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RESEARCH ARTICLE

Does Human Migration Affect International Trade? Network Perspective

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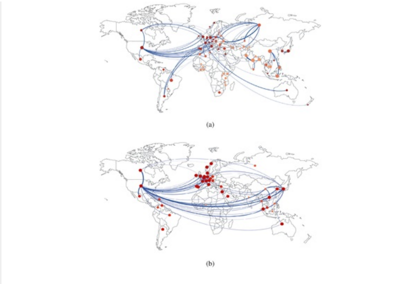
Correction

17 Apr 2015: The PLOS ONE Staff (2015) Correction: Does Human International Trade? A Complex-Network Perspective. PLOS ONE https://doi.org/10.1371/journal.pone.0126879 | **View correction**

Figures



	1960		1980		2000	
	ITN	IMN	ITN	IMN	ITN	IMN
No. Nodes	109	109	158	158	183	183
Density	0.3843	0.5808	0.4628	0.5080	0.5687	0.5503
Bilateral Density	0.8439	0.7234	0.8697	0.6975	0.9802	0.7097
Weighted Asymmetry	0.1424	0.1886	0.0953	0.5514	0.1151	0.6615
No. SCC	3	2	3	2	1	1
Size Largest SCC	107	108	156	157	183	183
No. WCC	1	1	1	1	1	1
APL (Undirected)	1.5646	1.2586	1.4811	1.3383	1.4217	1.2899

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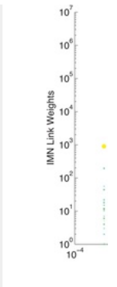

Abstract

This paper explores the relationships between international human merchandise trade using a complex-network approach. We firstly c topological structure of worldwide networks of human migration an the period 1960–2000. Next, we ask whether pairs of countries that the migration network trade more. We show that: (i) the networks of migration and trade are strongly correlated, and such correlation c by country economic/demographic size and geographical distance international-migration network boosts bilateral trade; (iii) intensive centrality are more trade enhancing than their extensive counterpa suggest that bilateral trade between any two countries is not only a presence of migrants from either countries, but also by their relative the complex web of corridors making up the network of internationa

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Introduction

Cross-border human migration and international trade account for mobility of people and goods across our planet, and their importan relentlessly growing during the last waves of globalization [1]. Over 2010, for example, the share of total world exports over real-domes increased by 172%, whereas human migration, in terms of number more than doubled, with an estimated migrant population of more t

Despite in the last decades governments have kept reducing barrie
proportionally lowering those to immigration, also the share of worl
population has increased by almost 20%. The extraordinary growth
human migration and trade did not occur only intensively, but also e
growth refers to increasing migration stocks over a fixed set of mig
whereas extensive growth concerns the creation of new migration
over the period 1960–2000, the number of newly-created export ch
countries exhibited a threefold increase. Similarly, simple back-of-th
calculations on World Development Indicators (WDI) data [2], show t
emigration corridors almost doubled.

The intensive and extensive time evolution of international trade ch
corridors has led, over the years, to an intricate web of relationship
which has been recently investigated using a complex-network per
feature of the existing works on migration and trade networks is tha
these two phenomena as they were completely independent [4–13
topological properties of the International-Trade Network (ITN) [8] a
Migration Network (IMN) [11] have been separately investigated as
were two fully disconnected layers of the same multigraph where w
represent the nodes and trade or migration links play the role of dif
interaction channels.

This paper tries to fill this gap and better understand, from a comple
perspective, the correlation and causal links between migration an
precisely, we address two related issues.

First, we compare the topological structure of the IMN and ITN and s
patterns. We are interested in exploring similarities and differences
are linked in the two layers of migration and trade networks, and wh
patterns do emerge between them. Note that our work focuses on a
See Ref. [14] for a complementary analysis that explores similar iss
specific trade perspective. We also investigate the main determina
correlations. Not surprisingly, we find that economic and demograp
well as geographical distance, play a key role in explaining differen
between IMN-ITN topologies, similarly to what happens to bilateral t
migration stocks.

Second, we study whether there exists any causal relationship betw
ITN. We are specifically interested in understanding if the relative p
countries in the IMN explains their bilateral trade. Note that a large
economics has deeply explored the causal connections between m
from a more standard econometric perspective. More specifically, s
quite a robust evidence suggesting that bilateral migration affects b
flows [15, 16]. As argued in Ref. [17], for example, trade between an
may be enhanced by the stock of immigrants present in either coun
the other one. This is because migrants originating in *j* and present
may foster imports of goods produced in their mother country (bilat
preference effect) or reduce import transaction costs thanks to the
both home- and host-country laws, habits, and regulations.

