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Testing the virtuous circle of innovation: Does it increase broadband investment? A preliminary discussion

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Introduction

The theory of the "virtuous circle of innovation" is an argument proffered in support of network neutrality. The virtuous circle is the notion that the growth of content and applications stimulates demand for internet subscriptions which generates revenue for operators which then invest in infrastructure. This argument was first introduced by the the Federal Communications Commission, the telecom regulator of the United States, in its Open Internet Report & Order of 2010.[1] Subsequently it was presented in a brief by the Open Internet Coalition[2] and another by a group of engineers[3] as part of the case *Verizon v. FCC.* In its decision[4] for the case, the District Court of Appeals of Washington, D.C. mentioned the virtuous circle. Earlier game theoretical work by Cheng, Bandyopadhyay and Guo[5] (2008) and Choi and Kim[6] (2010) provide implicit support this assertion, that by requiring broadband providers to treat all data equally will encourage them to invest in broadband infrastructure.

This paper offers a review of the design of an empirical test of this theory. More specifically it tests one suggestion of the theory. The test, an econometric model built with empirical data from a variety of countries (US, Chile, Peru, Netherlands, Brazil, Slovenia, France, and the Nordic countries), attempts to determine whether the imposition of net neutrality rules increases the network investment. The test is not yet complete, but its design is presented to highlight the many issues and challenges in developing empirical models to support net neutrality policymaking. The test and its outcome will likely be imperfect, but a discussion of the design of the test can be helpful to highlight questions and assumptions that underlie net neutrality.

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[1] *Open Internet Report & Order*, 2010, https://apps.fcc.gov/edocs_public/attachmatch/FCC-10-201A1.pdf.
[2] Goldberg and Michalopoulo, "Brief of Intervenors Open Internet Internet Coalition, Public Knowledge, Vonage Holdings Corporation, and National Association of State Utility Consumer Advocates." http://www.fcc.gov/document/brief-open-internet-coalition-no-11-1355-dc-cir
[3] *Internet Engineers Amicus Brief, No. 11-1355 (D.C. Circuit)*, November 1, 2012, http://www.fcc.gov/document/internet-engineers-amicus-brief-no-11-1355-dc-cir.
[4] Verizon v. FCC, 740 F. 3d 623 (Court of Appeals, Dist. of Columbia Circuit 2014). http://www.cadc.uscourts.gov/internet/opinions.nsf/3AF8B4D938CDEEA685257C6000532062/$file/11-1355-1474943.pdf
[5] "The debate on net neutrality: A policy perspective" Information Systems Research. 2011 http://pubsonline.informs.org/doi/abs/10.1287/isre.1090.0257
[6] Pil Choi, J. and Kim, B.-C. (2010), Net neutrality and investment incentives. The RAND Journal of Economics, 41: 446–471. doi: 10.1111/j.1756-2171.2010.00107.x

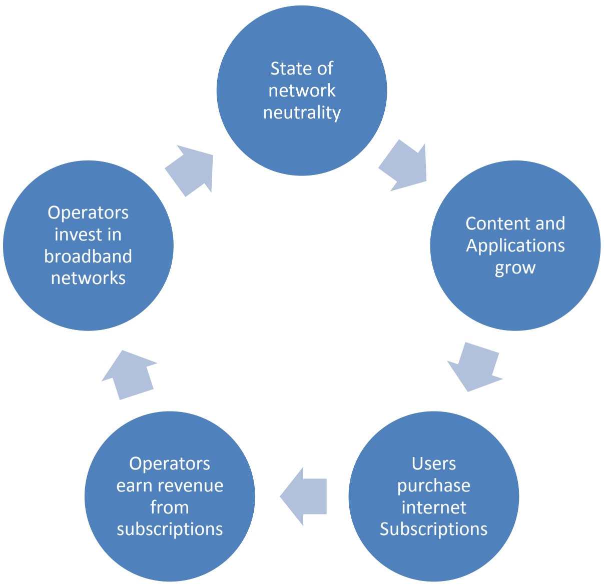
The paper reviews the virtuous circle and other theories of innovation. Then it discuss the analytical and technical issues which should be considered in designing a test. As it is possible to manipulate data to tell a story favorable to support a particular policy, this discussion is undertaken to educate readers to be more critical about the particular data sets and their analysis. The goal of the discussion is to uncover all the pitfalls and shortcomings of data so that the final conclusions can be as accurate as possible. It highlights possible outcomes of the test and and limitations for applicability. Though the test is not complete, it highlights some anecdotal findings to date.

