Re-thinking the aid-growth relationship: A network approach[1]

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Abstract

Over forty years of conventional economic analysis has not reached consensus on the effect of foreign aid on recipient country growth. We provide new insight into this relationship by using a network approach to characterize the topological properties of the OECD foreign aid network. Viewing the OECD foreign aid community as an interdependent and complex system, we characterize not only the amount of aid but also the position of both donor and recipient within the network. We find that the degree centrality of the recipient, with an edge inclusion threshold that sets a minimum share of a donor's aid to a particular recipient, is significantly correlated with the growth impact of that donor's aid. Contrarily, aid is uncorrelated with growth with a recipient-side filter on the importance of the donor to the recipient. These results suggest that the importance of a recipient within the donor's network, rather than the volume of aid alone, is associated with the growth impact of bilateral aid. We explore mechanisms for these findings that include the complementarity of aid from multiple attentive donors. Our findings speak to the aid-growth puzzle and suggest that network metrics may illuminate non-obvious channels of aid impact.

JEL Codes: O19, F35, D85, O40

Keywords: foreign aid, networks, economic growth, economic development, two-mode network, weighted network

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1. Introduction

Over forty years of empirical academic research has not yielded consensus on either the motivation or effect of foreign aid. Donors' self-declared motivation is typically poverty reduction and/or to facilitate economic growth. However, influential articles regularly begin with contradictory assumptions and reach diametrically opposing conclusions on both of these questions. Many models of aid assume the dominant donor motivation is self-interest associated with trade, security, resources, or other egoistic returns (Dudley and Montmarquette, 1976; McKinlay and Little, 1977; Fleck and Kilby, 2010). However, it is likely that typical donor-recipient relationships include multiple dimensions of incentives, interactions, and exchange (Civelli, Horowitz, and Teixeira 2016). The strategic dimensions, in particular, may be extremely complex. For example, strategic interaction likely occurs between donors and donors, donors and recipients, and recipients and recipients.[2] Even when the analyses abstract from strategic dimensions and are restricted to the aid-growth relationship, contradictory assumptions and findings abound. Clemens et al. (2012) and Rajan and Subramanian (2008), two of the most highly cited recent articles in the aid-growth literature, reach contradictory conclusions on the impact of aid on growth. Rajan and Subramanian (2008) find an insignificant (or negative) relationship between aid and growth while Clemens et al. (2012) argue that accounting for differential lags in aid-impact across sectors illuminates a positive aid-growth relationship.

Though Clemens et al. (2012) and Rajan and Subramanian (2008) reach different conclusions, both assume the *volume* of aid is the key variable intermediating the link between aid and economic growth. In this paper we move beyond aid volume and consider the position of both donor and recipient within the aid network as a correlate of the aid-growth relationship. An interpretation of our findings is that donor complementarities and the span of donor attention effects the impact of aid. There are clear reasons why donor attention could matter. A donor is likely to be more attentive to countries that are the focus of its aid efforts, as measured as a fraction of its total aid budget. Furthermore, a recipient that accounts for a significant share of the aid budget of multiple donors may receive complementary attention from multiple donors. Complementary donor attention may affect the quality of aid projects and a more efficient allocation of aid across sectors in the recipient country. This line of reasoning suggests that there could be both a within-donor attention effect and an across-donor complementarity effect.

In this paper, we embed network measures in a standard aid-growth model to explore the correlation between the topological properties of an aid network and the aid-growth relationship. We model foreign aid as a bipartite (two-mode) network with donors and recipients on either side, which allows a focus shift from monadic attributes of countries to dyadic attributes of pairs of countries. We develop network-based measures of foreign aid in both unweighted and weighted settings. In particular, we embed measures of donor and recipient connectivity (centrality), and the strength of the connections (edge weights), into some of the seminal models of the aid-growth relationship. We find that the degree centrality of the recipient, with a connectivity threshold that captures the importance of the recipient in the donor's network, is significantly correlated with the growth impact of that donor's aid. Contrarily, we

[2] See for example, Radelet (2006) and Fuchs and Nunnenkamp (2014).

find that aid is uncorrelated with growth with a recipient-side filter on the centrality measure. Our results suggest that the importance of a recipient within the complete donor network, rather than the volume of aid, is associated with the growth impact of bilateral aid. The kernel of this idea can be found in Tarp et al. (1999) and Berthélemy (2006) who explore the complementarity (or substitutability) of aid from multiple donors – though they do not utilize network analysis.[3] The network metrics provide a means to incorporate information regarding the simultaneous interdependence and complementarities of all the actors and the distinguishable impact of aid from multiple *attentive donors*.[4] The results have the potential to contribute to the more effective design of aid projects and programs. For example, the findings suggest that the mix of donors, and the weights of their contribution or participation, should be considered alongside the technical and traditional economic impact characteristics of a project.

Network analysis has been applied to a wide variety of fields, from the natural to social and economic sciences (see Newman 2010 and Jackson 2010). However, it has rarely (if ever) been applied to foreign aid in economic analysis prior to this study. In sociology, Swiss (2016) employs network analysis to explore the effects of aid on human rights treaty ratification and international organization memberships. Swiss (2017) further explores the effect of global ties on the foreign aid allocation, which provides an alternative explanation (institutionalist motives) for foreign aid. In political science, Peterson (2011) utilizes network analysis to examine the 'attractiveness' of aid recipients to International Non-Governmental Organizations (INGO) and vice-versa. Given the lack of consensus on the impact of aid generated by traditional economic analyses, it seems appropriate to bring this perspective to bear on the aid-growth puzzle.

The paper is organized as follows. Section 2 describes the data and definitions used to construct the aid network and reviews the relevant foreign-aid literature in economics. A threshold approach in the unweighted aid network setting is adopted to capture the extent of economically important aid relationships. Section 3 applies the network approach to characterize the topological properties of foreign aid network and develops network-based measures of foreign aid which capture network evolution. Section 4 then utilizes these measures to re-examine the effect of foreign aid on growth. The last section summarizes our main findings and concludes.

2. Defining a Foreign Aid Network: Data and Stylized Facts

A network is a system that is composed of different actors and the relationships among these actors. In network terminology, actors are referred to as nodes and the connections between nodes are links. In our context, each donor or recipient is a node in the network; and a link is established when a donor gives aid to a recipient. To define aid, we follow most of the foreign aid literature by focusing on Official Development Assistance (ODA) by member countries of the Organization for Economic Co-

[3] See also Annen and Moers (2017) who explore donor competition and coordination in a Nash equilibrium.

