

The Endogenous Modularity of the Internet

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Division of Innovative Labor in Internet Protocol Development

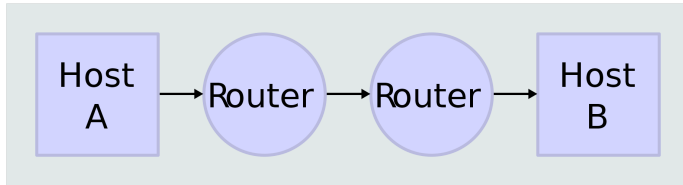
- Q1: Within vs. between firm specialization
 - Pin factories vs. wool coats
 - Hold-up & complements
- Q2: Platform dynamics
 - Technical inter-dependency: increasing or decreasing?
 - Protocol upgrades: modular or “architectural”?
 - Internet ossification?: IPv6 & DiffServ

Data

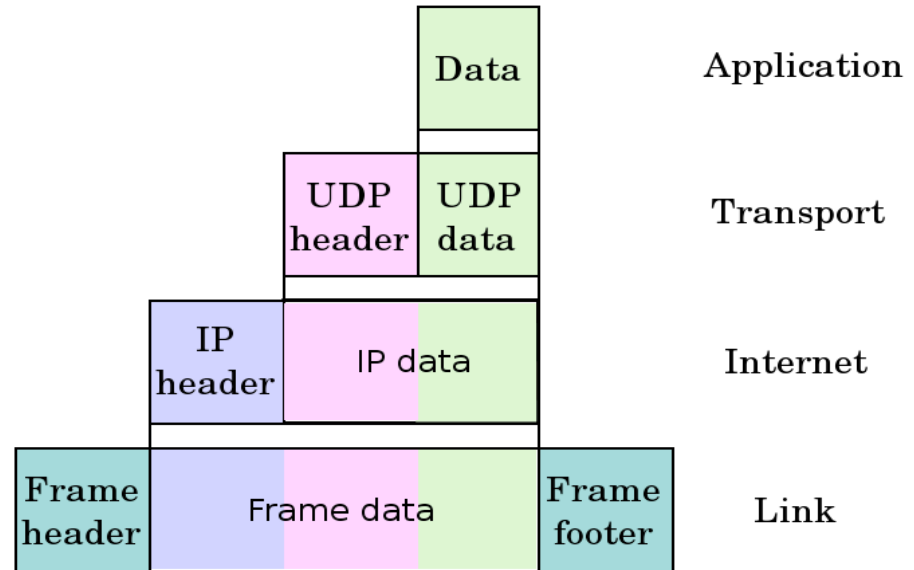
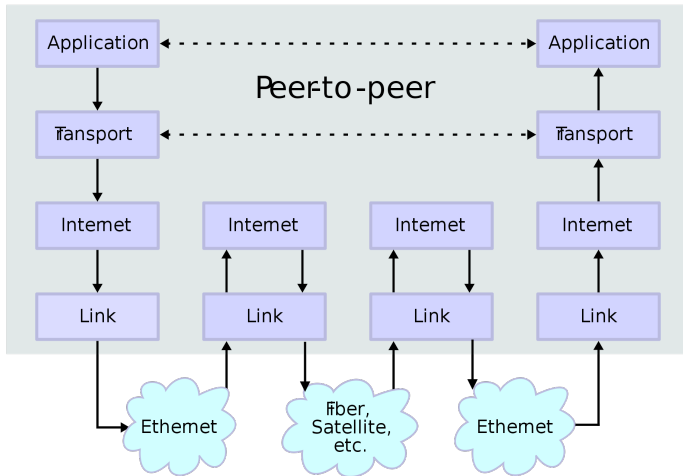
- Sample
 - IETF standards (1991-2012)
 - W3C standards (1998-2012)
- Document-level information
 - Publication Date, WG, **Network Layer**
 - Status: **Standards** vs. Informational
 - **Citation Flows**
 - Authors & **Affiliations**

Network Engineering in One Slide

Network Connections



Stack Connections



W3C | Application | Realtime | Transport | Internet | Routing

Technological Inter-dependencies

(Citation Flows in the Protocol Stack)

Cited Network Layer

		Cited Network Layer							
		W3C	Application	Realtime	Transport	Internet	Routing	Security	Operations
Citing Layer	W3C	870	91	6	0	16	0	8	0
	Application	37	1,075	14	3	90	0	131	26
	Realtime	63	238	1,720	70	176	14	173	21
	Transport	3	25	108	660	194	39	215	71
	Internet	0	32	15	57	1,850	140	266	148
	Routing	0	1	1	111	203	1,193	71	67