The Virtuous Circle and Other Theories of Innovation

In its Open Internet Report & Order, the FCC presented the theory of the "virtuous circle of innovation"[7] as an argument in support of network neutrality. It notes,

> *The Internet's openness is critical to these outcomes, because it enables a virtuous circle of innovation in which new uses of the network—including new content, applications, services, and devices—lead to increased end-user demand for broadband, which drives network improvements, which in turn lead to further innovative network uses. Novel, improved, or lower-cost offerings introduced by content, application, service, and device providers spur end-user demand and <u>encourage broadband providers to expand their networks and invest in new broadband technologies. (emphasis mine)</u>*

The virtuous circle might be illustrated in the following.



Author's diagram of "virtuous circle"

[7] FCC Open Internet Report & Order 10-201, December 21, 2010. Paragragh 14. https://apps.fcc.gov/edocs_public/attachmatch/FCC-10-201A1_Rcd.pdf

In the virtuous circle theory, one key actor is the innovator who has free rein to invent and is assured a network where he can distribute his invention to users.

Other theories that explain internet innovation include the end to end principle by Lemley & Lessig, creative destruction, diffusion of innovations, disruptive innovation, and the theory of complementary assets. However plausible any of these theories may be, they, like other explanations of innovation, are theories. For a policy to have salience and efficacy, it should likely be supported by evidence. Furthermore from a scientific perspective it should be possible to observe the theory in action and ideally to design experiments where the theory is proven.

To be sure, proving any one theory is very difficult. Any one of the innovation theories may be responsible for all, some, or none of internet innovation. It could be some or a combination of theories which account for innovation. However there is no known matrix that suggests theory #1 is responsible for x percent of internet innovation. Theories, until they are proven, are not economic laws. That is to say, they are by definition theoretical, not empirical. Even Lemley and Lessig observe that there there are other important features of the network's design and further, "As we have said, no one fully understands the dynamics that have made the innovation of the Internet possible."

The End to End Principle

In 2000 legal scholars Mark Lumley and Lawrence Lessig presented their manifesto[8] for preserving innovation on the internet, calling it the "end to end principle", appropriating the term from a 1984 paper[9] by engineers Saltzer, Reed & Clark. The original proposition follows:

> *The principle, called the end-to-end argument, suggests that functions placed at low levels of a system may be redundant or of little value when compared with the cost of providing them at that low level.*

In a speech[10] at the FCC's Open Internet Access Committee in 2010 author David Clark noted that the original paper was not about "openness" and in fact that the word was not even in the original paper. Instead the paper was about "correctness" and where it appropriate to place functionality in the network depending on the benefits to be delivered. As such, it could be interpreted that prioritization should be applied at the higher level (or core) of the network, and not the ends, when it is warranted.

In any case, Lemley and Lessig used the notion of the "end to end principle" to explain the virtues of internet architecture, its openness, how the "ends" of the network where users and applications reside should be "intelligent", and that the protocols and pipes be as simple and general as possible.

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[8] Lemley, Mark and Lawrence Lessig. "The End of End-to-End: Preserving the Architecture of the Internet in the Broadband Era." October 1, 2000. UC Berkeley Law & Econ Research Paper No. 2000-19

[9] J. H. Saltzer, D. P. Reed, and D. D. Clark, "End-to-End Arguments in System Design," *ACM Trans. Comput. Syst.* 2, no. 4 (November 1984): 277–88, doi:10.1145/357401.357402.

[10] Remarks from FCC Open Internet Access Committee meeting. http://www.fcc.gov/events/open-internet-advisory-committee-meeting, scroll to 65 min

Furthermore they decried the injustice that telephone and cable companies were regulated differently, that telephone companies were required to unbundle but not cable companies. They predicted that unless similar restrictions were placed on cable, that prices and innovation would be harmed. The predicted that the end to end principle which "governed the internet since inception" would be compromised. It may be difficult to tell whether internet innovation has been compromised because cable was not unbundled in the US. Indeed a number of application innovations have emerged since 2000 including Skype, Facebook, WhatsApp, and the online version of Netflix.

Essentially Lessig & Lemley's paper states that the internet's architecture should be left the way it is because it has produced so much benefit and innovation. Their notion of the end to end principle is frequently invoked as justification to preserve the internet architecture through network neutrality. However potent and compelling the Lessig & Lemley interpretation of end to end principle is, it is not a proof of innovation. It is a theory.

