The Internet at (around) 50 - Mid-life crisis or New Realism?

HENNING SCHULZRINNE

Overview

Economics – what can the Internet realistically accomplish (and not)?

- age 5-15: “You can be president/movie star/astronaut when you grow up”
- age 15-25: “You have so much promise!”
- age 25+: “What pays the rent?”

Internet economics drives the architecture & constraints

Predicting the next ten years

Thoughts on Internet architecture

Innovation = Internet

"It's finally happened. They've replaced the nightly news with cat videos."

Internet as the consensus answer

Health care costs → Internet-based EHR! Tele medicine!

Income inequality → Internet for job searches! Learn coding!

Cost of education → MOOCs!

Global warming → Replace business travel by video conferencing!

Political oppression → Twitter & FB as citizen organizers!

Natural disasters & terrorism → Change FB profile picture!

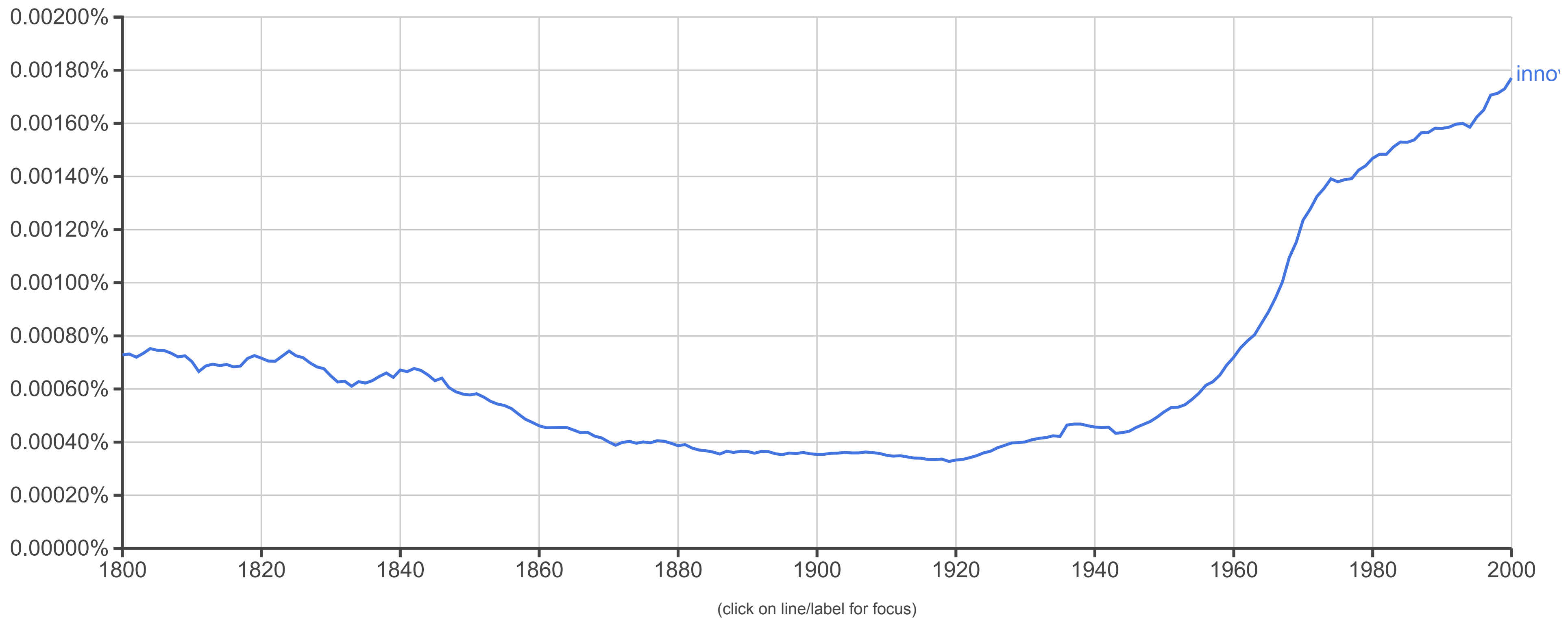
Global conflict → Get to know your (former) enemy via social media!

Traffic congestion → Smart cities!

Any difficult problem → Internet app!

→ Positive effects often not quantified or shown

Lots of talk about innovation…



Google n-gram

Popular Mechanics

MIRACLES YOU'LL SEE

In 2000, rocket passengers may arch through space from New York to San Francisco in less than two hours

for cutting tools and for massive machinery. The light metals have largely displaced it. Ways have been found to change the granular structure so that a metal is ultrastrong in a desired direction and weaker in other directions. As a result, the framework of an industrial or office building or apartment house is an almost lacelike lattice.

Thanks to these alloys, to plastics and to other artificial materials, houses differ from those of our own time. The Dobson house has light-metal walls only four inches thick. There is a sheet of insulating material an inch or two thick with a casing of sheet metal on both sides.

This Dobson air-conditioned house is not a prefabricated structure, though all its parts are mass-produced. Metal, sheets of plastic and aerated clay (clay filled with bubbles so that it resembles petrified sponge) are cut to size on the spot. In the center of this eight-room house is a unit that contains all the utilities—air-conditioning apparatus, plumbing, bathrooms, showers, electric range, electric outlets. Around this central unit the house has been pieced together. Some of it is poured plastic—the floors, for instance. By 2000, wood, brick and stone are ruled out because they are too expensive.

It is a cheap house. With all its furnishings, Joe Dobson paid only $5000 for it. Though it is galeproof and weatherproof, it is built to last only about 25 years. Nobody in 2000 sees any sense in building a house that will last a century.

Everything about the Dobson house is

A Declaration of the Independence of Cyberspace

1996

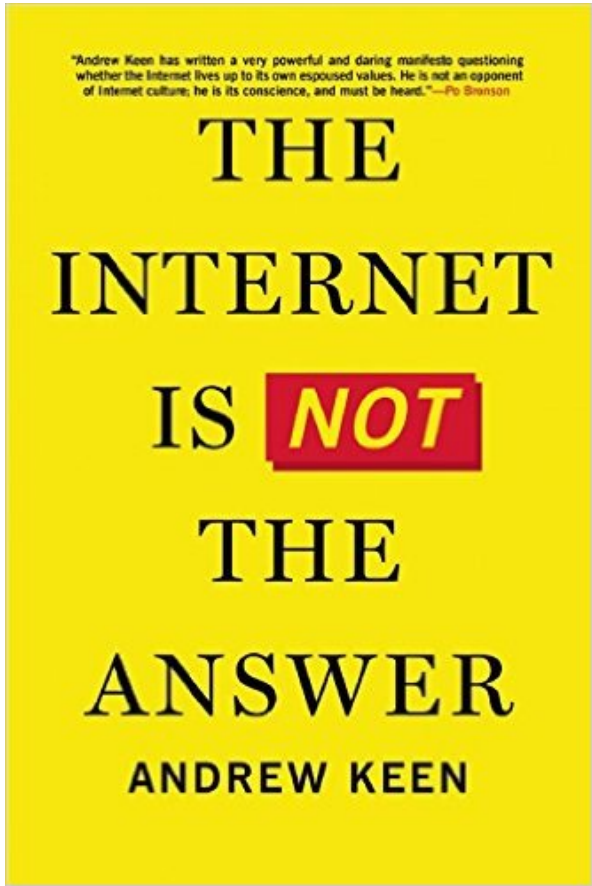
BY JOHN PERRY BARLOW

Governments of the Industrial World, you weary giants of flesh and steel, I come from Cyberspace, the new home of Mind. On behalf of the future, I ask you of the past to leave us alone. You are not welcome among us. You have no sovereignty where we gather.