[4] Theoretically, this mechanism is not dissimilar to economies of scope: that is efficiencies associated with variety (variety of donors in this case) rather than volume (the flow level of aid).

operation and Development (OECD). The OECD Development Assistance Committee (DAC) is a forum of OECD donors that facilitates coordination and harmonized accounting methods by OECD donors. For those not familiar with ODA data it is important to note that resource flows to developing countries are typically considered ODA only if they are provided by official agencies with the main objective of promotion of economic development or growth.[5] In the empirical aid literature, both ODA commitments and disbursements have been employed, and there are some advantages and disadvantages to each measure (see McGillivray and White, 1993; Tarp et al., 1999; Easterly, 2003; Odedokun, 2003; Lessmann and Markwardt, 2012). Our analysis utilizes *commitment* data as it allows more sectorial disaggregation and, arguably, better reflects donor intent.[6] We also note that the number of DAC members (donor nodes) is not static over our analysis, having increased from 15 to 29 from 1970 to 2015.

In our analysis, we want network links to reflect only the more economically significant aid relationships. To this end, some non-trivial decisions on the volume that constitutes a link in the network are required. As our baseline, we include only the top 15 DAC donors between 1970 and 2015,[7] who together account for 96.7% of the world's total bilateral aid. We do however conduct robustness checks on this sample selection and find our results are maintained. Within this donor set, a network link is present only when the aid flow between a donor and a recipient is above a defined threshold value. Since donors determine the distribution of aid, one reasonable threshold variable from the donor's viewpoint is the volume of aid given to a recipient as the share of a donor's total aid budget ($\frac{aid_{ij}}{aid_i}$). For example, a threshold value of 0% implies that a link is present if a recipient gets any positive amount of aid from a donor. Similarly, at a 1% threshold, a recipient will have a link with a donor if it gets at least 1% of this donor's total aid. Higher thresholds allow us to filter for larger aid shares. A similar threshold approach was adopted by Kali and Reyes (2007) to identify economically important trade links in the international trade network. Table 1 shows the mean number of links and the percentage of a donor's budget captured with the threshold variable $\frac{aid_{ij}}{aid_i}$ for all DAC donors. At the 0% threshold, donors were linked to 47 recipients on average in 1970. This number increased to 113 in 2012. As we increase the threshold value to 1%, there is dramatic reduction in the mean number of links. However, these remaining links still capture on average 85.19% of a donor's total aid commitment for the period of 1970-2012.

[5] The transfer must be concessional in nature, with a grant element of at least 25 percent (Measuring Aid, OECD 2011). ODA flows do not generally include military aid, peacekeeping expenditures, or charity work by NGOs.

[6] Commitments record the full amount of an expected project transfer and disbursements are the actual transfer recorded gross or net (gross less repayments). Commitment and net disbursement measures are highly correlated for the period of 1965 to 2015 . We calculated a correlation coefficient to be 0.957 over this period.

[7] Top 15 bilateral donors are: U.S., Japan, Germany, France, U.K., Netherland, Italy, Canada, Sweden, Australia, Norway, Denmark, Switzerland, Belgium, and Spain.

Table 1. Mean number of recipients and percentage of DAC donor's budget

Year	$\frac{aid_{ij}}{aid_i} \geq 1\%$			$\frac{aid_{ij}}{aid_i} \geq 0\%$	
	# of recipients	% of recipient budget	% of a donor budget	# of recipients	% of donor budget
1970	14	30%	93.2	47	100
1975	16	25%	89.9	63	100
1980	19	23%	86.9	83	100
1985	23	25%	86.1	93	100
1990	21	23%	85.2	90	100
1995	23	22%	83.6	104	100
2000	24	22%	81.7	108	100
2005	21	19%	83.5	111	100
2010	24	21%	83.0	116	100
2012	24	21%	81.7	113	100

Figures 1 and 2 below graph the aid network in 1970 and 2012 where $\frac{aid_{ij}}{aid_i} \geq 1\%$. Round nodes represent aid donors and square ones represent recipients. The size of nodes represents a donor's share of total global aid while the node distance in the figures are configured so that a recipient and a donor are placed closer if they have an aid relationship, and donors are placed closer if they have some recipients in common and vice versa. Moving from 1970 to 2012 we see that the network becomes denser, as is consistent with the statistics in Table 1.