Such a *bilateral effect* only takes into account the *direct* impact of mi
countries present in the other one to explain bilateral trade. Howev
trade between any two countries can be fostered not only by *direct*
effects, but also through *indirect effects* conveyed by migrants comin
parties" [18–20]. More generally, the more any two countries are co
the IMN, the larger the average number of third countries that they
immigration flows, and the more likely the presence of strong third-
communities in both countries. This may further enhance trade via
information effects. Moreover, it may happen that two countries are
connected in the IMN (in both binary and weighted terms) even if th
number of overlapping third parties. In such a case, one may ask w
environment engendered by the presence of many ethnic groups i
coming from non-overlapping origins can be trade enhancing—and

Building on these ideas, we study if *indirect network effects* may play
bilateral trade, beyond what we can explain through *direct bilateral*
hypothesis is that bilateral trade may increase the more the two co
consideration are inward central in the IMN. This may happen eithe
common immigration corridors or attract more immigrants from com
because they are more inward connected (in both intensive and ex
non-overlapping origins. Expanding upon the existing literature, we
fitting gravity models of trade where country centrality is added as
factor.

Our exercises strongly suggest that pairs of countries that are mor
IMN also trade more. Interestingly, we find that also inward third-pa
from corridors that are not shared by the two countries can be trad
addition to common inward ones.

We argue that this can be due to either learning processes of new
preferences by migrants whose origins are not shared by the two c
facilitated by an open and cosmopolitan environment) or by the pre
countries of second-generation migrants belonging to the same et
indicate that migration networks (in the sense of Ref. [18]) are cond
because they create linkages not only between pairs of countries t
destination of migration, but also among countries that are the des
flows from third (shared or non-shared) countries.

Finally, we test whether the migration-enhancing effect on bilateral
from an extensive or an intensive form of centrality into the IMN. No
literature only explores the impact of migration networks (in the se
intensive vs. extensive margins of trade. For example, Refs. [21, 22]
networks increase trade on the intensive margin more than on its e
However, no attempt is made to evaluate the relative importance o
intensive forms of migration in affecting bilateral trade. In this pape
which binary (extensive) vs. weighted (intensive) inward country ce
bilateral trade. We find that both forms of inward centrality separat
trade. However, when one compares them directly, intensive inwar
its extensive counterpart. Therefore, bilateral trade seems to be bo

number of immigrants (both common and non-overlapping) than by
corridors held by any two countries in the IMN.

Materials and Methods

Data and Definitions

Migration data employed in the paper come from the United Nation
Database [23], which comprises, for each year $y = \{1960, 1970, 198$
origin-destination square matrix recording bilateral migration betw
generic element (i, j) of each matrix is equal to the stock of migrant
last completed census round) originating in country i and present i
migrant status is consistently defined in terms of country of birth.

As to merchandise trade, we employ the dataset provided by Kristi
contains bilateral export-import yearly figures for the period 1950–
follow the flow of goods: rows represent exporting countries, wher
importing countries. The generic bilateral element (i, j) thus record
given year. Trade figures, which are originally expressed in curren
deflated to get real values.

We merged these two datasets by keeping, in each of the 5 years a
data, all countries that were present also in trade data with at least
export flow. This results in 5 origin-destination $N^y \times N^y$ matrices, wh
163, 183}. The sample of countries included explains more than 90
flows and migration stocks in each year.

We employ additional country-specific data such as real gross dom
population (POP) and per-capita real gross-domestic product (rGDP
Tables version 6.3 (https://pwt.sas.upenn.edu). We also use bilater
political and socio-economic data from the CEPII gravity dataset (se
The latter includes information about between-country (great-circl
distance ([redacted]), contiguity (CONTIG, i.e. whether two countries share a
a preferential trade agreements (PTA), common language (COMLAN
mostly used to perform gravity-like exercises (more on this below).

We use trade and migration data to build a time sequence of 5 weig
migration-trade (multi) graphs describing both bilateral-migration s
flows. More precisely, we define the international migration-trade n
directed weighted multigraph wherein between any two nodes (co
most four weighted-directed links, two of which describing bilateral
two concerning bilateral migration. Alternatively, we can think to th
sequence of 2-layer weighted directed networks, the first layer rep
the second the ITN. In both cases, the IMTN at each time $y = 1960, \ldots$
by the pair of $N^y \times N^y$ weight matrices (M^y, T^y), where M^y and T^y defi
weighted-directed International Migration Network (IMN) and the w
International Trade Network (ITN). The generic element of M^y repre
migrants mijy originated in country i and present at year y in countr

element of T^y records the value of exports tijy from country i to cou

Accordingly, we define the binary projection of the IMTN through th
adjacency matrices (AMy,ATy), where the generic element of AXy, X
one if and only if the correspondent entry in X^y is strictly positive (a