Creative Destruction

Austrian economist Joseph Schumpeter's presented his re-interpretation of Marx in *Capitalism, Socialism and Democracy.*[11] Giving the example of the dearth of wood forcing a need to find energy substitutes, he promoted the idea that necessity creates invention. Rather than see the business cycle as a Marxist process of accumulation and annihilation of wealth, Schumpeter proposed creative destruction as an engine of renewable economic growth. Creative destruction is a force "*that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one".* Schumpeter saw entrepreneurs as creating economic growth and destroying established industries and monopolies. He would have likely celebrated the emergence of over the top technologies (OTTs).[12]

In addition to his concept of "creative destruction", Schumpeter advanced other concepts of technical change into neoclassical economic theory. He is also known for his discussion of the trilogy of invention, innovation, and diffusion. He distinguishes between invention (generation of new ideas), innovation (development of new ideas into a marketable products and process), and diffusion (spread of these products and processes across potential markets). Search engines provide an example of Schumpeter's concepts. A search engine is an <u>invention</u>, the first of which was "Archie", a tool used to search webservers by scientists at McGill University in Canada in 1990. Some seven years later, Google created the <u>innovation</u> of pairing search results with advertising, an idea they engineered from the company Goto.com. <u>Diffusion</u> could be described as the process by which users adopt Google's services.

Some additional learnings from Schumpeter include the important distinction between <u>adoption</u> (the decision to incorporate a new technology into activities, typically a firm) vs. <u>diffusion</u> (how market share changes over time). Schumpeter believed adoption is driven by costs and benefits and prior investment decisions, e.g. replacement vs. new goods.

[11] J.A. Schumpeter, *Capitalism, Socialism, and Democracy.* (Harper, 1942).

[12] The author admits that the term OTT is imperfect, but do not know of another term to distinguish those services which are delivered "over the top" of the network from those that are delivered by network owners on their managed facilities.

When reviewed in light of Schumpeter, the "circle of innovation" may be better termed the "circle of diffusion". In Schumpeter's view, the firm creates its own inventions and innovations, but they are adopted by users through a process of diffusion.

Diffusion of Innovations

An understanding of adoption and diffusion leads naturally to the work of Everett Rogers, known for his Diffusion of Innovations[13] theory. He defined diffusion as a process in which innovation is shared over communication channels over time among the members of a social system. An innovation (also called technology) is an idea, practice or object that is perceived as new. It can include a hardware and/or software aspect. It may or may not be a part of a technology cluster. He also outlined re-invention as a change or modification of an innovation.

Rogers discussed the perceived attributes of the innovation including relative advantage (improvement over the status quo), compatibility (how it fits into the person's life), complexity (degree of difficulty of adoption), "trialability" (how much one can experiment before adoption), and observability (degree to which benefits are visible to others).

Rogers defined the communication channels as mass media (creates knowledge and awareness), interpersonal (persuades individuals), heterophly (experts), and homophily (peers). Rogers discussed time as steps in the innovation process: knowledge, persuasion, decision, implementation, and confirmation. Decision are made either optionally, collectively or by authority. Rogers emphasized that the diffusion of innovation as a social, not economic process. He described the norms, degree of networks, and interconnectedness in social systems. In Rogers' model, opinion leaders and change agents are important.

Rogers model and its attendant bell curve have been applied to numerous innovations and is especially popular to explain the growth in smartphones. The "virtuous circle" might be too general for Rogers, who would have likley emphasized the role of social actors in technology adoption. In Rogers' world, simply having an innovation, such as the internet, is not in itself enough to drive adoption. He was particularly interested in laggards, the people who don't adopt technology regardless of the benefits it brings. Rogers suggest that people have to be introduced to innovation through peers.

Indeed peers can be very important in getting others to adopt the internet and related technology. For example mobile phones are almost ubiquitous among teens and adults under age 25. Also these groups generally prefer online video over linear television.

Adoption can also be driven by fiat. For exmaple, the government can mandate the switch from analog to digital televison. It can make requirements for all providers to use the mobile same standards and so on.

[13] Everett Rogers, *Diffusion of Innovations*, 5th Edition (Free Press, 2003).

Disruptive Innovation

Disruption is a another term frequently used with innovation. It comes from Clay Christiansen's *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.*[14] Christiansen describes how "good", well-managed companies lose their footing because low-cost competitors focusing on an unprofitable market segment create "disruptive innovation".

Christiansen describes the difference between sustaining technologies and disruptive technologies and notes that most technological advances are sustaining technologies; they improve the performance of existing products. Occasionally technologies are disruptive. They underperform existing products at first, but then emerge to be simpler, better, faster, and cheaper than existing products.