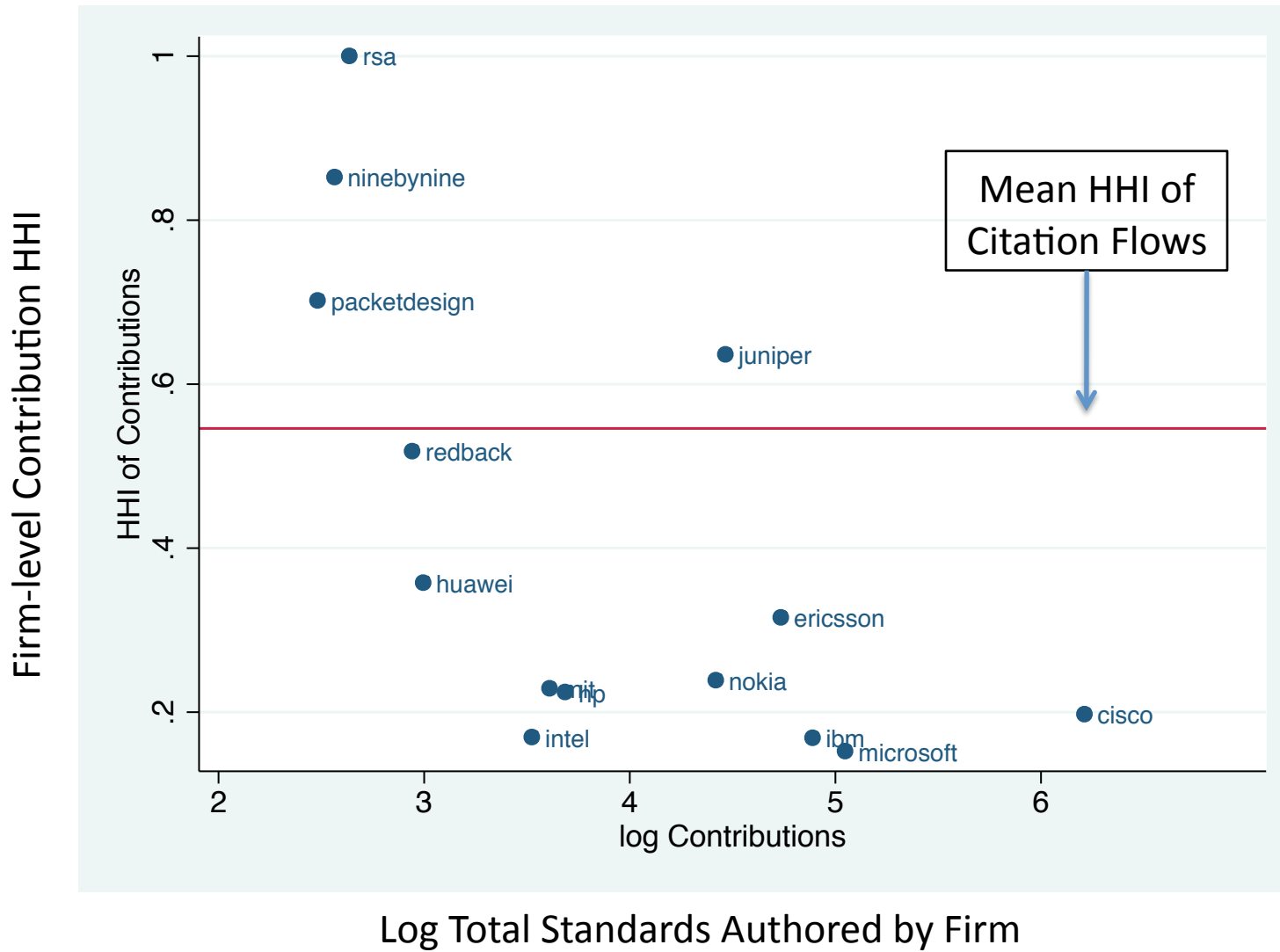
Raw citation counts between standards at all layers of Internet protocol stack

