Who Ties the World Together? Evidence from a Large Online Social Network

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Abstract. Social ties form the bedrock of the global economy and international political order. Understanding the nature of these ties is thus a focus of social science research in fields including economics, sociology, political science, geography, and demography. Yet prior empirical studies have been constrained by a lack of granular data on the interconnections between individuals; most existing work instead uses indirect proxies for international ties such as levels of international trade or air passenger data. In this study, using several billion domestic and international Facebook friendships, we explore in detail the relationship between international social ties and human mobility. Our findings suggest that long-term migration accounts for roughly 83% of international ties on Facebook. Migrants play a critical role in bridging international social networks.

Keywords: migration, social networks, big data

1 Introduction

Social connections between individuals in different countries provide a foundation for international trade and commerce, and for global peace and cooperation [23,40]. A rich literature documents *how* the world is connected, examining the nature, determinants and consequences of social connections between countries. While early studies relied heavily on customs data, foreign direct investment accounts, and international trade data [18], more recent research has integrated data from online sources such as messaging applications and social media sites [30,19,45]. Much less is known about *who* connects the world, and how micro connections affect macro network structure. Understanding how the world is connected has practical value, as it can provide a starting point for scholars and policy makers who seek to understand international relations from a network perspective [20], including, for instance, work on the importance of network brokerage (see [10]). More generally, a better understanding of this transition from the individual to the transnational comes to address the *micro-to-macro* problem identified by Coleman [13] as the fundamental challenge on the path to a science of society.

This study uses Facebook data to provide a disaggregated understanding of the network connections of migrants and non-migrants on one of the world's largest social networks. The Facebook dataset allows for a high-level view of the demographic characteristics and network structures of the world's "international brokers," i.e., the people whose social ties quite literally connect the world. This allows us to ask the central question of our study: who ties the world together?

We present three main results. First, we provide empirical evidence that migrants are a central binding force in the global social network. The act of migration reshapes the network by transforming domestic ties to international ones. The friends they made prior to their move now all know someone who lives in a different country. At the same time, the friends they make in the new country now potentially have a new international tie. These friends now know someone who is *from* another country. With such potential to convert or generate new international ties, it is perhaps unsurprising that over 83% of all international ties involve migrants. These results are consistent with macro-level analyses performed by Perkins and Neumayer [38], who found migrants to play an important role in international communication networks.

Second, we find that migrants act as a bridging force that shrinks the network distance between other people in the Facebook social graph. This is evident in simple descriptive statistics: migrants have higher betwenness in the Facebook graph, particularly when considering connections across countries. We also run simulations that compare the approximate average shortest path length in two graphs: one containing only ties between non-migrants, and one both locals and migrants. Despite our increasing the number of nodes in the graph, we find that the average shortest path length decreases when migrants are included. Both results emphasize the bridging role of networks in connecting distant sub-networks.

Finally, we expand our analysis to the characteristics of migrants and their *local* social networks, to better understand the role that migrants play in their immediate network neighborhood. We establish that migrants' ego networks have fewer dense cores, and that migrants tend to occupy a less redundant position in their ego network, leading us to the conclusion that migrants are also more likely to act as local network bridges. Taken together, these results emphasize the important role that international migrants play in binding together global communities.

2 Related work

A varied literature has examined social connections between countries. We distinguish between three main areas of research: urban networks, online social networks, and research on international migration.

Traditional international network analysis has focused on understanding urban networks using aggregated datasets such as flight passenger flows, telecommunication volume, and corporate organization [42,15]. Airline passenger flows have been used to proxy international human flows across urban networks, under

the assumption that important cities receive more airline passengers. Common inter-airport passenger flow datasets have been extracted from the International Civil Aviation Organization (ICAO) [42,27] and Marketing Information Data Transfer (MIDT) [14,17], which have been used to rank key cities in Western Europe and North America [42,14,25], find global hierarchical structures [44,55], and detect temporal changes of a city's importance in the global city network [44,35] by adopting network analysis methods. Derudder and Witlox [16] pointed out several limitations posed by the use of airline passenger flow data, including the lack of origin and destination information because of stopovers, missing inter-state flow, and possible flows to tourist destinations. In spite of these issues, airline passenger flows remain the most commonly used data source to analyze international urban networks.

