Pricing and Bundling Licensed and Unlicensed Spectrum

Xu Wang, Randall Berry
Unlicensed Spectrum

- Lower Barriers to entry
- More competition
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- More competition
- But also potential for over-congestion
Motivation
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Previously studied how unlicensed spectrum may impact competition among wireless service providers (e.g. Nguyen 2016).

Adapted model for price competition with congestible resources (e.g. Acemoglu et al 2007).

In prior work, licensed & unlicensed service priced separately.

Here, considering bundling these two services.
Bundling
Wireless Bundling Example 1
Wireless Bundling Example 1

AT&T

Select a Plan

Talk, Text & Data Plans

Choose a data amount to use with your new device

DataConnect

Select Your Plan

DataConnect

- Access to AT&T nationwide 4G LTE network. All data plans include unlimited usage on the entire national AT&T Wi-Fi Hotspot network.
- Overages: $10/100MB on 250MB plan and $10/GB for the 1GB, 3GB and 5GB plans.
Wireless Bundling Example 2
Wireless Bundling Example 2
Wireless Bundling Example 2

T-Mobile launches speedy LTE-U service in six cities

It's also squaring off against other in tests for even faster 5G networks...

T-Mobile store in a city.
Bundling Literature
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Basic Setting

- Incumbent SP
- Entrant SP
- Pool of customers
- Licensed band
- Unlicensed band
Competition Model
Competition Model

Providers

SPs set prices $p_i$ to maximize profit.

$$\pi_i = p_i x_i$$

$p_i = \text{price for service}$

$x_i = \text{customers served.}$
Competition Model

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**Customers**

Choose SP $i$ with minimum delivered price

$$p_i + G_i$$

$G_i = \text{congestion of SP } i.$
Idealized Congestion Costs  
(no bundling)

Licensed band

\[ G_1 = g \left( \frac{x}{B} \right) \]

Unlicensed band:

\[ G_u = g \left( \frac{w_1 + w_2}{W} \right) \]
Customers

Mass of non-atomic customers.

Inverse demand $P(x)$ specifies delivered price at which $x$ customers willing to be served.
Market Equilibria

Two-stage model: Provider’s first announce prices, customers then select provider with provider with lowest delivered price.

Given prices, customers must be in a Wardrop Equilibrium.

• Delivered price for all used bands must be the same and less than that on all unused bands.

Service providers’ prices must in a Nash equilibria.
Example

\[ P(x) \]

\[ g_1(x_1) \]

\[ g_2(x_2) \]

\[ p_1 \]

\[ p_2 \]
Welfare Measures
Consumer surplus: difference between the delivered price and consumer’s willingness-to-pay (integrated over users).
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**Consumer surplus:** difference between the delivered price and consumer’s willingness-to-pay (integrated over users).

**Total welfare:** sum of total consumer surplus and total SP profits.
Prior Results:
price competition without bundling
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Adding more spectrum as unlicensed will always improve consumer welfare compared to licensed.
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Equilibrium prices in unlicensed bands are always competed to zero.

Adding more spectrum as unlicensed will always improve consumer welfare compared to licensed.

But adding spectrum as unlicensed may lead to a loss in social welfare compared to licensed.
Bundling Model
Bundling Model

Incumbent SP \( p_1 \)

Entrant SP \( p_2 \)
Bundling Model
Bundling Model

Average percentage of time that customers are using the unlicensed spectrum.
Bundling Model

Average percentage of time that customers are using the unlicensed spectrum.
Bundling Model

Average percentage of time that customers are using the unlicensed spectrum.
Bundling Model

Incumbent SP

Entrant SP

Average percentage of time that customers are using the unlicensed spectrum.
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Congestion for choosing the bundle:

\[ (1 - \alpha) g \left( \frac{(1 - \alpha)x}{B} \right) + \alpha g \left( \frac{\alpha x + w}{W} \right) \]

Congestion on licensed band

Congestion on unlicensed band
Monopoly Case (no entrant)
Monopoly Case (no entrant)
Monopoly Case (no entrant)

No advantage to bundle!
One Incumbent/One Entrant
One Incumbent/One Entrant
One Incumbent/One Entrant

Moreover, when $\alpha$ is small the entrant can also make a positive profit.

But customer welfare is lower.
One Incumbent/One Entrant

Welfare comparison

![Graphs showing social welfare comparison for different sharing scenarios with parameters $B = 1, W = 1$ and $B = 1, W = 10$. The graphs illustrate the impact of sharing on social welfare at varying levels of $\alpha$.](image-url)
One Incumbent/One Entrant
Welfare comparison

$B = 1, W = 1$

$B = 1, W = 10$
One Incumbent/One Entrant

- Welfare comparison with licensed sharing (Linear case)
One Incumbent/One Entrant

- Welfare comparison with licensed sharing (Linear case)

**Theorem 5:**
For any value of $B$ and $W$, there exists some $\alpha > 0$ such that both of the customer surplus and social welfare of bundling is better than that of licensed sharing.
Revenue Optimal $\alpha$

Optimal $\alpha$ is decreasing in $B$.

For large $W$ and $B$, optimal $\alpha$ may be zero.

But for large $W$, welfare optimal $\alpha$ goes to one.
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