Thank you

• Thanks to Avi for giving me opportunity (and excuse) to put this together.

• Will present material quickly, & stress broad themes. You can read detail on your own.

• Will pause for short Q&A b/w sections. Happy to have extended conversations offline.
Goals today.

• What this talk does: Identify challenges and opportunities for economic research in digital infrastructure.
  – What are the most important (un)answered questions?
  – What are common errors and how can they be avoided?

• What talk does not do: Write your research proposal for you.
  – Will not underestimate your ability to take a creative approach to research.
The schedule

• Motivation
• Broadband
• Digital infrastructure more broadly
• Global deployment
• Pretentious & avuncular advice
Brief pause for Q&A

• Any questions?
What’s next.

• Motivation
• Broadband
• Digital infrastructure more broadly
• Global deployment
• Pretentious & avuncular advice

  – Why study this?
  – Why digital is similar but different from other infrastructure.
Research on digital infrastructure faces an uphill battle

- Biggest academic challenge: get an audience.
  - <sarcasm alert> A strategy for losing readership: Put “infrastructure” in the title & work in areas that lack a policy consensus. <end>

- Yet, nonetheless, researchers write about digital infrastructure & policy issues. Why?
  - Puzzles are intellectually engaging.
  - Policy issues merit attention.
  - Uses combination of statistics & stories.
  - Of interest to academic/policy/industry audiences.
But...What is digital infrastructure? It depends on the context.

- **Narrowly construed**
  - *Digital infrastructure* encompasses root servers, broadband lines, switches and routers, content delivery networks, data centers, cloud storage, cellular towers, and other physical assets.

- **Broadly construed**
  - *Digital infrastructure* includes complementary skilled labor for operating infrastructure that appears in same locations as digital hardware.
  - Includes both *provider & users* in a networked service, and both *public & private* providers of services.
Why study digital infrastructure?
Associated w/creating value.

• In 2017 payments for access in wireline forms contributed over $88.7 billion to US GDP, growing more than 30% from 2012 (in nominal terms).
• Payments for access in wireless forms amounted to over $96.0 billion in 2017, growing more than 57% from 2012.
• Astoundingly fast diffusion of smart phones in one decade. More than ¾ of US pop. On top of ¾ of households with wireline broadband.
• Online advertising contributed $105.9 billion to GDP in 2017 among Internet Publishing and Broadcasting and Web Search Portals. That has grown 250% since 2012.
• Electronic retailing, which the Census puts at over $545 billion for (NAICS 4541) electronic shopping and mail order houses. It grew 65% over the same period.
Why else? Digital does not seem to work like other infrastructure.

- **Rods and highways**
  - Finance out of tax $ & heavy users (e.g., gas taxes).
  - Privately financed R&D
  - Largely a gov’t function, with occasional self-provision. Occasionally priced toll roads & bridges. Unpriced roads.

- **Information super highway**
  - Financed for business interests. Mild subsidies.
  - Private & public R&D
  - Routine private supply & self-provision. Limited military. All priced. No price for open source.
  - Some subsidies, but few geographic obligations. Less in rural areas. Uneven competitive supply.
Why else? Changed a lot in a short time.

• **Dial-up era, c 2001.**
  – Dial-up dominates.
  – Half households online.
  – Web traffic dominates.
  – Pirated traffic growing.
  – Waiting for 3g.
  – Your grandparents use it for puppy pictures.
  – Concerns about MSFT & Intel & Cisco. Will there be any competition to the biggest platforms?

• **Broadband era, c 2016**
  – Broadband dominates.
  – 75% of HH online.
  – Streaming dominates.
  – OTT & gaming growing.
  – Waiting for 5g.
  – Your grandparents use it for cat videos.
  – Concerns about FB, Apple, MSFT, Amazon, Google, Tencent, Ali-Baba. Will there be competition to the biggest platforms?
Impressive growth. Digital infrastructure helped, but what role exactly?

Radio Shack Ad, c 1991.

- **Every activity in ad in smart phone.**
  - Record, store, play music & video
  - Take a picture, store it, reproduce.
  - Play a range of games
  - Calculate.