Figure 1. Foreign aid network in 1970

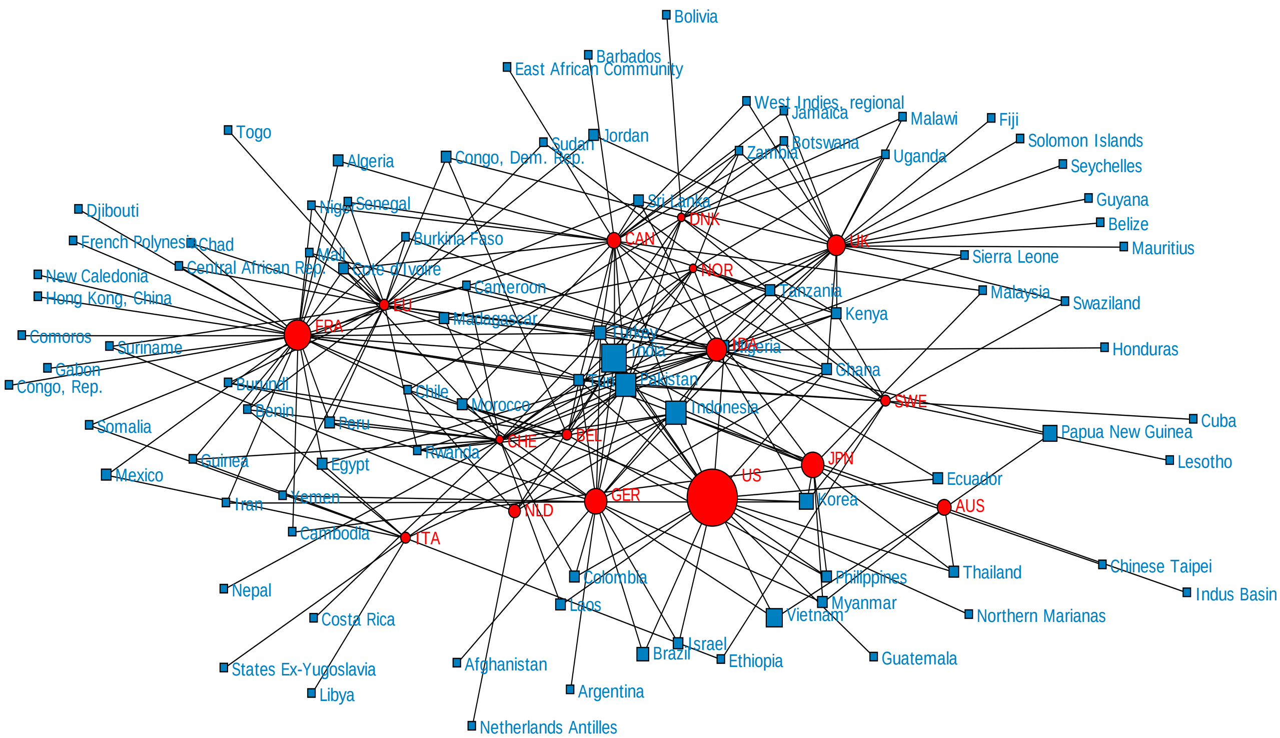
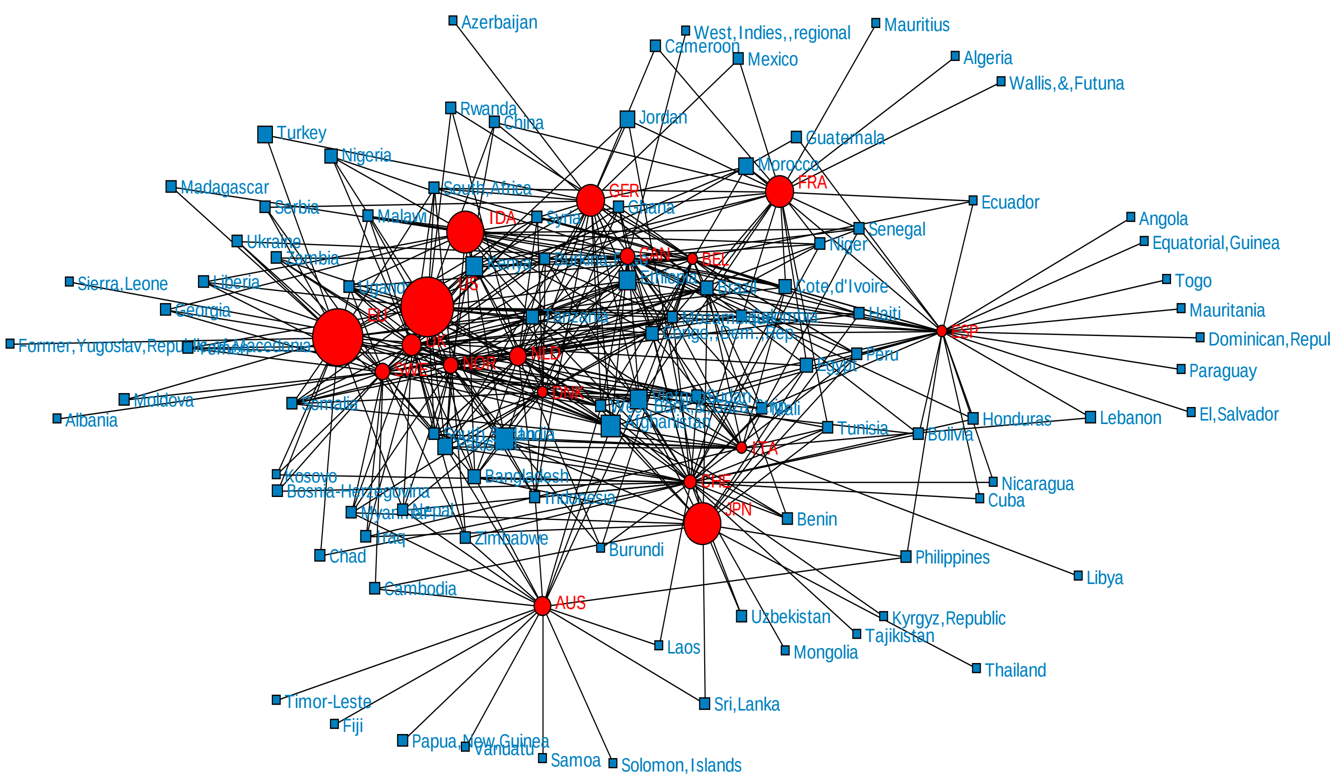


Figure 2. Foreign aid network in 2012



Analogous to the donor link criteria, a natural threshold variable from the recipient's point of view is the volume of aid given by donor i as a share of recipient j's total aid budget ($\frac{aid_{ij}}{aid_j}$). That is, a link between a donor and a recipient is present if the aid level from a donor to a recipient as a proportion of the recipient's total aid is greater than a threshold value. This criterion identifies the importance of a particular donor to the recipient. For example, in 1970, each donor accounted for, on average, about 17.53% of a recipient's aid. This number had fallen to 10.91% and 7.81% in 1990 and 2015 respectively (see Table 2).

Table 2. The change of aid share values

	$\frac{aid_{ij}}{aid_i}$ values		$\frac{aid_{ij}}{aid_j}$ values	
Year	mean	median	mean	median
1970	1.66%	0.17%	17.53%	2.85%
1975	1.30%	0.16%	14.54%	3.07%
1980	1.05%	0.17%	12.46%	3.19%
1985	0.90%	0.16%	11.19%	2.94%
1990	0.79%	0.13%	10.91%	3.41%
1995	0.70%	0.13%	10.74%	2.86%
2000	0.68%	0.15%	8.68%	2.66%
2005	0.69%	0.10%	8.37%	2.21%
2010	0.56%	0.09%	7.96%	1.62%
2015	0.47%	0.08%	7.81%	1.52%

Instead of using an arbitrary threshold (such as 1%) of a donor's bilateral commitment, we adopt a dynamic threshold, tied to the evolving moments of the aid-share distribution. Specifically, our dynamic threshold uses the mean share value as follows:

1) $\frac{aid_{ijt}}{aid_{it}} \geq md_t$ where md_t is the mean share of $\frac{aid_{ijt}}{aid_{it}}$ at time t.
2) $\frac{aid_{ijt}}{aid_{jt}} \geq mr_t$ where mr_t is the mean share of $\frac{aid_{ijt}}{aid_{jt}}$ at time t.

