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Network Theory

The Flip Side of Metcalfe's Law: Multiple and Growing Costs of Network Exclusion

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The study of networks has grown recently, but most existing models fail to capture the costs or loss of value of *exclusion* from the network. Intuitively, as a network grows in size and value, those outside the network face growing disparities. We present a new framework for modeling network exclusion, showing that costs of exclusion can be absolute, and might, at the extreme, eventually grow exponentially, regardless of underlying network structure. We find that costs of exclusion can also be spread to the "included" through several mechanisms such as parallel networks, and we also highlight how future research needs to capture the interaction of alternate or parallel networks to the network at hand. Backed by empirical evidence, this will have wide-reaching policy and design implications, particularly for the role of subsidies or direct intervention for network access and inclusion.

Inclusion and Exclusion from Networks

Networks are present in many physical and social phenomena, and extensive effort has focused on studying, measuring, and even reducing the distance between entities (nodes) (Albert, Jeong, & Barabasi, 1999; Barabasi & Albert, 1999; Watts & Strogatz, 1998). Network effects have been found throughout physical and economic phenomena, but exclusion from a network has only received limited analysis. In this paper, we present a new framework for studying network exclusion, showing how the costs of exclusion are not only significant, but able to rise exponentially, for almost any type of network (under assumptions of positive network values). We also show how there are implications from network

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exclusion not only for the excluded individuals, but also costs to the included or society overall. While we examine connectivity and telecommunications networks in some detail, this work has applicability across all network domains, including healthcare, infrastructure, etc.

Networks are both natural and anthropogenic, and there are a number of studies on “network effects” in economics (Economides, 1996). It has been hypothesized that the free flow of information and capital, through networks, is a driver of globalization. This has been modelled for various forms of networks by scholars who cite preferential attachment as one of the mechanisms leading to rich-get-richer, if not winners-take-all outcomes (Jeong, Barabasi, & Neda, 2003). Small world (network) models have been demonstrated in multiple domains, and the phrase “Six degrees of separation” has entered the lay lexicon, based on Stanley Milgram’s experiments in the 1960s (Milgram, 1967) sending letters across the United States only through close acquaintances.

Something known amongst domain scholars, but far less appreciated widely, is how few of Milgram’s letters ever made it to their final destination. The average of six hops was only for the small fraction (44/160) that made it, and unpublished experiments by Milgram not only yielded more hops on average, but these figures were for the tiny fraction (~5%) that made it (Kleinfeld, 2002).

Dealing mathematically with network or system exclusion is a challenging problem, because it nullifies many measures. The average energy or electricity consumption may be low because official figures fail to capture informal and non-commercial fuels, e.g., cutting down a tree, which is the norm for the majority of many rural developing country persons. The “average” number is skewed by a significant number of missing data points, but when we consider measures like the diameters of a network, network disconnection or exclusion become problematic. Even within telecommunications network measures for broadband, Internet access, or telephone penetration, most are further limited, failing to capture underlying granularity and distributions.

Beyond measurement in or outside a network, one has to determine alternative networks that are omnipresent but often go unaccounted for. After this, one has to determine the value of a network, which can be subjective and controversial. To help with quantification of such issues, we begin with using connectivity models of networks, but our framework can be applied to many other networks as well. After examining current network models, we highlight the shortcomings of such models when considering exclusion. Based on these, we present alternative framings for measuring exclusion, and we conclude with a discussion of the implications of exclusion, especially as reframed by our model.

Networks and Values

Extensive scholarly attention has been dedicated to calculating the benefits and utilities of connectivity, resulting in simple “laws” designed to capture the distributional effects of network membership, i.e., “network effects” (Metcalfe’s law, Reed’s law, etc.; see Table 1).[1] These “laws” all

[1] Network effects can be simplified as those where the overall or collective values differ from the sum of individual values due to interactions among members.

display monotonically increasing value, with growth ranging from linear (slowest) to factoral (fastest) models, but Metcalfe's, Reed's, and Odlyzko's laws are the most well-known. Like all such "laws," these too are based on necessary simplifications and assumptions. For our generalized analysis, we make the assumptions that membership in the network is a "good" (unlike a disease network), and we do not assign any value to limiting the membership in a network, such as exclusivity.

Table 1. Network Laws and Values.

Total Value *(proportional to)*	Chronology	Originator	Model	Example
N	1	Sarnoff	Broadcasting	TV
$n*\log(n)$	5	Odlyzko	A practical Metcalfe's law	Telephone
n^2	2	Metcalfe	Networks	Telephone
n^c	6	Nivi	A practical Reed's law	Google Groups
2^n	3	Reed	Communities	Google Groups
$n!$	4	Haque	NA	NA

Source: Adapted from "Between Metcalfe and Reed" by Nivi (2005).

