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Influencing Connected Legislators*

Abstract

This paper studies how interest groups allocate campaign contributions when congressmen are connected by social ties. We establish conditions for the existence of a unique Nash equilibrium in pure strategies for the contribution game and characterize the associated allocation of the interest groups' moneys. While the allocations are generally complex functions of the environment (the voting function, the legislators' preferences and the social network topology), they are simple, monotonically increasing functions of the respective legislators' Katz-Bonacich centralities when the legislators are office motivated or the number of legislators is large. Using data on the 109th-113th Congresses and on congressmen's alumni connections, we estimate the model and find evidence supporting its predictions.

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1 Introduction

There is a large theoretical and empirical literature studying interest groups' influences on congressmen. This literature aims to derive and test predictions about interest groups' activities, starting with the assumption that congressmen are self-interested, individualistic utility maximizers. However, a long tradition in political science notes that treating legislators as solely self-interested individuals may be reductive, because it ignores deep connections of friendship, respect and patronage that transcend partisan or ideological divisions.[1] Recent work has creatively used a variety of data sources and methodologies to map legislators' social ties and show that these connections can help explain legislative success (Fowler [2006], Cho and Fowler [2010]), voting behavior (Arnold et al. [2000], Masket [2008], Cohen and Malloy [2014], Harmon et al. [2017]), and may provide insights on congressional power centers (Porter et al. [2005], Zhang et al. [2008]). For the most part, however, social connections among legislators have been ignored by the literature on interest groups. If interpersonal relations truly play a role in legislators' behavior, then we should expect them to play a role in how interest groups allocate resources among legislators.

In this paper, we present a new theory of campaign contributions in which legislators care about how other legislators in their social network behave. Even for realistically complex networks, our theory provides sharp predictions on how the interest groups allocate their resources based on social network topology. We then use data from the 109th-113th Congresses to estimate the model. We find evidence that the measures of centrality suggested by our theory have a significant influence on the spending decisions of Political Action Committees (PACs).

In our model, n legislators vote to pass or reject a policy. Legislators care about the policy outcome, but also care about the resources they can obtain from interest groups and about the behavior of other legislators to whom they are socially tied. We assume that legislators like to receive resources from interest groups (for example, because these resources increase the likelihood of being reelected);[2] they also like to vote for the option that they think is chosen by their friends. Social ties are represented by a network matrix whose generic element $g_{i,j}$ represents the intensity

[1] See, among others, Eulau [1962], Caldeira et al. [1993], Baker [1980]. Among early quantitative studies of legislators' social interactions, see Rice [1927, 1928], Routt [1938], Patterson [1959] and Matthews and Stimpson [1975]. For historical discussions, see for example Truman [1951], Bailey and Samuel [1952] and Clapp [1963].

[2] While it is useful to think of the interest groups' resources as money, this does not need to be the case. An example of a non-monetary resource is information that the group can provide to the legislator.

of the influence of congressman j on i. Two interest groups compete for the legislators' votes. Interest group A aims to maximize the share of legislators who vote for a given policy; interest group B aims for the opposite result. Each interest group has a given budget and can commit to offer payments to the legislators that are contingent on the legislators' votes; the legislators cast their ballots after observing the offers. We establish the conditions for the existence of a unique pure strategy Nash equilibrium of this game and characterize the associated equilibrium allocation of resources.

Perhaps unsurprisingly, we find that the allocation of the interest groups' moneys is generally a complex function of the voting rule, the legislators' preferences for the policy and the geometry of the social network. While this relationship can be characterized in closed form, in practice it may be hard to compute it exactly for large networks, creating a challenge for empirical analysis. However, we show that when legislators are office motivated or when their number is large, the relationship between network topology and allocation of resources is simple: the interest groups allocate their resources in a way that is proportional to the Katz-Bonacich measure of centrality, a well known concept of centrality in network theory (see, for example, Zenou [2015]).[3]

We then estimate our model and test whether the legislators' Katz-Bonacich centralities are good predictors of PAC contributions. We construct social networks exploiting the idea that educational institutions provide a basis for social networks (see Cohen et al. [2008], Fracassi and Tate [2012], Cohen and Malloy [2014], Do et al. [2016], among others). We therefore construct social networks using the congressmen's alumni connections: two congressmen are connected if they graduated from the same institution within a given time window. This approach gives us a network that is exogenous by construction to the political process. We control for other potential confounding effects associated with school quality by adding school fixed effects.