Firms' Locations in the Stack

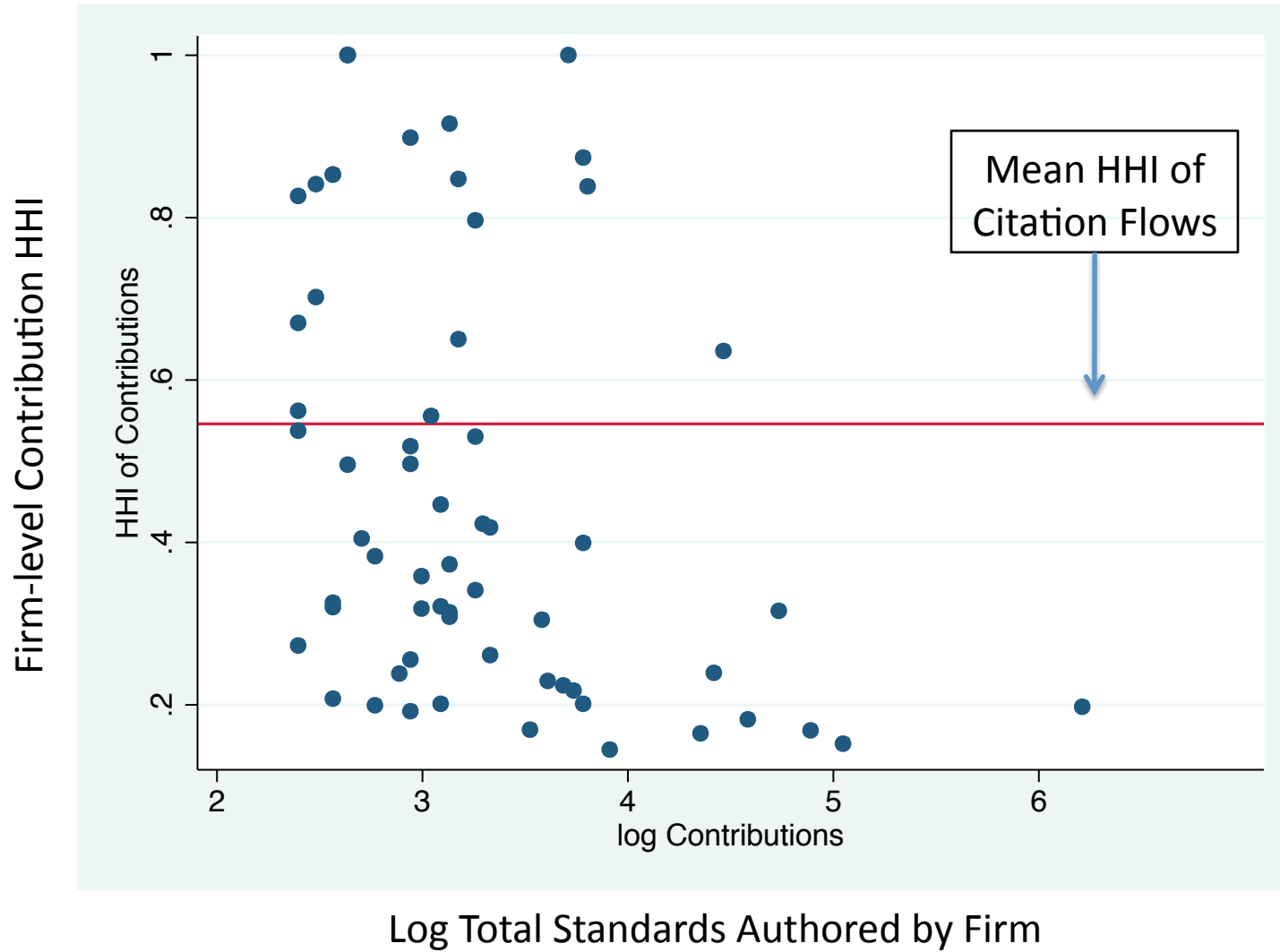
	W3C	Application	Realtime	Transport	Internet	Routing
Cisco	0	7	66	47	134	132
Juniper	0	0	0	4	13	68
Huawei	0	0	0	1	2	11
Microsoft	32	18	15	15	29	4
IBM	34	14	1	12	27	19
Ericsson	3	0	57	17	21	5
Nokia	5	1	25	8	29	4
Redback	0	0	0	0	3	13
NineByNine	1	12	0	0	0	0
PacketDesign	0	0	10	1	1	0