Metcalfe's law has become synonymous with connectivity, stating that, as more people join a network, they add to the value of the network nonlinearly; i.e., the value of the network is proportional to the square of the number of users. The underlying mathematics for Metcalfe's law is based on pair-wise connections (e.g., telephony).[2] If there are 4 people with telephones in a network, there could be a total of 3 + 2 + 1 = 6 links. The full math for Metcalfe's reasoning leads to the sum of all possible pairings between nodes, so the value of the network of size n is $\frac{(n)(n-1)}{2}$, which is simplified as being proportional to n^2.

Reed's law recognizes the value of groups within a network, not just pairs, so our group of four people could not only form pairs, but also groups of three, or even the superset of all four persons. Adding in the four groups of three, plus the entire group of four, all the sets equal $2^n - n - 1$; this approximates as being proportional to 2^n.

Odlyzko and colleagues (Briscoe, Odlyzko, & Tilly, 2006) pointed out that these network laws can be too optimistic in their values, and one can intuitively recognize that the growth rate of the network value growth must decrease as subsequent members join—since the most valuable links are likely to be

[2] We recognize that Metcalfe's original formulation was for the critical mass crossover of device compatibility in a network (a nonlinear growth), and not network value per se.

formed first. This parallels the concept of "diminishing returns" central to neo-classical economics. Such diminishing incremental value was modelled as totalling n*Log(n), where future memberships have decreasing (but still positive) growth in value.[3] This framework also fits well with the observation of power laws in real-world networks, which was highlighted by Barabasi et al. (1999).

Existing Models and their Limitations for Exclusion

It is beyond the scope of this article to detail fully the strengths and weaknesses of each law, but we note that *all* of the present network "laws" described here share common features. They attribute an increasing total network value, both in total and (for most formulations) per person.

What of the excluded? How should we conceptualize their non-participation? The first issue is whether exclusion is a binary phenomenon or not. Granovetter (1973) has pointed out the value of weak ties, but codification of strength is a challenge, notwithstanding analytic frameworks for dealing with strengths of ties such as weighted edges in network graphs once we know how to properly assign the weights. If we consider Internet connectivity, is exclusion binary for someone who has versus doesn't have connectivity? What if we care about speed of connectivity, e.g., broadband versus narrowband (or none at all)?

Regardless of the above issue of gradations of exclusion, it becomes self-evident that if we assume a disutility of *not* being in the network, then everyone outside the network faces a growing disparity (or "cost") of exclusion. Even if we start with no disutility for not being in the network, which, we will argue, is not true, the cost is then equivalent to the gap between the in-network value and the value held by those outside.

How do we establish a value of exclusion from a network? If we know the value of a network as per any law or formulation, and assuming each member is equal (a simplification we recognize is often untrue), we can calculate the value of inclusion per person. One might decide that the cost of exclusion is simply the difference between the outsiders' value (= 0) and the per person value of those included.

Thus, for example, if Metcalfe's law has a value approximating n^2, the per-person value of inclusion is simply approaching $(n^2)/n = n$. Thus, exclusion would lead to a disparity of n based on the size of the network, which is the difference between the values per person of those inside (= n) and those outside (= 0).

There are several flaws in the conventional formulations of network value, including (a) insufficient attention to differences in relative population size within the network, (b) confusion of individual and aggregate level value, and (c) individual recourse to multiple networks as a factor affecting "exclusion."

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[3] These would be natural logarithms (base e), but for convenience, these are written as Log(n) instead of Ln(n) or $\text{Log}_e(n)$.

A major gap in this inclusion-based framing of the disparity of exclusion is that it fails to capture the fact that any network is of a finite size (if not in theory, then in practice). For a network of size 19, Metcalfe's law would indicate that the cost of exclusion is proportional to $19^2/19$, or ~19.

We posit, though, that the cost of exclusion depends on the number (and/or proportion) of people excluded, as well. The previous formulation for exclusion indicates the same cost of exclusion, regardless of whether the total population (or rather, the applicable population universe) is 20 people or 200 people. All the above network laws assign a particular value to the network for a size of 19 in the network, but surely the disparity is different whether we have only one person excluded or 181?

(Re)Framing Exclusion

Traditional economics tells us that a network effect will remain an externality if it cannot be internalized, and that under such conditions, those in the network will suffer due to a diminishing of their own value given the network being smaller than it would be with more participation. By this measure, as network participation grows, the loss of value decreases. But this framing is precisely what an inclusion-based framing like the previous laws leads to.