One characteristic of disruption Christiansen observes is that it provides firms lower margins, not higher profits. This can be observed with Skype and WhatsApp. Skype's revenue was $860 million for the year ended 2010, its last published revenue before it was purchased by Microsoft for $8.5 billion. Skype had 668 million users, 18% of which were active users, and 8.8 million paying users.[15] With 124 million active users, Skype made less revenue than the annual operating profit of many mobile operators. It is worth noting that an operator with 124 million subscribers would earn many billions of dollars, but Skype made less than $1 billion.

Microsoft does not provide individual financials for Skype, but it is bundled in the same business line with the company's Lync platform, a communications platform for companies. Of the world's largest 100 companies, 90 purchase the Lync platform for enterprise communications.[16] Skype is being integrated into Lync, so it is not clear to what degree Skype earns revenue or is a "loss leader" for Microsoft. Companies purchases Lync for a fee, and Skype does generate revenue through off-net communications. However most of Skype's users are individuals who do not pay for the service. Like many internet companies, Microsoft may offer Skype both in free and premium versions, with the paying customers subsidizing the non-pay users. In any case Skype may be the single most powerful disruptor in the history of telephony, accounting for a third of all long-distance calls globally.[17]

Similarly WhatsApp is a service offered for free for the first year and then for $1 per year thereafter. These fees don't necessarily cover the operation of WhatsApp, but WhatsApp is used as a loss leader for Facebook to keep users on its platform. In the context of the "virtuous circle" discussion, it's important to realize that Skype and WhatsApp can't exist unless a larger network is already in place, which leads to the work of David Teece.

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[14] Clay Christiansen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.* (Harvard Business Review, 1997).

[15] "Microsoft Advertising International Skype Media Overview." (Microsoft, July 2013), http://advertising.microsoft.com/en-us/WWDocs/User/display/cl/brand_subproperty/1589/global/Microsoft-Advertising-International-Skype-Media-Overview.pdf.

[16] Dina Bass, "Microsoft Skype Unit Approaching $2 Billion in Annual Sales," *Bloomberg*, February 19, 2013, http://www.bloomberg.com/news/2013-02-19/microsoft-s-skype-unit-approaching-2-billion-in-annual-revenue.html.

[17] "Skype Costing Mobile Operators $100m per Day » Telecoms.com," accessed July 2, 2014, http://www.telecoms.com/183462/skype-costing-mobile-operators-100m-per-day/.

Complementary Assets

When thinking about internet innovation, David Teece's 1986 paper "Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy"[18] is a touchstone. Teece observed that most innovations are not products themselves. They have to be combined with complementary assets before they can be marketable products. Such partnerships lower barriers to entry for the innovator and can provide rewards to an innovator upfront.

Teece discusses a number of assets that must be in place before an innovation can take root. They include marketing, specialized manufacturing, and/or after-sales support. He distinguishes the assets into generic, specialized, and co-specialized categories. In the context of the internet, HTML may be a generic asset, a language that allows innovators to create websites. Just as a factory is needed to make shoes, a mobile application needs a network. Thus a specialized asset may be an operating system that runs on a mobile phone, such as Apple iOS or Android. A co-specialized asset may be a 4G mobile network and an Apple iPhone 4s, its complementary asset. The iPhone features can't be realized unless they are delivered on the appropriate 4G mobile network.

The Teece thesis contradicts Lemley and Lessig's end to end principle. Teece essentially says that different parties have to make partnerships or "join complementary assets" (e.g. content provider and broadband provider) in order to make applications known. Applications on their own have no value, or will almost never be found, unless they are joined with their complementary asset.

Among any of these theories it is possible to find examples and contradictions. However familiarity with the theories is important in crafting policy. A table of the theories and the number of their academic citations is offered below. To be sure, theories that are older tend to have more citations simply because they have been in the public domain longer. However Rogers diffusion theory is by far and away the most cited theory of innovation. The fifth edition and most popular edition of his book, *Diffusion of Innovations*, appeared in the same year as Tim Wu's paper "Network Neutrality, Broadband Discrimination."[19]

Theory, Year	Academic Citations[20]	Notion	Policy Prescription
Virtuous Circle (2010)	NA	Growth of internet traffic creates consumer demand	Net neutrality
End to End Principle (Lessig & Lemley, 2000)	494	Ability of data to reach any point in the network creates innovation	Net neutrality
Open Innovation	8420	Companies need to look outside their	Partnerships, shared risk and