Fig. 1 plots the undirected weighted version of the IMN (a) and of the
In the figures, link directions are suppressed to attain a better visu
and only the top 5% of link weights are plotted. Link thickness is pro
total bilateral migrants (mijy+mjiy) and the logs of total bilateral trad
respectively. To get a feel of migration and trade determinants, nod
proportional to the log of country population, while node color (fro
lighter to darker grey) represents logs of country rGDPpc (a measu
The map allows one to appreciate some of the main general differe
ITN, e.g. the central role of Russia in the IMN (absent in the ITN) and
connections between the United States and South-Asian countries
Also, as expected, notice the widespread presence of low-income c
(beige color), while the most relevant trade connections occur betw
higher rGDPpc (red color).

**Fig 1. The International-Migration Network (a) and the Internat
Network (b) in year 2000.**
The figure plots the undirected weighted version of the ITN and
5% of bilateral link weights (total number of bilateral trade and to
bilateral migrants) are drawn. Tickness of links in the plot is prop
of link weights. Node size is proportional to the log of country po
color represents country income (rGDPpc), from beige (low-inco
red (high-income countries).
https://doi.org/10.1371/journal.pone.0097331.g001

Comparative-Network Analysis

We begin with comparing the topological properties of the two laye
compute basic statistics [25] to describe connectivity and asymmet
and weighted networks. More specifically, connectivity measures i
density; (ii) number of strongly and weakly connected components;
average path length. As far as binary-network asymmetry is concer
bilateral density, defined as the share of existing directed links that
Furthermore, we evaluate weighted asymmetry by computing the i

[26].

We also study the extent to which the two layers of the IMTN display
behavior by exploring whether link weights (mijy,tijy) are positively r
simple way to visualize any existing relation is to scatter plot link we
(on a log-log scale) in each year, where each dot represents, in the
ordered pair of countries (i, j) for which either mijy>0 or tijy>0. If a po
natural candidates for explaining it are economic and demographic
rGDP and POP, respectively) and geographic distance ■ $_{ij}$ between
particular, we rely on the the well-known empirical success of the g
migration and trade [27, 28], which states that bilateral trade flows (
stocks) are well explained by a gravity-like equation involving coun
POP, respectively) and, inversely, geographical distance. If this is th
expect that most of the variation in the cloud of points (mijy,tijy) can
products of country sizes and smaller distances. We check this hyp
each dot in the scatter plots a size proportional to the product of co
divided by country distance (POPiy*(POPjy/■ ij), and a color scale (f
depending on the product of country rGDPs divided again by geogr
(rGDP$_i$*rGDP$_j$/■ $_{ij}$).

Next, we investigate matches and mismatches between ITN vs IMN
want to assess, firstly, whether the presence/absence of directed r
correlated with the presence/absence of trade channels. We do so
adjacency matrices (AMy,ATy) and counting the percentage of total
present or missing links), and the share of IMN links (respectively, IT
present in the ITN (respectively, in the IMN). Secondly, we ask if rGD
distances can explain matches and mismatches between binary st
this question, we assign in each year y all possible $N^y(N^y-1)$ pair of
four possible cases as far as presence/absence of a link in the two
concerned, namely: (C_1) no link in both IMN and ITN; (C_2) link in ITN a
(C_3) link in IMN and no link in the ITN; (C_4) link in both ITN and IMN. Th
we set up a partition of all possible $N^y(N^y-1)$ directed edges in four
(s1y,s2y,s3y,s4y), where subset shy contains all directed edges tha
then compute, for each year separately, average and standard dev
qijy=log(rGDPiy)·log(rGDPjy) and log(■ $_{ij}$) over each separate subse
time-sequence of subsets {shy}, where $h = 1, \ldots, 4$ and $y = 1960, \ldots$,20
characterized by four coordinates, i.e. conditional average and sta
and log(rGDPjy). To simplify things, we collapse standard deviations
defined as the product of standard deviations of qijy and log(rGDPj
20 subsets (number of classes times number of years) can then be
plot whose x- and y-axis feature the mean of qijy and log(rGDPjy), re
can then be characterized by a color representing its class, a size p
product of standard deviations, and a label identifying the year. Thi
allow one to investigate if dots of different classes exhibit different
and distance is concerned, and if dots of consecutive years are suf
other once within-class conditional standard deviation is properly t

Finally, we study correlation patterns of node-network statistics bet

the IMTN in both their binary and weighted representations. For eac
compute node in- and out-degrees and strengths [29], average nea
degrees and strengths [30], binary and weighted clustering coeffic
number of binary and weighted node-centrality indicators, ranging
and Page-Rank [35] centrality, to hubs and authority scores [36]. As
literature [8, 11], we compute weighted statistics using the logs of I
weights. We then ask whether countries that are more connected,
the IMN layer are also more connected, clustered or central in the I
whether country-size may drive any emerging correlation (e.g. cou
connected, clustered or central in both layers just because their ar
information on country rGDP and POP to country-specific network i
scatter plots.