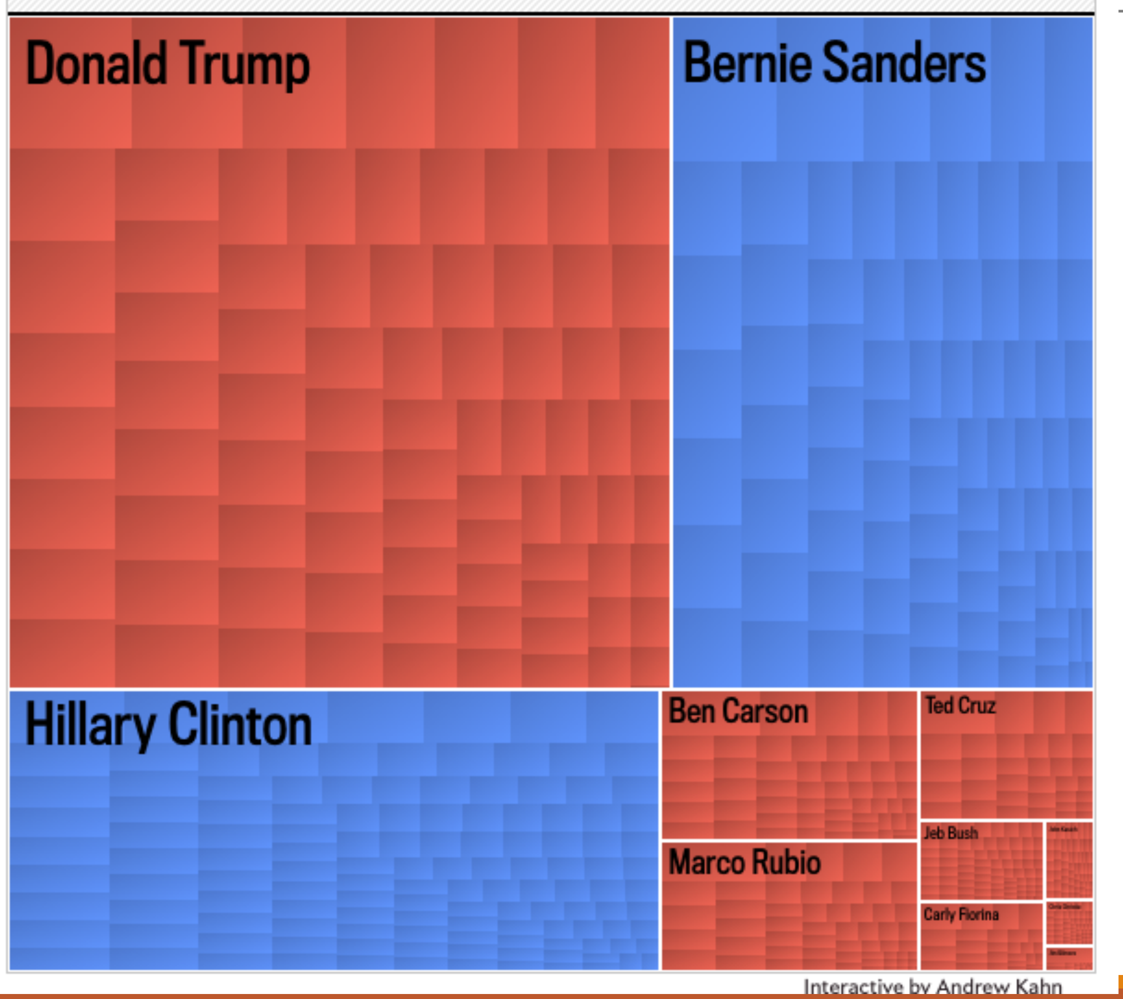
We have no elected government, nor are we likely to have one, so I address you with no greater authority than that with which liberty itself always speaks. I declare the global social space we are building to be naturally independent of the tyrannies you seek to impose on us. You have no moral right to rule us nor do you possess any methods of enforcement we have true reason to fear.

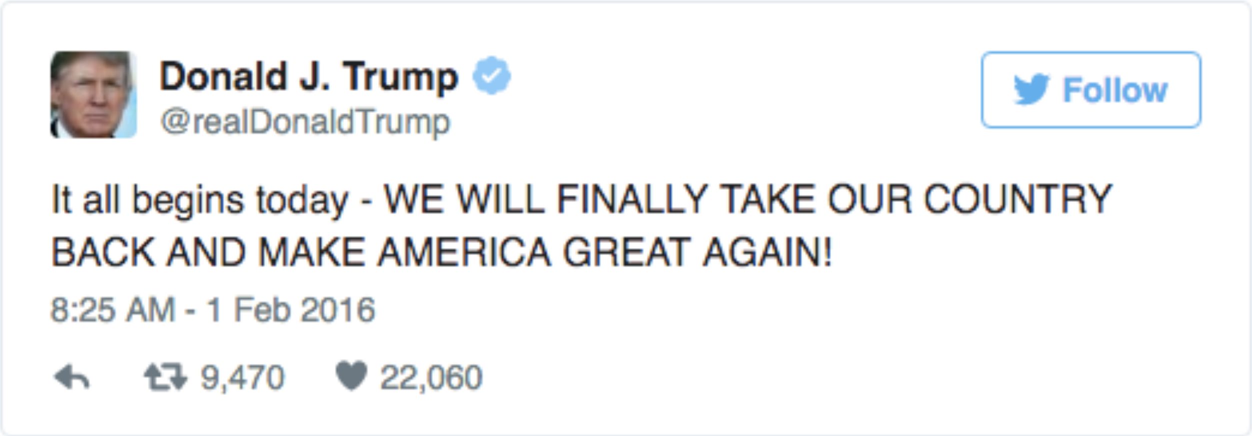
Why Learning To Code Won't Save Your Job

Brushing up on your tech skills might only make for temporary job security at best.



The Internet increases citizen engagement (if you don't care what kind)





Industrial revolutions

Classical economics: Labor ($ output/hour worked) & total factor (includes capital invested) productivity

- → higher income (on average)
- Improved quality of life (health, education, opportunities, …)

IR#1: 1760-1830

- Spinning jenny (1764), steam engine (1770), power loom (1780), Fulton steam boat, Liverpool rail road (1830), Macadam road (1820), Bessemer steel (1850)

IR#2: 1875-1900

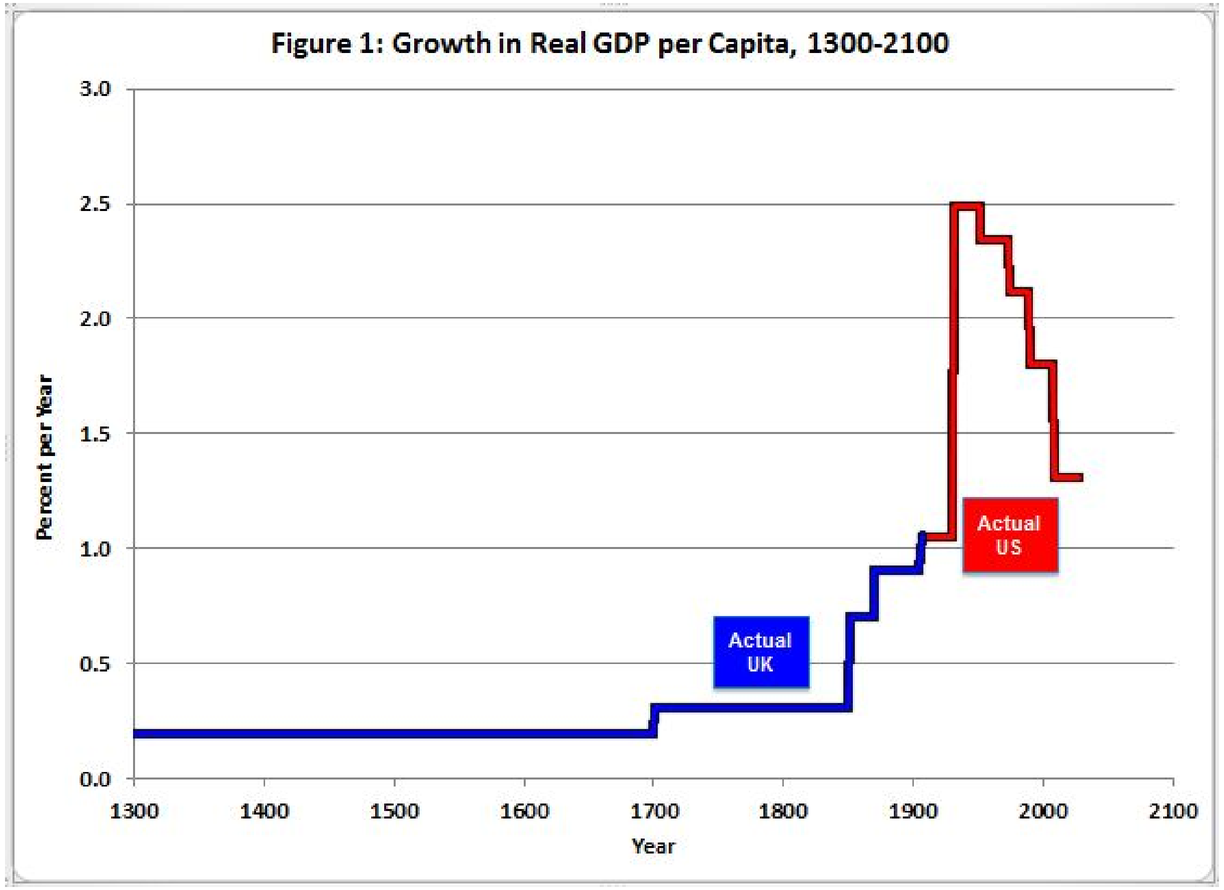
- Telephone, radio, automobile, record player, air craft, …

