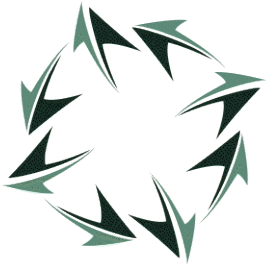

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Economics of IPv4 Markets on IPv6 Deployment

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Why Economics at the transition?

- The money underlies much of what we do
- When we push against the economics we are pushing up hill…which is hard

Brief History

- Since “the beginning of the Internet” allocations have been based on need
- Over time this process was formalized into RFCs and later into RIR policies
- The RIRs saw the need to for allowing transfers of IPv4 addresses after exhaustion
- Transfer policies were created to allow economics to effect transfers

Pros & Cons of an IPv4 Market

- Pros
  - Allows economic factors to bring IPv4 addresses to the right place in the market place
  - Increases the economic cost of IPv4 potentially forcing users to consider IPv6
- Cons
  - Potentially delays (or maybe deters) the adoption of IPv6
  - Deaggregation creates more routing table entries from larger blocks being “chopped up” to sell or lease

The IPv4 market to date

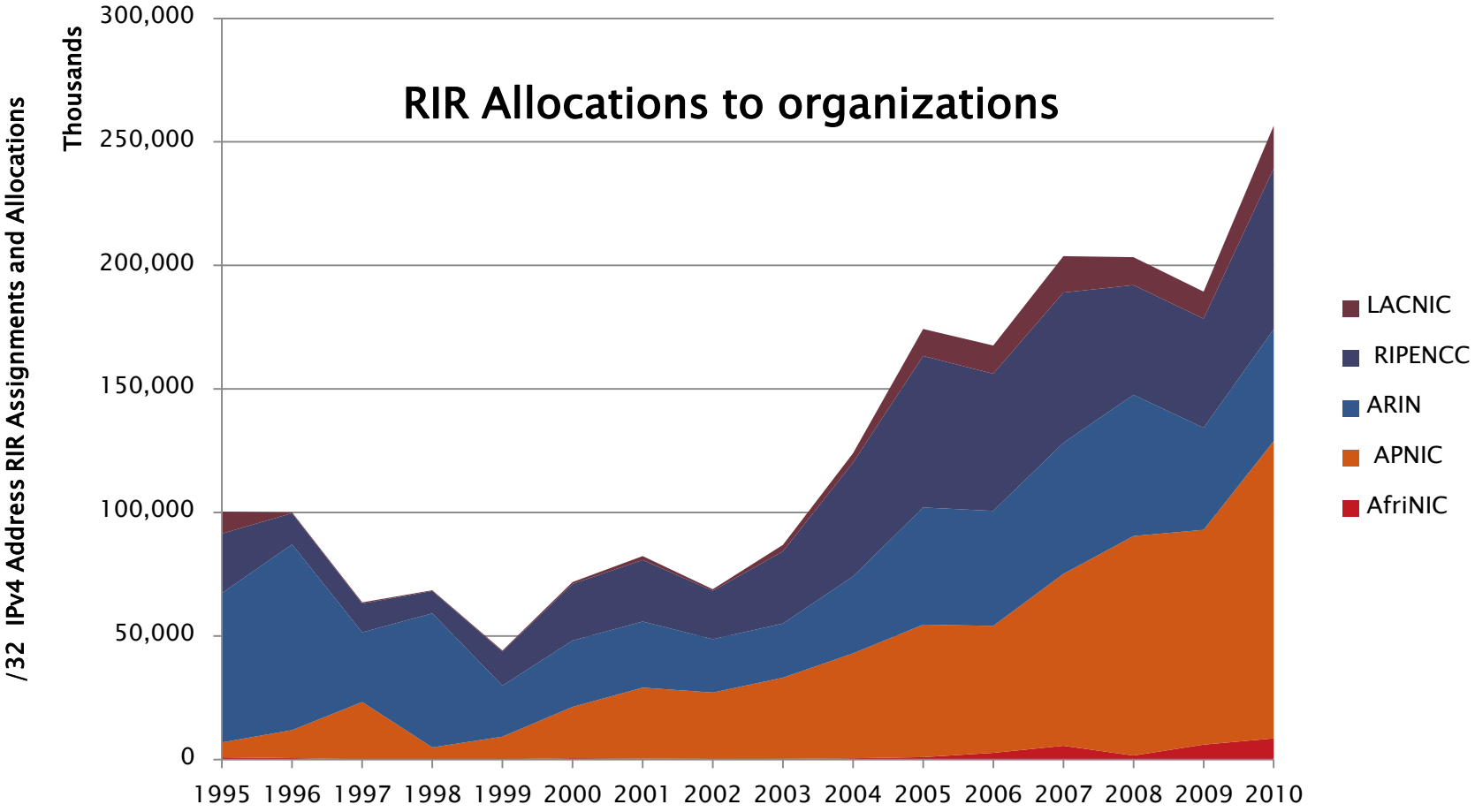
- Large known transaction from Nortel Bankruptcy to Microsoft in 2011
  - 667k IPv4 addresses for $7.5 million USD
    - $11.25 USD per IPv4 address
- Other small transactions have occurred
- Address brokers are forming
  - http://tradeipv4.com/
  - http://ipv4ex.com/
  - ARIN has a listing service