Panel Regressions

In addition to correlation patterns, we study whether network effec
causal link going from migration to trade. We want to test if bilatera
two countries is enhanced the more: (i) these two countries share r
themselves (direct bilateral effect); (ii) they are jointly more central i
we aim to check if having more inward connections or receiving mo
bilateral trade. This can happen either from inward channels share
country (common inward effect) or through non-overlapping ones (
inward effect).

We explore these issues by performing a set of econometric exerci
gravity-model of trade [27], expanded to take into account migratio
Building on Ref. [37], we fit to our data a gravity model whose gener

where ijy is the error term; ■ is a constant; ■ ijy=tijy+tjiy is total bila
are country-time importer-exporter dummies controlling for all cou
such as rGDP and POP; more precisely, ■ iy=1 (resp. ■ jy=1) if coun
importer (resp. the exporter), and zero otherwise; ■ $_{ij}$ is geographic
features bilateral country dummies (CONTIG, COMLANG, PTA^{y}); and
migration-related network variables accounting for bilateral and co
overlapping indirect effects. Results are robust to additional contro
religion, common colonial ties, and landlocking effects.

In the first battery of econometric exercises, we separately test five
specifications to check for alternative hypotheses about how netw
bilateral trade. In the first one, we only control for baseline gravity-
(log(■ $_{ij}$), CONTIG, COMLANG, PTA^{y}), i.e. Wijy does not appear. The se
augments the first one by including in Wijy only total bilateral migra
BIL_MIGijy=log(mijy)+log(mjiy).

In the remaining three specifications, we add also network, commo

overlapping, effects related to country inward centrality in the IMN.
between binary and weighted centrality indicators, to understand t
extensive migration margins (i.e. the number of inward corridors) a
margins (i.e. the stock of immigrants). For the binary case, we emplo
country centrality *in-degree country centralization*, defined as:

where indiy is country in-degree (i.e. the number of inward links of c
degree centralization is highly and positively correlated with all oth
weighted) centrality indicators in the IMN (i.e. eigenvector-based in
centrality, etc.). For this reason, our results are quite robust to alter
measures. We use inward corridors only because we expect inwar
relevant in explaining bilateral trade rather than outward channels.

Since we employ importer-exporter time dummies, in the third spec
log of the sum of country i and j in-degree centralization:

instead of the two separately.

Furthermore, we study the role of third-party (indirect) common and
inward migration channels. To do so, the fourth specification featu
share of common in-neighbors of any given pairs of countries (COM
the fifth and final specification, we control for both COMM_INijy and
inward channels that the two countries do not share (NOTCOMM_IN
computed dividing by N^y. In other words, given any two countries i a
directed links pointing to i and j originating from third countries h th
both i and j. The residual contribution accounts for the number of in
originated from third countries k that only send migrants to either i

In the weighted case, we explicitly consider link weights in the IMN (
stocks). We then replace in Eq. (3) country in-degrees (indiy/Ny) with
(insiy/Vy), where now we re-scale in-strength by the volume of the n
total sum of logged migrant stocks). We compute COMM_INijy by su
of commonly-shared inward channels. Similarly, NOTCOMM_INijy is
up link weights over all inward links originated from third countries
migrants to either i or j.

The second battery of econometric exercises aims at disentangling
importance of extensive vs. intensive forms of migration in enhanc
More precisely, we are interested in assessing whether trade betw
is boosted (if any) more by their *extensive* inward centrality (i.e., IN_C
using country in-degrees) or by their *intensive* inward centrality (i.e.
using country in-strengths). In other words, we want to understand
explaining bilateral trade is country centrality in terms of the numbe

(*extensive* form of centrality in the IMN) or in terms of the stock of imm of centrality in the IMN). To address this question, we estimate six ad specifications. In two of them, we include only the logs of extensive labeled as log(IN_CENTRijy)B, or only the logs of intensive measure, log(IN_CENTRijy)W. In two additional specifications, we add the bilat Finally, in the last two specifications, we add both extensive and int measures, again without or with the bilateral effect due to migrants and *j*.