IR#3: 1985-2010

- Mainly information technology: personal computers & Internet

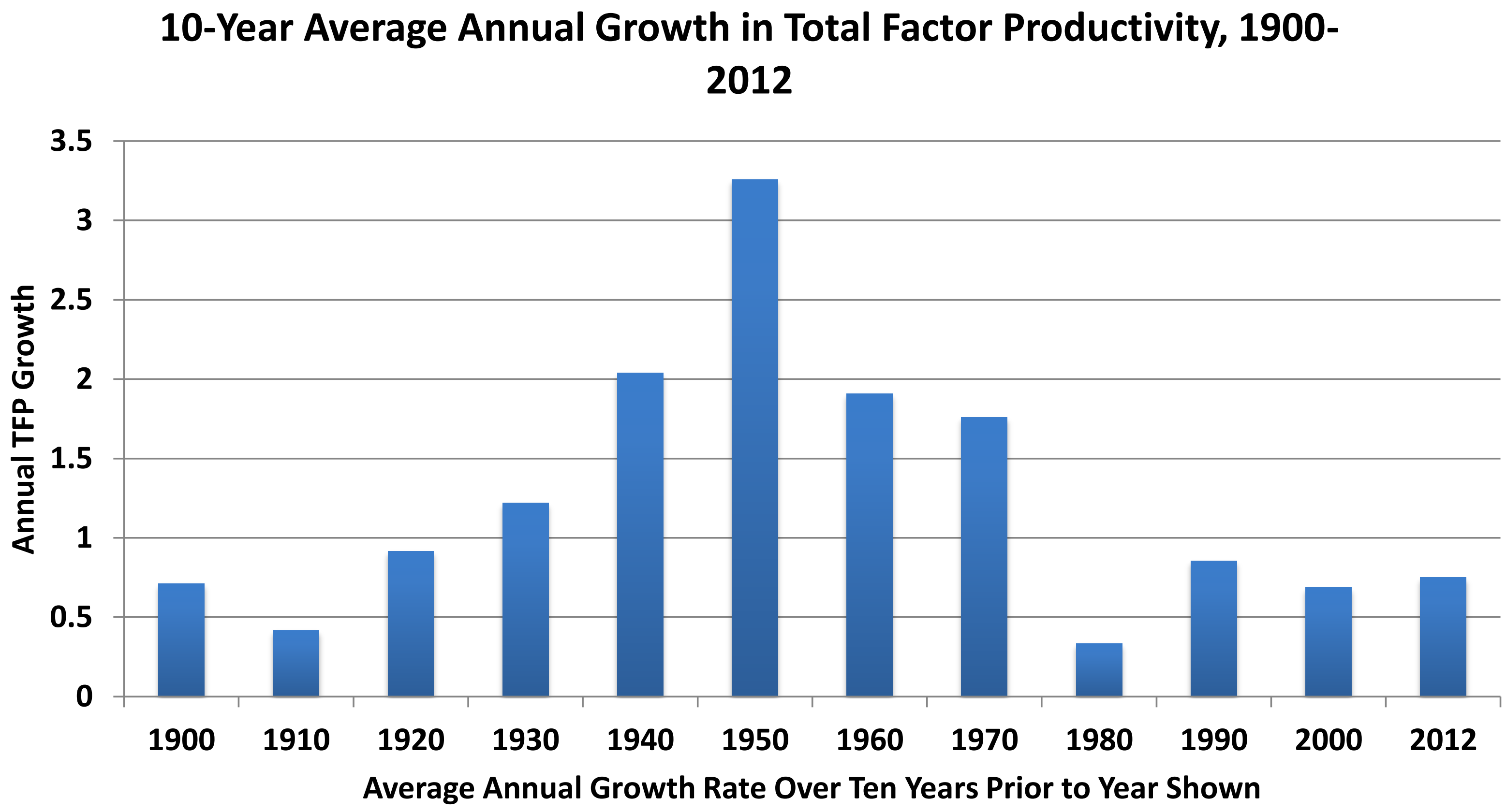
Growth in GDP per capita (~productivity)

Robert Gordon
2014



Robert Gordon
2014

How Did Innovation in the Past Compare with the Past 40 Years?

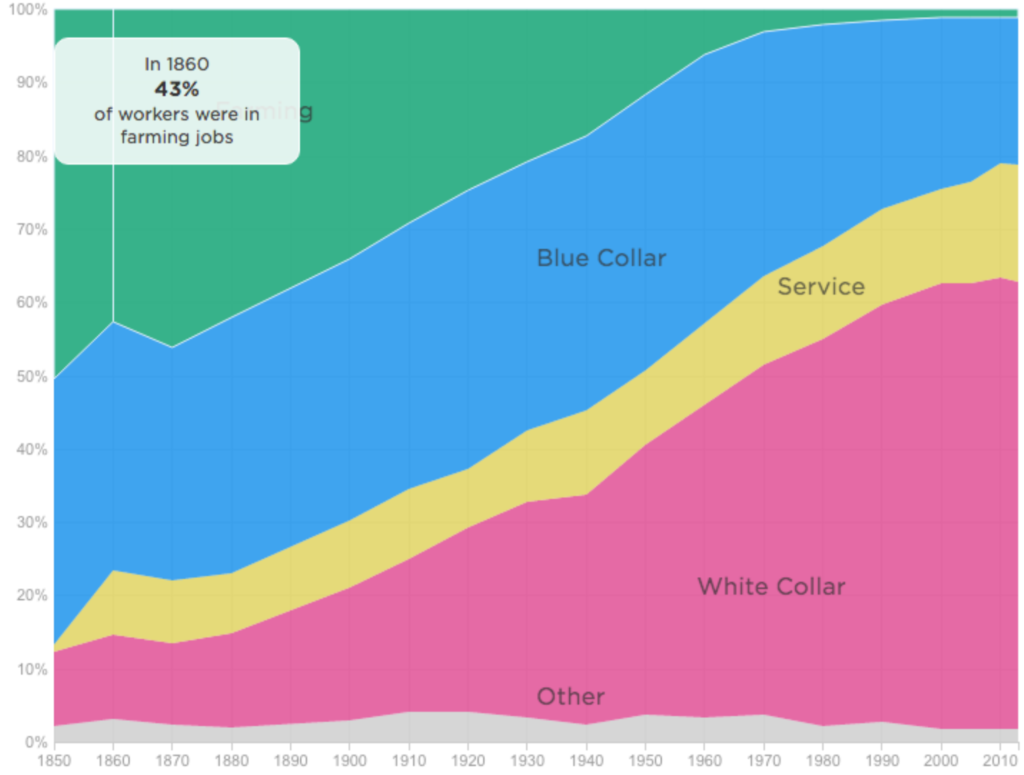


Robert Gordon
2014

Let's Think About How Minor the Progress Was in IR #2 vs. IR #3.

- **The introduction of GPS navigation screens on autos compared to the invention of the auto itself.**
- **The introduction of the cell phone compared to the invention of the phone itself and the telegraph.**
- **The invention of home-streaming of movies to the invention of the motion picture itself.**
- **The invention of the ipod to the invention of the phonograph.**
- **The invention of the microwave oven to the replacement of cooking on the open hearth by the enclosed cast iron stove and later the kitchen range.**
- **Icemakers in refrigerators compared to the invention of the refrigerator or even the icebox.**
- **The conversion of card catalogues in libraries to electronic screens with the invention of electric light that made it possible to read books at night.**

Transition in the labor force



Notes

White collar includes professional and technical, managerial, sales and clerical jobs. Blue collar includes machine operators, assembly, manual labor and construction jobs. Service includes food service, health care and personal service jobs

Source: IPUMS-USA, University Of Minnesota
Credit: Quoctrung Bui/NPR

The Great Prosperity: 1947–79
The Great Regression: 1980–Now
Pay Rose With Productivity ...
... And Then It Didn't
Wages and overall compensation, for production and non-supervisory workers (now about 82 percent of the private sector work force), tracked steadily upward alongside gains in productivity.
The rising value of goods and services per worker meant rising pay. But that relationship ended in the 1970s.
CHANGE, 1947-79
+119%
+100%
+72%
CHANGE, 1979-2009
+80%
PRODUCTIVITY
AVG. HOURLY COMPENSATION
CHANGE, 1979-2009
+8%
+7%
AVG. HOURLY WAGE
BASELINE IS 1947
'50
'60
'70
'80
'90
'00

Employment –old vs. new social network

	Revenue (2015, $B)	Employees	Revenue/employee
UNITED STATES POSTAL SERVICE.	$68.9	491,863	$0.14M
f	$17.9	12,691	$1.4M

Innovation did not disappear

Clearly, nobody would trade 2016 computer + smartphone for 1990 versions

- or a 1990s car
- or forego Amazon, FB, Google search & maps

But impact of Internet-related innovation did not fundamentally change work place

- for most occupations, at least
  - we **still** use LaTeX (*1985)!

Hunch: networks & IT are often just needed to compete for the same output

- e.g., high-speed trading (& overall financial sector)
- college applications

or to enable higher-complexity systems

- health insurance, taxes, advertising, …

1992

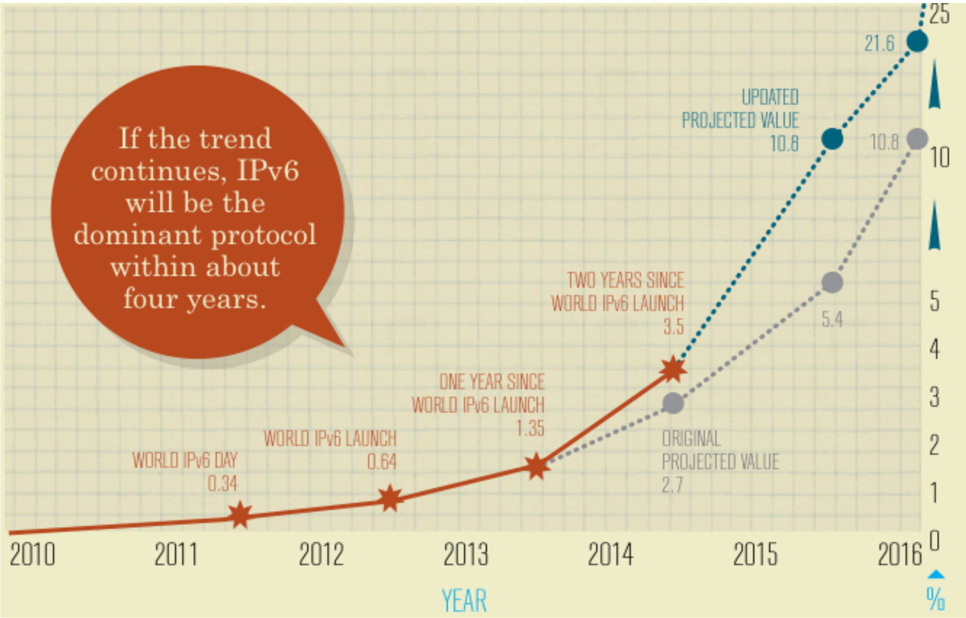
Change may seem sudden, but is visible

Early lab prototypes
- see "mother of all demos" (Doug Engelbart, 1968)