- **And a range of activities not on this ad**
  - Make phone call (w/o wires!).
  - Send/receive email.
  - Check the weather forecast.
  - Access Internet (except throttled streaming).
  - Find best route in traffic.
  - Get on an airplane or venue w/o paper.
  - Get calendar of appointments.
Why else study it? Lots of fun to make and display visuals.
Where is this going?

• Definition of digital infrastructure is a moving target, ranging from narrow to broad. So too are perceptions about the key policy issues.

• Hints at what economic researchers can contribute: defining the question, framing the ideas, and measuring the phenomenon in ways that inform and guide policy discussion.
Brief pause for Q&A

• Any questions?
What’s next.

• Motivation
• **Broadband**
• Digital infrastructure more broadly
• Global deployment
• Pretentious & avuncular advice
  – The naïve approach
  – Rural broadband
  – Supply
  – Demand
  – Opportunities and challenges
Many researchers intrigued by naïve questions about broadband

• A version of this key question: Should US gov’t spend $20 Billion dollars on upgrading rural broadband?
  – What are the economic benefits created by more broadband?

• Why interest in question?
  – Motivation by analogy with telephony, in which many providers received building & operational subsidies from universal service programs.
  – This was an actual proposal for part of 2009 stimulus package (which eventually reached $700B+).
The naïve approach to estimating effect of BB on local economy

• Find data on 3000 US counties. Label as i.
  – Key economic variable: average wage. \( W_i \)
  – Determinants: fraction business w/broadband. \( BB_i \)
  – Controls: ave est size, density, demograph. \( X_i \)

• Regress \( W_i = a*BB_i + b*X_i + e_i \)
  – Estimate yeilds \( a >> 0 \) and significant at 99% level.
  – Next: calculate wage gain from installing broadband.

• What is wrong with that naïve approach?
Improving on the naïve approach

• One approach: IV for $BB_{it}$
  – Estimate a first stage for $BB_{it}$. But what influences broadband supply but not wages? Good luck.

• Another approach: More data over time.
  – Growth of $W_{it}$ & $BB_{it}$, then first stage. What influences BB growth & not wage growth? Again, good luck.

• Conclusion: there is no easy way out.
  – Kolko, 2012, goes as far as possible w/this approach.
Confining the question to rural broadband

• Frontier infrastructure in less dense locations?
  – Again, BB → wages? Naïve approach is problematic.

• Might work as econometrics, but as economics?
  – Do you expect short-run & measurable response?
  – After years of neglect of low density areas, is that counter-factual relevant any longer?

• Warning: a specialized interest. Read widely.
Ask a different Q: Why more BB in some places and not others?

- Treat market entry/upgrade as endogenous.
  - Seamans, 2012, Cable firms react to threat of municipal entry. (Hint: they upgrade faster.)
  - Connolly, Prieger, 2013, entry/exit rates in BB differ across the country. Some areas more attractive.
  - Skiti, 2019. Anticipated potential entrants ➔ upgrade

- Identification: regions vary in attractiveness.
  - Attractive areas get (1) more providers (b/c more subscribers); & (2) higher bandwidth (b/c ARPU higher). Competition causes what? Hard to separate.
Many approaches to this topic

• If you have enough data at a fine-enough level, control for endogeneity of competitors...
  – Wallsten & Mallahan, 2010: Quality (speed) change when cable faces competitors? Speed increases.

• What about prices? Again, identification issues.
  – Chen & Savage, 2011: western cities with only monopolies or duopolies. How does pricing change w/rival? Price mediated by demand variety.

• Measurement constrained by data.
  – Opportunity? National broadband map?
Do we see market power in user behavior & contracting?

- BB ISPs increasingly offer multi-part pricing
  - Tiers of speeds w/caps on total monthly usage.
  - Interpret as behavior to exploit market power?

