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RESEARCH ARTICLE

The not-so-forbidden triad: Evaluating the assumptions of the Strength of Weak Ties

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Abstract

The Strength of Weak Ties is among the most influential social theories of the past 50 years. However, its prediction that weak ties are especially useful for obtaining novel information is sometimes not supported. To understand why, I investigate whether social networks typically satisfy the theory's assumptions, and whether the theory's prediction is robust to violations of its assumptions. First, examining a diverse corpus of 56 empirical social networks, I show that empirical social networks (nearly) satisfy some but not all of the theory's assumptions. Second, using a simulation of information diffusion, I show that the predicted utility of weak ties is not robust to violations of these assumptions. When the assumptions of the theory are violated, as is common in social networks, access to novel information depends on bridging ties, regardless of their strength. Moreover, when they exist, strong bridges (i.e., bridges with high bandwidth) are more useful than weak bridges (i.e., bridges with low bandwidth). I conclude by recommending that research applying this theory should first consider whether its assumptions are satisfied, and that a tie's strength and bridgeness should be measured and modeled independently.

Keywords: bridging; diffusion; meta-analysis; Strength of Weak Ties

1. Introduction

The Strength of Weak Ties (SWT; Granovetter, 1973) is among the most influential network theories, amassing over 70,000 citations in fifty years. Weak social ties (e.g., acquaintances) might be expected to have limited value due to their weakness. However, SWT hypothesized that, because bridges between different social worlds are more likely to be weak social ties than strong ties (e.g., close friends and family), weak ties can be especially useful as sources of novel information. In practical terms, despite their social weakness, weak ties can nonetheless be useful for finding information about things such as job opportunities (Granovetter, 1974). This logic has found application across a range of domains, from public health (Bavel et al., 2020) to physics (Battiston et al., 2020).

Although it has had enormous influence, the empirical support for its hypothesis is less clear (Kim and Fernandez, 2023). For example, an early review found only "partial confirmation" for the hypothesis that weak ties provide access to novel information (Granovetter, 1983), while some more recent studies have yielded findings contrary to this prediction (e.g., Bian, 1997; Gee et al., 2017; Rajkumar et al., 2022; Neal, 2022). In one of the most comprehensive reviews to date, Kim and Fernandez (2023) suggested these mixed findings may derive from "two challenges to. . .the validity of arguments underlying Granovetter's strength of weak ties (SWT) thesis": weak ties may often not be bridges, and even when weak ties are bridges, they may still not be as useful as strong ties (p. 177). In this paper, I investigate these possibilities, focusing specifically on the role that assumptions play in SWT.

All theories make assumptions, which may or may not be satisfied in any given case. Moreover, a theory's predictions may or may not be robust to violations of its assumptions. Therefore, in this paper I examine whether SWT's assumptions are typically satisfied by empirical social networks, and whether SWT's prediction is robust to violations of those assumptions. First, using a diverse corpus of 56 empirical social networks, I show that empirical social networks typically satisfy some but not all of SWT's assumptions. Although SWT has been applied to both whole/complete networks and personal/ego networks, this corpus and demonstration is restricted to whole/complete networks because public repositories of network data do not contain instances of weighted personal/ego networks. Second, using a simulation of information diffusion, I show that the SWT's prediction—that weak ties are especially useful for accessing novel information—is not robust to the violations of these assumptions that are common in empirical social networks.

The remainder of the paper is organized in four sections. In the background section, I review the assumptions that underlie SWT's prediction concerning the utility of weak ties. In Study 1, I describe the assembly of a corpus of social networks, and examine the extent to which each network satisfies SWT's assumptions. In Study 2, I describe a simulation of information diffusion, which I use to experimentally test whether SWT's prediction is robust to the violations of its assumptions that were observed in Study 1. In the discussion section, I conclude by reflecting on the implications of these results for future tests of SWT, and the roles that tie strength and bridging should play in future research on information diffusion.

2. Background

As information circulates through a social network, it can get 'stuck' in groups of people who interact frequently with each other and thus are joined by strong social ties. Membership in such a group, and the connections to other members by strong ties, provides access to information from others in the group, but not to information circulating elsewhere in the network. Gaining access to information circulating in other parts of the network requires a tie outside the group, and this tie is likely to be weak precisely because it is to an outsider with whom interaction is infrequent. As Granovetter (1973) explained, "the significance of weak ties, then, would be that those which are local bridges create more, and shorter, paths" (p. 1365), and therefore information "can reach a larger number of people. . .when passed through weak ties rather than strong" (p. 1366). He later clarified the practical implication of this phenomenon, noting that "individuals with few weak ties will be deprived of information from distant parts of the social system" (Granovetter, 1983, p. 202). Therefore, the prediction that has become synonymous with SWT is that *weak ties are especially useful for accessing novel information* because they can serve as bridges beyond one's immediate social circle.

The contributions of SWT to the social sciences and other disciplines are unambiguous. However, in their recent review, Kim and Fernandez (2023) observed that "when one considers how much confidence we have in the validity of [SWT] – as opposed to how generative it has been for research in various disciplines – the celebration might be a bit quieter" (p. 178). Pointing to tests of SWT that have reached mixed, ambiguous, or contrary conclusions (Bian, 1997; Gee et al., 2017; Rajkumar et al., 2022; Neal, 2022), they concluded that "the structural advantage implied by weak ties may not necessarily stand" (p. 186). To better understand the scope conditions of SWT and develop a more nuanced theory of the role of weak ties, they suggested that "the validity of the underlying. . .assumptions should be subject to empirical. . .inquiries" (p. 188). In this paper, I take up their recommendation, and in this section begin by reviewing the assumptions that underlie SWT.