	Sale (USD)		Lease (USD / year)	
Region	Min Offer	Max Bid	Min Offer	Max Bid
▶Cross-Region	4.00	20.00	2.00	0.10
▶AFRINIC	n/a	n/a	n/a	n/a
▶ARIN	7.50	8.00	1.50	1.00
▶APNIC	n/a	5.00	5.00	n/a
▶LACNIC	n/a	n/a	n/a	n/a
▶RIPE	4.00	3.00	2.00	n/a

PRICE INDEX IS PER ADDRESS.

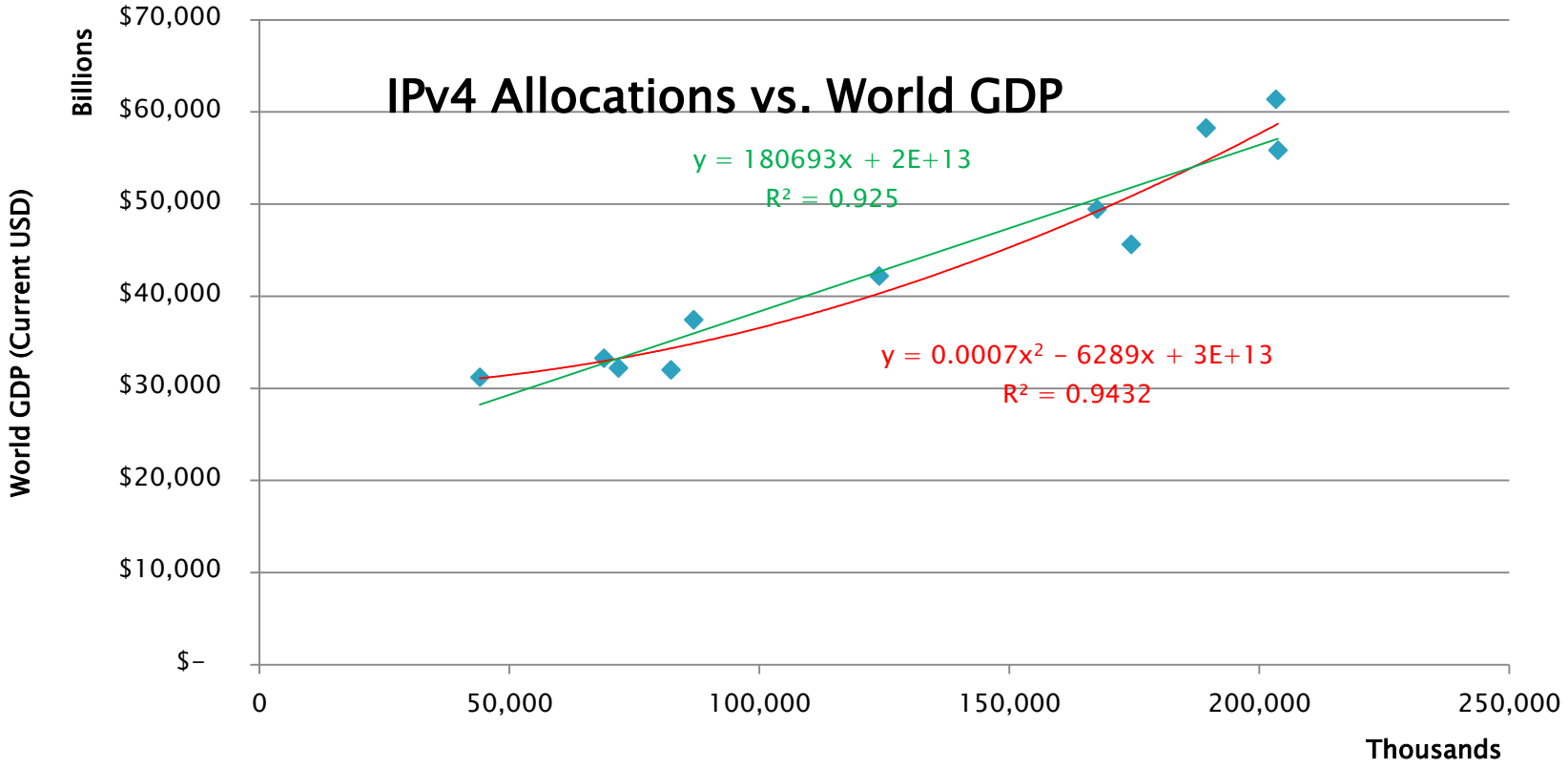
TRANSFERS ARE ON BLOCK LEVEL (MIN /24).