IPv6:
- discussion started in 1992
- standardized in 1996
- 10-25% deployment 20 years later

VoIP:
- tech demos 1978, revived early 1990s
- standards mid-1990s
- 2014: 40% deployment

Smartphone:
- first version 1994
- iPhone 2007



"The future has arrived — it's just not evenly distributed yet."
(attributed to W. Gibson, 1992)

“We wanted flying cars, instead we got 140 characters”

Innovation on the cheap

- “we can’t build a transcontinental railroad any more, so we’ll write an app”
  - that tells you how late Amtrak will be today

What tends to improve productivity

- reduce transportation lag (& cost)
- reduce labor for agriculture & manufacturing at scale
- reduce processing & coordination overhead for information-centric jobs

Economic impact

- tends to amplify differences in productivity

Can the Internet (or a better Internet) address

- global climate change?
- income inequality?
- chronic health conditions (obesity, dementia)

Some Internet economics

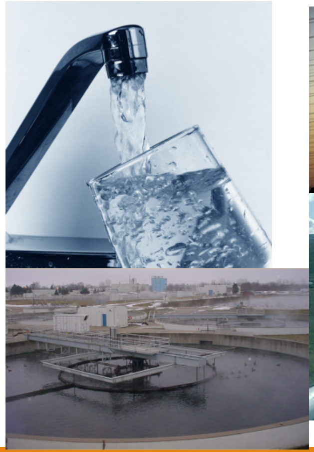
The great infrastructures

Technical structures that support a society → “civil infrastructure”

- Large
- Constructed over generations
- Not often replaced as a whole system
- Interdependent components with well-defined interfaces

Mostly noticed if absent

water



energy

transportation

communication

Innovations matter when they become infrastructure

Many of the fundamental advances matter only at scale

- public health & sanitation
- clean drinking water
- roads & railroads
- electricity
- telephone service

Not for all: medical, military, research tools, 3D printing, …

Thus, the Internet matters as infrastructure, not technology as such

Communication models – ca. 1980

TV (& radio) broadcast

CATV

Telephone service (voice, modem data, fax)

largely distributors

one-to-one
largely conduit

Internet economic models - now

Google
Chatroulette

content and applications

Level 3

IP

RCN

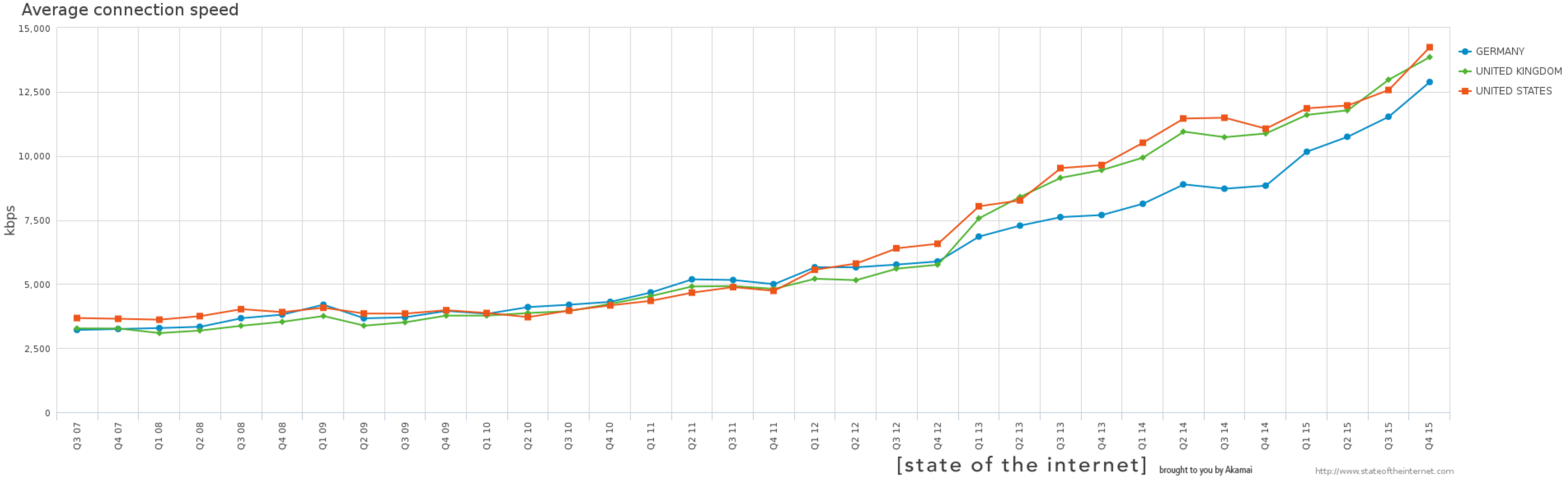
fiber or copper loop (“Homes with tails”)

vs.

content production (*)
advertising
content distribution
CDN
broadband access
local infrastructure
regional and national backbone

AT&T + DirectTV
Comcast/NBC (*)
Verizon + AOL

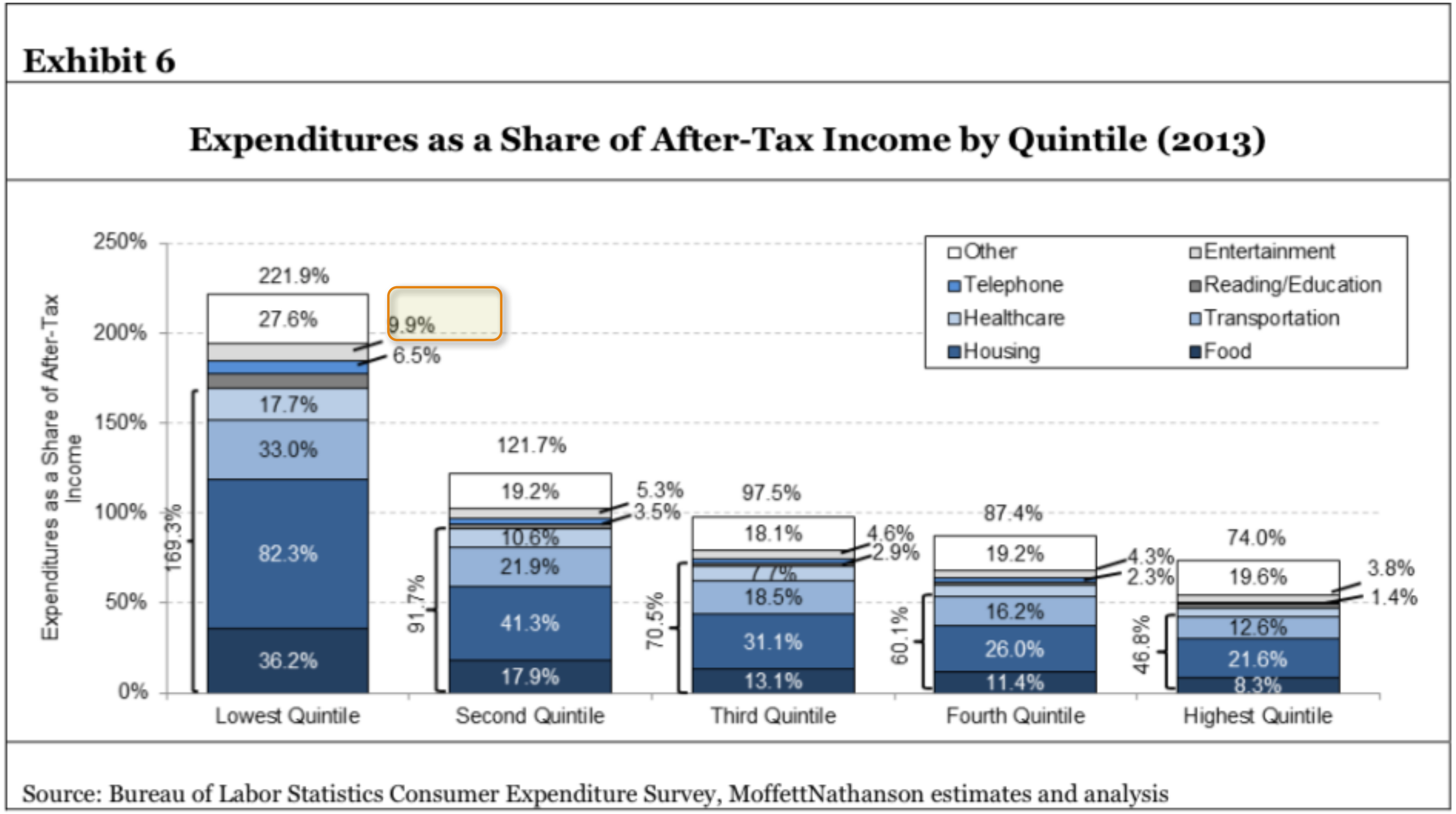
The residential Internet is still getting faster