The argument for the SWT is premised on the assumption that "the stronger the tie between *A* and *B*, the larger the proportion of individuals in [the network] to whom they will *both* be tied" (Granovetter, 1973, p. 1362). Indeed, this assumption is so essential to the argument that it appears in the paper's abstract: "the degree of overlap of two individuals' friendship networks varies directly with the strength of their tie to one another" ((Granovetter, 1973), p. 1360). This first assumption can be formalized as the claim that *friendship overlap and tie strength are positively correlated*:

$$\mathrm{cor}(\mathrm{overlap}, \mathrm{strength}) > 0 \tag{A1}$$

Kim and Fernandez (2023) recognized the importance of this assumption for the theory, explaining that "empirically verifying the. . .relationship between tie strength and [shared contacts] becomes critical in assessing the validity of the SWT thesis" (p. 180). Friedkin (1980) did provide early empirical evidence of the relationship in the research network of biology faculty at a university. However, research applying SWT usually does not evaluate whether this assumption is satisfied, or whether the theory's prediction is robust to violations of this assumption.

Granovetter (1973) did not specify the strength of the positive correlation assumed by A1 because a "mathematical model. . .becomes rather involved" (p. 1363). Instead, for the sake of simplicity in developing the theory, he exaggerated it. If overlap and strength are perfectly positively correlated (i.e., if $\mathrm{cor}(\mathrm{overlap},\mathrm{strength}) = 1$), then it is impossible for two individuals to have a strong ties to a shared contact, but not be tied to each other. He called this impossible configuration the 'forbidden triad,' and from it derived two additional assumptions.

A second assumption of SWT is that "*no strong tie is a bridge*" (emphasis in original; Granovetter, 1973, p. 1364). This second assumption can be formalized as a conditional probability:

$$\mathrm{P}(\mathrm{bridge} \mid \mathrm{strong}) = 0 \tag{A2}$$

That is, given that a tie is strong, there is a 0% chance that it is a bridge. Kim and Fernandez (2023) questioned the likely validity of this assumption in practice, explaining that "even though a tie's structural property [i.e., whether it is a bridge] seems possibly proxied by a tie's strength, strong ties may be either" (p. 183). Indeed, Park et al. (2018) observed that "long-range ties are nearly as strong as social ties embedded within a small circle of friends," and thus that strong ties can sometimes be bridges. As with A1, research applying SWT usually does not evaluate whether this assumption is satisfied, or whether the theory's prediction is robust to violations of this assumption.

A third assumption of SWT is that "*all bridges are weak ties*" (Granovetter, 1973, p. 1364). This third assumption can similarly be formalized as a conditional probability:

$$\mathrm{P}(\mathrm{weak} \mid \mathrm{bridge}) = 1 \tag{A3}$$

That is, given that a tie is a bridge, there is a 100% chance that it is weak. This assumption has frequently been misunderstood or misstated as suggesting that all weak ties are bridges (i.e., $\mathrm{P}(\mathrm{weak}|\mathrm{bridge}) = 1$; Takahashi and Inamizu, 2014; Kim and Fernandez, 2023; Van der Leij and Goyal, 2011). However, Granovetter (1973) knew that "weak ties. . .are certainly not automatically bridges" (p. 1364). This misunderstanding has hampered prior attempts to validate the assumption, potentially leading to erroneous conclusions about its invalidity. Indeed, in the one explicit empirical test, Friedkin (1980) observed support for A3. However, as with A1 and A2, research applying SWT usually does not evaluate whether this assumption is satisfied, or whether the theory's prediction is robust to violations of this assumption.

Evaluating any theory's assumptions requires two steps. First, it is necessary to consider the extent to which empirical data (as they are typically collected) satisfy the assumptions in practice. Second, because assumptions often represent simplifying exaggerations that are not expected to hold exactly in practice, it is necessary to consider whether a theory's predictions are robust to the violations of its assumptions that are typical in empirical data. Therefore, in the following sections I present two related studies. In Study 1, I ask: *Do empirical social networks, as they are usually measured, satisfy SWT's assumptions*? Specifically, I explore whether social networks satisfy, or nearly satisfy, these assumptions, and whether these assumptions are better satisfied in certain types of networks (e.g., communication vs. contact, or small vs. large). In Study 2, I ask: *Is SWT's prediction about the usefulness of weak ties robust to the violations of assumptions that are common in empirical social networks*? For example, although empirical social networks may not exactly satisfy the strict assumption that *all* bridges are weak ties, is SWT's prediction still supported if *most* bridges are weak ties.

3. Study 1: satisfying assumptions

3.1 Methods

3.1.1 Data

3.1.1.1 Assembly. To examine the extent to which empirical social networks satisfy SWT's assumptions, I assembled a corpus of weighted social networks from seven large network data repositories: SocioPatterns (Cattuto and Barrat, 2023), University of California Irvine Network Data Repository (UCINDR; DuBois, 2023), Netzschleuder (Peixoto, 2020), the KONECT Project (Kunegis, 2013), the Index of Complex Networks (ICON; (Clauset et al., 2016)), and two `networkdata` libraries for R (Schoch, 2022; Almquist, 2014). A network was included in the corpus if it (a) was unipartite, (b) was publicly available, (c) was composed of nodes that represent non-fictional people, (d) included empirically-measured tie weights capturing non-anonymous social interactions, and (e) was associated with a publication that documented the definition of the nodes, ties, and weights.

These inclusion criteria implied excluding certain networks. First, networks that were not publicly available (e.g., AddHealth) were excluded because they could not be included in a publicly shared corpus. Second, networks among fictional people (e.g., *Les Misérables* characters) were excluded because they may describe unrealistic social structures. Third, networks whose tie strengths were derived from the network's topology (e.g., number of shared neighbors) were excluded because they risk conflating measures of tie strength with measures of tie bridgeness (Kim and Fernandez, 2023). Fourth, although the corpus includes networks where the measured interaction occurred online (e.g., emails between colleagues; Michalski et al., 2011; Klimt and Yang, 2004), it excludes networks where there interaction occurred solely on anonymous social media platforms because anonymity is inconsistent with the formation of the kinds of strong personal ties described by SWT. Finally, although SWT has been applied to both whole/complete networks and personal/ego networks, none of these repositories included any personal/ego networks meeting the including criteria, and therefore in practice the scope of the corpus is restricted to whole/complete networks.