Demand continues to increase the supply is finite and now scarce



Current demand exceeds
250 million addresses per year

Demand appears to be tied to growth of economies

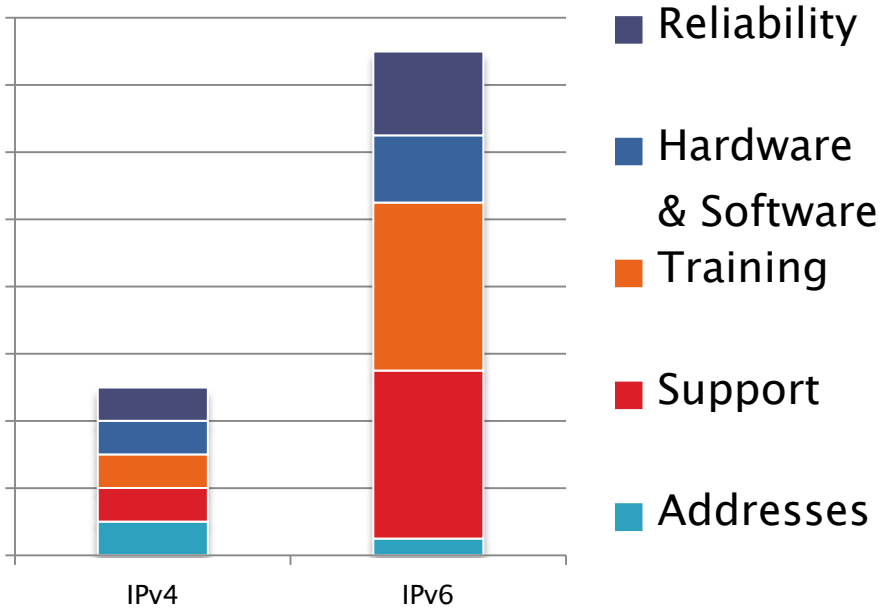


