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

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Abstract

The study of networks and network science has grown in the last decade, but most network 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. In this paper, we present a new framework for modelling network exclusion. We find most leading academic framings for network value are based on membership within the network, and not exclusion from it. Second, if we shift from an inclusion to an exclusion framing, over time the disparity (or cost) of exclusion becomes roughly exponential, regardless of the underlying nature of the network or its value. Third, while we recognize that calculating the costs of exclusion is inherently difficult, we conclude that exclusion from a network imposes costs not only on those excluded but also on those within the network or society overall. This analysis applies to all network domains, whether communications, energy, transportation, healthcare, biodiversity, etc., Fourth, populations excluded from a network will often resort to alternative or parallel networks, for which most modelling falls short (including multidimensionality and interconnections between the networks). Resort to alternative networks may attenuate but does not automatically eliminate the increasing costs of exclusion from a superior network. Future scholarly work on this subject should seek to capture both the bright side of network inclusion as well as the 'dark side' of the costs of exclusion. Our complementary framing says *"The more people included within and enjoying the benefits of a network, the more the costs of exclusion grow exponentially to the excluded, and spread across multiple dimensions and impose additional costs even on those who are networked included."* This new direction is relevant too for the design of policy interventions as well as for shifting the scholarly research agenda toward greater focus on inequality and exclusion.

Introduction: The Network Society

It is widely acknowledged that expanding access to networks is the hallmark of post industrial society, whether defined as 'knowledge society', 'information society' or 'network society' [1].

Scholars from sociology to engineering and economics regularly wrestle with issues of network structure and value. But regardless of the domain this work tends to concentrate on the positive values associated with network inclusion. Far less scholarly attention is devoted to rigorous explication of the costs of network exclusion. Perhaps the greatest, most cited example of a model of network inclusion is Metcalfe's Law, to which we return in greater detail below. It states that the value of a network is roughly equivalent to (technically, proportional to) the square of the number of network members.

Yet, for the most quintessentially modern example – the network of networks that is the Internet, twice as many people on earth are excluded from the Internet as are included – 4+ billion vs. 2 billion. Yet contemporary scholarship concentrates mostly on the minority, to the near exclusion of the excluded.

Despite the fascination network inclusion the current global economic financial meltdown should draw our attention to the deepening of inequality across a number of important dimensions. Indeed, the broader question of global equality and inequality has once again returned to the fore. Authors like Stiglitz [2] point to evidence of growing inequality in the world, both within and between countries. It has been hypothesized that globalization, which is dependent on the free flow of information and of capital, leads to a "winner takes all" phenomenon. 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.[3] In this context, it is even more essential to pay attention to network exclusion.

As the world moves more into a networked digital environment, where being on a high quality network is more and more of an advantage, then scholars should pay more attention to both sides of the network coin – inclusion and exclusion; the light side of networks benefits but also the 'dark side' of the costs of exclusion. The main purpose of this article is to encourage fellow scholars to re-consider costs as well as benefits of networks, and to provide an analytic framework for doing so.

When we review work on the digital divide, we find that studies over the past decade have become more sophisticated and moved from simple measures of telephone or Internet penetration to more granular, multi-dimensional measures capturing complementary issues such as literacy, gender,, age, geography, etc. Instead of a one-dimensional divide dominated by access to telephone lines, hardware and applications, authors have expanded the variables to encompass financial resources, knowledge and to formal Internet training [4-7].

In addition, the meaning of 'access', 'penetration' and network membership is a constantly moving frontier because of technological innovation, and more and more experts and consumer groups now insist that to be connected in the modern world consumers and citizens must have 'access' to broadband. Disparities in broadband network access abound, not only globally but even within the US, where limited rural availability has led to a global broadband rank estimated as low as 25th.[8]

Inclusion and Exclusion from Networks

The costs of network exclusion are not trivial in modern society, and grow higher as more essential services for citizenship, economic transactions and quality of life migrate from the traditional world of 'atoms and molecules' to the online universe. Initially, these services are largely discretionary and non-essential – easier and cheaper access to advertisements; access to online games and pornography. Over time, as Internet and other networks diffuse, discretionary services' migration are joined by more essential services – access to medical or employment information; later, the services extend beyond 'information' to include access to actual services that are essential for effective citizenship, education and economic competitiveness. Voting migrates online; banking moves online; college education moves online. Eventually, fewer services are available conventionally; instead of only 10% of essential services online, the majority migrate. Some of these services might only be online. But even when available in both environments, the benefits of inclusion into the more robust networks means that the included – and their children – get easier, faster, fuller and ubiquitous access to 'necessary knowledge' than the children of the network excluded.