Internet backbone networks can also reflect the role of cities and the connections between countries, under the assumption that important cities would have more high-speed internet connections and more connections to other cities [49,34,5,4]. This assumption is often untenable, however. A small city may act as a gateway between core cities and its centrality in the internet backbone network may exaggerate its importance in the worldwide social system [41]. Another traditional dataset comes from the realm of multinational corporate organization. International business companies create new offices globally to distribute their service for their corporate benefits. The transnational network formed by international offices captures the information flow and products flow [6]. The use of this dataset comes with its own limitations, given that transnational flows are inferred instead of directly obtained like airline passenger flows [16].

In recent years, the growing availability of large social datasets has enabled a new, fine-grained level for the understanding transnational social networks, thanks to increases in Internet penetration and the development of global social networking platforms, such as Microsoft Messenger instant-messaging system [30], Twitter [47,28,19], Flickr [11], and Facebook [52,3]. Network structures are analyzed to understand the properties of social networks, including degree distribution, clustering, the small-world effect, and homophily [50,2,37]. For example, Backstrom et al. [2] found that the degree of separation is 3.74 based on 721 million people at Facebook in 2011. The most recent result is 3.6 degrees of separation in 2016, showing that people have grown more interconnected [7].

There has been growing interest in combining spatial and social network analyses to understand the relationship between social networks and migration [1,32,12,8]. International and internal migration patterns have been explored using different sources of new datasets, such as geo-tagged tweets [21,45], IP geolocation [53,46], and social network profile fields [22]. This research has focused on the factors related to international social networks and migration, including distance and trade, community structure, and interactions across countries. In this line of work, three recent papers are most relevant to this study. Kikas et al. [26] found that social network features can explain international migration in terms of net migration per country and migration flow between a pair of countries. Herdağdelen et al. [22] analyzed the social networks of migrants in

the United States by leveraging profile self-reports of home countries. Zagheni et al. [54] showed the viability of conducting demographic research related to international migration through the public Facebook advertising API.

Our research comes to extend the study of international social networks using online data, shifting the focus from the country-to-country to the individuals whose social connections span the boundaries of countries and who quite literally connect the world. We develop a vocabulary to describe social ties in terms of both parties' home and current countries, which we use to provide an examination of both triads and ego networks. Our analysis concludes with a foray into the role of migrants with regard to the connectivity of the global Facebook social graph.

3 Data and Methods

Our analysis makes use of de-identified profile and social connection data available on Facebook, presently the world's largest social networking platform, which as of the time of writing numbered more than 2.25 billion monthly active users. These data have several key limitations: the population of Facebook users is not representative, particularly outside of the U.S. and Western Europe; the connections observed on Facebook are a biased sample of actual social connections; and the data are not broadly accessible to the research community [36,9]. Yet the ability to observe the social connections between such a substantial fraction of the world's population also provides unique advantages for social and demographic research.

We use the Facebook data to simultaneously observe social network structure and migration status for the full population of Facebook users (where available through profile self-reports) in 2018. Each active user represents a node in the network; two nodes are connected by an edge if they have mutually agreed to be 'friends' on the online platform. Example subnetworks are depicted later, in Fig. 3.

Separately, we use de-identified Facebook profile information to determine the current and origin country of each user. The country of origin is determined by the self-reported "home town" that users enter on their profile pages. The current country assignment is determined by Facebook for growth accounting purposes, and is based on typical country-level geolocation signals, such as recent IP addresses. There is a considerable amount of measurement error in this approach to inferring migration, as how people report their "home" town is the result of subjective interpretation. While we do not think this measurement error entirely undermines the high-level analysis that we present in this paper, such data may not be well-suited to more disaggregated analysis, or seen as a substittue for official statistics.

By aggregating home and current country of users we were able to generate a migrant stock dataset, showing the current numbers of individuals "from" one country who currently live in another country. We validated the country-to-country dataset we generated against data on international migrant stocks

provided by the World Bank [39]. Here we chose those countries with more than 1 million monthly active users, and those country pairs with more than 0.001% of migrants. The magnitude of migrant stocks quantified using Facebook data is highly (though not perfectly) correlated to migrant stock estimates produced by the World Bank (Pearson's ρ: 0.87), which is similar to the findings of Zagheni et al. [54]. Because migration events may be short-lived (e.g. study abroad or volunteer programs) for young adults, we focus our analysis on users aged over 30 at the time of our study.