- Very detailed data on usage $\rightarrow$ structural model.
  - Nevo/Turner/Williams, 2016. Shadow value of ceiling $\rightarrow$ diminished use before monthly cap binds.
  - Malone/Nevo Williams, 2016. Relieve congestion w/peak load pricing, throttling, or caching? (Hint: pricing and caching, not throttling.)
  - Estimate CS, conditional on purchasing access.
A danger w/BB research: Policy interest waxes and wanes.

• US is somewhat unique.
  – In US arose b/c regulators take “facilities-based” approach, & require no interconnection. Questions bargaining power of carriers. Other countries differ.

• Political winds are fickle. Long term issue?
  – For example, recently moved to big app firms.
  – Bargaining b/w big apps & carriers? We know little.

• Moving targets of interest as industry changes
  – Google Fiber or spread of cloud as a natural experiment for diff-on-diff?
Research opportunities associated with demand: consumer surplus

• Generate CS from estimates of demand.
  – Rosston, Savage, Waldman, 2010, demand for attributes. Do infra-marginal users value speed?
  – Greenstein & McDevitt, 2011, use general data on upgrade from dial-up to broadband.
  – Brynjolfsson & Oh, 2012, use value of time online

• Research opportunity: model for access & use?
  – Users pay monthly charges & no usage fees. Users display “plastic” & “bursty” surfing that fills up leisure time. NOT the standard McFadden model.
More new research opportunities associated with BB demand

• Over-The-Top & restructuring of leisure time.
  – Netflix, Sling TV, YouTube TV, HBO Go, & so on.
  – NOT linear TV: Unscheduled; Binge; Variable time.
  – Again, static leisure/labor model just not right approach to estimating how digital alters use.

• No wired telephone, no cable television.
  – What do wireless-only & internet-only households tell us about demand for wireless/BB?
  – Much private interest in this topic. Much public interest in establishing facts/trends.
Long term challenge for research: The price for what service?

• The price index for broadband (in the US) looks all wrong. Has remained flat for ten years.
  – No quality adjustment. Yet, we know speeds went up.
  – CPI defined as price of fixed quality service; does not incorporate value of new service.

• Big opportunities for good price work.

• Issue: price index work is thankless.
What else is missing? Vexing questions w/new opportunities.

• Buyer of broadband gets access to what?
  – Complementary services, but no role in price index.
  – Broadband comes as part of bundled services. No simple price index for data.

• Considerable research on cable firms.
  – Focused on operations behind linear TV viewing.
  – Not (yet) part of conversation about new era.

• Issue: Estimated value of new good? Not really.
  – Lots of room for new models/data on this topic.
Brief pause for Q&A

- Any questions?
What’s next.

• Motivation

• Broadband

• **Digital infrastructure** more broadly

• Global deployment

• Pretentious & avuncular advice

  – Broader conceptions of infrastructure.

  – Supply.

  – Effects.

  – Demand.

  – Opportunities & challenges.
Many researchers intrigued by history of internet’s origins

• A version of key question: Should US gov’t spend $100B on inventing the next big thing (such as the internet)?
  – Should the gov’t have spent it in the past? What were the economic benefits created by gov’t funded R&D?
  – Note: An ex-post rationalization b/c a close history suggests the economic benefits had little influence on actual behavior. (Greenstein, 2015).

• Calculating economic benefits not easy.

• Despite all caveats, much hunger for research on this topic.
What else motivates a broader conceptions of infrastructure?

- More than BB delivers the internet.
  - Hardware you can see: Data centers, cloud, CDNs, servers, cellular towers, smart phones...
  - But why stop there? Many interconnected pieces – hardware, software, skilled labor.

- Some cities get far better service than others, and many cities get far better service than rural areas.
  - Just as the BB literature splits b/w (1) studies of the determinants of its diffusion & (2) studies of the effect of diffusion on economic activity, so too does the literature examining digital infrastructure split b/w (1) & (2), just broadly construed.
Why do some regions have better infrastructure than others?

• Many complements vary by location.
  – Forman et al (2005): compare business use of basic/advanced internet. Basic almost everywhere, while advanced more frequent in some cities, right industries, etc.

• More opportunities in this line of inquiry.
  – CDNs, cloud, servers, skilled labor, cell towers?