[18] David Teece, "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy," *School of Business Administration, University of California, Berkeley, CA 94720, U.S.A.*, June 1986, http://www4.lu.se/upload/CIRCLE/INN005/Teece_Reflections.pdf.
[19] Tim Wu, *Network Neutrality, Broadband Discrimination*, SSRN Scholarly Paper (Rochester, NY: Social Science Research Network, June 5, 2003), http://papers.ssrn.com/abstract=388863.
[20] From Google Scholar July 20, 2014

(Chesbrough, 2003)		own walls for ideas	reward
Creative Destruction (Schumpeter, 1942)	27,386	Necessity creates invention	Upstarts will topple monopolies. Government does not need to regulate monopolies.
Diffusion of Innovation (Rogers, 1962)	57,261	Adoption is a social, not economic, process	Use peers to encourage internet adoption.
Disruptive Innovation (Christiansen, 1997)	9965	Technologies from the low end of the market become the standards	Profits are a signal for upstart firms to find disruptive innovation
Complementary Assets (Teece, 1986)	8081	An asset needs it complement in order to become an innovation	Allow partnerships across the internet value chain to stimulate innovation

Summary of of innovation theories and their possible implications to internet policy

This paper does not attempt to prove or disprove any of the theories as a whole, a far too ambitious goal. It attempts to test one just one of the assertions of the "virtuous circle of innovation", that broadband investment is driven by the growth of content, services, and applications on the internet. However, upon review of the other theories of innovation (most notably Teece), it might be concluded that internet innovation results *because of* pre-existing investment in network. Similarly, it is possible that the circle turns both ways and that there is mutually reinforcing relationship, rather than a one-direction relationship.

The design of the "virtuous circle" test

Like any econometric inquiry, this test will be designed to test a null hypothesis. The test will either accept or reject the null hypothesis. The null hypothesis is: there is no relationship between net neutrality regulation and broadband network investment.

If the test rejects the null hypothesis, the further conclusions may be (1) net neutrality regulation increases broadband network investment. Or (2) net neutrality regulation decreases broadband network investment.

Another possible outcome is that the relationship between net neutrality regulation and broadband investment cannot be determined because the data is not appropriate or reliable.

Limitations of investment data and other technical and analytical concerns

The following discussion outlines the challenges of making an empirical study of net neutrality.

The components of net neutrality laws

Net neutrality laws differ from country to country. The Chilean law, the first in the world to promulgate net neutrality, has provisions for virus protection, security and parental controls. The American rules noted lighter requirements for mobile than for fixed networks. As each law has different requirements, the market impact could be different. In the cases of Brazil and Peru, net neutrality is one provision of a larger law on the internet and telecommunications.

In addition to different definitions, each country makes its own provisions, enforcement, and punishments with net neutrality law. This can create different incentives for firms which may impact their behavior. For example Brazil notes that it can levy a fine of 10% of annual revenue for violation.

It can also be the case that laws could be promulgated but not enforced, so operators may act as if they are not beholden to laws. Similarly if a current law is currently under legal challenge, regulators may not enforce it as they would under other conditions.

This poses a challenge with the study in explaining firm behavior. For example though the Nordic countries have opted not for laws, but instead for multi-stakeholder dialogue with regulators, operators, application/content providers, and users. This governance model has been in effect longer than any net neutrality law in the world, and no violations are on record with regulators. It appears that this model deters bad behavior. The study will attempt a parallel investigation of the Nordic countries to see whether multi-stakeholder governance models can work in the same way as net neutrality laws.

Time

A key challenge of the investigation is that investment and innovation may take years to be observed. Capital investment is typically conducted over years and built upon on prior cycles, technologies, and decisions. With any technology, there may be a path dependency. Technological decisions of the past can influence investment in the future.

It could be that at the time of the imposition of a net neutrality rule, that firm(s) are in the midst of an investment cycle where commitments are already made and need to be honored. The impact of the law might not be felt until the next investment cycle.

However the supposition of the "virtuous circle" is that the growth of traffic is driving investment all along, so ostensibly the firm would have taken traffic growth into account prior to launching the investment cycle. If this is the case, the investment catalyzed by net neutrality laws should be observed in the test.

Innovation itself may take years and does not necessarily proceed in a linear fashion. Firms may have inventions or patents which they never release to market. Alternatively they propose innovations which are never adopted. These two situations could exist regardless of the state of infrastructure investment.

Another challenge is that countries have promulgated rules at different times. Some countries may offer a longer period to observe than others.