A research question that we pose is what happens to the excluded from a network? Do they close the gap, or does the gap widen? Consider Figure 1. These simplified curves assume two types of networks of growing value, the "included" or superior network, and the "excluded". Each of these sees a constant growth rate for value – the difference is whether the excluded grow at the same rate, higher, or lower.

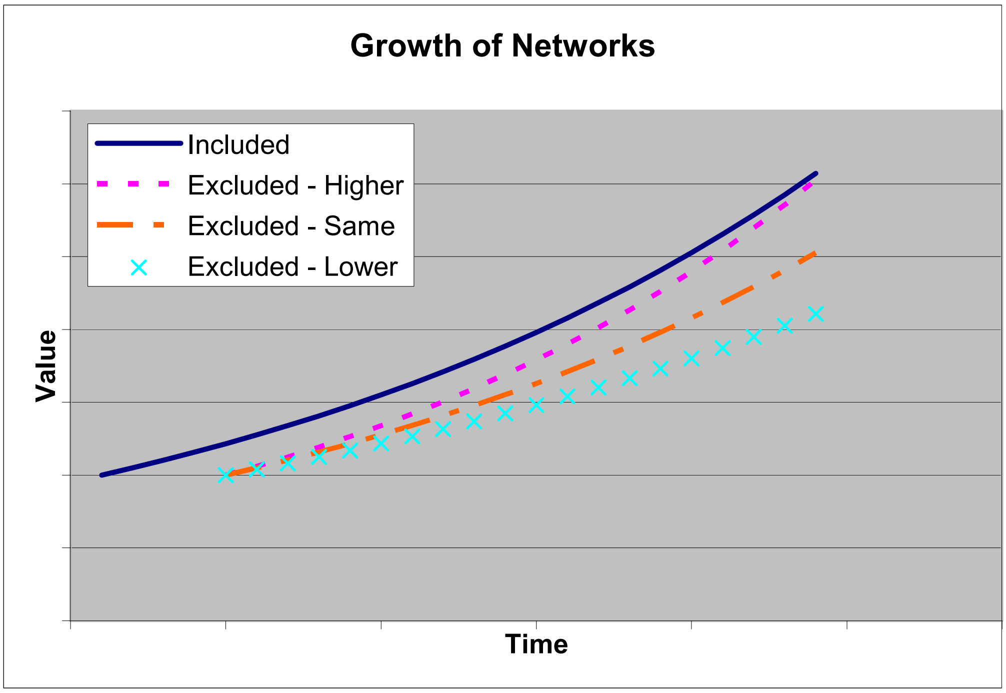

Figure 1: Growth of Networks over Time - "Included" (Superior) vs. "Excluded". The top line is the superior network growing at some given growth rate. The 3 lines below show three possibilities for an excluded network starting with a lower value at a point in time with

varying growth rates. "Same" indicates the same growth rate, but leads to higher gaps over time. Higher growth rates for those who start later indicate a closing of the gap.

In reality, most growth rates are not constant, but diminish over time as networks or systems saturate. Thus, even if the excluded grow faster (e.g., mobile phones in Africa), they are unlikely to ever catch up to regions like Taiwan with more than 100% penetration (more mobiles than people). What is interesting is that at the same growth rate, the absolute gap still grows over time.

In this light, we would anticipate that the costs of network exclusion relative to the benefits of inclusion could decline over time; remain constant relative to benefits; lessen but never reach equivalence; or worsen. In the following sections we formalize inclusion and exclusion, and point out the previous example actually we often find more than two states (inclusion or exclusion), such as connectedness in developed countries, connectedness in developing countries (e.g., with lower speeds and higher costs), and those who are entirely disconnected.