Network effects can be broken into two components (Economides, 1996). First, there is the *autarkic* (or intrinsic) component, where the value depends on the size of the network—e.g., a phone or fax is more valuable as more people have phones or faxes. The second is the *complementary* network effect, whereby associated goods and services become more available as a network grows. Examples include content for particular formats of media (e.g., High-Definition TV), or software that can run on a particular operating system. In this paper, we posit that these concepts are useful but incomplete in describing network exclusion, which has particular properties not captured by such models.

Is exclusion from any network really a cost? Traditional economics tells us that our individual utility does not change depending on how others are doing, but this view is increasingly being challenged by a number of studies that emphasize relative utility in addition to absolute values. How others are doing affects societal norms or baselines (Frank, 2007). There are macroeconomic (inflationary) implications of disparity driven by greater incomes for some fractions of the population, not to mention impacts in negotiations. In the simple example of connectivity, as more Internet users shift to broadband, Web pages and content become larger and richer, disadvantaging the remaining dial-up users more and more. This goes beyond impacts on the entirely offline, e.g., with banks or service providers charging fees for in-person or call center transactions (or even shutting down branches and physical outlets altogether).

In our framing, we make the costs of exclusion endogenous by adding into the formulation the number/percentage of people excluded, which inherently becomes a smaller base as the dominant network grows, adding additional valuable information that existing network "laws" fail to capture.

Because of the aggregate societal effects of the dominant network, we should reconceptualize "network impacts" as consisting of the character of both the included and the excluded. If the value of inclusion per person is simply the value of the network divided by the size of the network (included persons), as the network grows, we argue that, at the limit, due to the macroeconomic ("macro-societal") impacts, the cost of exclusion for the excluded is the value of the included network distributed (divided) across the remaining population *not* in the network.

It is not necessary that this distribution amongst the excluded holds in every case, and we examine this from several perspectives. For starters, consider if a person doesn't have a TV and doesn't want one or care. How is that a disparity or cost? Here, the better metric is applicable population universe. Take broadband, for example: There will be people who can't receive broadband, but want it (often these are rural or remote users). For the TV example, the measure for (included) network value is also likely to be exaggerated, as illustrated by Sarnoff's law stating the more users, the more value. Is this measured by footprint or actual reception of the TV signals? In this case, the value is more for the broadcaster than the network member, because the broadcaster can monetize advertising.

Now consider a network similar to Metcalfe's law-type networks, where the network grows from a very low penetration level to a very high level. In the initial periods, the complementary network effects would be negligible, and existing mechanisms (networks) would remain popular and of value. It would only be later on that the included (newer) network could dominate, and thus the reduced size of the excluded would put them at a further disadvantage than just the disparity value captured via inclusion-based framings.

Let's consider a simplified example of connectivity—broadband vs. dial-up (ignoring the "none of the above" category)—over a period of 10 years. Broadband is assumed to be 1,000 kbps (and for simplicity's sake, constant, though it is, in practice, getting faster) and dial-up is 56 kbps. Out of 10 possible users, at the end of the first year, there is one broadband and nine dial-up, and every year, one user switches from dial-up to broadband. If Web pages were relatively fixed in size, e.g., 30 kB = 240 kbit, then download times would be as below. Note, we ignore external objects, specialized media (which have grown over time), connection overheads, handshake times, etc.