4 Results

4.1 Migrants tie the world together

Our first set of results highlight the substantial fraction of international ties on Facebook that are comprised by migrants. Formally, we denote the home and current country of a person i by H_i and C_i, and say that i is a migrant if $H_i \neq C_i$. A social tie exists between i and j if they are friends on Facebook. International ties exist if i and j have different current countries ($C_i \neq C_j$) or different home countries ($H_i \neq H_j$).

A striking result is evident when we look at the fraction of international and domestic ties that involve migrants. While only 17.1% of all ties on Facebook involve a migrant, a staggering 82.91% of interantional ties involve at least one migrant. These results are presented and disaggregated in Table 1.

Table 1: Domestic and international ties (univariate statistics)

	International Ties (%)	Domestic Ties (%)	All Ties (%)
Non-migrants	17.09	99.14	82.90
Migrants	82.91	0.86	17.10
... Two migrants	7.66	0.86	2.21
... Migrant to a resident in the destination country	39.40	0	7.79
... Migrant to a resident in the origin country	27.88	0	5.52
... Migrant to a resident in other countries	7.97	0	1.58

Of the interantional ties we observe, 39.4% exist between migrants and locals in destination countries, and 27.88% of international ties connect migrants with people in the country of origin.

Only 17.09% of all international ties in our sample are between non-migrants – individuals in different countries whose own current countries are the same as their stated home countries. This leads to the staggering conclusion that international migration is responsible for over 83% of social ties between countries. Even this statistic may underestimate the percentage of international ties due to migration, given that our analysis does not account for return migration – i.e., the situation in which an individual has returned to their country of origin but maintains ties in their former migrant destination.

Further strengthening the conclusion regarding the crucial role migrants play in providing international ties is Fig. 1, which shows that the distribution of

the per-individual proportion of international ties is bimodal, comprised of a mixture of migrants, who have a high concentration of international ties (the average migrant's network contains 90.5% international ties), and non-migrants, whose social networks are dominated by domestic ties (only 10% of their ties are international).

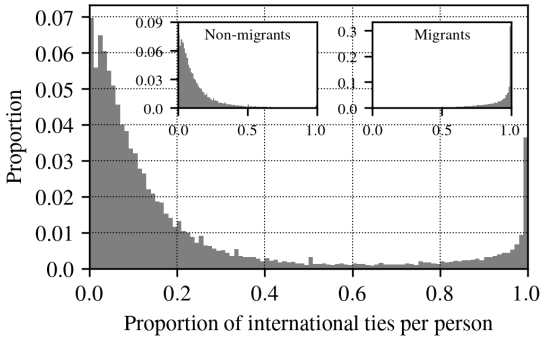
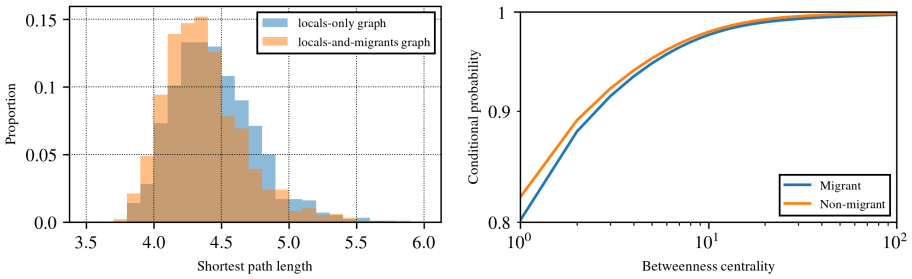


Fig. 1: Proportion of ties that are international.

4.2 Migrants and measures of global cohesiveness

Our second set of results investigate the extent to which migrants play a binding role in the global social network. Here we reproduce the approximation of the average shortest-path computed by Bhagat et al. [7] and Backstrom et al. [2], using two graphs as input. The *locals-only* graph, only contains those users for whom the home country is the same as the current country. The *locals-and-migrants* graph results from adding migrants (users with known different home and current countries) to the *locals-only* graph. We sample 1000 seed nodes in each graph to compute the approximate average shortest path using the methodology described in Bhagat et al. [7]. It should be noted that the approximate average shortest path length from these two graphs is not directly comparable to previous results about the entire Facebook social graph, since home-country self-reports are only available for a fraction of Facebook users. We found that the average shortest path length is 4.45 for the *locals-only* graph, and 4.37 for *locals-and-migrants* graph (Fig. 2a). In other words, the degree of separation is 3.45 in the *locals-only* graph, and 3.37 in the *locals-and-migrants* graph. A two sample t-test confirms that this difference is statistically significant ($p < 0.001$). Even though there are more nodes in the *locals-and-migrants* graph than the *locals-only* graph, the average shortest path in the *locals-and-migrants* graph is smaller, meaning that the migrants serve as a bridge to bring the world together.