Network Science and Exclusion

Networks are present in many physical and social phenomenon, and extensive effort has focused on studying, measuring, and even reducing the distance between entities (nodes) [9-11]. Small world 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 [12] sending letters across the US only through close acquaintances. But what if worrying about the distance and pathways between nodes is the wrong question to ask? What if what happens *outside* the network is not only poorly understood but also vitally important?

While 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 yielded not only more hops on average, but these figures were for the tiny fraction (~5%) that made it [13]. Did experimenters simply fail to find the possible links (no claim was made whether these were the shortest possible links), or were the links much much longer?

Mathematically dealing with network exclusion is a challenging problem, because it nullifies many measures. If we study average energy or electricity consumptions, this statistic may be low because official figures fail to capture informal and non-commercial fuels, e.g., cutting down a tree for cooking, which is the norm for the majority of many rural developing country people [14]. Here, of course, the "average" number is simply 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 network measures like for broadband, internet access, or telephone penetration, most measures are similarly limited, failing to capture underlying granularity and distributions.

Network Effects in Connectivity

Current Framings for Network Effects and Values

Extensive scholarly attention has gone 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.) (Table 1). [i] These 'laws' all display monotonically increasing value, with growth ranging from linear (slowest) to factoral (fastest), 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. The following table identifies and compares key aspects of leading network models.

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	??	??

Adapted from: "Between Metcalfe and Reed" [15]

In the contemporary discourse on the value of communication networks Metcalfe's law has become synonymous with connectivity, stating that as more people join a network, they add to the value of the network non-linearly, 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 pairwise connections (e.g., telephony).[ii] 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

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[i] Networks effects can be simplified as those where the overall or collective value differs from the sum of individual values due to interactions amongst members.
[ii] We recognize that Metcalfe's original formulation was for the critical mass crossover of device compatibility in a network (a non-linear growth), and not network value per se.

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 3, or even the superset of all 4 persons. Adding in the 4 groups of 3, 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 [16] pointed out that these network laws are likely 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 formed first. This parallels the concept of 'diminishing returns' so 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.[iii] This framework also fits well with the observation of power laws in real-world networks, which was highlighted by Barabasi and colleagues [11].

We can see (Figure 2) that all the network laws show increasing values, but some show faster growth than others.

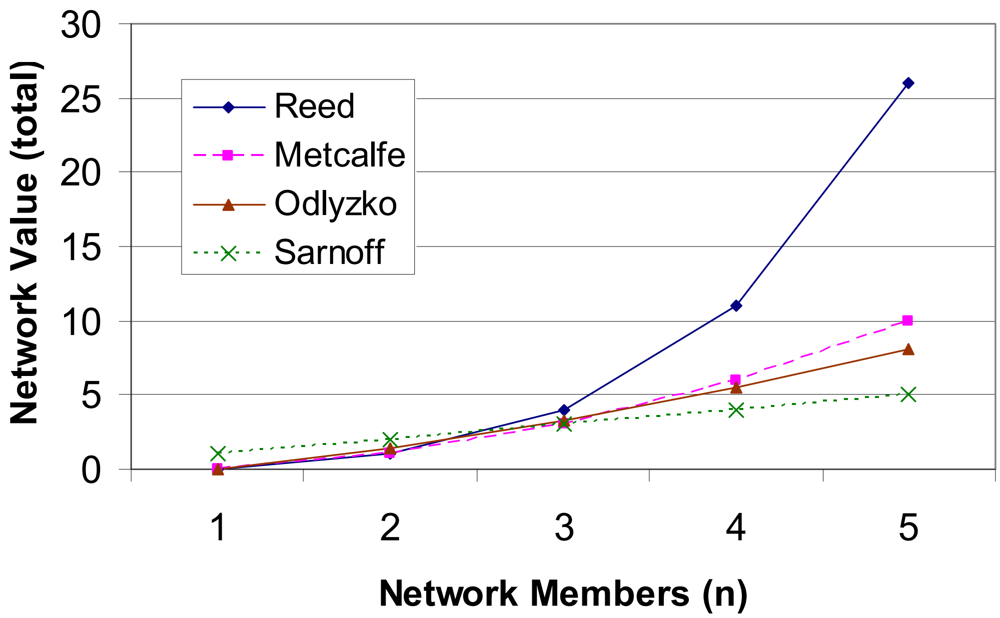

Figure 2: Network Values as per various "Laws"

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

Limitations of Existing frameworks

It is beyond the scope of this paper to detail fully the strengths and weaknesses of each law, but 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.[iv] One consequence is to conflate individual with aggregate benefits to membership. And clearly the Laws concentrate their intellectual firepower on the benefits to the included.