Using our alumni network, we obtain consistent results that support our theory. We find that standard measures of centrality like degree, betweenness, closeness and eigenvalue centralities have little power in explaining PAC contributions when compared to the Katz-Bonacich centrality, the measure predicted by our theory. The relevance of the Katz-Bonacich centrality, moreover, is robust to many natural controls suggested by the previous literature on the determinants of PAC contributions: measures of members' relative "power" inside the house (i.e.,

[3] The exact relationship between the Katz-Bonacich measure of centrality and the resources of legislators can also be characterized in closed form, but it depends on the specific assumptions on the legislator's utility function.

chairmanship, seniority, membership in the majority party, participation in important committees such as Appropriations or Way and Means), the margins of victory in the legislators' elections (as a proxy for the competitiveness in the district), gender, party affiliation, legislators' ideologies and Congress-specific effects (as captured by Congress fixed effects). We estimate that a one standard deviation increase in a legislator's Katz-Bonacich centrality induces an increase in interest groups' contributions that is roughly comparable to what a legislator would achieve by being a member of the party in the majority. Perhaps more importantly, adding information on network topology as suggested by the theory significantly improves the fit of the model compared with the alternative specification that ignores this information.

The intuition behind the result that Katz-Bonacich centrality is a sufficient statistic to determine the allocation of resources for a sufficiently large n depends on the following simple observation: as n increases, the equilibrium probability that a legislator is pivotal for the outcome converges to zero. As the preferences of the legislator for the legislative outcome become decreasingly important, the dominant factor becomes the social network (and the interest groups' moneys). At that point, only the Katz-Bonacich centrality matters (as opposed to other measures of centrality like degree or betweenness that focus on different dimensions of the network topology). This result depends on the fact that Katz-Bonacich centrality captures the recursive nature of the legislators' social interactions in the network, a feature that has also been highlighted in other environments (Ballester, Calvo-Armengol and Zenou [2006], Calvo-Armengol, Patacchini and Zenou [2009]).

Our work is related to three strands of literature that to date have had little overlap. First, it relates to the political science literature on social networks in Congress already mentioned above. In addition to providing a variety of approaches to describe the legislators' social networks, this literature has shown that legislators' social connections explain voting behavior (Arnold et al. [2000], Porter et al. [2005], Masket [2008], Ringe et al. [2013], Cohen and Malloy [2014] and Harmon et al. [2017]) and legislative success, as measured by successful amendments (Monsma [1966], Fowler [2006], Canen and Trebbi [2016]), or the number of bills passed (Cho and Fowler [2010]). These recent works follow an older (if less formal) tradition in political science (see Rice [1927, 1928], Routt [1938], Eulau [1962], among others).

Our work is also connected to a large theoretical and empirical literature exploring how interest groups influence Congress.[4] The theoretical literature has been characterized by two types of models: informative theories, in which interest groups influence legislators by providing information (Calvert [1985], Austen-Smith and Wright [1992], Austen-Smith [1995], Bennedsen and Feldmann [2002], Cotton [2012]), and campaign contribution theories, in which interest groups influence legislators by providing resources (Denzau and Munger [1986], Snyder [1991], Groseclose and Snyder [1996], Persson [1998], Diermeier and Myerson [1999], Helpman and Persson [2001], Baron [2006], Dekel et al. [2009]).[5] The empirical literature has studied the determinants of PACs' allocations of campaign contributions, documenting evidence of interest groups' strategic behavior consistent with the campaign contribution theories (Poole and Romer [1985], Snyder [1990], Grier and Munger [1991]), Stratmann [1992], Romer and Snyder [1994] and Ansolabehere and Snyder [1999]).[6] This literature, however, has for the most part ignored social networks in Congress and the impact that they may have on interest groups' activities.