Counts of standards by various firms at each layer of Internet protocol stack

Specialization and Scale



Specialization and Scale

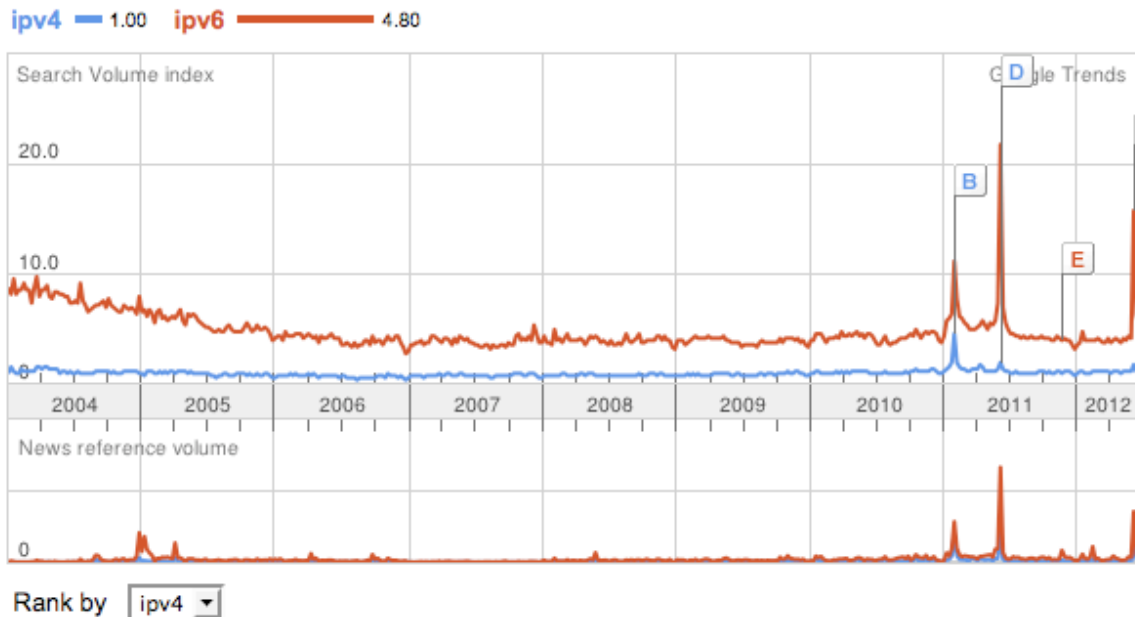


Summary & Interpretation

- Lots of specialization in the technology
 - Modular cite flows == few externalities / inter-dependencies
 - Possible exception of the Internet (IP) layer
- Division of labor between firms
 - Some (smaller) firms highly concentrated
 - Some (larger) firms less specialized
- Related to qualitative evidence on participation
 - Large firms want to define “connector markets”
 - Smaller firms need to shepherd core technology
 - *How to model / measure these incentives?*

Some Dynamics

- Broad Trends: Citation Level Regression ('92-'12)
 - $1[\text{OutCitation}] = \alpha + \beta \text{ Year} + \delta_{\text{citingLayer}}$
 - Between WG cites increasing 1% year
 - Between Layer cites increasing 0.27% year
- IPv6 Empirical Case Study
 - Major upgrade “just around the corner” for 15 years
 - Architectural innovation => More addresses
 - If standard builds on (cites) V6, does it also cite v4?
 - Diff-in-diffs: Internet Layer to other Layers