/32 IPv4 Address RIR Assignments and Allocations

Mobile devices and developing economies are a big driver of additional demand

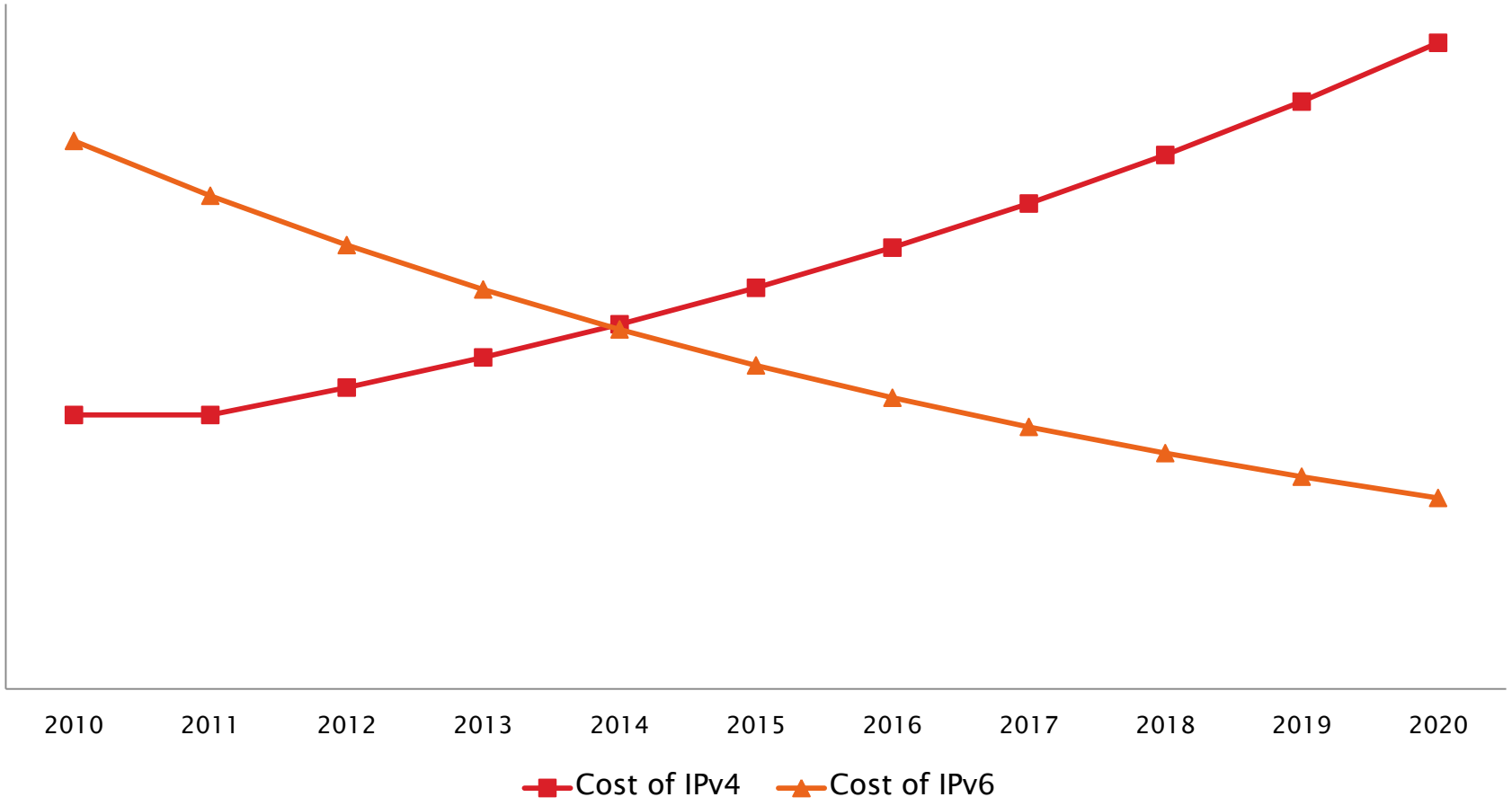
IPv6 deployment incentives (or lack thereof)