In addition to measuring the shrinkage in the global Facebook graph when migrants are added, it is also possible to compute the number of shortest paths which would be routed through migrants and non-migrants when a social search is performed. To this end, we compute weighted approximate betweenness centrality: starting from 24 randomly-selected seeds we compute shortest paths to



(a) Shortest path length in the *locals-only* graph vs. the *locals-and-migrants* graph.

(b) Betweeenness centrality distribution of migrants vs. non-migrants.

Fig. 2: Bridging role of migrants in international social networks

all nodes in the Facebook social graph (friendships of monthly active users). We then count the number of shortest paths passing through each vertex in the graph, weighted so that the weights of multiple shortest paths connecting any two vertices all sum to 1. Betweenness statistics for migrants and non-migrants are shown in Table 2, suggesting that migrants have higher betweenness despite having lower degree. To better understand what drives this dynamic we plot cumulative distribution function for migrants' and locals' betweenness centrality in Fig. 2b. The figure shows that migrants are over-represented among individuals with very high betweenness compared to locals.

Table 2: Betweenness centrality statistics for migrants (M) and locals (L).

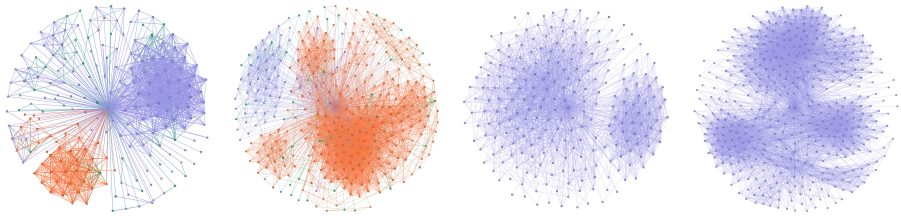
Statistic		Mean	S.D.	Median
Betweenness	M	8.12	25302.26	1.07
	L	7.66	69286.75	1.04
... same	M	45.95	90612.70	1.26
... country	L	79.99	305134.88	1.08
... different	M	6.25	16219.46	1.07
... country	L	3.79	8400.1	1.04
Degree	M	372	513	214
	L	395	544	244

While the majority of both migrants and locals have relatively low betweenness, there are more migrants among those who act as conduits for many of the shortest paths in the Facebook social graph. To better understand the role that migrants play in brokering international ties we can also distinguish between situations where ego and the seed are in the same country or in different countries. When making this distinction we can see in Table 2 that, among users in a different country than the seed, migrants help route almost twice as many (6.25) shortest paths as locals (3.79), whereas migrants only route about half as many shortest paths (45.95) as locals (79.99) to a seed in the same current country. This further seems to suggest that migrants have a particularly important role in providing inter-country connectivity: they not only participate in a

great number of international ties but their ties are also more likely to function as international network bridges.

4.3 Ego-networks

We have seen so far that migrants have more international ties, and that they play an oversize role in improving connectivity in the global social graph. A natural question arises as to whether migrants' *local* networks differ in other structurally meaningful ways from those of non-migrants. The analysis of ego-networks can help establish the extent to which individuals help connect disjoint collections of alters, providing important measures of network brokerage. Fig. 3 shows four example ego networks, two of migrants and two of non-migrants, with violet nodes and edges indicating connections in the current country and orange nodes and edges representing connections in the home country. We can see that the two migrants' home and current country networks are disjoint, with no direct connection between alters in the home and current country. In this case the migrant ego provides a shortest path between each pair of alters in the home and current country, respectively.



(a) Migrant A (b) Migrant B (c) Non-migrant A (d) Non-migrant B

Fig. 3: Ego networks of two migrants and two non-migrants. *Note*: The center node is the ego. All the other nodes are his or her friends. The node color refers to different countries: orange nodes are living in the ego's home country; violet nodes are living in the ego's current country; green nodes are living in other countries.

To measure the ego-networks of users we measure multiple statistics:

- size of ego network, i.e. a user's number of Facebook friends (alters).
- ego's clustering coefficient, or the proportion of triads ego participates in that are closed.
- k-cores, or the maximal subgraph of the ego graph, in which nodes have degree of at least k. We compute k-cores for all possible k's in the ego-network.