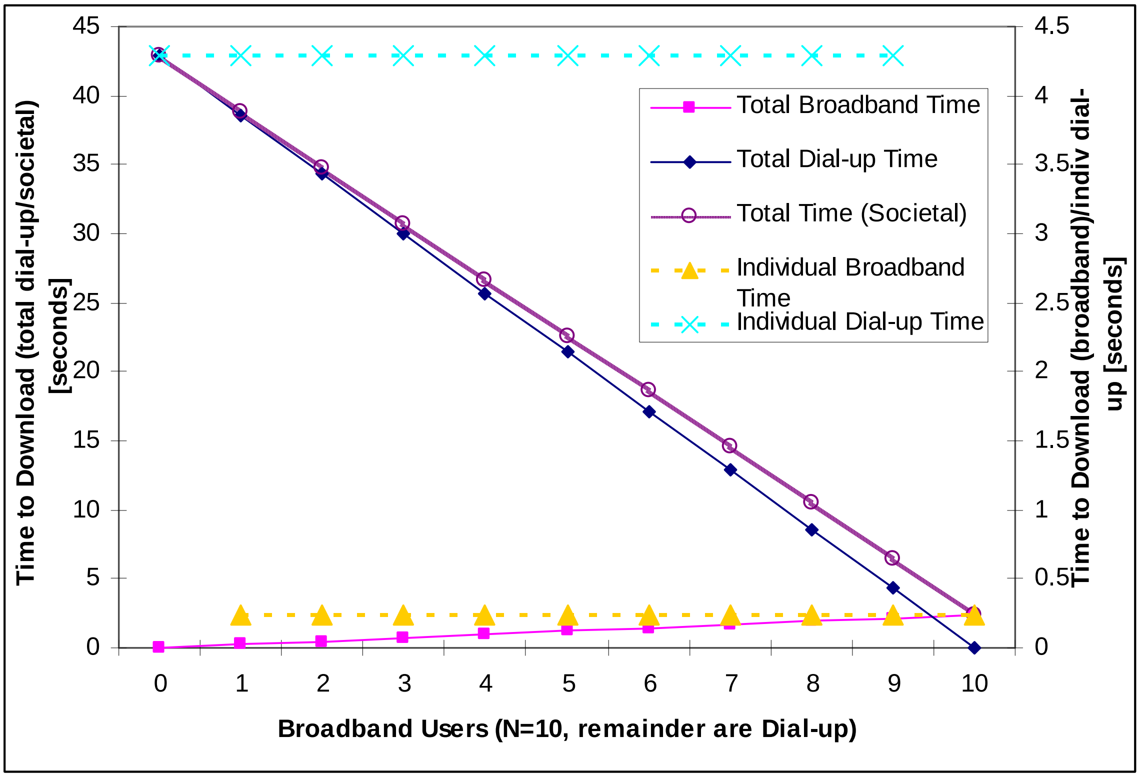

Figure 1. Time for Broadband vs. Dial-up: Fixed-Size Web page.

We can see in this simplified world (where there are no real network effects per se, since download times are linear) that the societal time spent to download decreases as the "included" (broadband) network grows. Per individual, the time spent is constant—0.24 seconds for broadband users, and 4.3 seconds for dial-up users. But society is better off since there is less time spent downloading.

This is the case where inclusion adds value without detracting from the excluded. But now, we add the practical reality of many networks, where they are not only adding value, but also detracting value through secondary network effects. To simplify, we do not factor in issues like increasing time spent online by broadband users, more transactions undertaken by broadband users, or even the richer content that they access (see Pew Internet Life surveys for such data), but simply examine the fact that Web pages have grown over time. The average Web page has increased approximately 30 times in size over the last 15 years, per Andrew King's data (2011). To the above calculations, we simply grow the average Web page by adding 30 kB (240 kbit) per year over the 10-year period from the first time period onward. We now see some interesting trends for society *and* individuals.