- Moving to IPv6 costs real money
  - Training
  - Hardware & Software
  - Reduced reliability
  - Not as well supported as IPv4



• For an exhaustible resource, a transition will not occur until the price of a current resource exceeds the cost of the replacement resource – Hotelling Rule

Hotelling Rule applied to cost of IP addresses



Fictional assumptions: IPv6 is initially 2 times the cost of IPv4, cost of IPv4 increases by 10% per year, cost of IPv6 decreases by 10% per year

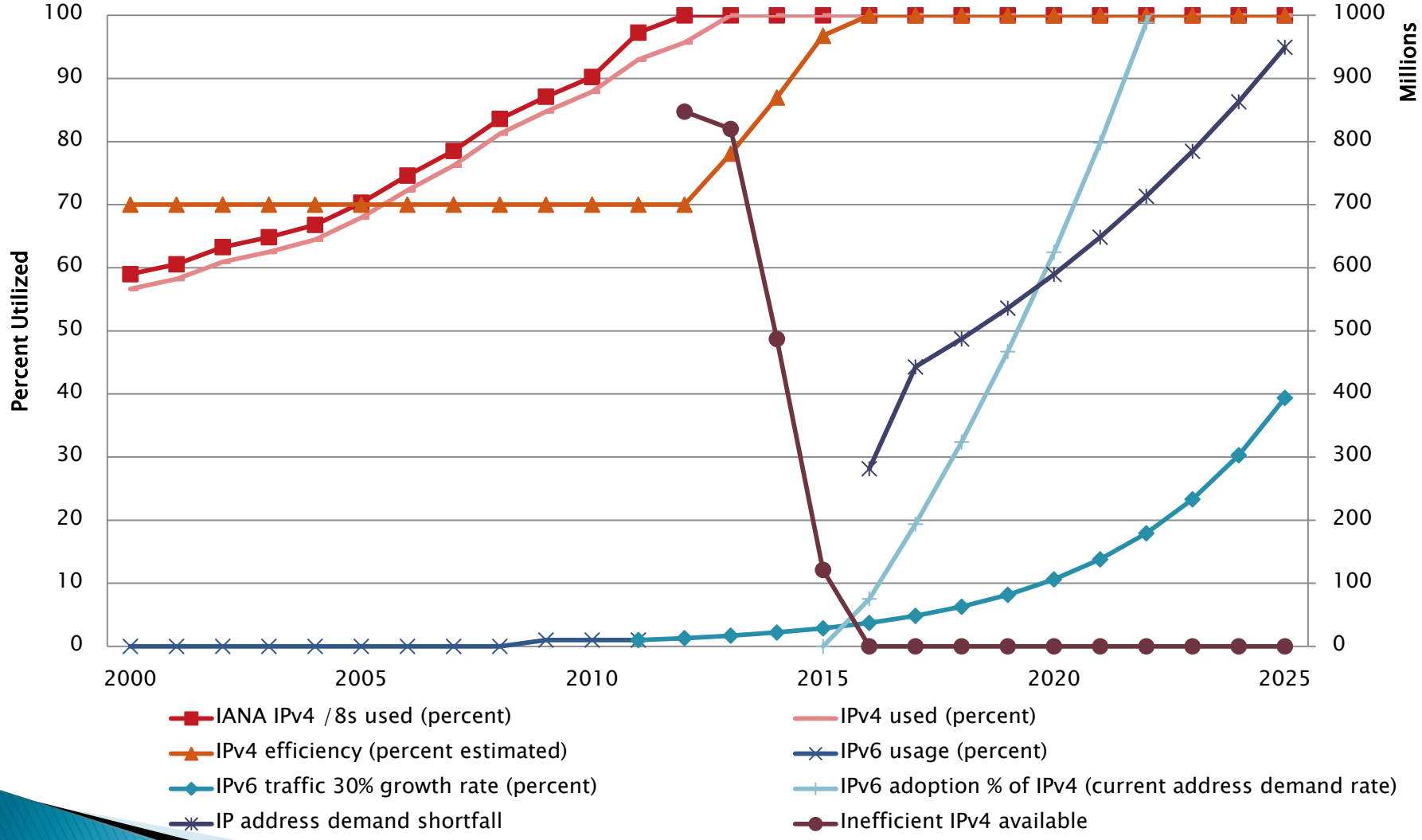
IPv4 Substitutes

- **IPv6 is not a perfect substitute for IPv4**
  - IPv6 costs more and fewer people are “on the network”
  - “Network effect” – Economic concept describing the homogeneity of an adopted protocol
- NAT
  - Provides a pretty good substitute for more IPv4 addresses at a small scale
    - Workarounds (STUN, ICE, UPnP, NAT-PMP) have been developed assuming “household” sharing of an IPv4 address
  - Scalability to carrier grade will likely be a challenge

IPv4 Market Dynamics

- IPv4 market is not perfect competition
  - There are significant switching and transfer costs
- Available supply is limited
- Demand continues to grow

Increasing efficiency of IPv4?



Assumptions: 10% growth rate in IP address demand, initial 70% efficiency rate of IPv4, RIRs IPv4 pools depleted in 2012

Game Theory in Industry

- Game theory can help us understand industry choices and the consequences of decisions
- Here we consider a coordination game
  - Payoffs (profits) are higher when the competitors adopt the same protocol

Payoffs: Profits	Competitor B		
Competitor A	*Strategy*	Adopt Protocol A	Adopt Protocol B
	Adopt A	$7, $10	$1, $3
	Adopt B	$4, $1	$8, $12 *

* Adopting Protocol Standard B is a Nash Equilibrium

IPv6 transition, a coordination game?

- IPv6 transition technology confusion