The components of investment metrics

Capital expenditure (CAPEX or capex) refers to the purchase of fixed assets which have a useful life beyond one year. In the accounting world this refers to plant, property and equipment (PP&E), generally things that are difficult to convert to cash. When capital expenditure is substantial, the purchase is formalized and approved by shareholders with the expectation that a firm will earn a return on the investment in the future. Such information is generally appears on a firm's cash flow statement under "Investment of PP&E".

The financial measure of capital expenditure should be differentiated from the larger discussion of investment, which can refer to the expenditure of time, energy or matter in expectation of future benefit. This study focuses primarily on the broadband infrastructure capital expenditure of operators. To be sure, operators may undertake research and development for new broadband delivery technology which is an "investment", but that would likely not be counted under capital expenditure.

Measurements of capital expenditure are not the same across companies or countries, and the kinds of metrics used can have an impact on amount of investment recorded. The effect can be negligible or material. Investment data can be found in financial statements of public operators; in reports by research firms, financial institutions, and equipment providers, in reports from regulators, and in the accounting systems of companies.

Capital expenditure (CAPEX) needs to be distinguished from operating expenditure (OPEX), the ongoing costs of running a business. The capex for an operator could be the purchase of mobile masts, while the opex would be electricity, salaries, sales & marketing and so on. However different companies may record these expenses differently, and different accounting rules may require certain treatments. In practice this means that the capex measures for some countries and companies may include some inputs that are not captured in others.

A good example is network infrastructure (base stations, servers, fiber optic cables) and customer premises equipment (set top box, router, etc). In some instances they both may be counted as capex, as premises equipment is in fact durable beyond one year. Indeed some operators have included subsidies on mobile devices. However in other instances only the infrastructure itself will be counted.

Another issue is how labor is treated with regard to capital expenditure. Laying wires requires labor which could be performed by employees or contractors, and that could also be counted differently.

Different countries also have different accounting rules which will also impact the metrics. In Japan for example the government has allowed operators to write off investment costs quickly (improving a company's financial performance) while in other countries such costs tend to be amortized over years.

When comparing investment between countries, the value and fluctuation of currency may also have an impact when interpreting final results, so some standardization may be needed to ensure consistency.

The way around this problem is to use a common data set to ensure the same inputs in each measure. However any one data set will have advantages and disadvantages relative to another.

Market composition

Each country will differ in its market for broadband provision. This can include the number of firms, market concentration, competition, regulation, subsidies, taxation, the number of users, geography, and not to mention, important social factors such as population and cultural norms. It can also be the case that operators invest at different rates for different reasons, or that some are investing while others are not. So at any one point or period of measurement, different investment amounts can be observed.

Competition can exist not only between two for more firms with the same kinds of network (e.g. mobile) but between technologies (DSL vs. cable vs. mobile etc). Providers can be national, regional or local. They can be incumbents or entrants. As such, the investment decisions can vary considerably in any market.

Networks

Network themselves can have different consequences for investment. The capital requirements for different networks vary and are impacted by the user base, geography, regulation and so on. The process and inputs to a fiber to the home (FTTH) network are different from a mobile network. A fiber network will require a process to secure rights of way while a mobile network requires spectrum. These two inputs may or may not be part of the capital accounting. Thereafter the equipment needs are different for each kind of network. While both networks have some amount of fiber optic cable, a mobile network while have significant inputs with site rental, towers, masts, base stations, and so on. The investment cost of the FTTH network may be a reflection of the distance the wires must be lain.

Whether operators practice network sharing can also have an impact. In general sharing will tend to lower costs and increase efficiency. This is an important point not to misinterpret. On the surface it would seem that operators are investing less, but if they share the cost of network, they are deploying network more efficiently. For example two or more mobile operators may share the same tower. This may be desirable for financial, environmental, aesthetic and other reasons.

Similarly some network deployment projects can be combined with other infrastructure projects such as a trenching for electricity. This could also lower the capex amounts.

Another issue seen increasingly is operators outsourcing network deployment to third parties. In that case, operators no longer have the capex on their financial statements. The capex cost becomes opex.

Role of infrastructure providers

The role of infrastructure providers is important to consider. Infrastructure providers can sell equipment to operators with a variety of arguments that new equipment will lower costs of operation, that it will make existing networks more efficient, or that it will allow an operator to be technologically advanced. There may be an argument that equipment can accommodate more traffic, but not necessarily.

Infrastructure providers are important to consider in the different business models which they offer to operators for capital expenditure on infrastructure. Some models entail an upfront delivery of equipment with payment over time versus an outright payment. Both models will have a different impact to the accounting. Other models are based on the amount of traffic delivered.