Finally, our work is related to the general literature on networks, which has also studied related issues of policy intervention and marketing in networks. The seminal paper studying policy intervention in networks is Ballester, Calvo-Armengol and Zenou [2006], which was among the first to propose an economic model of how the removal of a "key player" influences individual behavior. Our work differs from this because interest groups alter the agents' payoffs by making contingent promises, but they do not affect the network topology. The issue of marketing in networks has been studied in the computer science literature by Domingos and Richardson [2001] and Richardson and Domingos [2002], who considered the problem of a monopolist attempting to influence customers by allocating a budget of marketing resources.[7] The case of competitive influencers has been studied by Bharathi, Kempe and Salek [2007], who extend a contagion model by Kempe, Kleinberg and Tardos [2003] and [2005]. In these works, marketers identify nodes in a

[4] See Austen-Smith [1992] and Grossman and Helpman [2001] for surveys of theoretical research and Ansolabehere et al. [2003], Stratmann [2005] and de Figueredo and Richter [2014] for surveys of empirical research.

[5] Related but distinct literatures are the literatures studying the influence of the choice of a single policy-maker, and the direct acquisition of citizens' votes. For the first, see Stigler [1971], Grossman and Helpman [1994], Dixit [1996], Dixit, Grossmann and Helpman [1997], Besley and Coate [2001], among others. For the second, see Buchanan and Tullock [1962], Anderson and Tollison [1990], Piketty [1994], Dal Bo [2007], Dekel et al. [2008].

[6] More recent research has extended the analysis to behavior of lobbyists, uncovering evidence that they provide expertise and access (Blanes i Vidal et al. (2012), Bertrand, Bombardini and Trebbi [2014], Kang [2015], Kang and Young You [2017]).

[7] In their model, that is not based on an explicit microfoundation of behavior, the key determinant of the monopolist's allocation is a measure of centrality called the "network effect," which for an undirected network coincides with the degree centrality, a measure that is not relevant in our theory and does not appear significant in our empirical analysis.

network to start a contagion process. Contagion models have been applied in the political science literature to study influence on legislators by Groenert [2010], Lever [2010] and Groll and Prummer [2016]. These papers, however, do not provide microfoundations of the legislators' decisions, since they assume that legislators collectively decide according to an exogenous decision function and are influenced through mechanical contagion processes that do not account for legislators' incentives.

The remainder of this paper is organized as follows. Section 2 presents our model of legislative behavior and competitive interest groups' activities. In Section 3, we study the equilibrium of this game and characterize the relationship between the legislators' preferences, the voting rule, the network topology and the interest groups' resource allocations. Section 4 brings the model to data, Section 5 presents extensions to the model, and Section 6 concludes.

2 Model

Consider a legislature with n members who choose between one of two alternatives: a new policy, denoted by A, and a status quo policy, denoted by B. All members cast a vote for either A or B and the legislature deliberates according to a q-rule with a generic $q \in (1/2, 1)$, such that new policy A is chosen if it achieves a share q of votes.

Two factors determine a legislator's choice. First, each legislator cares about whether the policy is approved or not. This is described by a parameter v^i: the utility enjoyed by i if A is approved. Since v^i can be either positive or negative, we can normalize the benefit of approving B at zero.

Second, each legislator cares directly about the vote he casts. This reflects two facts: first, interest groups observe a legislator's actions and may choose to reward votes with monetary contributions; and second, a legislator is influenced by other legislators and derives utility from voting that depends on how his peers behave. We write legislator i's direct utility of voting for policy $p \in \{A, B\}$ as:

$$U^i(p) = \omega\left(s^i(p)\right) + \phi \sum_j g_{i,j}\chi_j(p) + \varepsilon^i_p. \qquad (1)$$