  - Too many options (CGN, Dual-stack lite, 6rd, etc)
  - Each option has different pros/cons
  - Deciding which transition technology to adopt is a “huge” decision: significant capital & operational expense
  - No clear path forward
- The lack of an adopted protocol standard may be creating a situation where competitors are delaying deployment due to the lack of a “front-runner” standard and risk associated with picking the “wrong” protocol
- Does the first adopter have an advantage or a disadvantage?
- How does the concept of “economic commitment” help or hurt the industries ability to move forward

Hypotheses #1

- Large scale adoption of IPv6 will not occur until IPv4 exhaustion is complete
  - Application of Hotelling Rule
  - Until the economic cost of IPv4 exceeds the cost of IPv6 most firms will not adopt IPv6

Hypothesis #2

- Transfer prices in various regions will be different due to the different rules, different supply, and different demand
  - Regions with fewer restrictions, lower supply, and highest demand will have the highest prices per IPv4 address
  - Inter-regional transfers could change this

Hypothesis #3

- Rational price of an IPv4 address will be driven by the revenue which can be generated from the resource
  - Some models show prices for “premier” use of IPv4 from $150-$1100 USD per IPv4 address

Conclusions

- Economics underpin the transition whether we like it or not
- Until the cost of IPv4 exceeds the cost of IPv6 mainstream adoption will not occur
- Understanding of how technology, policies, and other factors impact the economics will help us understand how the transition can occur
- What can we do as engineers and operators to change the economics landscape to encourage IPv6 adoption?

Thank you

Q&A

Full paper available here:
http://www.quark.net/docs/Economics_of_IPv4_on_IPv6.pdf