Some models are based on network performance such as the deal[21] between the Chinese infrastructure provider Huawei and TDC, the Danish telecom incumbent. TDC has agreed to pay Huawei 4 million DKK (€536 million or $717 million) over 6 years for a guarantee of providing the best 4G/LTE experience in Denmark. To date, 4G networks have been deployed in network sharing agreements by Telia and Telenor and separately by 3. Under the contract, Huawei must match TDC's competitors' performance in network quality regardless if the cost exceeds the total contract value. In practice this means that TDC's cash flow will have a drop in capex but an increase in opex.

While it may not be consistent with the notion of network neutrality, a number of equipment providers such as Cisco and Ericsson are developing smart and intelligent network solutions. These are networks predicated on the notion of smart networks that do more than just transport data.

For example the in a smart mobile network, each mobile base station can deliver mobile traffic on all frequencies and all standards rather than require multiple base stations, one for each standard or frequency. This kind of network is intelligent to manage bandwidth based upon the needs and requirements of the user. An SMS may only need the 2G standard, but a video will be rendered with 4G. Providers argue that this helps operators manage limited bandwidth for a variety or users and applications.

Another issue that can complicate capex measures is that the price of equipment has fallen over time. A router that cost $100,000 in 2004 would have a much lower price today. However an operator may expend the same amount but purchase more powerful equipment.

Technological change

Technology shifts can also impact capital expenditure. Indeed innovation and technological change occur in both applications and networks. In this way it is not just the general proliferation of applications and content that might matter with regard to the "virtuous circle", but the impact of specific technologies, companies, or business models.

VoIP, is an general-purpose technology that did not become disruptive until it was marketed through Skype. However VoIP is also used by network operators to provide telephony. Similarly with messaging, SMS itself was not disruptive, but SMS deployed by WhatsApp becomes disruptive.

Network innovation can also drive investment. Consider the upgrade of a mobile network from from the 2G to 3G standard. It may be the case that operators want to offer 3G so that they can sell data packages, but many operators may continue to have a viable business on the 2G standard. Some users, particularly the elderly, may be satisfied to maintain a feature phone on a 2G network. With wireline, the invention of DOCSIS and ASDL as technological innovation undertaken by providers to earn profit, cannot be dismissed as part of the investment calculus.

[2121] http://www.fiercewireless.com/europe/story/huawei-wins-tdc-lte-deal-away-ericsson/2013-09-18

Similarly cable operators are keen to enter the wireless business so they deploy neighborhood wifi solutions as competition to mobile, such as Telenet Belgium or Comcast in the US. Given that they don't have to pay for spectrum, wifi is an interesting opportunity for cable operators.

In addition engineering innovations may also increase or decrease network investment. Consider McCann's Law[22] which states the bit rate required to achieve the same audio and video quality is halved every five years. This means that today's networks will continue to deliver more data because the amount of throughput keeps improving through innovation. This important point is recognized in the FCC's statement from the 2010 order, the same document which offers the virtuous circle theory, *". . . restricting the ability of broadband providers to put the network to innovative uses may reduce the rate of improvements to network infrastructure."*[23]

Another innovation is multicasting. Switching from unicast to multicast delivery, incorporating multiple OTT video streams into the same stream, might allow an operator to realize lower average capital costs. Such an investment, quite large upfront, might prove a way to deliver video traffic more efficiently over time.

Consolidation

In general when an industry is in a period of consolidation and even leading up to it, investment may slow. However investment picks up as the industry completes the consolidation. Remaining firms have greater capital and a larger user base over which to deploy. They begin to invest once the consolidation is complete.

This notion explains in broad strokes explain the difference in capital expenditure between US and EU operators. The US is a highly consolidated market with large broadband providers. However there is a higher rate of investment per household and per user as a result. EU has more providers (also on account of regulation), but a significantly lower level of broadband investment per household.[24] To be sure, there are other factors to consider, namely geography and population density. American firms also invest more because they have a larger ground to cover and dwellings are less concentrated than in the EU. It may also be the case that Americans on average consume more traffic, so networks have been and continue to be upgraded to manage this volume.

Qualitative

Data does not explain everything. It is probably not possible to get a clear picture without some sort of qualitative research through interviews. Qualitative retails entails human judgment, but can be helpful to explain conclusions. A valuable addition to the study will be interviews with various stakeholders to give their impressions why investment occurs and its relationship to the growth of internet traffic.

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[22] McCann K. and Mattei A. (2012), *Technical Evolution of the DTT Platform, An independent report by ZetaCast, commissioned by Ofcom,* 28 January 2012, Zetacast

[23] Supra

[24] Roslyn Layton, *The European Union's Broadband Challenge* (American Enterprise Institute, February 2014), http://www.aei.org/files/2014/02/18/-the-european-unions-broadband-challenge_175900142730.pdf.