• Key issue: Recognize which margin is identified.
  – Some infrastructure available everywhere, some not. Varies over time. Today, satellite at worse.
What effect does better infrastructure have on activity?

• Regions/cities vary in thickness of supply of the local labor market for skilled labor in software. Interpret as infrastructure of a location.

  – Tambe, 2014, asks: how does the local supply shapes the productivity of firms in those areas?
    • Productivity estimate on use of Hadoop w/interactions of use w/supply conditions for Hadoop programmers. Higher in areas w/better supply. Potential extensions?

  – Forman et al, 2008, asks: Does city provide third party services that substitute for internal provision?
    • Observe in propensity to employ in-house employees.
Does digital infrastructure alleviate or acerbate regional inequality?

• Relate wage growth, etc. $Y_i$
  – Determinants: Advanced Internet investment, $II_i$

• Regress $Y_i = a*II_i + b*II_i*Xi + e_i$.
  – Approach: internet generates different outcomes in different places. Exacerbation of regional inequality.


  • Placebo tests. Tests for right timing.

  – More room for extensions of this puzzle.
Challenges w/broad conception: What precisely are we measuring?

• “Regions” = a bundle of factors.
  – Positive correlation of factors: Frontier programmer & IT admins. More local data centers & lines to data exchanges → Identification issues in x-section.

• Recent challenge: geographic association.
  – Cloud has become footloose. It shapes productivity, but difficult to make one-to-one association at a geographic level.
Digital as one of many innovative features of a region

- Delgado et al, 2012, ask: Do regions have different capacity to innovate?
  - Determined by accumulation of private firms action.
  - Capacity of regional infrastructure & digital infrastructure difficult to disentangle.
  - Tied to different levels of entrepreneurial startups and different rates of patenting.

- Pull out different roles of digital infrastructure?
  - Opportunity: Many authors find internet encourages communications & innovative activities. What else?
Underexploited opportunity: wireless access

- Big variance around the US in quality of access over time, over the different carriers.
- Policy interest: What is economic value of new phenomenon (e.g., smart phone, 4G)?
- Wifi also a common access mode. Same question arises.
- Tablets & smart phones diffused into wireless ecosystem, & changed usage, & motivated investments in digital infrastructure. How much?
- Principal challenge for estimating demand: need own demand estimate & substitution w/alternative forms of wireline access.
Another opportunity? Spectrum as infrastructure?

- Spectrum allocation.
  - Couch it in trad’l economic terms, such as misallocation issues. E.g., Hazlett & Munoz, 2009.
  - Fun topic. (Almost) unbelievable stories of goofy policy.
- From auction data.
  - Participants write about the economic lessons. E.g., Cramton et al, 2011.
- Spectrum value varies by regions, anticipated uses.
  - Changes in value over time. E.g., Connolly et al, 2017.
- Have allocations altered regional experiences?
  - Map US data into regions.
- Big differences around the world in allocation policy.
Opportunities? Look one step down from digital infrastructure

• How productivity/behavior of firms changed.
  – Ewens et al, 2017. VCs & the cloud? Variable costs decline → more spray and pay models of startups.

• Growing area of research recently.
More opportunity? Restructuring → network quasi-natural experiments?

• Dispersion of responsibility: Interoperability designs are public; Yet, investment & operations are private. Researchable?
  – Rate of improvement slowing in public organizations? (See e.g., Simcoe, 2012)

• E.g., Smart phones diffusion → demand for equipment & towers, & rise in demand for programmers.
  – Some cities benefit, others not. Which ones? Why?

• Apple, Google, FB, Amazon, MS & vertically integrate into CDNs, fiber?
  – Opportunity for natural experiment?

• What is value of activity displaced by internet?
  – Analysis without stakeholder bias.
Brief pause for Q&A

• Any questions?
What’s next.

• Motivation
• Broadband
• Digital infrastructure more broadly
• **Global deployment**
• Pretentious & avuncular advice

  – Natural experiments
  – Investment
  – Digital measurement
  – Opportunities and challenges
Many researchers intrigued by global policies for digital

• A version of this key question: Should the World Bank lend $10 Billion dollars to upgrade the wireless system in an emerging economy?
  – What are the economic benefits created by digital infrastructure?
  – What has been the payoff in recent past?