What of the excluded? How should we conceptualize their non-participation? The first issues is whether exclusion is a binary phenomenon or not. Granovetter [17] 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 equivalent to the gap between the in-network value and the value held by those outside. We examine this issue below , but begin by recognizing that well-recognized network effects give rise to a non-linear growth in value for a network, e.g., the system of telephony users (Figure 2).

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 likely 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 (i) insufficient attention to differences in relative population size within the network, (ii) confusion of individual and aggregate level value, and (iii) individual recourse to multiple networks as a factor affecting 'exclusion'.

[iv] It may be the case that network values peak at a certain point, either due to rising supply costs or overhead/management costs. Exclusivity may be a desired feature of some networks, instead of universal membership.

A critical issue before us is under what conditions, or in what sequence, do the costs of exclusion become most severe to the excluded (and might they even extend to the included)?

There is a range of possible judgments about costs one can make as the balances between the excluded and included shift over time. As a thought experiment, at what point are the costs of exclusion greater? When the conditions are:

a) 10% of the population is included, and 90% are excluded
b) 50% of the population is included, and 50% are excluded
c) 90% of the population is included, and 10% are excluded

(In making such judgments, analysts should be aware that normative as well as efficiency criteria should be considered.)

Here are some considerations that other inclusion based models fail to capture – any network is of a finite size (if not in theory then in practice). If we state our network size is 19, Metcalfe's Law would indicate the value is proportional to 19x19 = 361, and the per person included value is ~19. Thus, the cost of exclusion for *n*=19 is also 19 (difference between 19 and zero, the value for those who are not in the network).

However, we posit the cost of exclusion would depend 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 (rather, 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 the disparity is certainly different whether we have only one person excluded or 181!

Framing Exclusion

Traditional economics tells us that a network effect will remain an externality if it cannot be internalized, and under such conditions, those in the network will suffer due to a diminishing of their own value given the smaller network than 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.

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

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

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

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 crossover (are equal) only at n = (0.5)(N). This means that exclusion-based formulations become higher as and when a network (e.g., technology adoption) crosses half the population.