Estimation of Eq. (1) can be plagued by endogeneity issues. Indeed correlated with the explanatory variables due to a reverse-causatio to migration. This is true whenever we use BIL_MIGijy as a regresso augment the equation with *weighted* network-related variables. We problem may be almost irrelevant in terms of binary network variab migration corridors only, as it is very unlikely that changes in bilater destroy or form new links in the IMN. When link weights in the IMN a country in-centrality, however, it may well be the case that changes also impact on migration stocks and in turn on country centrality. To employ a standard instrumental-variable (IV) approach. Borrowing f set up an auxiliary streamlined gravity regression to instrument bila mijy. More formally, we use ordinary least-squares (OLS) to fit to the specification:

where (■ iy,■ jy) are origin and destination country-time dummies a noise error. The specification in Eq. (4), as expected, is able to expla variation in bilateral stocks. Furthermore, according to the F test (tes the employed instruments are valid.

Next, we use the predictions ■ ijy of the model in Eq. (4) to replace in the definition of BIL_MIGijy. Furthermore, in order to instrument we indicators, we employ ■ ijy to build, in each year *y*, a predicted log matrix logMy={■ ijy}. Notice that since we use logs of mijy in Eq. (4 only strictly-positive migration stocks, i.e. we only consider non-zero predicted IMN weighted matrices are characterized by a binary pro exactly equal to the observed one in each year, i.e. AMy=AMy. We weighted IMN matrices to re-compute in the weighted case IN_CENT NOTCOMM_INijy and use them as instrumented regressors in Eq. (1 using OLS. Similar results are obtained with Poisson pseudo maxim estimation [40].

Two remarks are in order. First, the presence of (serial) autocorrela estimation and possibly inflate goodness-of-fit statistics. To check i have computed Wooldridge-Drukker statistics [41, 42] to test for the correlation in linear panel-data models. We report the p-value of the regression tables for the null hypothesis of no autocorrelation in th

Second, our regression exercises may be affected by biases due t
towards-the-mean (RTM) effect. This may lead to, e.g., overestimatic
links and underestimation of long-distance ones. Potential biases m
mitigated by the inclusion of dummy variables such as bordering ef
agreements, which we both include in all regression exercises. Furt
dynamic perspective, RTM effects on trade can be induced by fluct
exchange rates back to their normal (fundamental) levels, which we
account for in our data and gravity exercises. Despite all that, the o
estimation results is difficult to quantitatively evaluate, and we leav
research.

Results and Discussion

ITN vs. IMN: Descriptive Statistics

We begin with a comparison between the topological properties of
across time. Table 1 reports for the years 1960, 1980 and 2000 the
two networks. We show only these three waves for the sake of simp
1990 to the Table does not add additional insights to our descriptiv
both networks are extremely dense. The ITN increased its density b
period covered by our data, and became more dense than the IMN
the ITN is also more symmetric than the IMN, as testified by a larger
the percentage of reciprocated directed links). This is because a tra
to reciprocate than a migration corridor. This is true also when one
weights of the links: weighted asymmetry [26] is indeed larger in the
fact that countries tend to be more bilaterally balanced in trade tha
also that both networks are always weakly and (almost) strongly-co
number of weakly connected components is always one and strong
achieved before year 2000 only because of the presence of one or
connected countries, typically small and peripheral nations. Finally,
Refs. [8, 11], the IMN features a more marked small-world property,
lengths smaller than in the ITN.

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Table 1. IMN vs. ITN: Descriptive Network Statistics.

Note: SCC: Strongly connected components. WCC: Weakly conne
APL: Average path length.

https://doi.org/10.1371/journal.pone.0097331.t001

ITN vs. IMN: Correlation patterns

We now study the extent to which the two layers of the IMTN display
behavior. In what follows, we illustrate our findings for year 2000 or
results consistently hold also for the other years in the sample.

We start exploring whether link weights (mijy,tijy) are positively rela
shows a scatter of link weights in the ITN vs IMN (log scale) in year 2
stronger link-weight in the ITN is typically associated to a stronger r
exports a higher trade value to *j*, in *j* there is also a larger stock of r

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Fig 2. IMN vs ITN link weights.
Logarithmic scale. Markers size is proportional to the log of POP
scale (blue to red) is from lower to higher values of logs of rGDP
= 2000.
https://doi.org/10.1371/journal.pone.0097331.g002

Fig. 2 also suggests that most of the variation in the cloud of points
explained by larger country sizes and smaller distances in a gravity
large dots (higher values for POPiy*POPjy/[redacted] ij and rGDP$_i$*rGDP$_j$/[redacted] i
north-east part of the plot. This is more evident for the relation betw
[redacted], than in the case of migration. Indeed, there exist large (and red)
high trade values but relatively low migration stocks. This is the cas
Chinese people to India, which is historically feeble, unlike correspo
Similarly, there are large dots associated with intermediate trade le
migration stocks. These refer to the triangle Bangladesh, India and
experienced huge migration flows at the time of partitioning of India