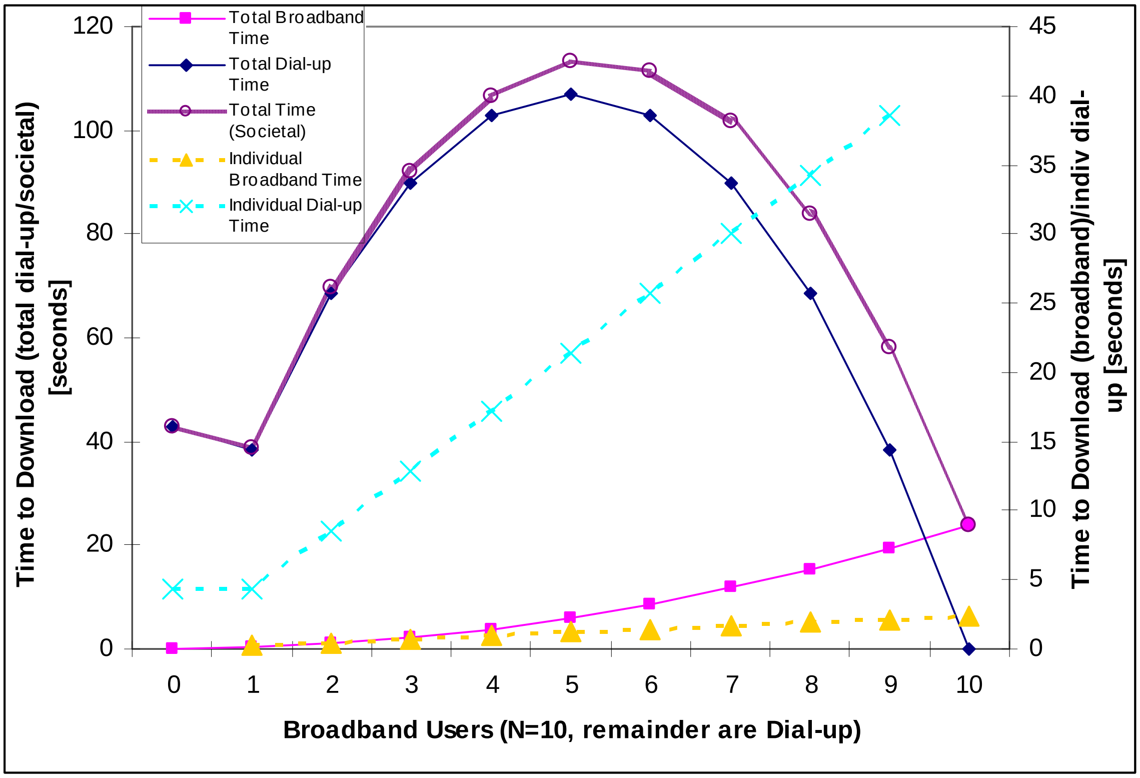

Figure 2. Time for Downloading, Broadband vs. Dial-up—Growing Webpage Sizes.[4]

The total societal time (in this example, eventually) decreases (which is a positive value, saving time), but the excluded (dial-up) users end up spending more and more time for the same online transaction. The individual time spent per person increases linearly in this case, since we have no real network effects and the Web page sizes are increasing linearly. But, data show that complementary network effects are often nonlinear, and so the impact on the excluded individuals would thus also be worse than linear.

At the extreme, the complementary network effects could be such that the remaining excluded find less and less value in their alternative (e.g., dial-up) network, and this could be signaled by the proportion of users that are remaining excluded, i.e., $(N - n)/N$. Thus, as a bounding, one could find the excluded's cost based on a combination of the disparity (captured by the included network's value, V) and the remaining people in excluded network.

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[4] Here, the growth in Web page sizes was directly and linearly linked to the growth of the included network, as a hypothetical signaling mechanism for complementary network effects

Existing exclusion cost (i.e., disparity) formulations = per person included value	$\frac{[Network\ Value\ as\ per\ any\ Law]}{Members\ in\ the\ Network\ (=n)}$	Proposed exclusion cost formulation = total network value divided by number of people excluded	$\frac{[Network\ Value\ as\ per\ any\ Law]}{Members\ outside\ the\ Network\ (=N-n)}$ (Where N = total applicable population)
Equation 1:	Inclusion-based framing	**Equation 2:**	Exclusion-based framing

Figure 3. Alternative Framings for Network Exclusion.

If we compare the framing from included to excluded, the ratio of these two formulations is the same for any network law, and equal to $\frac{n}{N-n}$ where *n* is the people in the network, and N is the total *applicable* population size. We can recognize that this ratio is growing, and inclusion and exclusion formulations cross over (are equal) only at *n* = (0.5)(N). This means that exclusion-based formulations become more disparate as and when a network (e.g., technology adoption) crosses the half mark of the population.

Inclusion Framing vs. Exclusion Framing

Using Metcalfe's Law as an example, we can compare inclusion-based and exclusion-based disparity.