Inclusion Framing vs. Exclusion Framing

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

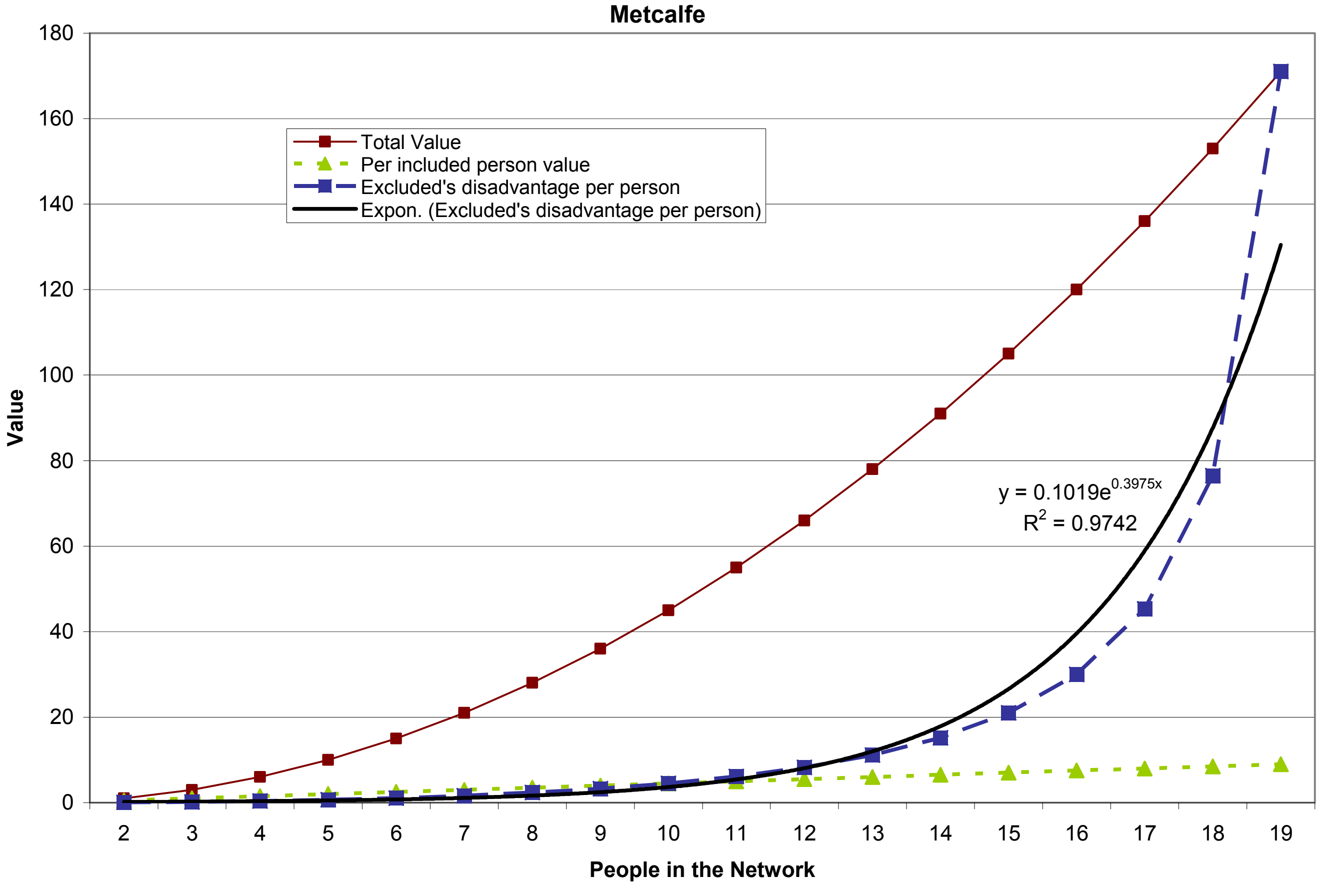

Figure 3 Metcalfe's Law and Network Values. The top line is the total network value, growing strongly non-linearly. The inclusion value per person included (triangles) shows linear growth in this network formulation, but the cost of exclusion (blue squares) shows rapid growth (trendline for exclusion, the solid black line, is approximately exponential).

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 ~exponential costs of exclusion, also with high R^2 values.

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 Tilly's [18] 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 are higher upto a point (Figure 3). This might be appropriate if we consider when only a few people are members of a network, 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. Mathematically, this translates into saying for $n < 0.5N$, the included have an advantage they share, while for $n > 0.5N$, the excluded have a disadvantage they share. In such a formulation, the lowest disparity between frameworks is when $n = 0.5N$.

One might argue such an exclusion-cost framing is picking the worst of both worlds, and for consistency only one formulation should be chosen (included network *or* excluded network). However, 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. Hence, it might be appropriate to use inclusion-based disparity costing in the initial growth of the network, and exclusion-based disparity costing as the network grows. However, a fully robust model should be able to analyze both sides of the coin across the relevant time periods.

In the information technology (IT) world, there have been studies 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 [19]. 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 [20] 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*[v].

Coming back to the thought experiment of distributions at 10:90 vs. 50:50 vs. 90:10, say for having a car in society. The least disparity is not when almost everyone has a car (as the few left behind are really left behind) but when half the population has a car and half doesn't.[vi] In all network laws we have seen, with increasing network values with network size, 10% exclusion is much worse than the disparity caused by 10% inclusion. This is not to claim society is better off with 50% network participation compared to 90%, just that *individual* disparity becomes exacerbated as the network grows to include greater fractions of the population. We do not take a firm position on the point at which exclusion becomes most unfavourable. We do insist, however, that this is a subject deserving more attention than it has received.

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[v] 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 posit that exclusion is not merely an individual to individual issue but individual to network level.