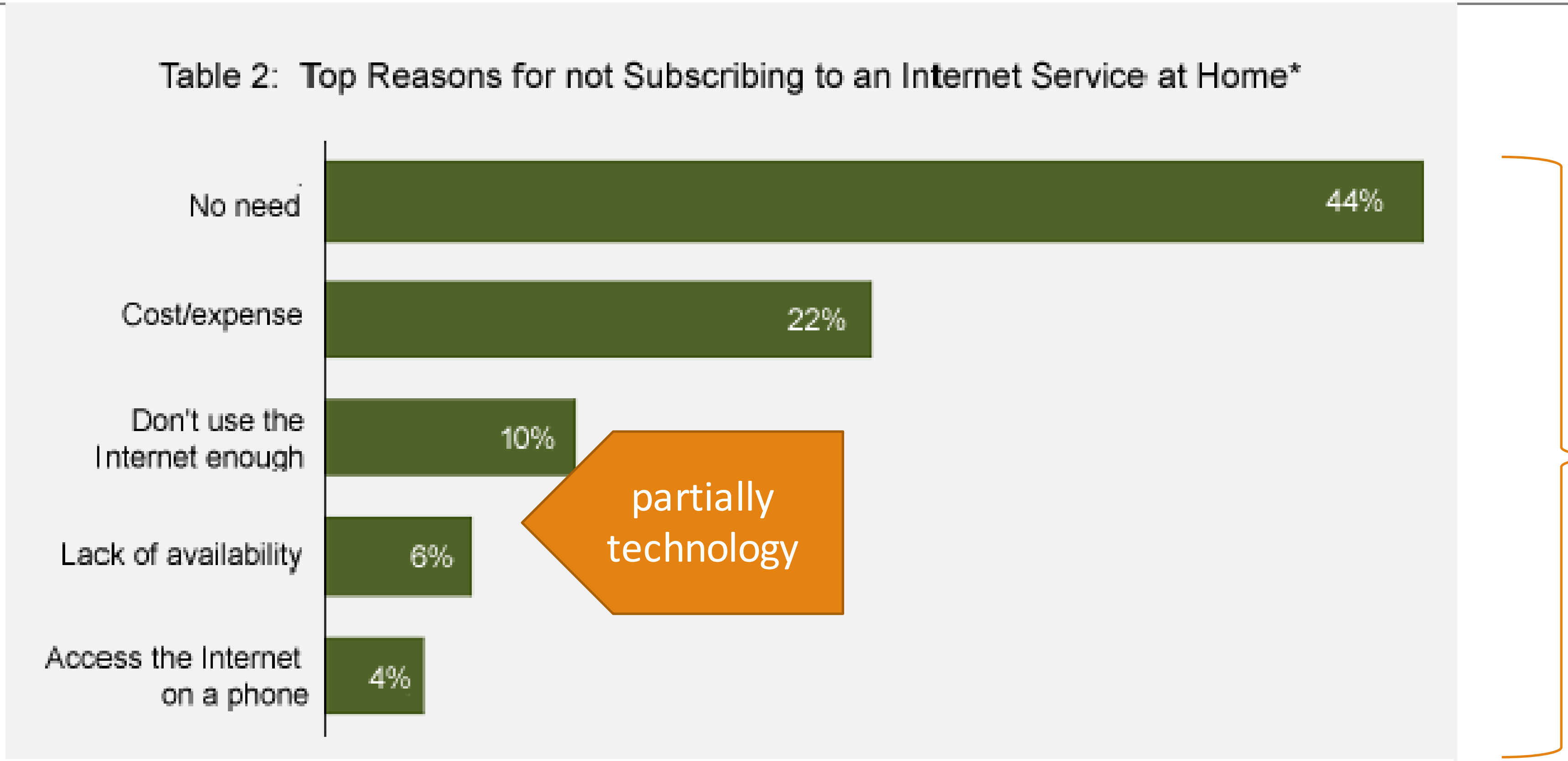
Akamai

entrance of DOCSIS 2+ in several countries
VDSL in others

Broadening participation: the problem



Reason for non-adoption

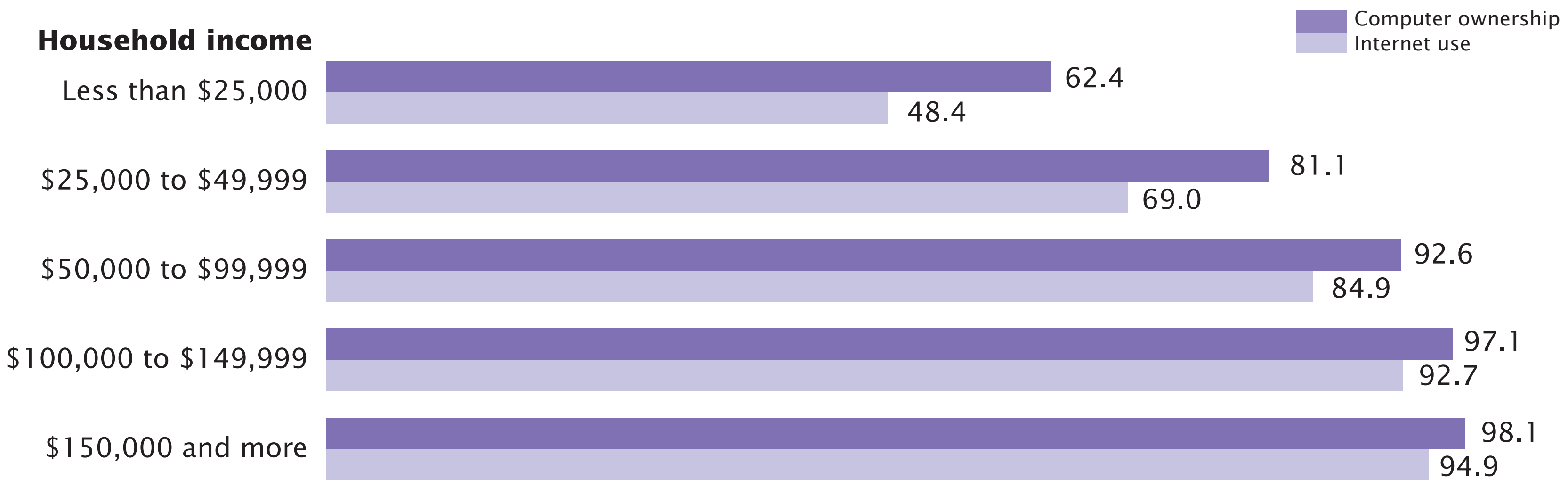


= economics & policy

* *Asked of those who do not currently get an Internet service at home and do not plan to subscribe in the next six months*

Leichtman Research Group
Research Notes
1Q 2016 *Actionable Research on the Broadband, Media & Ente*

Internet usage by income



Note: About 4.2 percent of all households reported household Internet use without a paid subscription. These households are not included in this figure.

Barriers to Internet adoption

Non-Internet users face four categories of barriers

	Incentives	Low incomes and affordability	User capability	Infrastructure
Barriers directly affecting consumers	Lack of awareness of Internet or relevant use cases Lack of relevant (e.g., local, localized) content and services Lack of cultural or social acceptance	Low income or consumer purchasing power Total cost of ownership for device Cost of data plan Consumer taxes and fees	Lack of digital literacy Lack of language literacy	Lack of mobile Internet coverage or network access Lack of adjacent infrastructure (e.g., grid electricity)
Root causes (e.g., providers, government/ regulatory, industrial)	▪ High content and service provider costs and business model constraints ▪ Low awareness or interest from brands and advertisers ▪ Lack of a trusted logistics and payments system ▪ Low ease of doing business ▪ Limited Internet freedom and information security	▪ Challenging national economic environment ▪ High device manufacturer costs and business model constraints ▪ High network operator costs and business model constraints ▪ High provider taxes and fees ▪ Unfavorable market structure	▪ Under-resourced educational system	▪ Limited access to international bandwidth ▪ Underdeveloped national core network, backhaul, and access infrastructure ▪ Limited spectrum availability ▪ National ICT strategy that doesn't effectively address issue of broadband access ▪ Under-resourced infrastructure development (e.g., FDI limits)