We move now to a comparison of ITN and IMN binary topologies. Re
Fig. 3. Two main findings stand out. First, the two networks have bec
similar in terms of presence/absence of links. Second, this has hap
increasing number of migration corridors that became also trade cl
contrary, the share of trade channels that are also migration corrid
and even declined. Notice that all these shares are statistically larg
ones obtained under null models in which the in- and out-degree se
and links are accordingly reshuffled [43]. A possible explanation fo
lies in the joint effect on the ITN of a relatively small initial density (a
and the massive lowering of barriers occurring in world trade in the
century. Another possibility is the existence of a causal link from mi

we shall explore in more details below in our regression exercises.

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Fig 3. IMN vs ITN: Comparison of binary structure.

Tot Matches: % of total matches (either missing or present links) of IMN links which are also present in the ITN. ITN Links in IMN: % are also present in the IMN.

https://doi.org/10.1371/journal.pone.0097331.g003

To see if real GDP and distances can also explain matches and mis binary structures, we plot for each year the averages of the quantit qijy=log(rGDPiy)log(rGDPjy) and log(■ $_{ij}$), conditional to the four po with different colors), namely: (i) no link in both IMN and ITN (red); (ii) in the IMN (green); (iii) link in IMN and no link in the ITN (blue); (iv) link (magenta), see Fig. 4. It is easy to see that a simultaneous absence due to the combination of, respectively, low rGDPs and high distanc short distances. Furthermore, as expected, the IMN is more sensible ITN: a link in the ITN that is not present in the IMN is typically associa On the contrary, the ITN is more sensible to rGDP. Even at smaller di plays a difference: when the latter is small enough, links in the IMN the ITN. Note also that these results are very robust across time (all very close to each other) and display quite a good precision (cf. the conditional dispersion, i.e. colored balls do not overlap). Similar find when rGDP is replaced by country population.

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Fig 4. Scatter plot of average log(rGDPiy)·log(rGDPjy) versus av conditional on matches/mismatches between IMN vs ITN binary

Colors: Red = Absence of link in both ITN and IMN. Green = No lin Blue = No link in ITN, link in IMN. Magenta = Link in both ITN and IN proportional to the product of standard deviations of log(rGDPiy log(■ $_{ij}$), conditional to matches/mismatches between IMN vs ITN https://doi.org/10.1371/journal.pone.0097331.g004

We now contrast ITN and IMN layers in terms of node network statis
brevity, we only show results related to: (i) total degree: the sum of i
links of a node; (ii) total strength: sum of inward and outward link we
total average nearest-neighbor degree (ANND) and strength (ANNS
degree (respectively, strength) of the neighbors of a node, no matte
the links held by the node. Whereas total degree and ANND are cor
IMTN, node strength and ANNS employ its weighted representation.
for the whole range of network statistics that we have computed, in
binary/weighted clustering and centrality indicators.

Fig. 5 shows that both node degrees and strengths are positively a
the two layers, see panels (a) and (c). This means that if a country h
channels (respectively, trades more), it also carries more migration
(respectively, holds larger immigrant/emigrant stocks). Again, it is e
positive relation is mostly explained by country demographic and e
find that if a country trades with countries that either trade with ma
trade a lot, is also connected to countries that hold a lot of migratio
i.e. both ANND and ANNS are positively correlated in the two layers,

Fig 5. Correlation of node network statistics between IMN and I
(a) Total degree; (b) Average nearest-neighbor degree (ANND); (
Average nearest-neighbor strength (ANNS). Marker size is propo
POPiy. Colors scale (blue to red) is from lower to higher values lo
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However, unlike what happens for degrees and strength, smaller le
ANNS in the IMTN are associated to larger demographic and econo
see why this is the case, we study binary and weighted disassortat
two IMTN layers. Fig. 6 scatter-plots node total degree (respectively
(respectively, ANNS), separately for ITN and IMN, and correlates this
country population and rGDP as in Fig. 5. As already known [8, 11, 4
display a marked (binary and weighted) disassortative behavior: th
strongly connected nodes are weakly connected. However, larger
higher levels of rGDP and POP) also hold larger degrees and streng
countries with larger levels of ANND and ANNS are smaller, in both e
demographic terms.

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Fig 6. Disassortativity patterns within IMN and ITN in year 2000

Marker size is proportional to logs of POP_{iy}. Colors scale (blue to to higher values logged $rGDP_{iy}$.