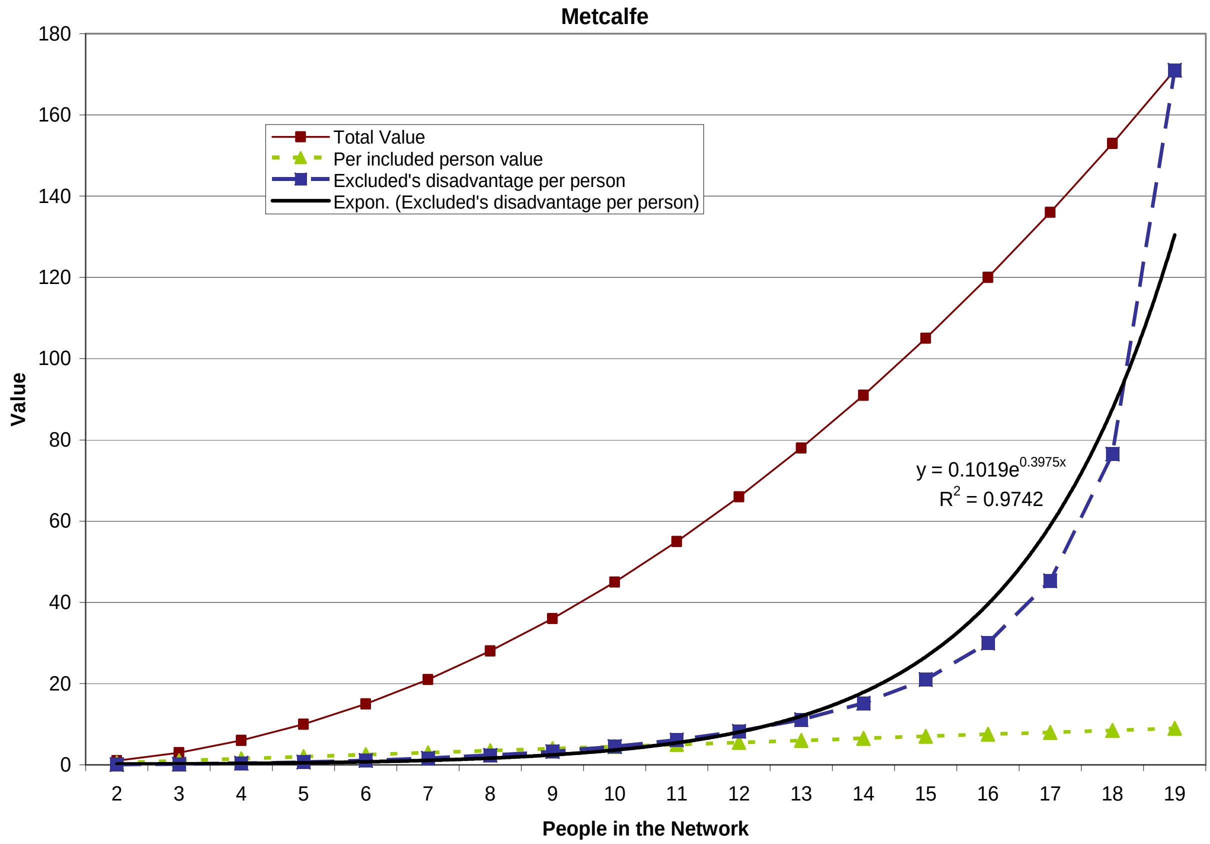

***Figure 4. Metcalfe's Law and Network Values.*[5]**

For all the network framings, inclusion- and exclusion-based framings are similar in value up to a point (roughly half the population). *It's precisely when only a minority of the population is not in the network that the costs of exclusion rise dramatically*. For the other network framings as well, exclusion-framings lead to similar (almost, but not mathematically, exponential) costs of exclusion, also with high R^2 values. We recognize that closed-form solutions for exclusion exist, but we find that, for all such network structures and corresponding laws, per-person exclusion is more or less exponential as fewer and fewer members are excluded.

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[5] The top line is the total network value, growing strongly nonlinearly. The inclusion value per person included (triangles) shows linear growth in this network formulation, but the cost of exclusion (blue squares) shows rapid growth (the trend line for exclusion, the solid black line, is approximately exponential).

This is not to say that exclusion costs aren't high when the fraction of population included in a network is low. If we accept Odlyzko and colleagues' premise that the first few memberships of a network are the most valuable (e.g., assuming some order in a scale-free network), then the relative advantage the first 10% have is the highest for any decile of the population subsequently joining the network.

There are good reasons why we could frame costs of exclusion to be the higher of either inclusion-based or exclusion-based frameworks. Inclusion-based costs per person are higher up to a point on the horizontal axis (3, see Figure 4). This might be appropriate if we consider the situation when only a few people are members of a network, as the exclusion is spread out amongst the majority of the population, but the *advantage* is held by only a few. Once a network includes the majority of the population, the *disadvantage* is held only by a few, and this is when the complementary network effects may dominate, to be captured at the limit by the denominator in our framing, ($N – n$).

We argue that, as the fraction of a population in a network increases, there is a phase transition (occurring, perhaps, at 50% penetration) where the framing for "costs" of not being in the network should shift from inclusion to exclusion. When only a small fraction of the population is in the network, the *median* person in the population is excluded. Hence, inclusion is the exception, and not the norm. When the majority of the population is in the network, exclusion is the exception, and not the norm; this is the signalling for complementary network effects. A fully robust model should be able to analyze both sides of the coin across the relevant network growth periods. For which cases are these effects and models best applied? Without empirical data, one might not be able to answer this, but it is also the case that single simplified network models (linear, logarithmic, polynomial, exponential, etc.) may not be accurate for practical networks as they go from being fledgling, to growing, to approaching saturation (which should now bring in not only percentage penetration, but rate of change of penetration, as well).

While not factoring in network effects per se, in the information technology (IT) world, studies have been published that confirm such findings, where a new technology (such as the use of IT applications) confers an advantage to early adopters, but over time, the advantage diminishes as the technology becomes more widespread, if not a commodity (Clemons, 1986). But, for the few who may not have a technology, not having it hurts even more, as it moves from being a competitive advantage to a competitive necessity. The argument for considering both inclusion- and exclusion-based framings is ably characterized by Carr, who states:

> From a practical standpoint, the most important lesson to be learned from earlier infrastructural technologies may be this: When a resource becomes essential to competition but inconsequential to strategy, the risks it creates become more important than the advantages it provides.[6] (2003, p. 48)

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[6] Carr's central thesis, that IT is important at an industry level, but perhaps not necessarily at an individual firm level (in terms of competitive advantage), maps well to our idea that exclusion is not merely an individual-to-individual issue, but an individual-to-network issue.