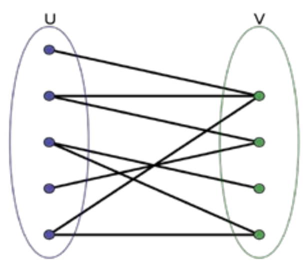
Take the donor-side filter as an example. In year 2000, a link between a donor and a recipient will be present if a donor commits 0.68% of its total bilateral aid to a recipient. In year 2010, a link will be established if a donor commits 0.56% of its aid. Similarly, for the recipient-side filter, a recipient will have a link with a donor if a donor accounts for 8.68% and 7.96% of its aid budget in 2000 and 2010 respectively.

3. Network-based Foreign Aid Measures

3.1 Foreign Aid Network Structure

In a traditional network matrix, the rows and columns refer to a single set of actors and this is known as a one-mode structure. A typical example is the international trade network where any two countries (actors) in the set could have a link due to their trade relation. However, there are also situations where we have two sets of actors and connections are only between these two sets of actors but not within (see Figure 3). This network structure lacks ties within sets is by design (Borgatti and Halgin, 2011). The foreign aid network, in general, has such structure, with countries categorized as either donors or recipients of development transfers.[8] That is, aid flows only from a donor to a recipient, but there are no aid transfer links within the donor community U nor within the recipient community V. This structure is called 1a *two-mode structure* or *bipartite network*.

Figure 3. Two-mode structure (bipartite network)



One approach to dealing with two-mode data is to transform them into one-mode data on which standard network analysis can be applied. Latapy et al. (2008) suggests applying a projection such that two nodes in the same set are considered to have a link only if they have a common neighbor in the network. However, it is not always clear how to interpret this transformed connection between actors within the same set and there could also be a loss of information. Faust (1997) argues that the relationship between the centrality of one set of actors and the centrality of the other set of actors cannot be studied just by looking at the transformed one-mode data separately.

In this paper, we follow the methodology established in Borgatti and Everett (1997) to work with a two-mode matrix directly. In the foreign aid context, the primary interest of maintaining a two-mode matrix is to focus on the connection between donors and recipients, not how the donors are connected to each other via recipients.

[8] There are a few countries which were aid recipients and currently are aid donors. But these transition countries enter only the recipient set of nodes under our threshold. As an example, South Korea was a recipient before 2000, so it was in the recipient set. When it became an aid donor, it only contributes 0.31% of total bilateral aid on average and was not included in our network using any threshold.

3.2 Foreign Aid Network as an Unweighted Network

Next we develop some network-based measures of foreign aid in both unweighted and weighted settings. The foreign aid data were extracted from OECD Aid Statistics for the period 1970 to 2012. The data is organized in matrix form as 2-mode bipartite network, with columns denoting donors and rows aid recipients. We denote the donor and recipient set as l_i and l_j respectively. The binary matrix $l_i * l_j$ has element $R_{ij} = 1$ if a link between donor i and recipient j is present at a certain threshold value and $R_{ij} = 0$ otherwise. Table 3 is the 2-mode binary matrix for the top 15 donors and the first 5 recipients in the sample where $\frac{aid_{ij}}{aid_i} \geq 0.5\%$ is used as the threshold for 2012. Hence, $R_{61} = 1$ denotes that there is a link between Albania and Germany, and Albania gets more than 0.5% of Germany's total aid budget in 2012. Since all relationships that pass the threshold are treated equally ($R_{ij} = 1$) regardless of aid volume, this is an *unweighted network*.

Table 3. Partial binary matrix

	Aid Donors														
	AUS	BEL	CAN	DNK	FRA	GER	ITA	JPN	NLD	NOR	ESP	SWE	CHE	UK	US
Aid Recipients															
Albania	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0
Belarus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bosnia-Herzegovina	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0
Croatia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyprus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: this is an example of the year 2012 when the threshold of $\frac{aid_{ij}}{aid_i} \geq 0.5\%$ is applied.

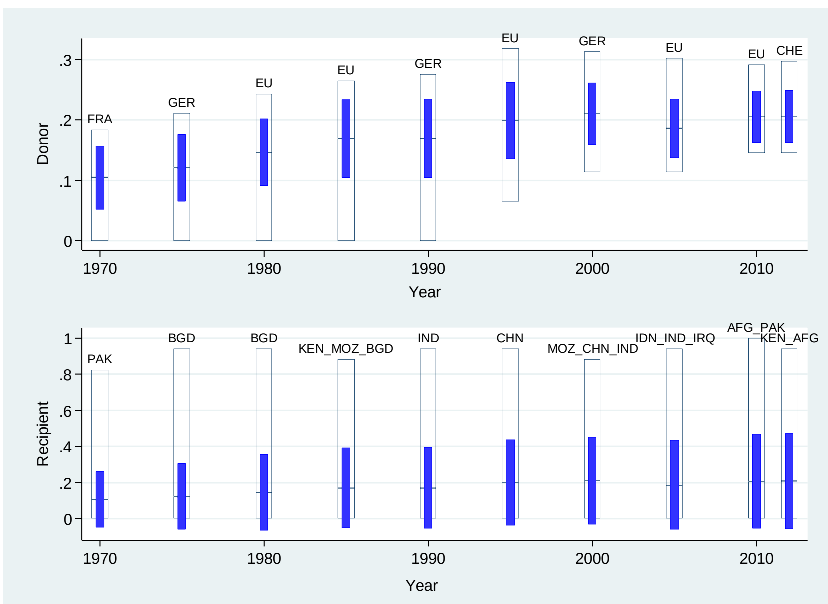
(1) Node Degree

Node degree is a basic component of network analysis. Before defining node degree, we introduce some notation. At an aggregate level, the aid of recipient j is the total amount of aid from all donors *i*, $aid_j = \sum_{i=1}^{I} aid_{ij}$. Define an active donor at time t as $aid_{ij} > 0$. Let I_i^A be the set of all active donors. A donor i' is inactive with respect to recipient j if $aid_{i'j} = 0$. Let I_i^N be the set of all inactive donors for recipient j. Then let $I_i = I_i^N + I_i^A$. The node degree indicates the number of edges or links connected to a given node. For recipient j, it is denoted as $d(n_j) = I_i^A$. In the aid context, the degree of a donor node is the number of active recipient links, and the degree of a recipient node is the number of donors from whom she receives aid. So the node degree reflects each country's involvement in the aid system and it could help to identify those highly connected (or influential) donors and recipients in the network.