SOURCE: Literature review; expert interviews; McKinsey analysis

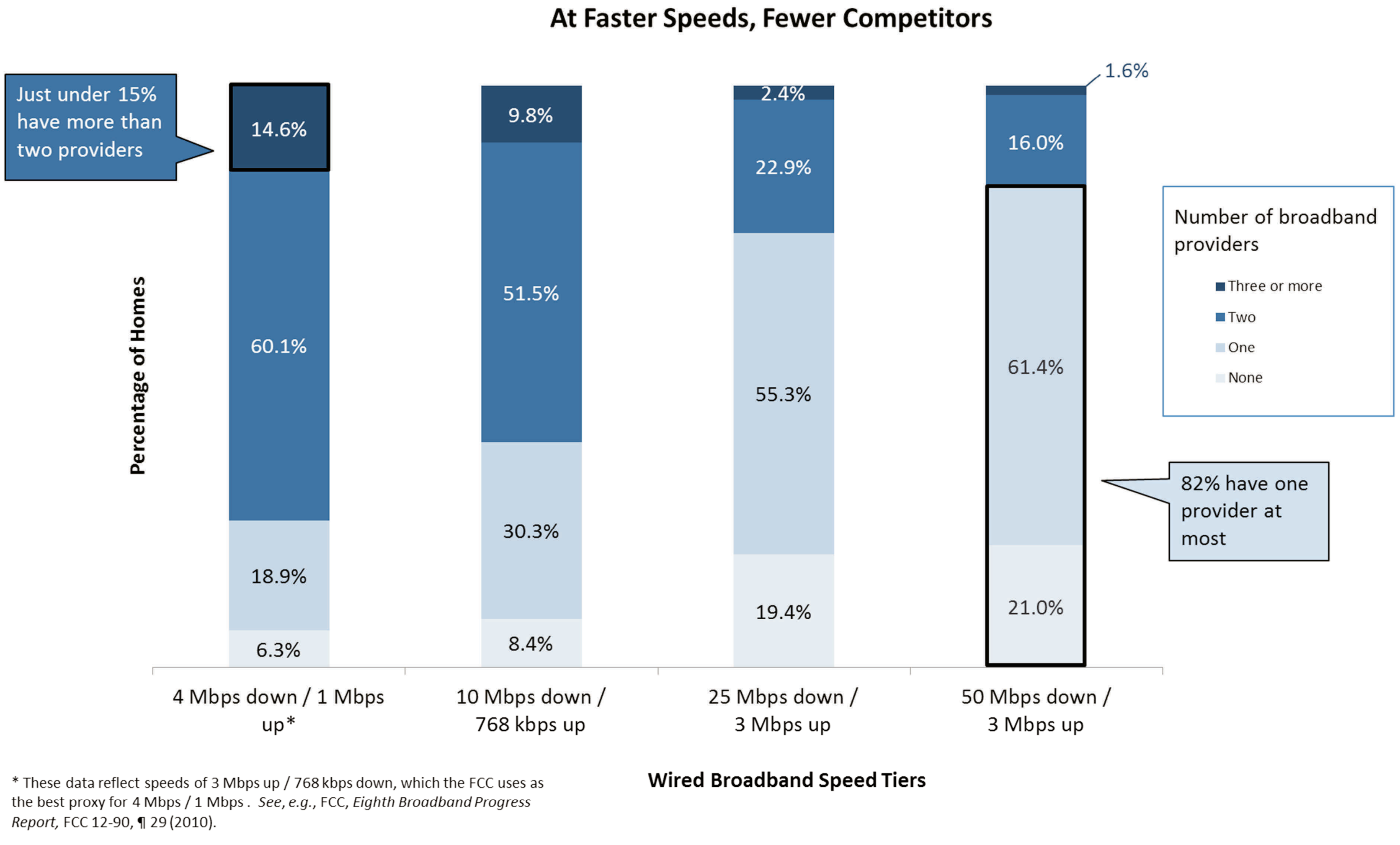
Internet industries have network effects

→ new Internet industries dominated by one or two players

- was partially true for broadcasting (“The Big Switch”)
- even more for Internet at all layers
  - government monopolies: intellectual property (copyright, patents), spectrum
  - scale effects (platforms)
  - network effects (social networks)
  - natural monopolies (infrastructure) → rarely more than two competitors

→ rent seeking behavior

Broadband competition challenges



Competition models

Unbundled loops (asymmetric regulation)

- regulated pricing for dominant provider
- mainly for copper DSL (e.g., Germany, Italy, UK)

Two infrastructures → duopoly

- historical accident: copper + cable (in urban areas)
- Netherlands, US, Canada, W Germany

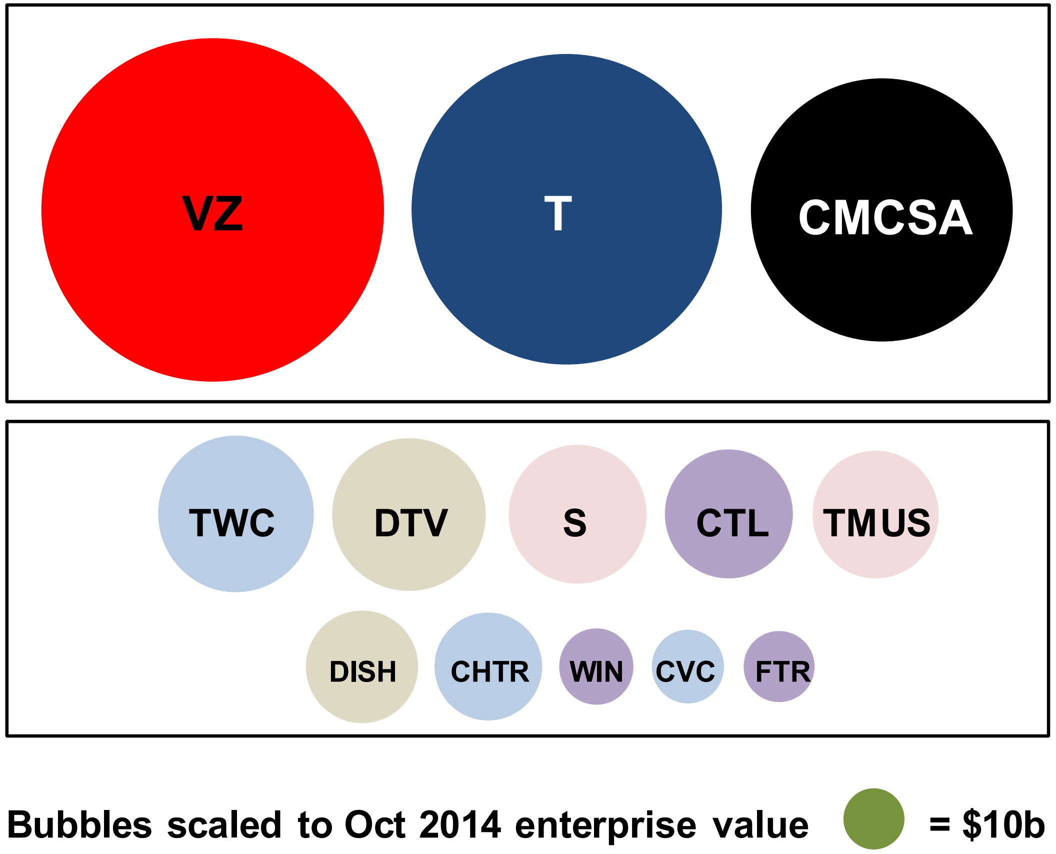
Fiber sharing

- works well in countries with lots of MDUs
- e.g., Korea, Japan

No country with more than two PHY providers for wireline

- economics for 2nd and 3rd overbuilder very hard
- except maybe for municipal networks competing with DSL

US industry structure



Bernstein Research, 2014

US industry is dominated by ~12 providers

Top Broadband Internet Providers in the U.S.

Cable Companies	**Subscribers at End of 2015**	**Net Adds in 2015**
Comcast	23,329,000	1,367,000
Time Warner Cable	13,313,000	1,060,000
Charter	5,572,000	497,000
Cablevision	2,809,000	49,000
Suddenlink	1,223,000	73,900
Mediacom	1,085,000	72,000
WOW (WideOpenWest)	712,500	(15,300)
Cable ONE	501,241	12,787
Other Major Private Companies*	6,725,000	190,000
Total Top Cable	**55,269,741**	**3,306,387**
Telephone Companies		
AT&T	15,778,000	(250,000)
Verizon	9,228,000	23,000
CenturyLink	6,048,000	(34,000)
Frontier^	2,444,000	101,500
Windstream	1,095,100	(36,500)
FairPoint	311,130	(8,785)
Cincinnati Bell	287,400	17,500
Total Top Phone	**35,191,630**	**(187,285)**
Total Top Broadband Providers	**90,461,371**	**3,119,102**

Capital investment is roughly 15% of revenues

Company	Revenue	Capital expenditures	%
Comcast (US) [3Q14]	$11.04B	$1.644B	14.9
Telekom (DE) [3Q14]	€15.6B	$2.58B	16.5
Safaricom (KE) [H1FY15]	Ksh 79.34B	Ksh 12.37	15.5

Comcast's Q2 2014 Capital Spending Trends

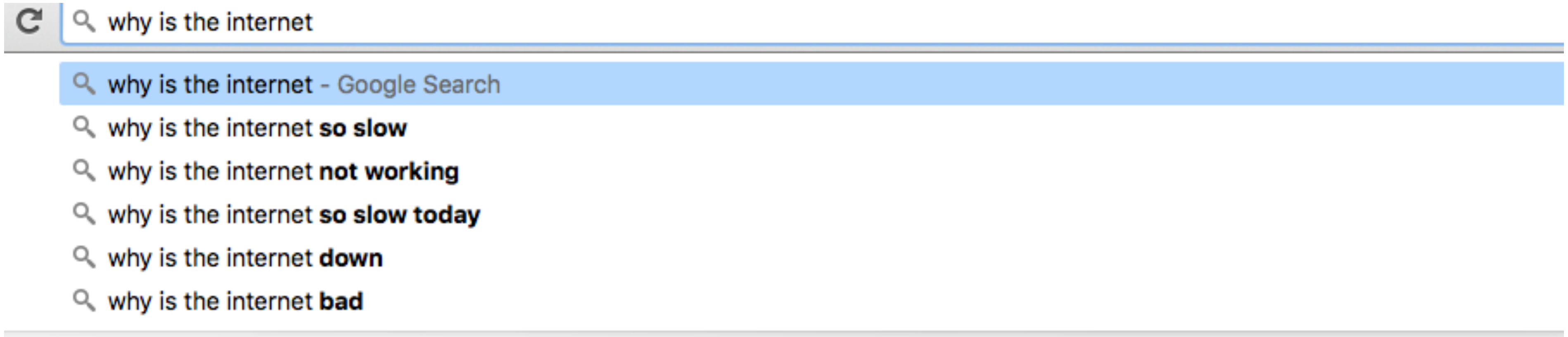
Category	Growth CapEx ($ mil.)	% of Total (%)	Maintenance CapEx ($ mil.)	% of Total (%)	Total CapEx* ($ mil.)	% of Total (%)
Consumer Premises Equipment	668	65	72	16	740	50
Network Infrastructure	107	10	287	64	394	27
Support Capital	48	5	89	20	137	9
Commercial	209	20	0	0	209	14
Total*	**1,032**	-	**448**	-	**1,480**	-