This search process yielded a corpus of 56 networks. A table describing each network in the corpus, including its source, measurement, and topological characteristics is provided in the *Supplementary Information*.

3.1.1.2 Processing. For each included network, the raw data was minimally processed to obtain an undirected weighted `igraph` object (Csardi and Nepusz, 2006). Loops were removed, node and edge attributes (except edge weights) were removed, and multi-edges were collapsed into simple edges. Transforming directed networks into undirected networks required collapsing tie strengths. When the original network was directed and tie strength was measured using a count variable (e.g., the number of emails), the strength of an undirected tie was defined as the sum. For example, if i sent j 10 emails, and j sent i 5 emails, then the undirected network records the tie strength between i and j as 15 (i.e., i and j exchanged 15 emails). When the original network was directed and tie strengths were measured using a scale variable (e.g., friendship closeness), the strength of an undirected tie was defined as the mean. For example, if i reported a closeness of 5 toward j on a 5-point Likert scale, and j reported a closeness of 3 toward i, then the undirected network records the tie strength between i and j as 4 (i.e., i and j feel a mean closeness of 4).

3.1.1.3 Relevance. Each of the networks in the corpus captures a human social network of communication or interaction among friends and acquaintances, and therefore broadly matches the types of friendship networks for which SWT was proposed. However, because the criteria for inclusion in the corpus were broad, these networks are diverse in terms of where (e.g., school, work) and how (e.g., survey, sensor) they were collected, and what the ties (e.g., communication, contact, friendship) and their strengths (e.g., frequency, intensity) represent. Therefore, it is important to consider whether each of these networks is relevant for evaluating SWT's assumptions.

Granovetter (1973) suggested that tie strength should be defined by some "combination of the amount of time, the emotional intensity, the intimacy, and the reciprocal services which characterize each tie" (p. 1361). However, he did not offer any particular operationalization of tie strength, or suggest how these different components might be weighted. Instead, he left the precise definition of tie strength in SWT ambiguous, explaining that "it is sufficient for the present purpose if most of us can agree, on a rough intuitive basis, whether a given tie is strong, weak, or absent" (p. 1361). In the absence of an explicit operationalization of tie strength, I remain neutral about whether the operationalization of tie strength by any given network in the corpus—which includes both amounts of time (e.g., how often do you talk; Bernard et al., 1979) and emotional intensities (e.g., how close do you feel; Van de Bunt et al., 1999)—matches the theory's requirements. Instead, I include networks using a range of tie strength operationalizations, and explicitly test whether certain operationalizations yield networks that better satisfy the theory's assumptions.

Granovetter (1973) also suggested that SWT "is not meant primarily for application to small, face-to-face groups or to groups in confined institutional or organizational settings" (p. 1376). However, he relied on networks of small, face-to-face groups (e.g., Davis, 1970; Newcomb, 1961) and networks of organizational settings (e.g., Friedkin, 1980; Weimann, 1983) for early empirical support of the theory. Because it is ambiguous whether SWT is intended to apply to small or organizational networks, I remain neutral about whether the size ($N = 11 - 86978$) or setting (school, work, online, crime) of any given network in the corpus matches the theory's requirement. Instead, I include networks with a range of sizes and from a range of settings, and explicitly test whether networks of certain sizes or in certain settings better satisfy the theory's assumptions.

Finally, the networks in the corpus vary in the age of their members (e.g., children, young adults, or adults) and in their topological characteristics, including their density ($d =$ less than $0.001 - 0.973$) and degree centralization ($DC = 0.015 - 0.783$). Granovetter (1973) did not comment on whether SWT is intended to apply only to networks of individuals of a certain age, or only to networks with certain topological characteristics. Therefore, I remain neutral about whether the age or topology of any given network in the corpus matches the theory's requirement. Instead, I include networks with a range of ages and topolological characteristics, and explicitly test whether networks with members of a certain age or with certain topological characteristics better satisfy the theory's assumptions.

Because the corpus is diverse, there is no expectation that all of its members will satisfy SWT's assumptions. Instead, examining a diverse set of networks makes it possible to examine both (a) whether empirical social networks satisfy SWT's assumptions on average, and in a more nuanced way (b) whether certain types of networks are more consistent with these assumptions.

3.1.2 Measuring friendship network overlap

The first assumption (A1) refers to "the degree of overlap of two individuals' friendship networks" (Granovetter, 1973, p. 1360). There are many ways that friendship overlap might be measured. In the primary analysis, I follow Granovetter (1973) by measuring overlap as "the proportion of individuals in [the network] to whom they [are] both be tied" (p. 1362). However, in the sensitivity analyses I also consider measuring overlap using the Jaccard (Jaccard, 1912) or Dice (Dice, 1945) coefficients of similarity, which normalize this measure by the sizes of the two individuals' friendship networks.

3.1.3 Identifying bridges, weak ties, and strong ties

The other assumptions (A2 and A3) refer to bridges, strong ties, and weak ties. Therefore, evaluating whether a network satisfies these assumptions requires measuring ties' 'bridgeness', determining whether a tie is a bridge, and determining whether it is weak or strong.

There are many ways to measure a tie's bridgeness. In the primary analysis, I measure a tie's bridgeness using the inverse Jaccard coefficient because it is most commonly used in prior SWT research (Friedkin, 1980; Neal, 2022; Rajkumar et al., 2022). However, in the sensitivity analyses I also consider measuring bridgeness using local bridge degree (Granovetter, 1973), betweenness (Brandes, 2001), long ties (Jahani et al., 2023), and the Dice coefficient (Dice, 1945).