The first term in (1) is the utility of the interest groups' contributions: $s^i(p)$ is the sum of contributions pledged to i in exchange for a vote for p and $\omega(s)$ is the utility that legislator i receives from contribution s. We assume $\omega(\cdot)$ is an increasing, concave, twice differentiable function with $\lim_{s\to 0}\omega'(s) = \infty$, $\lim_{s\to\infty}\omega'(s) = 0$. The second term describes the social interaction effects. As in Ballester, Calvo-Armengol and Zenou [2006], the social network is described by a $n \times n$ matrix G with generic element $g_{i,j}$: $\chi_j(p)$ is an indicator function equal to one if legislator j votes for p and zero otherwise, and $g_{i,j}$ measures the strength and sign of the social influence of legislator j on legislator i. When $g_{i,j} > 0$, i's preference for A increases if j votes for A; when $g_{i,j} < 0$, i's preference for A decreases if j votes for A: this later effect may occur if i perceives that voting as j could be embarrassing if, for example, j has taken positions that are unpopular in i's electoral district. We assume that $\sum_i g_{i,j}$ is the same for every i and we normalize this sum to one.[8] The final term in (1) represents other exogenous factors that may affect i's preference for or aversion to voting for p. We can set $\varepsilon^i_B = \varepsilon^i$, where ε^i can be positive or negative, and normalize ε^i_A to zero.

For future reference, we say that a legislator is *office motivated* if he does not care about the policy outcome (so $v^i = 0$); we say that a legislator is *policy motivated* if he does care about the policy outcome (so $v^i > 0$ or $v^i < 0$).[9]

The key assumption in (1) is that legislators like to conform to the behavior of the members of their social circle. This type of preferences (in which the utility of an action depends on the other players' actions) are standard in the literature on social network externalities and have been applied to study social interactions in a variety of contexts (see, for example, Schelling [1973], Becker [1991], Glaeser et al. [1996], Brock and Durlauf [2001], Becker and Murphy [2001], among others). They appear especially appropriate in the context of social networks in legislatures. Conformism in organizations is a phenomenon that has been well documented in the psychology literature (e.g., Asch [1951], Deutsch and Gerard [1955], Ross, Bierbrauer and Hoffman [1976], Jones [1984]) and, more specifically, in legislatures. Cohen and Malloy [2014] and Harmon, Fisman and Kamenica [2017] have recently shown that peers affect voting behavior in the U.S. Senate and the European Parliament; in Section 4.2 we show evidence that a similar phenomenon is true for the U.S. Congress. On the theoretical front, various authors have proposed microfoundations of conformist preferences as in (1), rationalizing them as implications of the agents' quests for social

[8] When the $g_{i,j}$s are all non-negative, the assumption that $\sum_j g_{i,j} = 1$ can be interpreted as reflecting the fact that i has a limited budget of attention that can be given to the behavior of other legislators. In this case, $g_{i,j}$ can be interpreted as the share of i's attention that is devoted to j.

[9] Besides being interesting in itself, the case of office motivated legislators is important since most of the existing literature on "buying legislatures" has focused on this case. See, for example, Groseclose and Snyder [1996], Banks [2000], Dekel, Jackson and Wolinsky [2009].

status (see Akerlof [1980], Jones [1984] and Bernheim [1994]).[10]

Two interest groups, also denoted A and B, attempt to influence the policy outcome. Interest group A is interested in persuading as many legislators as possible to chose policy A; interest group B, instead, is interested in persuading the legislators to choose policy B. Each interest group is endowed with a budget W and promises a contingent payment to each legislator who follows its recommendation. Specifically, interest group A promises a vector of payments $\mathbf{s}_A = (s_A^1, ...s_A^n)$ to the legislators where s_A^i is the payment received by legislator i if he chooses A; similarly, interest group B promises a vector of payments $\mathbf{s}_B = (s_B^1, ...s_B^n)$ to the legislators where s_B^i is the payment received by legislator i if he votes for B.[11]

We assume that the interest groups do not know with certainty the legislators' preferences, and so are unable to perfectly forecast how payments affect their voting behavior. Specifically, we assume ε^i is an independent, uniformly distributed variable with mean zero and density $\Psi > 0$, whose realization is observed only by i.[12] Let φ_i be the probability that i votes for A and $\boldsymbol{\varphi} = (\varphi_i)_{i=1}^n$ be the associated vector of probabilities. Moreover, let $q^i(\varphi)$ be legislator i's pivot probability, that is the probability that a vote by i for A changes the outcome from B to A given $\boldsymbol{\varphi}$. Legislator i is willing to vote for A if and only if:

$$E\left[U^i(B) - U^i(A)\right] \leq v^i q^i(\boldsymbol{\varphi}). \tag{2}$$

The right hand side of (2) is the expected benefit of helping policy A win: the utility of the policy v^i times the probability that the vote is actually decisive in determining the outcome. The left hand side is the implicit cost of voting for A in terms of loss of monetary contributions, personal aversion and "social" pressure.[13] Naturally, we must have $\varphi_i = E(\chi_i(A))$, so (2) can be re-written as a