Given the computational requirements of the analysis, running it for all users would be prohibitively expensive. Because we are interested in the structural differences between migrants and non-migrants, we chose to run an analysis on a balanced sample of users. We analyzed a sample of 20,000 users (10,000 migrants and 10,000 non-migrants) drawn at random from among monthly active Facebook users aged between 30 and 80. Ego-network statistics were computed

for the entire ego-graph, as well as for two subgraphs: the graph of all users who share their current country (G_C), and the graph of all users who share their home country (G_H). As Table 3 reveals, migrants appear to have slightly lower degree than locals. On average, a migrant in our sample had 373 Facebook friends, whereas a local had 388 Facebook friends, this difference being statistically significant at the 0.05 level ($p = 0.04$ using a two-sample t-test).

Table 3: Ego-network statistics for migrants (M) and locals (L). *Note*: G_H is the graph of all users who share their home country. G_C is the graph of all users who share their current country.

		Whole		G_H		G_C	
Statistic		Mean	S.D.	Mean	S.D.	Mean	S.D.
Degree	M	373	517	129	228	160	312
	L	388	533	255	358	352	491
	p-val.	0.04		< 0.01		< 0.01	
Density	M	0.120	0.134	0.247	0.248	0.209	0.206
	L	0.118	0.119	0.139	0.136	0.126	0.127
	p-val.	0.19		< 0.01		< 0.01	
8-core	M	0.865	0.553	0.462	0.557	0.498	0.548
	L	0.871	0.512	0.732	0.561	0.839	0.515
	p-val.	0.38		< 0.01		< 0.01	
64-core	M	0.070	0.256	0.014	0.116	0.025	0.157
	L	0.077	0.267	0.041	0.198	0.067	0.251
	p-val.	0.07		< 0.01		< 0.01	

Migrants were also comparatively less connected to their home and current countries than locals. On average, the home ego-network G_{Hi} of a migrant i – composed of people with the same stated home country as the ego – had 129 nodes, whereas the home ego-network G_{Hj} of a local j had 255 nodes. Similarly, the ego-network in the current country G_{Ci} of a migrant i had a mean of 160 nodes, whereas the ego-network in the current country G_{Cj} of a local j had 352 nodes. Given that their ego networks are split between home and current country, it is not surprising that migrants have fewer alters to draw on in each country. These alters are more likely to be connected to one another however: migrants' home-country ego networks have a density of .247, compared to .139 for locals. The same numbers are reflected when G_{Ci} are considered: .209 for migrants and .126 for locals. This result would seem to suggest that migrants' home and current countries are more cohesive than non-migrants, but one has to consider the fact that degree and clustering coefficient have been found to be inversely correlated [29,31,24]. That is, it is possible that migrants have different network foci split between home and current country, whereas all of a local's foci will be in their current country. For instance, a migrant who leaves after high school to attend university in a different country may have one high school friendship group in the home country and another college friendship group in the current country, whereas a local will have both groups in the same country. Even if the two friendship groups have the same density, the migrants' home and

current countries will appear to be denser because they only contain their high school and college friendship groups, respectively.

Table 3 also reports the average number of 8- and 64-cores in migrants' and locals' ego-networks. A k-core is defined as a subset of nodes in the ego-network network which have a degree of at least k when connected to one another. These results reveal that migrants have fewer 8- and 64-cores in their home and current country ego networks, while the difference between the number of k-cores in their overall ego networks is much smaller (.865 for migrants vs. .871 for locals for 8-cores, $p = 0.38$ and .070 for migrants vs. .077 for locals for 64-cores, $p = 0.07$). This suggests that migrants ties' are about as clustered as non-migrants', but the cores in their ego-networks are divided between multiple countries. The k-core structure reinforces the multiple country-foci explanation advanced above.

4.4 Triadic closure

Beyond the direct connections between two individuals, larger graph structures can provide insight into the role that migrants play in the broader social network. In particular, network *triads* – which indicate whether two friends of an individual are themselves friends – have long been recognized as fundamental elements of social networks irreducible to their parts [43].