There are also many ways to decide whether a given tie is a bridge, and whether it is a weak or strong tie. Because no theoretical rationale exists for choosing a specific cutoff value for such decisions, quantiles offer a straightforward option. In the primary analysis, I use quintiles, which means that a tie is identified as a bridge if its bridgeness is in the top quintile (i.e., top 20%), a tie is identified as strong if its strength is in the top quintile (i.e., top 20%), and a tie is identified as weak if its strength is in the bottom quintile (i.e., bottom 20%). In the sensitivity analyses I also consider using tertiles and deciles. One important limitation of the quantile approach is that the relevant quantiles must have unique boundaries. Consider a very small network in which the tie strengths take the values {1,1,1,1,3}. The boundary of the bottom tertile (i.e. the bottom 33%) is 1, but the boundary of the top tertile (i.e. the top 33%) is also 1. As a result, tertiles cannot be used to distinguish weak from strong ties in such a network. Therefore, in all analyses, I only include networks for which the relevant quantiles have unique boundaries.

3.1.4 Analytic plan

To evaluate the extent to which a network satisfies A1, I compute the Spearman correlation between (a) the strength of the tie between two people and (b) the proportion of others who are mutual friends. I use a Spearman correlation coefficient because A1 only assumes a monotonic, but not necessarily linear, association. To evaluate the extent to which a network satisfies A2, I compute the probability that a strong tie is a bridge. Finally, to evaluate the extent to which a network satisfies A3, I compute the probability that a bridge is a weak tie. In each case, I summarize the variability observed in the corpus using a histogram and by reporting the mean and standard deviation of these values. The data and code necessary to replicate these analyses, are available at https://osf.io/jp2d9/.

3.2 Results

3.2.1 Primary analysis

Figure 1a shows the Spearman correlation between tie strength and friendship overlap in all 56 networks in the corpus. SWT assumes that this correlation is positive (A1), and on average it is positive in these networks ($M = 0.31, SD = 0.16$). A one-sample t-test confirms that this value is statistically significantly larger than zero ($t_{55} = 14.24, p < 0.001$), and thus that this assumption is satisfied in this sample of empirical networks. However, there is substantial variation. Some networks satisfy the assumption more strongly (e.g., a school contact network, $\rho = 0.84$; McNett and Voelker, 2005) than others (e.g., a multiplex criminal network, $\rho = 0.06$ Grund and Densley, 2012), and some fail to satisfy it (e.g., a network of affective ties at work, $\rho = -0.05$, Sampson, 1968).

Figure 1b shows the probability that a strong tie is a bridge (i.e., P(bridge | strong)) in each of 50 networks. SWT assumes that this probability is zero (A2), and on average it is close to zero in these networks ($M = 0.09, SD = 0.08$). Although the mean is near zero, a one-sample t-test confirms that this value is still statistically significantly larger than zero ($t_{49} = 8.06, p < 0.001$), and thus that this assumption is not satisfied in this sample of empirical networks. Instead, the

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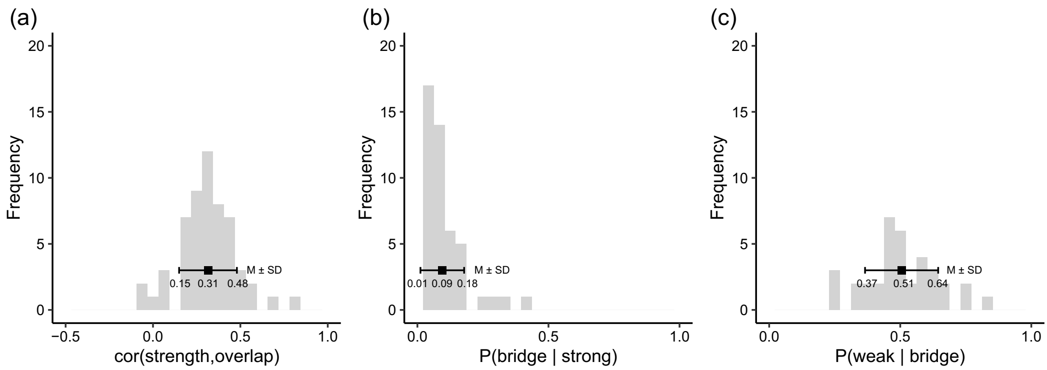

Figure 1. Evaluating whether empirical social networks satisfy SWT's assumptions: (a) correlation between tie strength and friendship overlap in 56 networks, (b) probability that a bridge is a strong tie in 50 networks, (c) probability that a weak tie is a bridge in 36 networks.

assumption is nearly satisfied; although SWT assumes that no strong tie is a bridge, on average 9% of strong ties *are* bridges. There is variation in the extent to which networks satisfy this assumption. A few networks satisfy the assumption exactly (e.g., a criminal communication network, $P = 0$; Natarajan and Hough, 2000), many networks nearly satisfy it (e.g., a workplace contact network, $P = 0.025$; Webster, 1995), and a few fail to satisfy it (e.g., a criminal communication network, $P = 0.43$; Morselli, 2009).

Figure 1c shows the probability that a bridge is a weak tie (i.e., P(weak | bridge)) in each of 36 networks. SWT assumes that this probability is one (A3), however on average this probability is much lower in these networks ($M = 0.51, SD = 0.14$). A one-sample t-test confirms that this value is statistically significantly smaller than one ($t_{35} = -21.28, p < 0.001$), and thus that this assumption is not satisfied in this sample of empirical networks. Although SWT assumes that *all* bridges are weak ties, on average *only* 51% of bridges are weak ties. There is variation in the extent to which networks satisfy this assumption. Some networks approach satisfying this assumption (e.g., a workplace email network, $P = 0.75$; Michalski et al., 2011), but most networks fail to satisfy it (e.g., a school friendship network, $P = 0.44$; Van de Bunt et al., 1999). However, although bridges are not always weak ties, bridges are at least more likely to be weak ties than to be strong ties (i.e., P(weak | bridge) > P(strong | bridge); see *Supplementary Information*).