[vi] Technically, the lowest disparity is when everyone (or even no one) has a car.

Other Factors of Exclusion

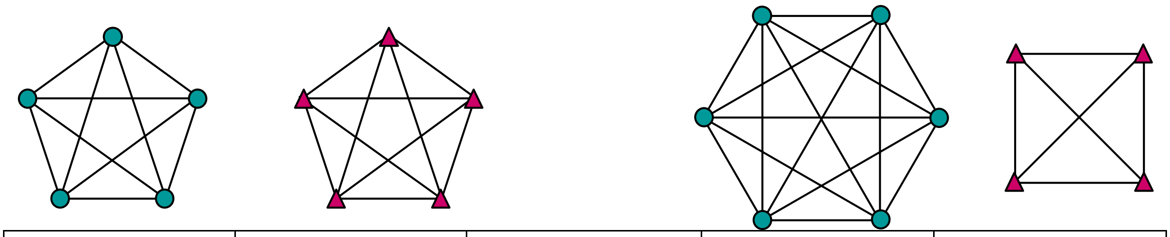
Recourse to Multiple Networks

Because an individual or population is excluded from one valuable network does not mean exclusion from all networks. While it is the main thrust of this paper to provide a framework to reconsider the costs of exclusion from a single superior/dominant network, we underscore another failure of the literature on networks directly relevant to a new research agenda on network exclusion and inclusion. Too many analysts fail to consider that individuals and/or populations have recourse to multiple, alternative networks through which they can seek desired serves and goods. Networks may be complementary or substitutive, but 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, or call, or 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.

Structural Changes in Networks (both included and excluded)

In a simple binary world, with only two choices open to an individual (Network A and Network B), any growth of one comes at the expense of the other – and this transference of value is non-linear (Figure 4). While networks A and B were both of size 5 initially, shifting just one member from B to A causes disproportional shifts in value, e.g., using Metcalfe's Law.



Network A	Network B	← Before After →	Network A	Network B
5	5	Number of nodes	6	4
25	25	Total value (approximated Metcalfe, full mesh)	36	16
50%	50%	Share of total nodes	60%	40%
50%	50%	Share of total value	69.2%	30.8%

Figure 4: Network growth and value changes (example under full-mesh assumptions, ala Metcalfe)

As A grows to 8 in size and B declines to 2, B declines to 5.9% of the total value, despite having 20% of the total nodes. We see that B's relative value falls faster than its fall in size. A similar *trend* holds regardless of underlying network structure and network value formulation (Odlyzko, Reed, etc.) It is only at the linear (Sarnoff) limit that relative declines are the same.

In reality, the relative impact of exclusion from the dominant/growing network is worse than such simple math. Not only should there likely be greater value to the dominant network than shown in Figure 3 (broadband over dialup, insured vs. lacking insurance, etc.), the assumption of "full-mesh" and equivalence of nodes may be an oversimplification (a full mesh network is where each node is equal in value to the other, like in Figure 3, and the underlying assumption for Metcalfe's Law). If we consider a more real-world (e.g., scale-free) network as defining Network B, losing different nodes to Network A can have vastly greater implications on network value, e.g., losing a central node. (Figure 5). Mathematically, such a loss might be computed by a multiplier or exponent to be added to Equation 2 (exclusion-based framing).

It is premature to make claims as to whether node dynamics are a random process, or there are probabilistic biases impacting whether a more valuable node is more likely to migrate or stay. But we can imagine that the most highly connected individuals in an inferior network are the most likely to migrate to a higher value network, thereby diminishing the value of the original network even more than if a less connected individual left.

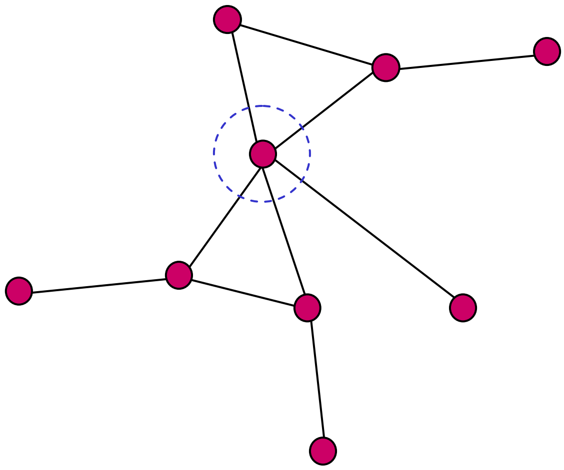


Figure 5: Typical real world (~scale-free) network, showing the importance of central nodes.