• Why interest in question?
  – These type of proposals do, in fact, get made at the World Bank & elsewhere.
  – Emerging economies do, in fact, want to know if such investment are worth the expense.

• Lots of policy interest from OECD, IMF, World Bank, and many NGOs.
What are the bottlenecks to moving forward?

• Int’l statistics available for IT at country level.
  – But US & China dominate many internet mkts.

• Bottlenecks to progress.
  – Only so much variance between 200+ countries.
  – What is identified? Much infrastructure correlated within country. The rich are rich on multiple dimensions, and the poor are poor in everything.
  – Can estimates inform a compelling policy debate?

• Quasi-natural experiments in policy details?
  Difficulty of keeping up w/details (e.g., EU case).
One agenda: Natural experiments for identifying the effects of digital.

- The UK deployed DSL in a somewhat random way, leaving neighbors w/different service
  - A way to identify the consequence of speed on productivity. (DeStefano et al, 2018).
  - Changes property prices for homes (Ahfeldt, Koutroumpis, Valleti, 2014).

- France & Italy required all gov’t agencies use Linux, but only France enforced the decree.
Related agenda: Nat’l experiments in emerging economies

• Africa provides numerous experiments
  – Jonas Hjort and Jonas Poulsen, 2017. When cable was first strung along the African coast. A comparison of firms with access to those without.

• Growing field. Advantages & disadvantages.
Yet another direction: Endogenize world wide business investment.

- What determines investment in digital infrastructure around the world?
  - Athey and Stern, 2014. Where do operating system users use pirated software and proprietary software? Tension b/w explanations based on “affordability” & “institutions.”
  - Ackermann and Greenstein, 2019. Where are the web servers? Which countries have large numbers of open source or not? Affordibility & institutions, plus network quality, & technical sophistication of the local populace.
New direction: Digital enables new measure of economic activity

• Valuable for now-casting in emerging mkts, where GDP measurement apparatus absent.
  – Do geo-located IP addresses give as much information as light from satellite photos? Ackermann et al, 2017, provides evidence.
  – Activity on Twitter (as measured thru GPS-labeled photos) give as much information as the light from satellite photos? Indica, 2018, finds evidence.

• Geographic variance within countries? Yes.
  – Room for matched estimates of cities.
Brief pause for Q&A

• Any questions?
What’s next.

- Motivation
- Broadband
- Digital infrastructure more broadly
- Global deployment
- Pretentious & avuncular advice
  - Policy/profundity tradeoff
  - What is neutral?
  - Journalists
  - Nat’l academies
  - Quid-pro-quos
  - Testifying
  - Trolling
I have spent much of my career at the boundary of academic/policy

- Nobody ever gives you a manual on how to navigate the opportunities and challenges.
- Here are a few reflections on being a neutral policy analyst in a world inhabited (mostly) by advocates.
- FWIW, these are just one person’s opinions. There is no right or wrong answer.
First advice: Never lose sight of the policy/profundity trade-off

- Pass on projects destined for A. Allocate your time during tenure clock to B & D. That’s your job.
- Much policy work falls into C. An occasional project that falls into C is OK, but not too much before tenure. Has to be packaged well at tenure-time.
- Important consideration: Big learning curves in policy research. Can work towards B & D by learning while doing A & C?

<table>
<thead>
<tr>
<th>Policy &amp; profundity trade-off.</th>
<th>Not a profound result that academics read or talk about.</th>
<th>A profound result that academics read, and talk about.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No short run impact on firms or policy</td>
<td>A. Most of the time this is what happens to research. <em>sigh</em></td>
<td>B. The senior faculty member in the office next door is happy with you.</td>
</tr>
<tr>
<td>Large impact on firms and policy.</td>
<td>C. Intrinsically satisfying, but must be packaged for letter writers so they appreciate.</td>
<td>D. Rare. Worth the trouble when the opportunity arises. Savor the experience.</td>
</tr>
</tbody>
</table>
How to participate in policy research as a neutral academic

• What is neutral? Shorthand for NBER’s position.
  – Thou-shall-not-shorthand: never use the phrase... “The government should do x...”
  – Thou-shall-do-shorthand: There is (always) a measurement dimension, & (usually) an identifiable reader (in policy circles) for the facts & analysis.
  – BE AN HONEST BROKER: Fair consideration of POV.