3.2.2 Sensitivity analyses

The results presented in section 3.2.1 are obtained by examining a diverse corpus of empirical social networks. However, it is possible that SWT has a more nuanced scope and applies only to networks in particular settings, that capture particular relationships, that measure tie strength in particular ways, that were measured for particular age groups, or that have particular topological characteristics. To investigate these possibilities, Table 1 repeats the primary analyses for specific types of networks. The first row of the table reproduces the results obtained from the full corpus and shown in Figure 1. The remaining rows describe subsets of the full corpus. For example, the 'Settings: Work' row shows that the correlation between tie strength and friendship overlap in the 19 networks measured in a workplace setting is $\rho = 0.262$, which is smaller than the value observed in the corpus as a whole ($\rho = 0.315$). This means that, on average, the networks measured in a workplace setting satisfy A1 less well than other networks.

The value observed for each subset of networks is similar to the value observed in the full corpus. There are no cases where cor(strength,overlap) is statistically significantly closer to 1, where P(bridge|strong) is statistically significantly closer to 0, or where P(weak|bridge) is statistically

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Table 1. Sensitivity of results to network type

	cor(strength,overlap)		P(bridge|strong)		P(weak|bridge)	
	N	M (SD)	N	M (SD)	N	M (SD)
Full corpus	56	0.315 (0.165)	50	0.095 (0.083)	36	0.505 (0.14)
Setting						
Work	19	0.262 (0.15)	17	0.085 (0.055)	13	0.499 (0.139)
School	20	0.333 (0.194)	18	0.097 (0.088)	15	0.539 (0.119)
Crime	6	0.278 (0.139)	4	0.132 (0.203)	1	0.333 (NA)
Online	7	0.352 (0.099)	7	0.114 (0.048)	5	0.509 (0.189)
Relation						
Affect	8	0.328 (0.173)	8	0.084 (0.035)	7	0.467 (0.132)
Contact	22	0.342 (0.179)	21	0.082 (0.07)	15	0.539 (0.155)
Multiplex	7	0.214 (0.136)	4	0.1 (0.093)	3	0.471 (0.06)
Talk	19	0.314 (0.153)	17	0.115 (0.11)	11	0.492 (0.142)
Tie strength						
Count	8	0.225 (0.13)	5	0.101 (0.081)	4	0.474 (0.049)
Frequency	41	0.329 (0.166)	38	0.097 (0.091)	26	0.519 (0.148)
Intensity	7	0.331 (0.186)	7	0.082 (0.037)	6	0.465 (0.144)
Age						
Children	5	0.227 (0.184)	5	0.165 (0.144)	3	0.539 (0.199)
Young adults	14	0.323 (0.146)	12	0.083 (0.046)	11	0.53 (0.105)
Adults	37	0.323 (0.171)	33	0.089 (0.08)	22	0.488 (0.15)
Topology						
Low *N*	28	0.31 (0.185)	26	0.111 (0.106)	17	0.462 (0.147)
High *N*	28	0.319 (0.147)	24	0.078 (0.045)	19	0.544 (0.124)
Low *d*	28	0.304 (0.157)	23	0.088 (0.088)	13	0.569 (0.131)
High *d*	28	0.326 (0.175)	27	0.101 (0.08)	23	0.469 (0.133)
Low *DC*	28	0.261 (0.14)	24	0.103 (0.069)	17	0.508 (0.134)
High *DC*	28	0.368 (0.173)	26	0.087 (0.095)	19	0.502 (0.148)

High = above median, Low = Below median; *N* = Number of nodes, *d* = Density, *DC* = Degree centralization

significantly closer to 1. This suggests that the results reported in Section 3.2.1 and shown in Figure 1 are not sensitive to a network's setting, relation, operationalization, age, or topology.

It is also possible that observing the assumed positive correlation between tie strength and friendship overlap requires measuring overlap, or computing the correlation, in a different way. To investigate these possibilities, Table 2 repeats the analysis of A1 using alternative overlap and correlation measures. There are no cases where the correlation is statistically significantly closer

Table 2. Sensitivity of results to measurement of friendship overlap

Measurement		cor(strength,overlap)	
Overlap	Correlation	N	M (SD)
Jaccard	Spearman	56	0.309 (0.169)
Dice	Spearman	56	0.309 (0.169)
Mutual friends*	Spearman	56	0.315 (0.165)
Jaccard	Pearson	56	0.254 (0.16)
Dice	Pearson	56	0.245 (0.15)
Mutual friends	Pearson	56	0.285 (0.185)

* Specification used in primary analysis

Table 3. Sensitivity of results to measurement of bridges

Measurement		P(bridge|strong)		P(weak|bridge)	
Bridgeness	Quantile	N	M (SD)	N	M (SD)
Jaccard	3	53	0.233 (0.103)	53	0.58 (0.114)
Jaccard*	5	50	0.095 (0.083)	36	0.505 (0.14)
Jaccard	10	43	0.029 (0.035)	11	0.29 (0.188)
Dice	3	53	0.233 (0.103)	53	0.58 (0.114)
Dice	5	50	0.095 (0.083)	36	0.505 (0.14)
Dice	10	43	0.029 (0.035)	11	0.29 (0.188)
Betweenness	3	53	0.26 (0.079)	53	0.534 (0.112)
Betweenness	5	50	0.121 (0.065)	38	0.46 (0.151)
Betweenness	10	51	0.055 (0.062)	14	0.225 (0.186)
Local degree	3	4	0.34 (0.1)	4	0.449 (0.135)
Local degree	5	7	0.161 (0.125)	4	0.422 (0.183)
Local degree	10	3	0.042 (0.035)	0	—
Long ties	3	31	0.095 (0.17)	31	0.627 (0.282)
Long ties	5	29	0.084 (0.175)	18	0.531 (0.307)
Long ties	10	32	0.089 (0.195)	5	0.317 (0.19)

* Specification used in primary analysis

to 1. This suggests that the results reported in Section 3.2.1 and shown in Figure 1a are not sensitive to the measurement of friendship overlap or the choice of correlation coefficient.