(2) Node Centrality

Normalized degree centrality is node degree divided by the size of the opposite vertex set. For example, active degree centrality for recipient j is $\frac{d(n_j)}{I_i}$. The *node centrality* enables us to identify the presence of a center of gravity for the network. In the aid context, a country with higher centrality is more central in the network. Figure 4 summarizes the degree centrality for both donors and recipients in 2012. The transparent bars show the range of scores and blue bars show the mean with standard deviation. The country that has the highest score is labeled on the upper bound of the score range. The results suggest France, Germany, and EU institutions were the most central donors in general, with Switzerland becoming the most central donor recently; Pakistan, Bangladesh, Kenya, Mozambique, China, India, Indonesia, Iraq, Afghanistan have been the most central recipients at different points in time.

Figure 4. Descriptive statistics for degree centrality



3.2 Foreign Aid Network as a Weighted Network

Table 4 below presents the weight matrix that provides significant flexibility relative to the framework above. Recall that donor i's aid to recipient j is weighted by donor i's total bilateral aid budget ($\frac{aid_{ij}}{aid_i}$) while from recipient j's perspective, the weight matrix takes the form of $\frac{aid_{ij}}{aid_j}$. For example, in 2005, Vietnam received 1.98% of France's aid budget and 10.34% of its foreign aid is from France (see Table 4).

Table 4. Weight matrix of Vietnam in 2005

	AUS	BEL	CAN	DNK	FRA	GER	ITA	JPN	NLD	NOR	ESP	SWE	CHE	UK	US
$\frac{aid_{ij}}{aid_i}$ matrix	1.66	1.18	2.04	4.49	1.98	0.65	0.08	4.85	1.28	0.64	0.41	1.66	0.91	1.13	0.14
$\frac{aid_{ij}}{aid_j}$ matrix	2.08	1.12	4.11	4.44	10.34	3.39	0.13	53.71	2.60	1.02	0.57	2.66	0.91	5.06	2.33
aid volume	39.14	23.36	79.93	91.32	210.61	71.13	2.8	864.3	53.85	20.6	11.69	55.63	17.97	100.38	46.83

Note: the last row is the amount of aid Vietnam received from each donor in constant price (millions USD 2013)

The weighted matrix can then be used to construct network measures that incorporate the weights of the links. Take the node degree and degree centrality as examples. Following Newman (2004), the degree of a vertex in a weighted network is the sum of the weights of the edges attached to it. An example from donor i's perspective is the node degree being $\sum_{j=1}^{J} \frac{aid_{ij}}{aid_i}$, while degree centrality is $\frac{\sum_{j=1}^{J} \frac{aid_{ij}}{aid_i}}{J}$. The node degree is interpreted as the mean share of a donor's budget or the mean share of a recipient's aid. Again in the Vietnam 2005 example, on average each donor gave 1.5% of its budget to Vietnam and each donor account for 6.3% of Vietnam's total bilateral aid.

4. Application: Recipients' Aid Connectivity and Economic Growth

4.1 Aid-Growth Relationship: Empirical Model

Much of the prior ODA-growth literature seeks to identify the relationship between a country's per-capita income growth and the volume of aid. Controls typically employed include initial income, policy, institutional quality (governance), and geographic location. Not surprisingly, much attention has been devoted to addressing the endogenous allocation of aid and the identification of causation. To address this issue we mimic Rajan and Subramanian's (2008) highly cited work, using the extended data for the period 1970-2005 from Clemens et al. (2012).[9] The network-based measures added to the original model are: degree centrality in both unweighted and weighted networks. This yields the specification:

$$3)\quad rgdpchg_{it} = \beta_0 + \beta_1(aid/GDP)_{it} + \beta_2 degc_{it} + \beta_3 yc_{it} + \beta_4 policy_{it} + \beta_5 le_{it} + \beta_6 geog_{it} + \beta_7 inst_{it} + \beta_8 inf_{it} + \beta_9 (M2/GDP)_{it} + \beta_{10} bb_{it} + \beta_{11} revol_{it} + \beta_{12} ethfra_{it} + \varepsilon_{it}$$

where $rgdpchg$ is the five-year average annual growth of per capita GDP, aid/GDP is aid to GDP (a normalized measure of aid volume), yc is the initial level of per capita GDP, $policy$ is the initial level of trade policy index, le is the initial level of life expectancy, $geog$ is geography (the average of number of frost days and tropical land area), $inst$ is institutional quality, inf is the initial inflation, $M2/GDP$ is the

[9] The generosity of the authors to share their extended data is very much appreciated.

initial financial depth, bb is the budget balance as proportion of GDP, $revol$ is the average number of revolutions, and $ethfra$ is ethnic fractionalization.[10] The $degc_{it}$ is the degree centrality measure which takes different forms in the unweighted and weighted network settings.[11] Note that the measure from the donor's point of view is called the *Donor Threshold Model* and the one from the recipient's point of view is called the *Recipient Threshold Model* when reporting the results.

We estimate equation 3 with the following questions in mind: (i) Is connection to more donors who contribute a meaningful aid share positively correlated with recipient growth? (ii) Are unconditional connections with donors positively correlated with recipient growth? (iii) Is connection with more donors who account for a larger share of a recipient's aid positively correlated with recipient growth? (iv) Does weighting of linkages with donors who commit a larger share of aid budget illuminate a stronger positively correlated with recipient growth? We explore these questions empirically in the following sections.

4.2 Estimation Strategy and Evidence

We follow Rajan and Subramanian (2008) and employ GMM to estimate the equation above. Identification relies on first-differencing and using lagged values of the endogenous variables as instruments. In the difference-GMM estimator (or the Arellano and Bond procedure), lagged levels are used to instrument for the differenced right-hand-side variables. We begin by looking at the results based on unweighted network measures. Table 5 summarizes the results across different specifications. Column 1 reports the core specification in Rajan and Subramanian (2008), and it fails to find a significant aid-growth relationship. Columns 2 and 3 shows the results for Donor Threshold Models where a recipient is important to a donor. The connectivity-growth evidence is tested controlling for the aid/GDP ratio by adding the degree centrality term to the core specification. The results indicate (at 10% confidence level) that a 1 percentage-point increase in aid/GDP is associated with 0.18 percent point *decrease* in average annual growth of GDP. However, a one percentage-point increase in degree centrality within the aid network is associated with an *increase* of the average annual growth rate of per capita GDP by 6.8 percentage points (at 5% level). Column 3 adds the interaction of centrality and aid/GDP into the specification. The negative and significant sign suggest that aid connectivity does not work better with a larger amount of aid. In the Recipient Threshold Models (columns 4 and 5), filtering links to those donors who account for a larger share of a recipient's total aid, does not indicate that ODA linkages contribute significantly to growth.