Networks A and B are not the only choices, there is often "none-of-the-above" – but such a scenario may actually be Network C, or D, etc. Under the simplification of just two networks, A and B, we assume A is the superior and growing network. At one level, if network B is not changing, one is just as well (or poorly) off as before. On the other hand, the growth of A impacts the macroeconomic or broader environment surrounding B, e.g., people nearby becoming immunized impacts my odds and risks of disease.

Costs of Exclusion

Is exclusion from network A really a cost? Traditional economics tells us that our individual utility does not change regardless of 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.[vii] How others are doing affects societal norms or baselines [21], and there are implications of such pressures in terms of people's demand. In addition, there are macroeconomic (inflationary) implications of disparity driven by greater incomes by some fractions of the population, not to mention impacts in negotiations. As ones neighbours and fellow citizens earn more, this pushes up the price for many goods and services, especially ones with limited supply such as housing.

In light of this, this disparity between those included and those excluded might be considered a *cost* of exclusion. E.g., in the network world, as more and more people move from dial-up to broadband (already over 50% of homes in the US), webpages grow dramatically in size, hurting dial-up users. Tongia and Wilson find typical global webpages, even from developing regions, would take multiple minutes to access on a typical dial-up. With the expectation of broadband, and the same website has grown multiple-fold in size in the last few years.[22]

[vii] A classic example is comparing two scenarios such as one where an individual earns $85,000 per year, and everyone else earns, say, $100,000, and the other where he or she earns $110,000/year, but everyone else earns $200,000/year. While the absolute purchasing power of $85,000 is lower than $110,000, many people would sense greater disparity in the second case.

Network effects have been studied in numerous domains and disciplines, and contrary to standard economic models, network economics have led to increasing returns (REF Arthur), which explains why certain technologies have won or lost, e.g., the victory of VHS players over Betamax. As one technology grows, network effects lead to greater value for that network, and the alternative technology loses yet further value (Figure 4 on page 13).

Network effects can be broken into two components [23]. First, 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 incomplete in describing network exclusion, which has particular properties not captured by such models.

Why should exclusion cost be considered differently, and based on the *overall* (dominant) network value? Considering webpages and have they have grown in size, someone who is on a dial-up instead of broadband finds themselves worse off in an absolute sense, and not just a relative sense compared to someone who has a faster connection. The dominant (or, in the binary example of included vs. excluded, the included) network's growth signals complementary networks through not just its inherent value but its growing size or share of the population. This is where the *dynamics* of network changes can indicate a concentration of value and power (see Castells [24] for more on such issues). For networks, the structure and the dynamics can both matter [25]. In the simplified model of one superior network, the structure may matter more than the dynamics, and they can be coupled.

Exclusion hurts the included and society overall

We have demonstrated that the network-excluded face increasing disparity (or costs) 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.[viii] 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 costs and time delays for all patients.[26]

As Lloyd Benston, then Treasury Secretary observed during a Press Briefing on July 20th, 1994 regarding health insurance inclusion and exclusion:

[viii] Value of a network is closely linked to context – with diseases, *exclusion* from a network may be a superior state.

> *If you have insurance, it's easy to say, well, you know, this doesn't affect me; the uninsured -- that's their problem, not my problem. Don't you believe that; that's not right. It's your problem, too, because insurance costs are then higher. You've got a bed that isn't paid for in that hospital, you've got a doctor that's not paid, you've got a nurse that's not paid -- those fees go up. The hospital cost per bed goes up for those of us that have the insurance. Or if you have a public-owned hospital, like a city hospital, and the bills aren't paid, your taxes go up.*

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.[27] 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. E.g., the US touch-tone telephone system also allows pulse dial instruments for the very small minority of older instruments in use. This is one reason that a transition to digital TV might be better as a replacement than as a parallel overlay. The value of the spectrum that can be released can more than compensate for buying necessary equipment (digital receivers and converters) for the estimated ~10% of the US population relying on over-the-air television.