Finally, it is possible that observing networks to satisfy A2 or A3 requires operationalizing bridges, weak ties, or strong ties, in a specific way. To investigate these possibilities, Table 3 repeats the analysis of A2 and A3 using alternative measures of bridgeness and alternative quantiles for identifying specific types of ties. There are no specifications where P(bridge|strong) is statistically significantly closer to 0 and where P(weak|bridge) is statistically significantly closer to 1. This

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suggests that the results reported in Section 3.2.1 and shown in Figure 1b and c are not sensitive to the measurement of bridgeness or the choice of quantile to identify types of ties.

3.3 Preliminary discussion

These results present a mixed picture of the extent to which empirical social networks satisfy SWT's assumptions. On average empirical social networks satisfy A1 and nearly satisfy A2, but they fail to satisfy A3. Additionally, sensitivity analyses indicate that the extent to which a network satisfies these assumptions does not depend on how or where the network was measured.

Granovetter (1973) offered these as assumptions for the sake of developing SWT, and not as hypotheses about or expectations for empirical networks. Therefore, while it is unsurprising that empirical networks do not always satisfy the theory's assumptions, it is notable they often come close. In Study 2, I investigate whether SWT's prediction is robust to the violations of its assumptions that appear typical in empirical social networks.

4. Study 2: robustness to violating assumptions

Although the results in Study 1 suggest that empirical social networks often come close to satisfying SWT's assumptions, the question remains, *do they come close enough*? Granovetter (1973) noted that "whatever results are inferred from [these assumptions] should tend to occur in the degree that" the assumptions are satisfied, and thus expected SWT's prediction to be robust to violations of these assumptions (p. 1363). Therefore, in Study 2, I test the robustness of SWT's prediction—that weak ties are especially useful as sources for novel information—in networks that *nearly* satisfy SWT's assumptions. Specifically, I simulate the diffusion of information in networks that satisfy SWT's assumptions to varying degrees, examining which types of ties are most useful for obtaining novel information.

4.1 Methods

4.1.1 Initialization

The simulation begins by generating a small world network containing 100 individuals. I use a small world network because real social networks often exhibit a small world structure, and because small world networks contain some distinctively bridging ties. In this network, a tie's strength is initially defined as its Jaccard coefficient because A1 holds that "the degree of overlap of two individuals' friendship networks varies directly with the strength of their tie to one another" (Granovetter, 1973, p. 1362). A tie's bridgeness is defined as its inverse Jaccard coefficient to match the operationalization of bridgeness used in Study 1. By defining ties' strength and bridginess in these ways, the network satisfies all of SWT's assumptions: there is a perfect correlation between strength and friendship overlap (A1), no strong ties are bridges (A2), and all bridges are weak ties (A3). Therefore, the simulation unfolds in a network where SWT's prediction concerning the utility of weak ties should be most readily supported.

Each tie is classified as a bridge or non-bridge based on its bridgeness using the same quintile method as in Study 1. After identifying bridges and non-bridges, the extent to which the simulated network satisfies SWT's assumptions is manipulated by perturbing the tie strengths of selected ties. Specifically, the tie strength of a given fraction of bridges, and a given fraction of non-bridges, is defined as the inverse Jaccard coefficient, thereby making their strength equal to their bridgeness. In the simulations described below, I manipulate the fraction of bridges and non-bridges whose strength is perturbed from 0 (i.e., network satisfies all of SWT's assumptions) to 0.5 (i.e., network violates all of SWT's assumptions). After any strength perturbations, each tie is classified as weak or strong based on its strength using the same quintile method as in Study 1.

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4.2 Dynamics

In each step of the simulation, a random individual i obtains a piece of information that they may share with their contacts j. The probability that i shares the information with a given j is defined by their tie strength, such that information sharing is more likely through strong ties and less likely through weak ties. This reflects the fact that strong ties interact more frequently, or trust one another more, and therefore have more opportunity or inclination to share information (Aral and Van Alstyne, 2011; Kim and Fernandez, 2023). Contacts who receive the information may share it with their own contacts, again with a probability defined by tie strength. A single piece of information can be shared up to three times, reflecting the fact that information eventually becomes too outdated or distorted to be useful. Through this diffusion process, a given individual may never hear a given piece of information, may hear it once, or may hear it many times from different sources. Each model run simulates the diffusion of 1000 different pieces of information.

SWT predicts that having weak ties is especially useful for accessing novel information. At the end of a model run, I measure individual i's access to novel information as:

$$I_i = N \times \frac{N}{T},$$

where N is the number of novel pieces of information i hears, and T is the total number of times i hears information. The left part of this equation is simply the number of novel pieces of information i hears, which captures the fact that having access to more novel information is better. The right part of this equation is the proportion of information i hears that is novel, which captures the fact that hearing mainly novel information is better because does not get lost in the noise of redundant, distorted, outdated, or conflicting information.

4.2.1 Analysis

I estimate the value of different types of ties using a linear regression that predicts I_i as a function of i's number of weak bridges, strong bridges, weak non-bridges, strong non-bridges, and ordinary ties (i.e., ties that are neither bridges nor non-bridges, or neither weak nor strong). Standardized regression coefficients permit direct comparisons of the usefulness of each type of tie for accessing novel information. Observing that i's number of weak bridges have a larger positive effect on I_i than other types of ties would provide support for SWT's prediction.

4.3 Results

4.3.1 When assumptions are satisfied

I begin by evaluating whether the simulation supports SWT's hypothesis under ideal conditions, that is, when all of SWT's assumptions are met. In the context of simulation modeling, this is described as demonstrating the model's 'generative sufficiency' (Epstein, 2006), and is a necessary step to show that the model performs as expected.