[10] Appendix A provides precise definitions and sources for these variables.

[11] As noted previously, the unweighted form is $d(n_{jt})/I_{it}$ and the weighted form is $\sum_{i=1}^{I} \frac{aid_{ijt}}{aid_{it}} / I_{it}$

Table 5. GMM regression results (unweighted network measures, varying threshold values)

	Baseline Model	Donor Threshold Models		Recipient Threshold Models	
Variables	(1)	(2)	(3)	(4)	(5)
aid/GDP	-0.105	-0.177*	0.135	-0.153	-0.328*
	(0.105)	(0.103)	(0.154)	(0.117)	(0.192)
degree centrality		6.831**	8.012*	-2.845	-7.253
		(3.311)	(4.673)	(8.534)	(12.47)
(degree centrality)*(aid/GDP)			-0.716**		1.795
			(0.321)		(1.658)
yc_penn	-2.654*	-1.937	-2.041	-2.585	-2.704
	(1.564)	(1.953)	(2.071)	(1.662)	(1.987)
le_wdi	-0.128	-0.119	-0.0846	0.0918	0.000693
	(0.135)	(0.156)	(0.179)	(0.169)	(0.153)
sw1_i	0.440	0.314	0.223	0.550	0.158
	(0.934)	(0.719)	(0.798)	(1.023)	(1.083)
INST_QLTY	-1.137	-1.335	0.0640	-0.451	0.982
	(2.994)	(3.054)	(2.756)	(3.393)	(3.856)
lninfl	-1.360**	-0.810	-0.849*	-1.214*	-1.409**
	(0.635)	(0.572)	(0.439)	(0.632)	(0.570)
m2final	-6.563	-6.205	-7.300**	-5.925	-6.992*
	(4.670)	(4.861)	(3.315)	(3.728)	(3.884)
bbfinal	12.04	8.218	18.46*	7.668	4.606
	(9.219)	(9.662)	(9.898)	(8.832)	(11.13)
revolutions	-2.674***	-2.185***	-2.271***	-1.931**	-1.943**
	(0.765)	(0.627)	(0.797)	(0.855)	(0.778)

Note: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Threshold values (the mean share of $\frac{aid_{ij}}{aid_i}$ and $\frac{aid_{ij}}{aid_j}$) vary each year when constructing the matrix as described in Section 2.

When the threshold value is set to be 0%, which means any amount of aid constitutes an aid relationship, we find no association between centrality and recipient growth (see Table 6). It is the volume of links with attentive donors, not the number of unconditional links, or aid levels, which is associated with recipient growth. Removing the threshold filter introduces many casual donors into the sample that dilutes the effect of connectivity from *attentive* donors. That is, unconditional connectivity or aid amount are not significantly associated with growth per-se, while connectivity with attentive donors is.

Table 6. GMM results (unweighted network, Donor Threshold Models, threshold value=0)

Variables	(1)	(2)	(3)
aid/GDP	-0.105	-0.143	-0.520*
	(0.105)	(0.161)	(0.288)
degree		1.981	-1.138
		(2.354)	(2.754)
degree * aid/GDP			0.499
			(0.362)
yc_penn	-2.654*	-3.780	-2.769
	(1.564)	(2.497)	(2.269)
le_wdi	-0.128	-0.0163	-0.168
	(0.135)	(0.173)	(0.162)
sw1_i	0.440	0.634	0.329
	(0.934)	(1.048)	(0.749)
INST_QLTY	-1.137	0.453	0.701
	(2.994)	(2.867)	(2.868)
lninfl	-1.360**	-1.434**	-1.500**
	(0.635)	(0.727)	(0.669)
m2final	-6.563	-2.830	-3.305
	(4.670)	(5.503)	(4.767)
bbfinal	12.04	4.411	10.84
	(9.219)	(11.93)	(11.78)
revolutions	-2.674***	-1.243*	-0.906
	(0.765)	(0.700)	(0.733)

Note: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The results for the weighted aid network are reported in Table 7. In this case, degree centrality ($degc_{it}$) becomes $\sum_{i=1}^{I} \frac{aid_{ijt}}{aid_{it}} / I_{it}$. Note that weighted linkages remain associated with increased recipient growth. However, the magnitude and significance are weakened in comparison to the unweighted networks. The negative aid/GDP result, which was quite robust in the unweighted networks, becomes insignificant here. In the Recipient Threshold Models, the weighting of linkages with donors who contribute significantly to a recipient's aid budget does not change the general insignificance.

Table 7. GMM regression results (weighted network measures)

Variables	Baseline Model (1)	Donor Centrality Models (2)	(3)	Recipient Centrality Models (4)	(5)
aid/GDP	-0.105	-0.121	0.125	-0.118	-0.382
	(0.105)	(0.128)	(0.150)	(0.0926)	(1.866)
degree centrality		-0.0136	1.701*	0.355	0.321
		(0.516)	(0.900)	(0.236)	(0.336)
(degree centrality)*(aid/GDP)			-0.261**		0.0292
			(0.119)		(0.282)
yc_penn	-2.654*	-2.957	-1.682	-3.081*	-3.912*
	(1.564)	(2.044)	(2.199)	(1.721)	(2.178)
le_wdi	-0.128	0.0223	0.0901	-0.0914	-0.0426
	(0.135)	(0.170)	(0.149)	(0.219)	(0.176)
sw1_i	0.440	0.714	-0.00327	-0.00433	0.290
	(0.934)	(1.018)	(0.667)	(1.157)	(0.846)
INST_QLTY	-1.137	-1.448	0.924	0.278	0.245
	(2.994)	(3.428)	(2.673)	(3.117)	(2.504)
Lninfl	-1.360**	-0.862*	-1.262***	-1.265	-0.785
	(0.635)	(0.518)	(0.466)	(0.801)	(0.529)
m2final	-6.563	-5.189	-6.722*	-4.169	-1.973
	(4.670)	(3.894)	(3.792)	(4.298)	(4.087)
bbfinal	12.04	16.58	10.00	11.57	12.99
	(9.219)	(11.92)	(9.321)	(13.10)	(8.471)
revolutions	-2.674***	-2.252***	-2.317***	-2.157***	-2.000**
	(0.765)	(0.769)	(0.750)	-4.169	-1.973

Note: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4.3 Supporting Evidence of the Complementary Attentive Donor Hypothesis

The positive relationship between recipient growth and connectedness to more donors who contribute a higher share of their budget to this recipient is novel since such network measures have not been previously embedded in the standard aid-growth regressions. There are several potential mechanisms by which connectivity with attentive donors may be associated with growth. First, there may be synergies or complementarities in the aid from multiple attentive donors. These complementarities may be associated with specialized sectorial focus (or expertise). For example, suppose one donor specialized in building roads and another with bridges in a recipient country with many rivers. Combined, balanced aid by these donors would be likely to yield greater growth effects than if the value of their joint contributions were towards only bridges or only roads. A Kremer O-Ring model can capture the critical nature of sector complementarities in producing growth. Donor complementarities can also be modeled as a type of economies of scope.