It is important to recall the differences between total and individual values. If V is the value of a network (regardless of its underlying model), as *n* grows, *V* grows as well, but the disparity grows exactly as much as the increase in *V*, since the increasing per-person disparity or cost is due, in part, to the decreasing *N* – *n*. Instead of the above per-person costs, the total values of inclusion and exclusion equal (*V*). Using equation 2,

$$\text{Total Exclusion cost} = \text{per person exclusion cost x number of excluded} = \frac{V}{(N-n)} \times (N-n) = V$$

This trivial result highlights that any disparity-based cost will have the same *total* value for exclusion, but it is the *per person* value which could grow exponentially. This is an outcome of the 1/(*N* – *n*). In fact, due to the mathematics of 1/(*N* – *n*), for typical network types the disparity eventually grows faster than exponentially as *n* approaches *N*. Of course, such mathematics indicate that as the last person joins the network, there is a discontinuity, and there is no remaining cost of exclusion.

In fact, one could have examined any technology, e.g., having a car vs. not, and come to similar results that exclusion per person becomes worse and worse as more people have the technology. The disparity is even higher with network technologies where *V* grows faster than linearly.

With non-network technologies, the benefits for inclusion often accrue due to secondary or complementary network effects; for example, as more and more people have cars in a town, more and more goods might be packaged in larger sizes (so, e.g., those with cars can buy cheaper bulk-packaged goods). But with network systems, there is an intrinsic growth in value, as well.

In reality, the exclusion may not actually approach the exponential. First, the network value itself may not grow as much from adding the last few persons (the numerator). Second, the excluded are likely not fully excluded, but able to participate in alternative networks or solutions (discussed in more detail later). Thus, the proposed framing may be considered an upper bound for cost of exclusion.

Is there really a zero-sum-game between inclusion and exclusion, or is there intrinsic value to the included without an expense for the excluded? Without empirical data, we cannot make any claims, but we believe that, just as a single network law may not apply to the growth of a network, a simple inclusion vs. exclusion calculus may also be insufficient for value. The reality is likely in between, but it might rapidly move toward the exponential, as there are fewer and fewer people left in the excluded (or alternative) network. There are examples of this where it becomes a non-discrete function, and thus, as (N-n) approaches zero, the cost becomes higher and higher, since the alternative network is sustained entirely by fewer and fewer users. For example, as satellite broadband failed to grow, partially due to the spread of mobiles, the cost of that system per user grew nonlinearly to the point that it became unviable. Here, the simplification is that the alternative system's costs are now borne entirely by the shrinking base of users (denominator). As that decreases, the per-user cost increases, and approaches close to exponential due to the mathematics of 1/(*N* – *n*).

In practice, the user of an alternative network will stop using the alternative well before they are the last or nearly last user, as the marginal cost of switching to the included network would likely be lower, or the provider of the alternative (older) network may simply pull the plug on the network, as was the case with the Iridium satellite network.

Other Factors of Exclusion

There are two other issues when we consider exclusion. The first issue not fully captured by today's models or in literature is the use of alternative or parallel networks.

Networks may be complementary or substitutive, but they may also be inferior or superior to one another in terms of their convenience, cost, power, flexibility, and other network features. Being excluded from one network doesn't mean exclusion from all networks.

In fact, if we consider those who are excluded from a network, they are likely part of an alternative network. For example, if one cannot download a government form online, one might write for it, call, fax, or get in line for the form. The latter may involve driving, taking a bus, or walking. All of these are alternative networks that have differing levels of cost, convenience, etc. We can often assume a superiority or dominance of some networks over others, e.g., broadband over narrowband, those with health insurance vs. those lacking health insurance, etc.

The second issue is whether the changing levels of exclusion/inclusion can cause changes in either the network structure or in dynamic signalling, both important for networks (Strogatz, 2001), especially as impacting external systems or complementary networks. If we consider simple network effects, these can show how networks can change in value nonlinearly. But these may not factor in dramatic shifts that can occur due to, say, the loss of a central node from one network to another, which is a common case when we consider non-uniform networks, where all members (or their links) are not assumed equal (such as real-world scale-free networks seen in many phenomena). There is also some evidence that the *dynamics* of network changes can indicate a concentration of value and power (see Castells [2009] for more on such issues).

Exclusion Hurts the Included and Society Overall

We have modelled that the network-excluded face increasing disparity (or costs) *individually* as the dominant/superior network grows. What are less well quantified are the costs of exclusion borne by the included, or society overall.