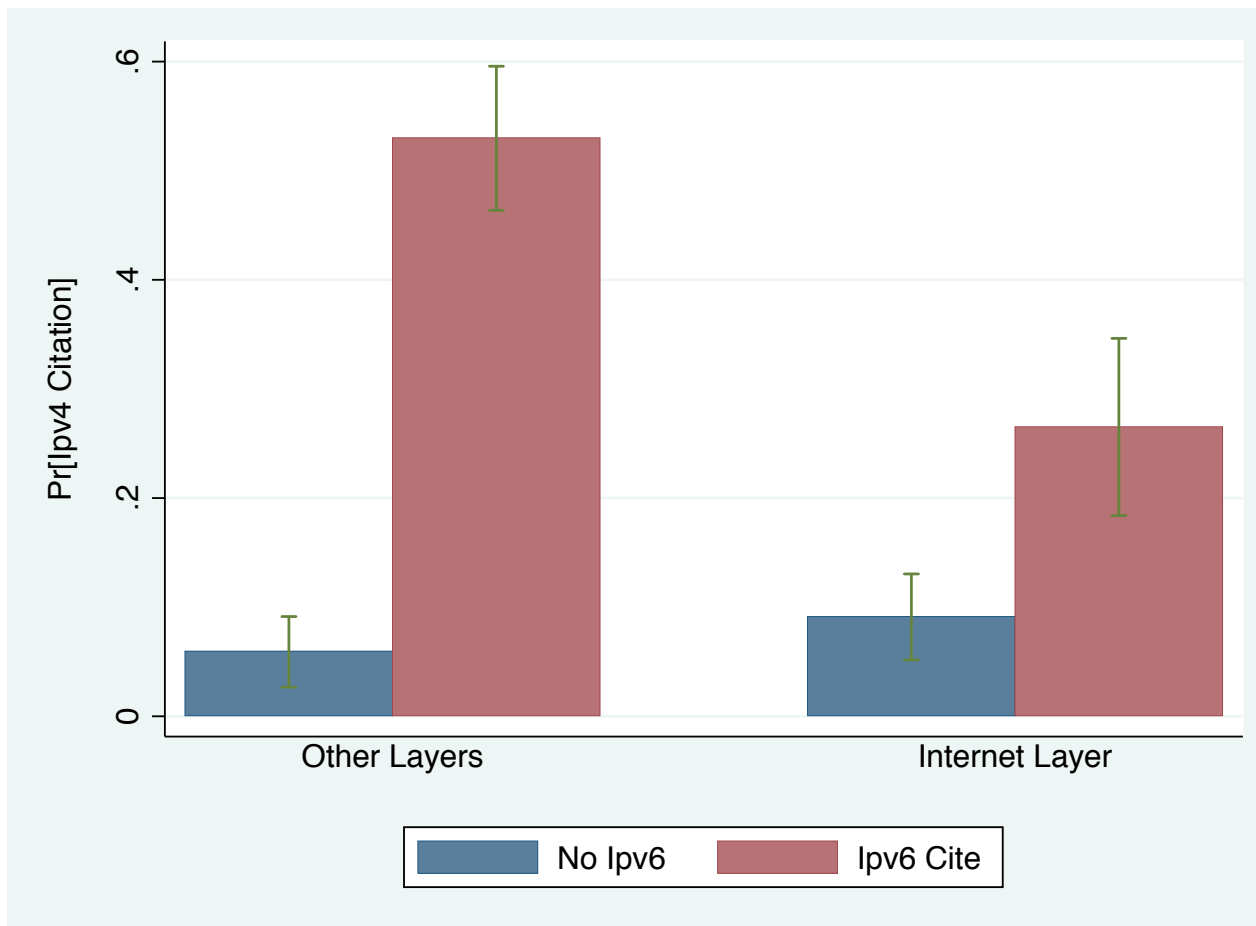
- A** [Net powers: IPv4 is over. All hail IPv6!](#)
CNET - Feb 3 2011
 - B** [ICANN Assigns Its Last IPv4 Addresses](#)
PC World - Feb 3 2011
 - C** [Happy World IPv6 Day!](#)
CANOE - Jun 8 2011
 - D** [Lack of IPv6 networks may lead to IPv4 blackmarketing](#)
Economic Times - Jun 8 2011
 - E** [Boost in IPv6 Use Is Only One Step to Solution](#)
PCWorld - Nov 22 2011
 - F** [Internet switches to IPv6, for breathing room](#)
AsiaOne - Jun 6 2012
- [More news results »](#)

Prob [Citing IPv4 Protocol]

	Does Not Cite IPv6 Protocol	Cites IPv6 Protocol
Internet Layer Protocol	11.3%	25.6%
Other Layer Protocol	6.7%	51.3%

N= 5,528 Standards

Upgrading vs. Multi-homing



$$\text{CitesV4} = \alpha_{\text{Year}} + \beta_1 \text{CitesV6} + \beta_2 \text{InternetLayer} + \beta_3 \text{CitesV6} * \text{InternetLayer}$$

Conclusions

- Division of labor in protocol development
 - Strong specialization at technical level
 - Specialization varies at firm level
 - Reflects different incentives to contribute?
- Modularity declining over time
 - IPv6 and difficulty of major upgrades
 - *Is this a general phenomenon, or is IP layer special?*
 - “Boundary layer” => harder coordination problem

Thank You!

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