To provide some supporting evidence for this hypothesis we utilize OECD/DAC Aid Statistics to explore the sectorial distribution of aid. The second moment (e.g. the standard deviation) is reported in

Figure 5, where a larger variation indicates more uneven aid across sectors (or a greater concentration of aid). The variation among sectors in the aid allocation changes over time, but in general countries such as the United States, Japan, France, and Germany have larger variation while Switzerland, Belgium, Denmark, and Sweden have tighter sectorial focus. For example, in the period 2001-2005, the United States distributed approximately 42% of its aid to social infrastructure and services, 15% to action relating to debt, and 14% humanitarian aid, but Switzerland has a relatively more evenly distribution pattern (see Table 13). In addition, countries with larger variation may still have different priorities. Japan allocates the most to action relating to debt (33%), followed by economic infrastructure and services (23%), and social infrastructure and services (20%).

Figure 5. Standard deviation of sectorial aid by donors

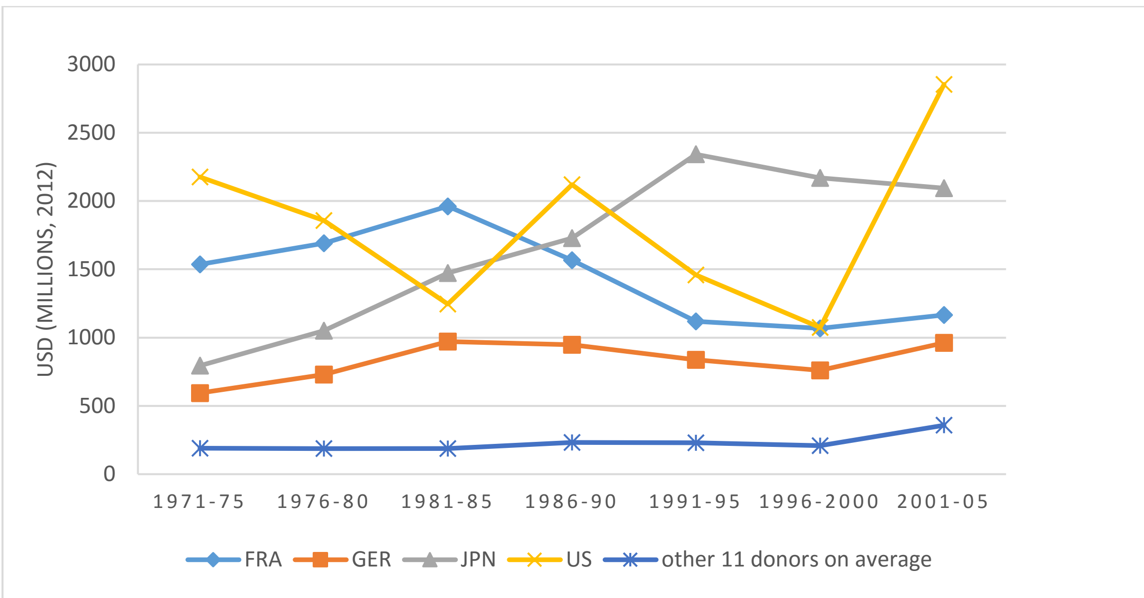


Table 8. Mean share of aid allocation by sectors (2001-2005)

Sectors	US	JPN	CHE
social infrastructure & services	42.15718	19.82215	19.56017
economic infrastructure & services	8.825572	23.33967	6.21822
production sectors	5.997024	7.712764	7.625802
multisector/cross-cutting	3.917148	3.073994	13.88052
commodity aid/general program assistance	4.05043	1.591165	2.355999
action relating to debt	14.77651	33.34954	15.86613
humanitarian aid	14.26292	3.56235	13.48448
unallocated aid /unspecified	6.013218	7.548365	21.00869

We next look for evidence of the complementarities/sector dispersion conjecture. When adding the aid variation among sectors to our previous model, all specifications return a positive and significant relationship towards recipient growth (Table 9). This is consistent with the idea that connection to donors who concentrate aid in fewer sectors is associated with higher recipient growth. Moreover, the interaction term suggests greater concentration does not work better with a larger amount of aid.

Table 9. GMM regression results (sector concentration and recipient growth)

	Unweighted Network			Weighted Network	
Variables	Donor Threshold Model (1)	Recipient Threshold Model (2)	Donor Threshold Model (=0) (3)	Donor Threshold Model (4)	Recipient Threshold Model (5)
Aid/GDP	-0.0125	0.0338	-0.107	0.0184	-0.0104
	(0.115)	(0.108)	(0.147)	(0.111)	(0.119)
degree centrality	2.287	4.682	1.687	-0.507	0.0345
	(4.079)	(8.309)	(2.698)	(1.401)	(0.324)
sectorial variation(std)	1.168***	1.279***	0.931*	1.496**	1.045***
	(0.369)	(0.320)	(0.497)	(0.647)	(0.345)
(sectorial variation)*(aid/GDP)	-0.112**	-0.117**	-0.0861	-0.120**	-0.105**
	(0.0486)	(0.0504)	(0.119)	(0.0483)	(0.0500)
yc_penn	-1.783	-2.593	-1.190	-2.292	-1.916
	(1.879)	(1.580)	(2.350)	(2.072)	(1.680)
le_wdi	0.0265	0.131	0.0210	0.0103	-0.0770
	(0.181)	(0.167)	(0.224)	(0.190)	(0.175)
sw1_i	0.691	0.331	0.998	0.268	0.274
	(0.735)	(0.673)	(0.980)	(0.777)	(0.746)
INST_QLTY	1.367	0.989	1.274	2.809	1.692
	(3.014)	(2.632)	(3.555)	(2.446)	(2.513)
Lninfl	-1.187**	-1.365***	-1.926***	-1.528***	-1.515***
	(0.584)	(0.517)	(0.742)	(0.462)	(0.548)
m2final	-6.449*	-3.384	-4.634	-6.130	-6.797*
	(3.633)	(3.567)	(4.000)	(3.840)	(3.798)
Bbfinal	7.839	2.607	6.846	12.07	7.278
	(8.386)	(7.142)	(11.36)	(10.69)	(8.925)
revolutions	-1.375**	-0.986	-0.746	-1.551**	-1.424**
	(0.584)	(0.886)	(0.832)	(0.769)	(0.606)

Note: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Furthermore, managing multiple donors may discipline the recipient and induce learning that would not occur if the total volume of aid were from fewer recipients. Project proposal, implementation, and maintenance for multiple donors require improved governance and administration capacities by the recipient which may spill over beyond the projects themselves.