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The fact that country size and geographical distance can explain to correlation between migration and trade link weights is not surprisi know empirical success of the gravity model. What cannot be fully t ability of the same variables to account for the correlation between topological (binary and weighted) properties. Indeed, existing work a gravity specification is not always able to replicate the topologica trade network [45], especially at the binary level. Our results seem the correlation picked up by country size and geographical distanc IMN side, where a gravity specification attains a much better perfor

Does Migration Affect Trade?

In the preceding sections, we have explored the patterns of correla layers of the ITMN and their determinants. We move now to assessi exists any causal relationship between the IMN and the ITN. As we h when discussing the evidence on binary structures (see Fig. 3), the the ITN seems to be driven by existing migration corridors. More ge if (as already found in several papers, see e.g. Ref. [17]) bilateral tra and j is boosted by the presence of migrants in i coming from j and bilateral effect). Furthermore, we want to understand if indirect netw role in enhancing bilateral trade. Our main hypothesis is that bilater the more the two countries under consideration are inward central

To test these hypotheses, we estimate Eq. (1) using our migration a separately perform two sets of exercises, one when binary network considered and one when country centrality is measured using we each exercise, we estimate the five specifications discussed above right-hand side of the regression either BIL_MIG_{ijy} or weighted cent appear, we instrument them using Eq. (4) and the procedure explai and Methods section.

Regression results are reported in Tables 2 (binary centrality indica centrality indicators). The first two columns of Tables 2 and 3 obviou

reported for clarity and comparability sakes. Note first that all speci
high goodness of fit, as it always happens in empirical gravity estim
residuals of the regression specifications where we instrumented r
not correlated with the instruments, indicating that the latter are ac
addition of network statistics induces an increase in adjusted R^2, al
adjusted R^2 values do not seem to be inflated by the presence of a
the reported p-values of Wooldridge-Drukker F-test [41, 42] lead on
hypothesis of no autocorrelation. Similar p-values are obtained usi
autocorrelation test [46]. We argue that this may be due to the fact
yearly data, but waves at 10-year lags.

Table 2. Gravity-model estimation with binary network variable
Full-sample (pooled) ordinary least-square (OLS) fit. Years y = 19
Dependent variable: logs of total bilateral trade ■ ijy=tijy+tjiy. Co
variables for importer/exporter effects and constant included. E
variables: See main text. WD (p-val): Wooldridge-Drukker F-test f
in linear panel-data models (p-value) [41, 42]. Significance levels
* = 10%

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Table 3. Gravity-model estimation with weighted network varia
Full-sample (pooled) ordinary least-square (OLS) fit. Years y = 19
Dependent variable: logs of total bilateral trade ■ ijy=tijy+tjiy. Co
variables for importer/exporter effects and constant included. E
variables: See main text. WD (p-val): Wooldridge-Drukker F-test f
in linear panel-data models (p-value) [41, 42]. Significance levels
* = 10%.

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The impact of distance, contiguity, common language and participa
agreement are strong, significant, and signed in line with existing s
migration positively affects bilateral trade as expected, and its impa
no matter the chosen specification [37].

In both tables, columns (3)–(5) report regressions where country-ne
indicators are accounted for. We find that the more total inward-mig
immigrants a pair of country holds, the larger their bilateral trade, i.e
positive and significant effect on trade in both extensive and intens

To check whether this is due to common vs non-overlapping in-neig
columns (4) and (5) report specifications where only COMM_INijy or
NOTCOMM_INijy enter the model. Estimates suggest that: (i) commor
stocks of immigrants coming from common origins have a positive e
trade; (ii) once one controls for common third-party effects (either b
number of non-overlapping channels or the stock of immigrants ori
common third parties are also trade enhancing, even if with a small

As a robustness check, notice that all the results hold true also if co
exporter dummies are removed and replaced with country rGDPs. F
results are obtained if we employ tijy as dependent variable and we
regressors country-centrality indicators (IN_CENTRiy and IN_CENTRjy
positive effect on trade of NOTCOMM_INijy is preserved when one e
the regressions without COMM_INijy.