Classic examples include disease vectors, or health insurance networks. Individuals who fall outside a health insurance network are unlikely to address their medical issues until their health significantly deteriorates, making their individual treatment much more expensive, while also imposing greater health care costs on the insured within the network. In addition, if they have a communicable disease, they increase the risks to others who are in the network. Also recognized is their greater reliance on emergency rooms, which raises both costs and time delays for all patients (Wilper et al., 2008).

There are numerous other examples of network exclusion leading to higher societal costs. Bhagwati et al. have shown how preferential trade agreements (PTAs) can be inferior to global free trade agreements by distorting trade incentives depending on underlying cost structures (Bhagwati, Greenaway, & Panagariya, 1998). In essence, lowest-cost (and least environmentally degrading) producers may be excluded by not being a member of the PTA. In communications networks, information suppliers often have to maintain alternative and parallel networks, even for just a handful of users. For example, the U.S. touch-tone telephone system also allows pulse dial instruments for the very small minority of older instruments in use.

Parallel systems or networks have existed throughout history, but it is only now that we are revisiting the costs of network exclusion. Consider the example of computer operating systems. While each iteration has an intended life of only a few years, there are still numerous Windows 98 users, not to mention the many more Windows 2000 users. At some point, the user or even the product provider (here, Microsoft) stops supporting the product with security and other updates, and the older system becomes an increasingly parallel system, instead of one that coexists though backwards compatibility. Such an exclusion hurts the included, as there are estimates that 80+% of spam comes via “zombie” computers,[7] and it is precisely the older computers that are most likely to go unpatched.[8]

Implications and Discussion

We leave it for subsequent work by scholars to examine empirical evidence for our proposed framing(s), but emphasize that there are a number of network domains where such issues will be similar, such as healthcare. The paucity of data on exclusion and alternative networks (and their interactions) is one major challenge to applying our proposed framing. Even with limited data, there is evidence that exclusion costs are disproportionate and growing. For example, consider that those in Africa who lack cell phones are losing enormous economic and political opportunities to those who have cell phones, and this is exacerbating the socio-economic divide (Jagun, Heeks, & Whalley, 2008).

One of the few real-world data sets on healthcare costs amongst included vs. excluded people is illustrative of the applicability of our model. There is a study of California hospital costs across hospitals comparing private insurance, government coverage (Medicare or Medi-Cal), and no insurance (Melnick & Fonkych, 2008). Our model would have predicted that the excluded would be the worst off. This is buttressed by personal experiences that show, in medical tests, having insurance helps significantly because the tests conducted *“in-network”* are substantially lower than listed prices, due to negotiated rates. However, the study indicated that the highest charge-to-cost ratio is for third-party payments

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[7] Zombies are machines that have been taken over by malicious entities without the knowledge of the owner for nefarious purposes such as sending spam (or worse, such as Trojan or Virus attacks). Computers become zombies usually through a vulnerability in the operating system or a particular application. There are reports that Microsoft may offer selected security updates even for pirated copies of recent Windows software.

[8] Windows Service Pack 2 for XP (SP2) qualifies as a new version from a security point of view, but there were many XP users (note, we didn’t use the term customers!) who didn’t or weren’t able to upgrade.

(private insurance), followed closely by individuals, and then government insurance plans. This counter-intuitive result was clarified on discussion with one of the authors, who mentioned that "self-pay" has two factors they could not include properly—the number of persons who actual pay individually (as opposed to being billed), and any transaction costs associated with the use of debt collection agencies. Hence, the average costs for those who actually do pay (smaller denominator) would be much higher.

Additional impacts of exclusion are multiple. Direct impacts relate to the added costs of using alternative networks, but far greater are the (opportunity) costs that result from lack of participation in utility-increasing activities. If we think of broader issues of exclusion, Raphael (2001) indicates that low income and social exclusion are leading causes of cardiovascular disease and its impacts in Canada, beyond the usual suspects of diet, exercise, genetics, etc.

Be it healthcare or broadband, there are a few unanswered questions this framing raises. Conventional wisdom indicates that society is always better off with increasing participation in a beneficial or superior network. Thus, even if we can't reach 100%, we are better off with 80% or 70% participation. This work questions parts of that. Society may be better off, but what about excluded individuals? Depending on the underlying network and how it is impacted by the included network, the individual cost of exclusion rises faster than any rise in value for the included individuals. With the current U.S. Government push for "faster broadband," should there be a focus on *universal* "low-grade" broadband instead? At the least, we hope this work indicates that we need to expend far greater attention on the excluded than has previously been the case.

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