Table 4 reports the results of a regression predicting an individual's access to novel information, as a function of the individual's number of different types of ties, in a network where all of SWT's assumptions are met: tie strength and friendship overlap are perfectly correlated, no strong tie is a bridge, and all bridges are weak ties. As predicted by SWT, weak ties (all of which are bridges) promote access to novel information ($\beta = 0.39$), while strong ties (none of which are bridges) suppress it ($\beta = -0.669$). Ordinary ties—ties that are neither strong nor weak, or are neither bridges nor non-bridges—are also not helpful. Because this network satisfies SWT's assumptions, it does not contain any strong bridges or weak non-bridges. These results confirm SWT's validity by demonstrating that when SWT's assumptions are met, SWT's predicted outcome is observed. They also suggest that the model plausibly simulates the information diffusion dynamics relevant for SWT.

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Table 4. The importance of ties when assumptions are satisfied

	β	*SE*	*p*
Weak bridge	0.390	0.100	< 0.001
Strong non-bridge	-0.669	0.108	< 0.001
Strong bridge	–	–	–
Weak non-bridge	–	–	–
Ordinary ties	-0.352	0.099	0.001
R2		0.858	

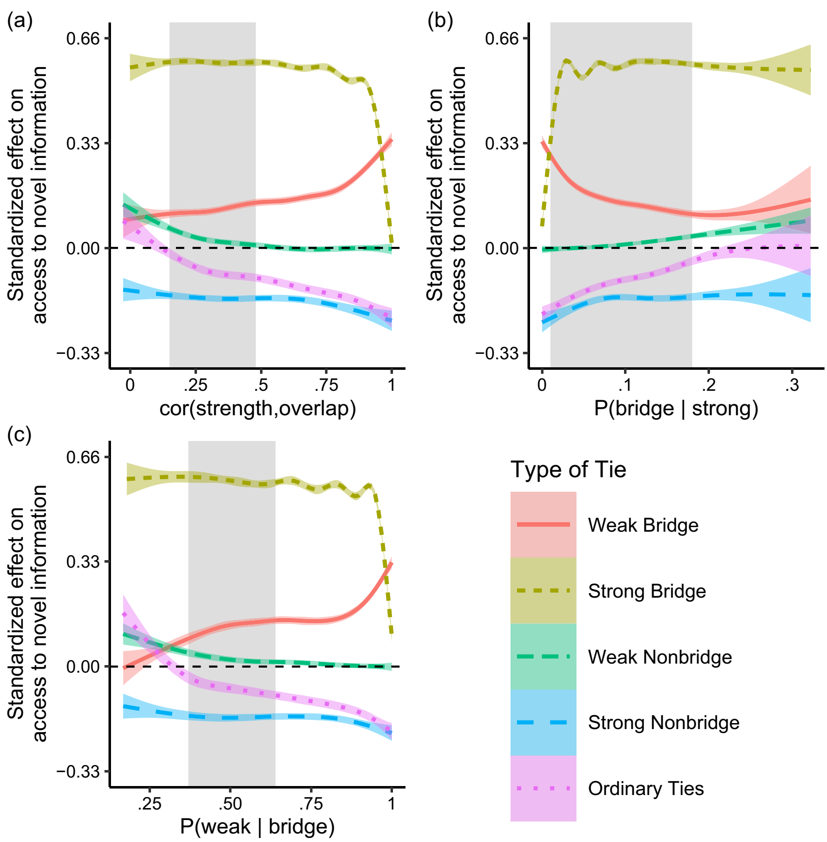

Figure 2. The importance of ties when assumptions are violated.

4.3.2 When assumptions are violated

Figure 2 summarizes the results of 2500 simulation model runs. Each line plots the mean standardized effect of the respective type of tie on accessing novel information (y-axis) in a network with a given structural property (x-axis). The shaded regions around each line show these estimates' 95% confidence intervals over the simulation model runs. Each panel summarizes the same 2500 model runs, but does so with respect to a different structural property corresponding to a different assumption. Within each panel, the gray region marks the values of the property that are typical of empirical social networks (i.e., $M \pm SD$ from Study 1).

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Figure 2a examines the usefulness of different types of ties at varying levels of correlation between tie strength and friendship overlap. When SWT's first assumption (A1) is strongly satisfied and these values are perfectly positively correlated, then weak bridges are indeed the most useful type of tie for accessing novel information, as predicted by SWT. However, as this assumption is increasingly violated and the correlation declines, then weak bridges cease to be especially useful. When cor(strength,overlap) lies between 0.15 and 0.48, which Study 1 found is typical in empirical social networks, strong bridges are substantially more useful for accessing novel information.

Figure 2b examines the usefulness of different types of ties at varying levels of the probability that strong ties are bridges. When SWT's second assumption (A2) is satisfied and this value is zero, then weak bridges are indeed the most useful type of tie for accessing novel information, as predicted by SWT. However, if this assumption is violated, then weak bridges cease to be especially useful. When $P(bridge|strong)$ lies between 0.01 and 0.18, which Study 1 found is typical in empirical social networks, then strong bridges are substantially more useful for accessing novel information.

Figure 2c examines the usefulness of different types of ties at varying levels of the probability that bridges are weak ties. When SWT's third assumption (A3) is satisfied and this value is one, then weak bridges are indeed the most useful type of tie for accessing novel information, as predicted by SWT. However, if this assumption is violated, then weak bridges cease to be especially useful. When $P(weak|bridge)$ lies between 0.37 and 0.64, which Study 1 found is typical in empirical social networks, then strong bridges are substantially more useful for accessing novel information.