The triadic view poses a more complex challenge due to the exponential increase in complexity resulting from the various combinations possible between the home and current countries of the three actors who participate in a triad. We therefore downsample the Facebook graph to 10% of all monthly active users for whom both home and current country were available. We counted 15bn triads connecting this subset of users

Fig. 4 shows a sample of possible triads. The figure suggests that when two people share a friend in common as well as the same home and current country, they are most likely to be friends themselves. People who share neither home nor current country are unlikely to be friends, even if they share a common friend, while friends-of-friends who share either home or current country are moderately likely to be acquainted themselves. Given that triads – and the extent to which they are closed or not – form the building blocks of social networks, we hope that these closure probabilities can be useful to future research efforts into the topology and dynamics of large-scale social networks.

5 Conclusion

Both mundane and essential, social ties underpin the global political and economic system. The connection between social networks and globalization has long elicited a great deal of interest among social scientists. Studies of the global social network have only become possible recently, thanks to increases in Internet penetration and the development of global social networking platforms. Increasingly, we can understand international interactions not just through proxies of international flows such as air passenger data and internet bandwidth between

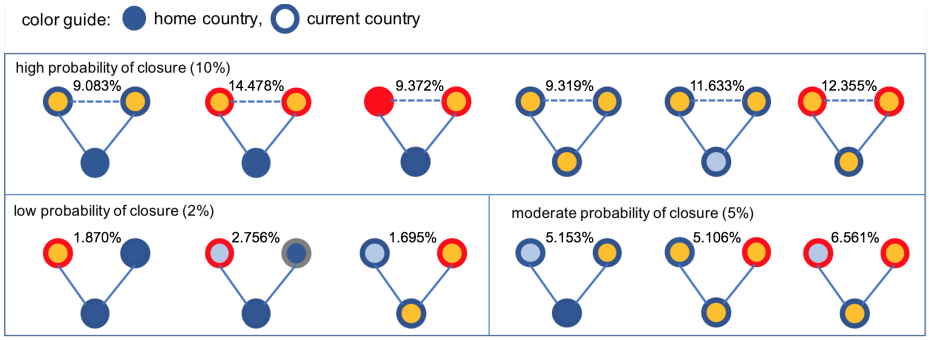


Fig. 4: Triadic closure probabilities for a sample of triads, illustrating that closure is most likely for migrants sharing home and current country. Each node is an individual, with fill color designating a home country, and the border color designating their current country.

countries, but also through the records of connections between people. In this study, to our knowledge the first of its kind at this scale, we focus on the people who connect the world's social network.

We use an de-identified, aggregated dataset from the Facebook platform to examine the relationship between human mobility and the development of international ties. Our findings suggest that long-term migrations likely account for about 83% of the world's international ties. Our ego network analysis revealed that migrants' networks have higher density, but lower degree, in both home and current countries than non-migrants'.

We also confirmed the "bridging" role of migrants in connecting the world's social network. By computing the average shortest path length in a social graph with and without migrants, we showed that migrants effectively decrease the length of the average shortest path. We also learned that migrants tend to act as conduits for more shortest paths than non-migrants. From these results we can conclude that migrants play an important role in the global economy and society [48,33], effectively bringing the world closer together.

We acknowledge the particularly strong tension in network datasets between data privacy and research reproducibility, and hope that both academia and industry will continue working together to find effective ways for sharing large datasets for social science research purposes. To help future researchers with understanding the complex interactions between friendship and international mobility, we have also computed exhaustive triadic closure probabilities between all combinations of migrants and locals. We found that, generally speaking, triads tend to be closed when migrants are present, but only if a current or home country is shared between alters. We hope these aggregations will likewise help advance future social network analysis research, for instance by providing the baseline for simulations.

While this paper has focused on the structure of the network formed by friendship ties between people, there are other types of connections which span the globe. One could ask, for example, what fraction of newspapers' interna-

tional readership stems from migrants? For local newspaper readership, do migrants read more international news? Do they share international news with their friends? What role do migrants play in helping artists become globally popular? Since migrants help to make the world just a bit smaller, by stretching their own ties across the globe, it would also be interesting to examine the role of social media in helping to sustain such long-range ties. We leave these and other questions for future work.

Even though much remains to be done until the mechanisms of social networks will be fully understood, the analyses presented in this paper would have been hard to conceive of 50 years ago when Travers and Milgram [51] performed the first social search experiments. A half century later, it is possible not only to measure the world's connectivity but to ask novel questions of it. We hope that our work will advance scientists' grasp of the social web that envelops the Earth, and of the people who effectively connect the world.

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