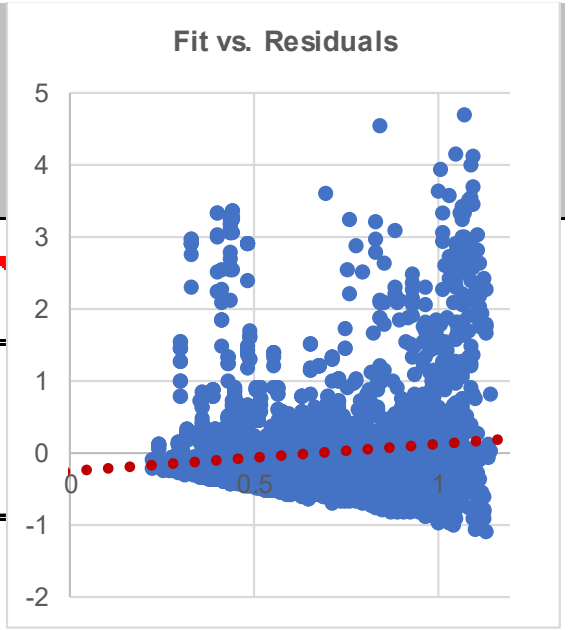
Regression Results – “After”

StatTools Report

Analysis: Stepwise Regression of FCC Spectrum Auctions 97 and 1002
Performed By: Miranda, Ruben
Date: Friday, January 19, 2018
Updating: Static
Variable: $ per POP-MHz

Stepwise Regression for $ per POP-MHz Summary	Multiple R	R-Square	Adjusted R-square	Std. Err. of Estimate	Rows Ignored
	0.7016	0.4923	0.4918	0.686411066	0

ANOVA Table	Degrees of Freedom	Sum of Squares	Mean of Squares	F	p-Value
Explained	4	1958.877059	489.7192647	1039.390243	< 0.0001
Unexplained	4288	2020.334731	0.471160152		



Regression Table	Coefficient	Standard Error	t-Value	p-Value	Confidence Interval 95% Lower	Confidence Interval 95% Upper	Multicollinearity Checking VIF	Multicollinearity Checking R-Square
Constant	0	NA	NA	NA	NA	NA		
isMidBand	0.380097129	0.021486599	17.68996282	< 0.0001	0.3379723	0.422221978	1.53349063	0.347892983
paired	0.476959907	0.027414187	17.39828757	< 0.0001	0.4232139	0.530705897	6.30853728	0.841484649
MedianIncomePercentile	0.314612753	0.038362229	8.20110713	< 0.0001	0.2394029	0.38982257	5.13764674	0.805358358
MedianAgePercentile	-0.313727743	0.042633155	-7.358773801	< 0.0001	-0.3973108	-0.230144702	3.183454942	0.685875874

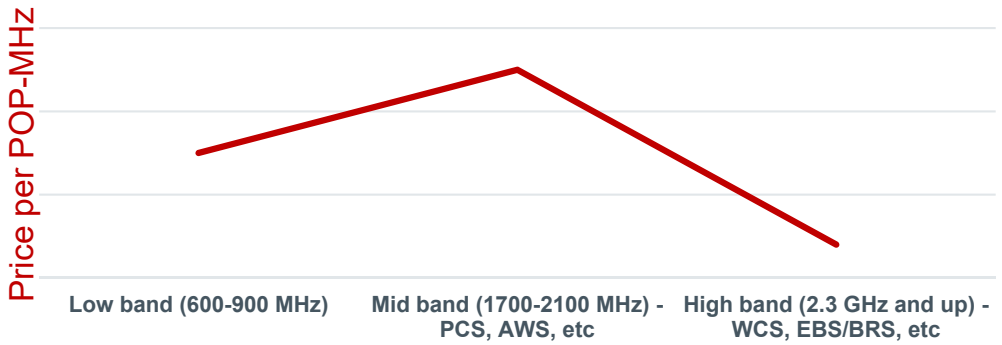
Regression Summary
"Before" and "After" Equations

- Five (5) statistically significant variables identified by stepwise regression:
  1. MedianIncomePercentile (min $11.3k, max $125.6k)
  2. MedianAgePercentile (min 21.5 yrs, max 66 yrs)
  3. paired (no = 0, yes = 1)
  4. isMidBand (Less than 1000 MHz = 0, 1000 to 2100 MHz = 1)
  5. DensityFactorPercentile (min Yukon AK, max NYC)

"Before" Price per POP-MHz =	"After" Price per POP-MHz =
$0.55 × MedianIncomePercentile	$0.31 × MedianIncomePercentile
– $0.35 × MedianAgePercentile	– $0.31 × MedianAgePercentile
+ $0.49 × paired	+ $0.48 × paired
– $0.76 × isMidBand	+ $0.38 × isMidBand
+ $0.45 × DensityFactorPercentile	

Conclusions

- Carriers' uses of low- and mid-band spectrum have evolved.
  - After Auction 97, mid-band now seen as premium vs. low-band
  - Evidence: small cell networks, DAS systems rarely include low-band spectrum.
- Does this mean existing low-band holdings should be repriced? Has the curve "inverted" permanently?



  - Unlikely, as spectrum holdings are valued as a single portfolio.
  - Jefferson-Pilot network construction would maximize coverage before capacity.
  - Recent private transactions still support overall linear value decline. [1]
- Next steps
  - Analysis of high-band and mmWave prices per POP-MHz

[1] – Goldman Sachs. "Spectrum auction applicant list reveals few surprises…we think." Americas Telecom Services Equity Research: March 21, 2016, page 4.