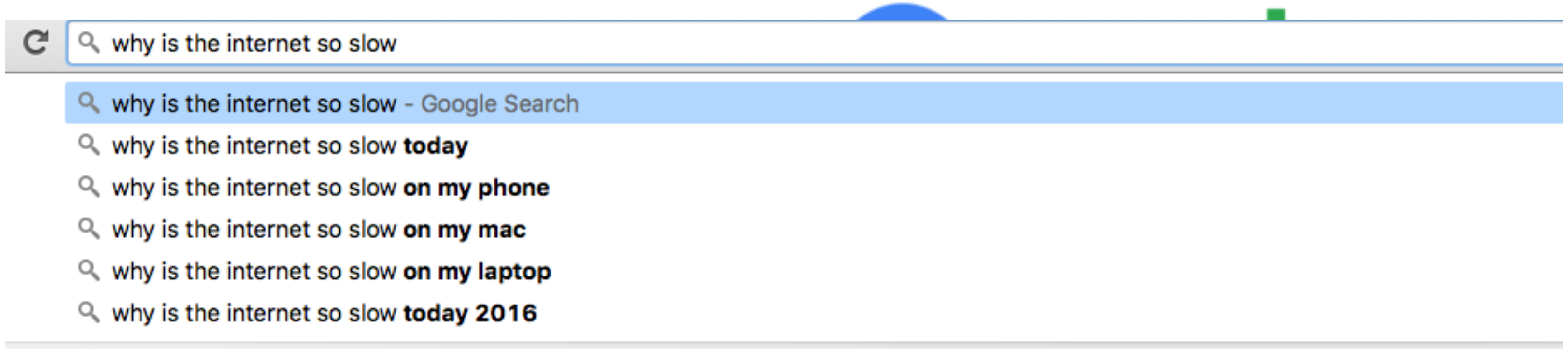
As of Aug. 2014. * Total excludes $13 million in discretionary capital. Total including discretionary spending was $1,493 mil. Source: Comcast.

Broadband cost

70%

30%


why is the internet
why is the internet - Google Search
why is the internet so slow
why is the internet not working
why is the internet so slow today
why is the internet down
why is the internet bad

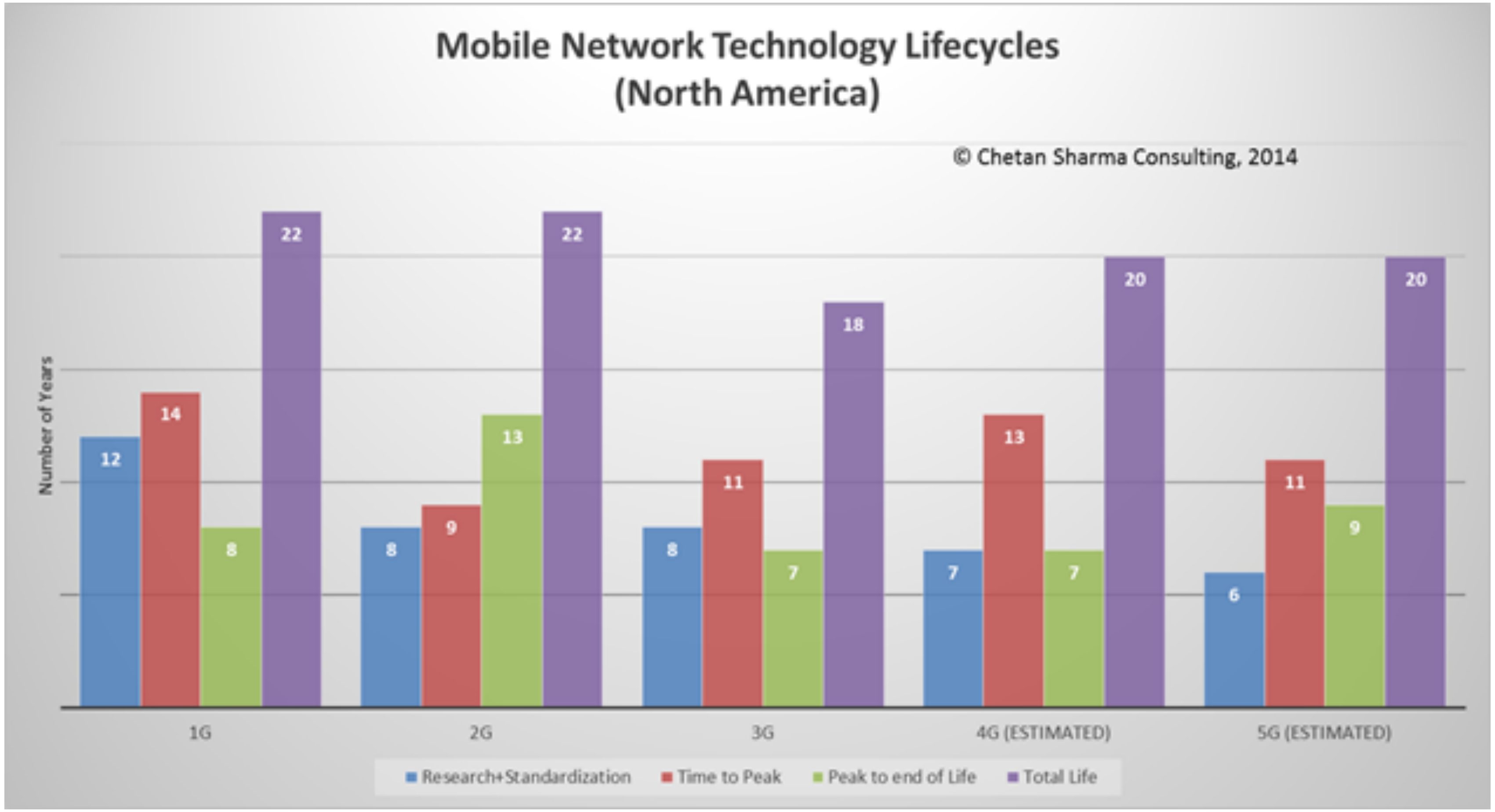

why is the internet so slow
why is the internet so slow - Google Search
why is the internet so slow today
why is the internet so slow on my phone
why is the internet so slow on my mac
why is the internet so slow on my laptop
why is the internet so slow today 2016

Internet architecture evolution

Networking is getting into middle years

	idea	current	age
IP	1969, 1980?	1981 (RFC 791)	35
TCP	1974 (RFC 675)	1981 (RFC 793)	35
telnet	1969 (RFC15)	1983 (RFC 854)	33
ftp	1971 (RFC 114)	1985 (RFC 959)	31
http	1996 (RFC 1945)	1999 (RFC 2616)	20
SIP	1999 (RFC 2543)	2002 (RFC 3261)	17

Networks last a long time



What made the Internet successful?

generality
(cf. circuit
switching)

+

leverage
semiconductor
speed increases

+

distributed service
creation
(with improving tools)

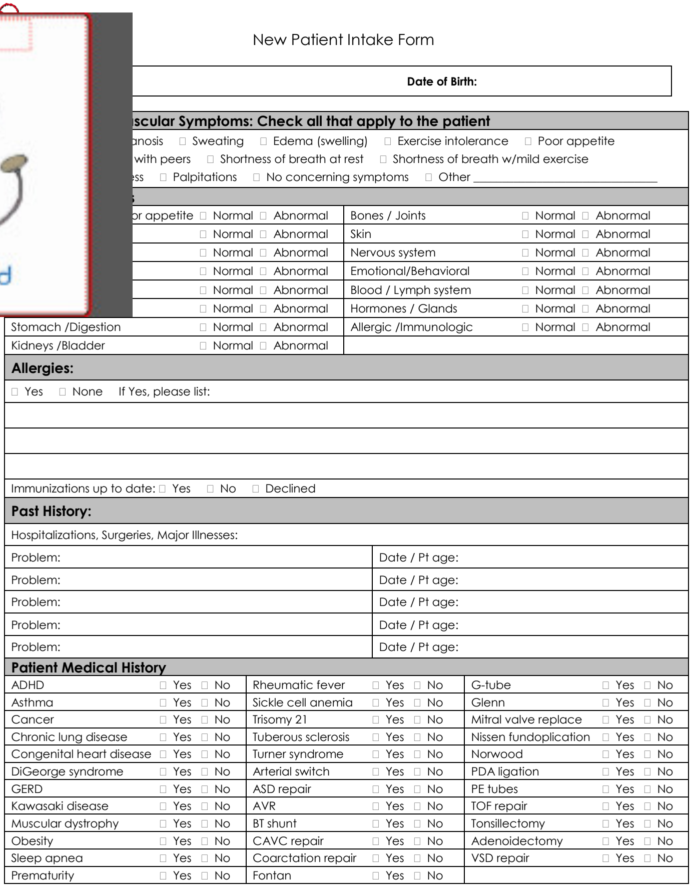
Still mostly intranets at layer 7

Standards progression
- Adobe Flash → HTML5, SVG, etc.