In contrast, the recipient threshold model fails to find a significant relationship between recipient growth and connection with more donors who account for a larger share of the recipient's aid. This lack of significance juxtaposed with the significance of the Donor Threshold Model is interesting and informative. A first interpretation is that it is the size of the attentive donor set, rather than the volume of aid itself, which is significantly associated with growth. This contradicts the focus of nearly thirty years of research searching for the effect of aid on growth. This literature almost universally looks at aid volumes (though sometimes filtered by sector or time impact) and not connectedness. As discussed previously, this lack of significance reinforces the interpretation that it is the presence of multiple complementary "attentive donors", rather than aid volume that is associated with growth. The second explanation for this pattern of significance across the threshold models is that this threshold may select for strategic (rather than altruistic) ODA relationships. Large donations intended to buy influence (e.g. UN votes, port landing rights, etc.) rather than spur development may not receive attention from the donor once the "transaction" is complete.

5. Conclusion

Treating foreign aid as a bipartite social network allows us to generate new measures of aid connectivity among actors that appear significantly related to economic growth. Most prior analyses focus on aid volumes rather than connectivity as quantitative explanatory variables of aid impact. As a precursor to quantitative analysis, we characterize the network topology to illuminate the OECD aid network structure. We find that consideration of network topology illuminates relationships and mechanisms that are difficult to discern with traditional analyses. Node specific measures (e.g., degree centrality and eigenvector centrality), illuminate the position of a particular donor and/or recipient in the network. To explore the usefulness of network-based measures, we embed degree centrality (in both weighted and unweighted networks) in Rajan and Subramanian's (2008) highly cited paper. Their conclusion was that aid volume had a little relationship with economic growth.

We find that the degree centrality of the recipient, with an edge inclusion threshold that sets a minimum share of a donor's aid to a particular recipient, is significantly correlated with the growth impact of donor aid. Contrarily, foreign aid is uncorrelated with recipient growth with a recipient-side filter on the importance of the donor to the recipient. Unconditional connectedness with casual donors also dilutes the effect of connectivity from an attentive donor upon aid. These results suggest that the importance of a recipient within the *donor's* network, rather than aid volume alone, is associated with the growth impact of bilateral aid. We explore mechanisms for these findings that include the complementarity of aid from multiple attentive donors. There are associated policy implications. For example, the impact of a given aid volume on recipient's economic growth may be higher if it comes from more donors, allowing each to focus more intensely on specific sectors. An interpretation is that it is the focused attention of donors, not the volume of aid alone, is critical in the aid-growth connection. This paper represents a first effort to apply network analysis to the foreign aid system to address important unresolved questions. The results appear promising.

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Appendix A.

Variable Name	Variable Description	Source
rgdpchg (real economic growth)	Annual average growth rate of real GDP (PPP) per capita where the averages are taken over the relevant time period. Countries are included in the sample for the 1960–2000 horizon if there are data for at least 35 years; for the 1970–2000 horizon for at least 25 years of data; for the 1980–2000 horizon for at least 15 years of data; for the 1990–2000 horizon for at least 5 years; and for the panel for at least 3 years.	PWT, version 6.1
aid/GDP (Aid to GDP)	The ratio of aggregate net development assistance that is disbursed in current U.S. dollars to GDP in current U.S. dollars. It includes all loans and grants undertaken by the official sector with the promotion of economic development as the main objective and where loans have a grant element of at least 25%. In all the regressions, the aid-to-GDP is averaged over the relevant time period in the regression. If the aid horizon is 1960–2000, then the aid-to-GDP variable in the regression is averaged over this period of the annual aid-to-GDP ratios. The variables are averaged similarly (that is, over five years) in the panel regressions. These averaging procedures are used for all the aid variables.	OECD, DAC
yc (initial GDP)	Log of per capita (PPP) GDP at the beginning of the relevant time period. For example, for the horizon, initial GDP is for the year 1960.	PWT, 6.1
policy (initial policy)	The Sachs-Warner trade policy index as updated by Wacziarg and Welch and prevailing at the beginning of the relevant time horizon or the year closest to it. For the 1960–2000 and 1970–2000 horizons, using the initial value causes the variable to drop out, so for these two horizons we use contemporaneous values of the variable.	Wacziarg and Welch, 2003
le (life expectancy)	Life expectancy at birth in years at the beginning of the relevant time period. For example, for the horizon, initial life expectancy is for the year 1960 or for the closest year for which data are available. The same procedure is applied in the panel estimations.	WDI
geog (geography institutional quality)	Average of number of frost days and tropical land area. For the GMM regressions, data are averages for the relevant five-year period.	Bosworth and Collins, 2003
inst (institutional quality)		
inf (inflation)	The average annual rate of growth of CPI-based inflation for the first five years of the relevant time horizon. For example, for the period 1960–2000, this variable is measured for the period 1960–1964. In the panel, the inflation measures are averages of the relevant five-year period.	Easterly's Web site (www.nyu.edu/fas/institute/dri/global%20development%20network%20growth%20database.htm

M2/GDP (financial depth)	The ratio of M2/GDP for the first five years of the relevant time horizon. In the panel, averages of the relevant five-year period are used.	Easterly's Web site
bb (budget balance	The ratio of general government budget balance to GDP for the first five years of the relevant time horizon. In the panel, averages of the relevant five-year period are used.	WDI
revol (revolutions)	The average number of revolutions per year in the relevant time horizon. Revolutions are defined as any illegal or forced change in the top governmental elite, any attempt at such a change, or any successful or unsuccessful armed rebellion whose aim is independence from the central government.	Arthur S. Banks