• What is NOT neutral?
  – Motivated reasoning to a predetermined answer, supported by self-interest, ideology, or convenience.
Challenges in feeding policy analysis to journalists

• One challenge: it can put you in the position as “Contrarian economist who obsesses on limits.”
  – Firms have $$$ at stake → do not want to hear it.
  – Ideologues have a view → dismissive or unyielding.
  – Can be lonely/unpleasant. Use PR. Use SSRN. Etc.

• Another challenge: no sharp result on Twitter.
  – “On the one hand, on the other hand” ignored.

• But honest journalists do want to find experts.
  – Establish credentials quickly. Be ready w/stories.
When advocates & academics mix at national meetings

• Academics have something advocates lack.
  – Facile use of statistics, visual aides, breadth of facts.
  – Any insight that takes time and depth to assemble.
  – Tenure/gravitas/memory. Your paycheck depends on being right in the long run, not on scoring a “win.”

• Advocates have something the academics lack.
  – Willful/strategic myopia about statistics.

• Remember: reports can inspire.
  – One did for me at an impressionable moment.
Mixing analysts & advocates can be enjoyable or awkward.

• Enjoy conversation at dinner/receptions.
  – My goto phrase: “In your shoes it may appear to be X, but from the outside looking in, it appears to be Y.”

• There are smart people everywhere.
  – Most advocates know stuff. Listen closely. Many are closet intellectuals. Many dislike motivated reasoning & disdain political divisiveness. (Some don’t)
  – Some crave conversation & dialogue. (Some don’t.)

• Be wary if advocates pay. It’s their job to recruit.
  – Before you know it... you “picked a side.” COI applies.
Be thoughtful about picking a side: Quid-pro-quo-quo have consequence

• Quid-pro-quo-quo that work for neutral academics.
  – Walk out with a paper, or unrestricted use of data.
  – Deep understanding of firm & it guides next paper.
  – Temp data mercenary → pay for engagement ring.

• Quid-pro-quo-quo that do not work for academics.
  – Damaged reputation. Conflict of interest that restricts. Waste of time during the tenure clock.
  – Never give a corporate or policy lawyer the right to censor work. Be wary of the unstated conditions.

• Ask questions before agreeing to commitment.
Testifying to Congress: distinguish b/w show and substance.

• Have right expectations.
  – Representatives want to look good. It’s their show.
  – Political staff wants to win.
  – Discussion highlights points of (dis)agreement. That’s the point!

• Just do it.
  – Goes in the written record.
  – Makes your parents, spouse & friends proud – albeit, not your teenage kids.

• How work mostly gets done.
  – Make efforts to testify at the FTC, FCC, DOJ, CEA, FDA, etc. Agencies do the work.
  – You don’t always get credit. Needs to be packaged at tenure-time as “the expert.”

• Staff have limited time.
  – They read WSJ, NYT, WP, short pieces in HBR, SMR, VOX, Quartz, some blogs.
  – Write for them!
Political trolling & stalking: a vexing new problem for the digital era.

- Congrats! You know you reached the big leagues when the crazies start paying attention to you.
  - First act: apologize to the IT dep’t after your post brings down university’s servers.
    - You need them on your side.
  - Can be unpleasant. Hard to know what is right thing to do.
    - Don’t face it alone. Involve dep’t chair, dean, research admin.
    - Early involvement is better.
  - If you can, ignore sound & fury.
    - Beware of Streisand effect. (i.e., bringing awareness to it invites more unwanted attention).
    - Sometimes it can die on its own.
- If it gets ugly, engage police & lawyers for university.
Thanks for your attention

• We are done.
• Any questions?