Standards regression
- instant messaging (SMS → SIP/SIMPLE + XMPP → WhatsApp)
- two identifiers (E.164 + RFC822) →

Lacking (modern) standards for
- electronic health records
- interconnecting medical devices
- traffic data exchange ("this traffic light is red")
- financial data exchange (still "wires" and manual entry of credit card numbers)
- invoices (e.g., travel reimbursement)

Most common Electronic Health Record "System"



New Patient Intake Form

Date of Birth:

...scular Symptoms: Check all that apply to the patient

...anosis ☐ Sweating ☐ Edema (swelling) ☐ Exercise intolerance ☐ Poor appetite
... with peers ☐ Shortness of breath at rest ☐ Shortness of breath w/mild exercise
...ess ☐ Palpitations ☐ No concerning symptoms ☐ Other ____________________

...r appetite	☐ Normal ☐ Abnormal	Bones / Joints	☐ Normal ☐ Abnormal
	☐ Normal ☐ Abnormal	Skin	☐ Normal ☐ Abnormal
	☐ Normal ☐ Abnormal	Nervous system	☐ Normal ☐ Abnormal
	☐ Normal ☐ Abnormal	Emotional/Behavioral	☐ Normal ☐ Abnormal
	☐ Normal ☐ Abnormal	Blood / Lymph system	☐ Normal ☐ Abnormal
	☐ Normal ☐ Abnormal	Hormones / Glands	☐ Normal ☐ Abnormal
Stomach /Digestion	☐ Normal ☐ Abnormal	Allergic /Immunologic	☐ Normal ☐ Abnormal
Kidneys /Bladder	☐ Normal ☐ Abnormal		

Allergies:

☐ Yes ☐ None If Yes, please list:

Immunizations up to date: ☐ Yes ☐ No ☐ Declined

Past History:

Hospitalizations, Surgeries, Major Illnesses:

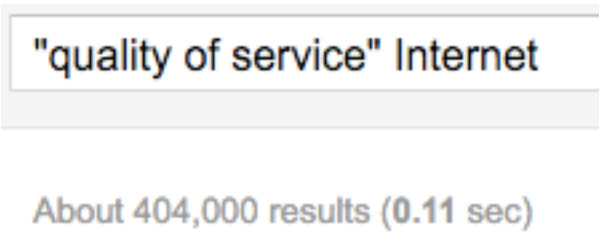
Problem:	Date / Pt age:
Problem:	Date / Pt age:
Problem:	Date / Pt age:
Problem:	Date / Pt age:
Problem:	Date / Pt age:

Patient Medical History

ADHD	☐ Yes ☐ No	Rheumatic fever	☐ Yes ☐ No	G-tube	☐ Yes ☐ No
Asthma	☐ Yes ☐ No	Sickle cell anemia	☐ Yes ☐ No	Glenn	☐ Yes ☐ No
Cancer	☐ Yes ☐ No	Trisomy 21	☐ Yes ☐ No	Mitral valve replace	☐ Yes ☐ No
Chronic lung disease	☐ Yes ☐ No	Tuberous sclerosis	☐ Yes ☐ No	Nissen fundoplication	☐ Yes ☐ No
Congenital heart disease	☐ Yes ☐ No	Turner syndrome	☐ Yes ☐ No	Norwood	☐ Yes ☐ No
DiGeorge syndrome	☐ Yes ☐ No	Arterial switch	☐ Yes ☐ No	PDA ligation	☐ Yes ☐ No
GERD	☐ Yes ☐ No	ASD repair	☐ Yes ☐ No	PE tubes	☐ Yes ☐ No
Kawasaki disease	☐ Yes ☐ No	AVR	☐ Yes ☐ No	TOF repair	☐ Yes ☐ No
Muscular dystrophy	☐ Yes ☐ No	BT shunt	☐ Yes ☐ No	Tonsillectomy	☐ Yes ☐ No
Obesity	☐ Yes ☐ No	CAVC repair	☐ Yes ☐ No	Adenoidectomy	☐ Yes ☐ No
Sleep apnea	☐ Yes ☐ No	Coarctation repair	☐ Yes ☐ No	VSD repair	☐ Yes ☐ No
Prematurity	☐ Yes ☐ No	Fontan	☐ Yes ☐ No		

What has been less than successful?

What can we learn from 40+ years of Internet research?



Network-layer functionality

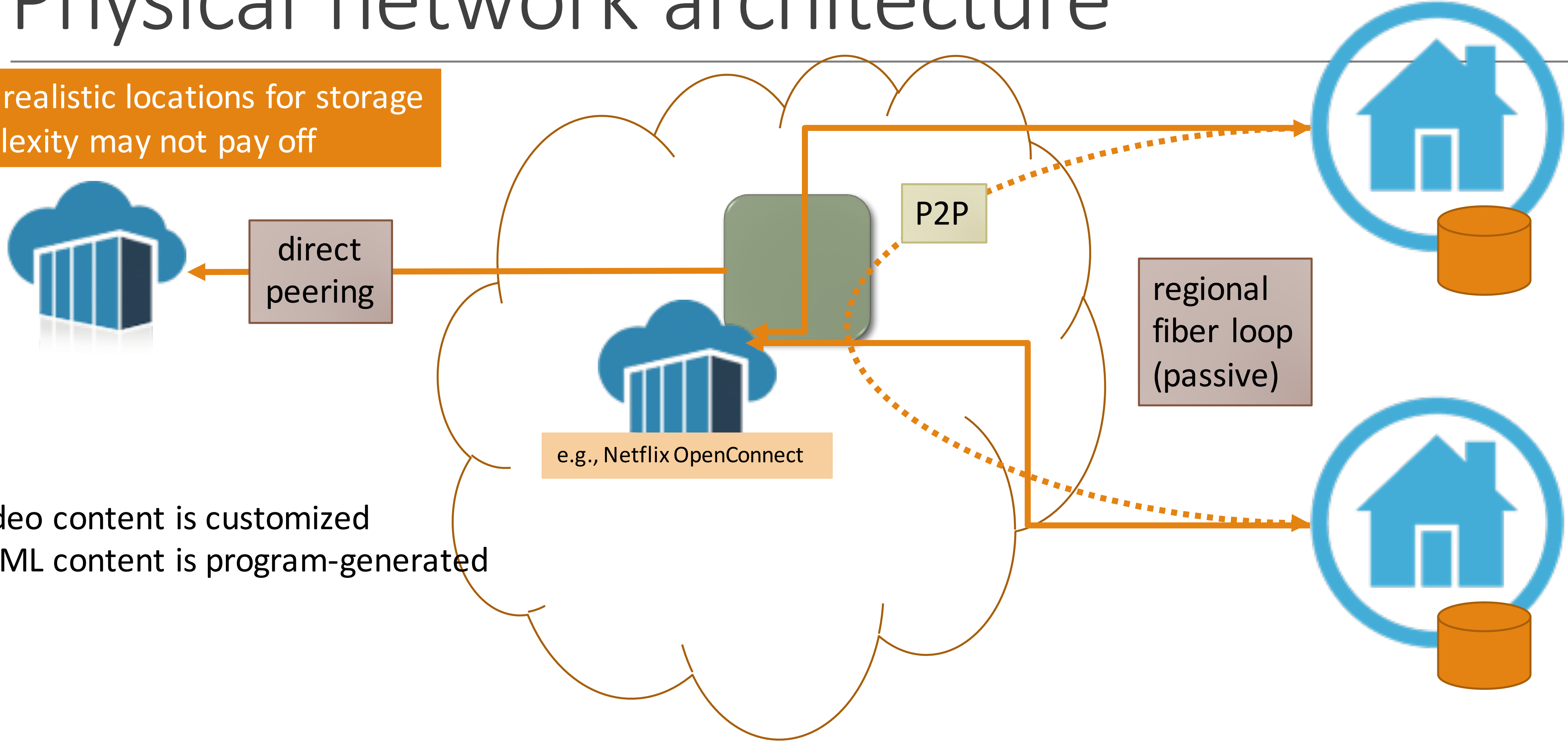
- IP mobility
- IP multicast
  - beyond local network
- IPsec (cf. to TLS)
- QoS
  - beyond basic two-level priority
- CCN (predicting)
  - static content and deep network architecture

Goal of maintaining low complexity has faded

- only a handful of implementations of most network protocols
- 3 browsers, 3 web servers, 2 operating systems (Android = Linux here)

Physical network architecture

only 3-4 realistic locations for storage
→ complexity may not pay off



some video content is customized
most HTML content is program-generated

Evolving towards a new architecture

Keep IPv6 as a substrate
- as well as eBGP, TCP, …

Unlikely, but…: unified control protocols
- patterns: configuration, on-path control, route exchange
- share encoding, security, reliability, discovery, session

Generalize SDN + fog model + CCN
- any node can host (authorized) code
- some provides CDN functionality
- some control nearby switches
- provide generalized location-based discovery (rather than specialized CCN model) of resources

What’s missing?

Increasing dominance of network operations costs (cf. to capacity costs)

→ Much better autonomous management systems at scale

Network management without a human in the loop

Automated discovery of failures & performance problems

More robust network support functions (AAA, DNS, DHCP)

My 2026 predictions

Still largely the same transmission technology
- fiber, OFDM

Still largely the same lower-layer protocols
- even for 5G
- but finally mostly IPv6

Similar applications
- but scaled up & integrated

Lots of boring new applications
- electric meter reading! finding parking spots!

Fewer cords (last mile & last foot)

Could things get worse?

Technology always gets better, but society doesn't

Risk factors:

- income stagnation → limited mass-market deployment
- geographic fragmentation
- privacy risk by integration of carrier traffic data into advertising
- "cableization" fragmentation of Internet
- political fragmentation & tribalization increased by Internet personalization
- security risks – Internet suitable only for cat pictures
- RF discovered to have significant health risks

Summary

As engineers, we should not overestimate the impact (and ignore the trade-offs)

Internet as cheap substitute for larger changes that we are unable or unwilling to make

Reflect more critically on what technical contributions have mattered and why

What are plausible architecture options and what's missing?