5. Discussion

Strength of weak ties (Granovetter, 1973) is among the most influential network theories of the past 50 years. It hypothesizes that weak ties, despite their weakness, are nonetheless especially useful for accessing novel information. Despite enjoying broad theoretical and empirical support, some studies have yielded contrary results (e.g., Bian, 1997; Gee et al., 2017; Rajkumar et al., 2022; Neal, 2022), which Kim and Fernandez (2023) speculate could be related to the validity of assumptions that underlie the theory. To investigate this possibility, I explored two related questions. First, do empirical social networks typically satisfy SWT's assumptions? Second, is SWT's prediction about the importance of weak ties robust to violations of its assumptions?

To answer the first question, in Study 1, I examined the extent to which each of 56 empirical social networks satisfy three of SWT's assumptions. I find that on average social networks *do satisfy* the assumption that tie strength and friendship overlap are positively correlated (mean $\rho = 0.31$). I also find that on average social networks *nearly satisfy* the assumption that no strong tie is a bridge; only 9% of strong ties were bridges in these networks. However, on average social networks *do not satisfy* the assumption that all bridges are weak ties; only 51% of bridges were weak in these networks. Collectively, these results suggest that empirical social networks tend to (nearly) satisfy some, but not all, of SWT's assumptions.

To answer the second question, in Study 2, I used a simulation of information diffusion to examine whether weak ties are useful for obtaining novel information when these assumptions are violated. I find that when SWT's assumptions are satisfied, weak bridging ties are especially useful for obtaining novel information, as predicted by SWT, thereby supporting the theory's validity. In contrast, when SWT's assumptions are violated in ways that are common in empirical social networks, weak ties cease to be useful. In such cases, strong bridging ties are more useful for obtaining novel information than weak bridging ties. Collectively, these results suggest that SWT is valid, but its predictions are not robust to violations of its assumptions that are common in practice.

These results provide a more nuanced understanding of the role of weak ties, highlighting that their unique benefits predicted by SWT depend in part on the satisfaction of a few assumptions. It is important to note, as Kim and Fernandez (2023) did, that these results "should not be seen as diminishing the substantive generative value of the SWT thesis" (p. 188). Indeed, quite to the contrary, they confirm SWT theoretical validity, demonstrating that the theory's prediction is supported whenever the theory's assumptions are satisfied. Likewise, they suggest that when a study reaches findings contrary to SWT's predictions, it may simply be because the network under investigation failed to satisfy the theory's assumptions. It is to be expected that the empirical support for any theory's predictions would be restricted to cases that satisfy the theory's assumptions, and SWT is no exception.

While these results confirm the validity of SWT when its assumptions are met, they also point to a phenomenon that was known prior to SWT (e.g., Harary et al., 1965; Haggett and Chorley, 1969; Bavelas, 1948): bridges are essential for information diffusion. Why, then, did Granovetter (1973) develop a theory of weak ties that required such restrictive assumptions, rather than just focus on bridges? The reason is more about form than function (Granovetter, personal communication, 30 April 2024). An early version of the paper was titled "Alienation reconsidered: The strength of weak ties" (reprinted in Granovetter 1982), and aimed to refute the notion that cities lead to the proliferation of weak ties, which makes them alienating settings (e.g., Wirth, 1938). However, reviewers at *American Sociological Review* did not like this framing and rejected the paper (Kkan, 2014). The version that was eventually published in *American Journal of Sociology* abandoned this framing, but retained the focus on weak ties.

Although Granovetter's (1973) original reason for focusing on weak ties may have been lost on the cutting room floor, it still yielded some potentially unanticipated conceptual and methodological advances. First, the abstract structural concept of a 'bridge' was, at the time, primarily the domain of graph theorists, whereas the concept of 'tie strength' was the domain of sociology. Theorizing an association between bridges and tie strength forged a connection between these fields that spurred decades of further research. Second, identifying bridges in networks, especially large networks, was quite challenging at the time, whereas measuring tie strength was relatively straightforward using conventional data collection methods. Theorizing an association between bridges and tie strength identified strength as a possible (albeit imperfect) proxy for bridgeness. However, the situation has changed since SWT was first articulated: the concept of bridges is now well-known and widely-used in social science (e.g., Burt, 2007), and it is now relatively easy to directly measure a tie's bridgeness (Marsden and Campbell, 2012). These changes have enabled researchers to measure tie strength and bridgeness independently, and therefore to consider the roles of bridges and weak ties separately, which in turn has led to a more nuanced understanding of the contribution of each (e.g., Aral, 2016; Neal, 2022).

The analyses that support these conclusions have a number of strengths. First, the conclusions are robust to numerous alternative specifications that vary how and where networks are measured, how bridges are operationalized, how weak and strong ties are operationalized. Second, they are drawn from a large and diverse corpus of empirical social networks that enabled evaluating SWT's assumptions on average, as well as within networks from specific settings, capturing specific relationships, measuring tie strength in specific ways, for specific age groups. Third, the data and code are publicly available, which facilitates replication and subsequent research on tie strength and bridges. However, corpus is composed of whole/complete networks that were collected primarily in the United States or Western Europe. These patterns reflect broader tendencies both in what network data is publicly available, and in the contexts where SWT has previously been examined. Future research should aim to replicate these findings in personal/ego networks, and in networks collected in other contexts.

This work offers the most comprehensive evaluation of SWT's assumptions, and its prediction's robustness to their violation. When SWT's assumptions are satisfied, its prediction is supported: weak ties are uniquely helpful for obtaining novel information. In contrast, when

SWT's assumptions are violated, as they often are in empirical social networks, its prediction is not supported: strong bridges are more useful than weak ties. These findings point to two recommendations for future research on the SWT. First, when applying SWT, verify whether its assumptions have been satisfied, and when observing results that seemingly contradict SWT's predictions, verify whether its assumptions were violated. Second, when exploring the importance of different types of ties for diffusion and other processes, measure tie strength and bridgeness independently, then consider the roles of bridges and weak ties separately.

Competing interests. The author declares no competing interests.

Data availability statement. Supplementary information, including the data and code necessary to replicate these analyses, is available at https://osf.io/jp2d9/.

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