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 co-exists though backwards compatibility. Such an exclusion hurts the included as there are estimates that 80+% of spam comes via "zombie" computers,[ix] and it is precisely the older computers that are most likely to unpatched.[x]

Implications and Discussion

Near the start we suggested that the costs of network exclusion relative to the benefits of inclusion could decline over time; remain constant relative to benefits; lessen but never

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[ix] 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.

[x] 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.

reach equivalence; or worsen. Our findings suggest that these relationships shift over time depending in part on the relative percentages of the population included and excluded (10% vs. 90%; or 50% vs. 50%); on the differential quality of the 'new' network; and on the availability and relative quality of other networks. But over the long term it appears that the costs to individuals – and perhaps society – grows substantially.

Given the failures of existing network 'laws', we offer the following alternative***:*** "The more people included within and enjoying the benefits of a network, the more the costs of exclusion grow exponentially to the excluded, and spread across multiple dimensions and impose additional costs even on those who are networked included***."*** In our view, a 'grand unified theory' of network participation would recognize the complementarities of Metcalfe (or, say, Odlyzko, et. al.) and Wilson-Tongia formulations:

> **While the value of a network to an individual is equivalent to the square (or, say, $\log_n$) of the number of members in the network, the costs to the excluded are substantial, multiple and growing for the universe of actual and potential participants.**

We leave it for subsequent work by scholars to examine empirical evidence for our proposed framing(s), but emphasize there are a number of networks where such issues will be similar, e.g., healthcare. 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, e.g., 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 [28].

One of the few real-world data sets on healthcare costs amongst included vs. excluded 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 [29]. 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 *when "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 (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.

Be it healthcare of 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. What it does state is that we require far greater attention on the excluded than was previously the case.

Extending this analysis, some questions that demand empirical analysis include the relative trade-off between individuals and society overall. Are there optimal network sizes after which point the costs of supplying services (e.g., 100% health insurance) outweigh the benefits? Or, if, as we find, individual and perhaps societal costs of exclusion rise, does this call for greater policy interventions than previously believed?

This work has raises several other questions. If someone says they have no TV signal reaching them, and they don't care, how is exclusion a cost to them? Without getting into issues of personal choice and preferences, or the fact that all members of a network are likely not equal (as postulated by Odlyzko, et. al.), the dual of this implies the exclusion is lower than calculated only because any value of inclusion is also overstated. Thus, that an included network is worth less despite any exclusion is the basis for diminished costs of exclusion. This might be another framing for the debate over valuing viewers for cable TV with bundles versus ala carte pricing.

Additional impacts of exclusion are multiple. Direct impacts relate to the added costs of using alternative networks, but far greater are the (opportunity) costs due to lack of participation in utility-increasing activities. If we think of broader issues of exclusion, a report [30] indicates 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.

Several practical implications flow from our analytic framework for network exclusion. First, public officials should apply a more favorable discount rate to government support for inclusionary policies than they might otherwise consider without using this framework. Social costs that seem modest in the short term explode exponentially over time. Second, because the costs are born by all – network-included and as well as the excluded – they should expect future burdens to grow for their entire electorate. Total economic costs could be reduced on all citizens/taxpayers/voters by timely and early interventions at the front end of any network design and build out. These are two timely issues as the Obama administration considers which broadband policies it will pursue.

Third, there are also political implications as these digital, ubiquitous networks grow. The rules and regulations of the network are most likely to be set by the more privileged included, who will have different perspectives and priorities than the excluded. As high value networks grow, the interests of the latter may receive less and less attention by the included and their political representatives. Early participants are more likely than later ones to influence the 'rules of the game' which lead to technological and business 'lock in' that tend to reflect the interests and perspectives of the influential.

Taken together, these fundamental issues of digital inclusion and empowerment that have fallen off the research and policy agendas [31] should be revisited by scholars and policy makers alike. We need to give more attention to the dark side of Metcalfe's Law.

Certainly, we need to continue to seek the bright side of network inclusion; but not to the exclusion of the excluded.

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