The foregoing evidence suggests that in addition to bilateral-migrat
between any two countries (i, j) may increase due to their binary ar
connectivity in the IMN. This might happen via two related mechanis
countries holding more inward links or more immigrants are more li
increasing number of inward corridors and/or immigrants coming fr
party migration origins $k \notin (i, j)$ and therefore, thanks to consumptio
information effects, more bilateral trade [18–20]. Second, a smaller
trade-enhancing effect can come from the presence in both countr
of inward migration corridors that are however not shared by i and
immigrants coming from such corridors. In other words, if countries
originated respectively from countries $I = \{i_1, \ldots, i_m\}$ and $J = \{j_1, \ldots, j_n$
larger m and/or n, and the higher the stock of migrants originating
higher bilateral trade between the two countries. This second trade
have a twofold explanation. On the one hand, more immigrants com
overlapping migration channels, coupled with commonly-shared or
cosmopolitan and inclusive environments in both countries, which r
ethnic groups, learning processes about consumption patterns of e
commonly shared by the two countries, and therefore more bilatera
hand, more immigrants arrived through non-overlapping inward mig
a higher probability to find in both countries more second-generatio
to the same ethnic group. Indeed, our data record migrants accordi
and not necessarily their ethnic origin. Therefore, it may be the case
h_i and h_j are not shared as inward channels by i and j respectively,
second-generation migrants belonging to the same ethnic group to

enhancing their bilateral trade. This effect cannot be entirely picke
and it can thus show up, as Tables 2 and 3 suggest, in the binary ar
of NOTCOMM_INijy.

Finally, we test whether bilateral trade is more enhanced by extens
forms of centrality in the migration network. We aim at disentanglin
that extensive country centrality (proxied by the number of inward
intensive country centrality (proxied by the total number of country
boosting bilateral trade. We do so by running a second battery of re
include either log(IN_CENTRijy)B (to control for extensive inward cer
log(IN_CENTRijy)W (to control for intensive inward centrality), or both
bilateral effect BIL_MIGijy. Results are presented in Table 4. Notice t
of Table 4 coincide, respectively, with the third columns of Tables 2
columns report our findings for the specifications where only exter
(columns 1 and 2) or intensive centrality (columns 3 and 4) are inclu
As expected, both extensive and intensive inward centrality separa
trade, independently on the presence of absence of a bilateral effe
instead, display the case where extensive and intensive inward cer
considered in the regression. It is easy to see that extensive inwar
almost completely its importance in explaining trade, whereas the e
for intensive centrality remains positive and statistical significant. T
that both forms of migration separately increase bilateral trade. Ho
centrality in the IMN appears to outweigh extensive centrality. *Ceter*
larger number of immigrants seems more important than holding m
corridors.

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Table 4. Extensive vs. intensive forms of migration and bilateral

Gravity-model estimation. Full-sample (pooled) ordinary least-sq
y = 1960, …, 2000. Dependent variable: logs of total bilateral trac
Country-year dummy variables for importer/exporter effects and
Explanatory variables: log(IN_CENTRijy)B = country i and j *in-degr*
centralization; log(IN_CENTRijy)W = country i and j *in-strength* (we
centralization. WD (p-val): Wooldridge-Drukker F-test for serial co
panel-data models (p-value) [41, 42]. Significance levels: *** = 1

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Conclusions

This paper has explored the relationships between international mi
using a complex-network approach. More specifically, we have per
exercises. First, we have investigated the patterns of correlation be
IMN, comparing link weights, topological structures and node netwo
found that trade and migration networks are strongly correlated an
mostly explained by country economic and demographic size and g
Second, we have asked whether country centrality in the IMN can e
Expanding upon the existing economic literature, we have fit to the
bilateral trade adding migration-network variables among the regre
for country inward centralization, and the number and intensity of c
overlapping inward migration channels. Our results indicate that th
and the intensity of inward—both common and non-overlapping—r
held by any two countries, the higher bilateral trade.

This suggests that migration networks (in the sense of Ref. [18]) wo
bilateral level, but they are also able to create linkages among cour
destinations of migration flows from third (shared or non-shared) pa
provide evidence pointing towards a preponderance of intensive o
centrality in enhancing bilateral trade.

This work can be extended in several ways. First, one may explicitly
geographic dimension in trade and migration data by using spatial-
techniques in gravity regressions [47]. Indeed, the absence of seria
trade and migration data (as documented by Wooldridge-Drukker t
the presence of autocorrelation at the spatial level (either in the de
the disturbances). This may introduce spurious effects in gravity es
might go beyond a migration-trade network representation and sta
graph characterization of the macroeconomic network, where betw
there may exist many links, each representing a different type of be
interaction (i.e., trade, mobility, finance, foreign investment). This ma
whether different layers display similar topological properties, and
properties are correlated, or causally linked, between layers. Third,
towards a better understanding of how the properties of a network
nodes behave and perform over time [48, 49]. Once possible endog
properly taken into account, this empirical research program may c
interesting insights on the importance of network structure in shapi
dynamics of the societies and economies where we live.

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Author Contributions

Conceived and designed the experiments: GF MM. Performed the e
Analyzed the data: GF MM. Wrote the paper: GF MM.

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