Cost of measurement and analysis

As the previous discussion illustrates, measurement is difficult, costly, and hard to interpret. It is frequently for this reason that many things are not measured, for in many cases the costs of measurement exceed the benefits. However it is important not to use the difficulty of measurement as an excuse not to perform it. At the very least, a critical overview of the input of public data can be helpful to the policy discussion.

Typical problems with measurement and analysis

Taking into account the previous limitations, there are still issues to address once the information is processed. This section discusses those issues.

Randomization

Even if a perfect investigation can be designed and implemented, it still does not provide the possible value of a randomized test. A randomized test would likely be impossible but could provide more scientific certitude. A randomized test would impose the same set of net neutrality rules across a given set of similar countries while keeping another set of countries free from net neutralith as a control group. Then data would be gathered randomly from both sets.

Correlation does not imply causation

This is a typical issue addressed in science and statistics to conclude that one variable causes another. Here is the fallacy used to explain the problem of concluding that correlation is causation.

As ice cream sales increase, the rate of drowning deaths increases sharply.
Therefore ice cream consumption causes drowning.

The outcome is explained by showing that ice cream sales and swimming both increase during the summer, but the drowning is related to increased exposure to water, not ice cream.

As such, the test may show that regulation is correlated with investment, but does not necessarily cause it.

Preliminary Results

Though the results of the test are not complete, a preliminary review of the data shows some different outcomes. For example both Denmark and the Netherlands have high rates of broadband investment. But Denmark has purposely avoided making a net neutrality law, instead relying on operator-driven self-regulation since 2011. Meanwhile the Netherlands implemented a net neutrality law in 2012.

From the outset, the major shortcoming of the "virtuous cycle" is that broadband investment is not consistent with the growth of internet traffic. Internet traffic is indeed increasing globally, but the rate of investment varies across countries. To be sure, the global outlay for capital investment in communications networks is high, some $328 billion annually in 2013.[25] However that amount is not equally distributed across the world's regions, nor commensurate with population or traffic growth.

The US has just 4% of the world's population, but has accounted for a quarter of the world's broadband investment for nearly a decade.[26] Other regions, however, don't fare so well. The European Union's share of capex has fallen from from a third of the world's total to less than one-fifth—even though internet traffic has increased in the region over the same period. China, Africa, and Latin America underinvest given their population size and internet traffic growth.[27]

Also interesting is the fact that while internet traffic increases, many mobile telecom operators experience a decline in revenue. Voice and text revenue used to account for 80% or more of mobile revenues but that amount has declined as consumers switch to data where they use free over the top (OTT) services for long distance calling and messaging. Operators' selling of data packages does not necessarily replace the lost revenue from traditional services. The decline in revenue means there are less resources to invest in infrastructure in spite of the growing internet traffic. This would seem to point to another issue mentioned by net neutrality supporters, that of vertical foreclosure by operators in the face of competitors. However this charge would need to be balanced against the staggering growth of these services around the world.

Furthermore the simple direct correlations suggested by the "virtuous circle" don't account for enhancements from engineering efficiency and innovation. It is possible for a broadband provider to upgrade software technology or standards in a network and increase network capacity without purchasing new equipment.

Alternative theories for broadband infrastructure investment rest upon classical microeconomic explanations. Why an operator invests in infrastructure may be a complex decision based on many factors and objectives such as to

- Increase supply, serve more customers
- Improve efficiency through technological progress and innovation
- Minimize cost and exploit economies of scale and thereby bring down long-run average total cost
- Create a barrier to entry - extra capacity can force out potential competitors in a market, protect the monopoly power of existing firms and thereby increase profits in the long run
- Avoid loss
- Keep up with competitors
- Comply with a a regulatory requirement
- Signal to shareholders

[25] "Infonetics Research | Telecommunications Market Research | Telecom Market Analysis," Infonetics Research, 2013, http://www.infonetics.com/.
[26] Horney, Michael James and Roslyn Layton, *Innovation, Investment and Competition in Broadband and the Impact on America's Digital Economy*. Forthcoming TPRC September 2014. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2417777
[27] Ibid

- Alleviate congestion

It is also important to note that firms did invest in infrastructure and networks before the internet, so it was not always the virtuous circle driving their investment decisions, as the theory suggests. In any event, the "virtuous circle" is an important and compelling assertion worthy of further investigation.