[10] In an alternative interpretation, i may like to vote similarly to j not because of conformism, but because he expects an act of reciprocity from j in the future (i.e. that j will vote similarly to i on a bill that i would like to pass), or because i and j are in a vote trading equilibrium in which they exchange favors over time. The stronger the social compatibility between i and j, the more we should expect these phenomena. For example, in the presence of multiple equilibria, cooperative vote trading equilibria may be more focal if i and j went to school together. Indeed, Cohen and Malloy [2014] find that vote trading is more common among connected legislators. While providing an explicit microfoundation for these types of dynamic interactions goes beyond the scope of this paper, we note that (1) can be seen as a reduced form version of these types of interactions.

[11] In Section 5, we extend this basic model in various directions: we allow for more than two interest groups (Section 5.2); we allow for asymmetric interest groups with different budgets (Section 5.3); we consider alternative objective functions for the interest groups (Section 5.4); we consider the case in which the legislators vote on multiple policies and interest groups have heterogeneous preferences on the policies (Section 5.5); and we consider the case in which legislators can abstain from voting (Section 5.6).

[12] Formally, therefore, ε^i is uniformly distributed on $[-1/(2\Psi), 1/(2\Psi)]$.

[13] From (1), we can see that $U^i(p)$ is a function of the actions of the other legislators, $x_j(p)$ for $j \neq i$. Since the

condition on s_A^i, s_B^i, φ and ε^i only:

$$\varepsilon^i \leq \omega(s_A^i) - \omega(s_B^i) + v^i q^i(\boldsymbol{\varphi}) + \phi \sum\nolimits_j g_{i,j} \left(2\varphi_j - 1\right), \tag{3}$$

In the following, we focus on environments in which for any feasible s_A, s_B there is sufficient uncertainty that the probability of (3) is interior and so no interest group can be sure about a legislator's decision. Let $\overline{v}$ be the highest valuation in absolute value: $\overline{v} = \max_i \left|v^i\right|$. A sufficient condition for this to be true, which we will maintain throughout the paper, is the following:

Assumption 1. $\Psi\left(\overline{v} + \phi + \omega(2W)\right) < 1/2$.

The important observation is that this condition is satisfied if Ψ is sufficiently small, i.e. if there is sufficient uncertainty on the legislators' preferences.

A strategy for interest group l is a probability distribution over the set of feasible transfers S, that is:

$$S = \{s : \sum\nolimits_i s^i \leq W,\ s^i \geq 0 \textit{ for } i = 1, ..., n\}.$$

A pair of strategies constitute a Nash equilibrium if they are mutually optimal: the strategy of interest group A maximizes the expected number of legislators who adopt A given $\boldsymbol{\varphi}$ and interest groups B's strategy; and the strategy of interest group B minimizes the expected number of legislators who adopt A given $\boldsymbol{\varphi}$ and interest group A's strategy. In the remainder of the paper we focus on equilibria in pure strategies, that is on pairs of vectors $\mathbf{s}_A, \mathbf{s}_B$ in $S \times S$ that are mutually optimal. Propositions 1 and 2 guarantee that a pure strategy equilibrium exists and is unique.

In the following pages we consider very complex networks that cannot be easily visualized.[14] In these cases it is useful to define simple statistics that describe the position of an agent in the network. A standard measure in the theory of networks that will play an important role in the analysis below is Katz-Bonacich Centrality (Bonacich [1987], Ballester, Calvo-Armengol and Zenou [2006], Bramoulle et al. [2014]). For a given network matrix $\widehat{G}$, the vector of Katz-Bonacich centralities, if it exists, is defined as:

$$\mathbf{b}\left(\delta, \widehat{G}\right) = \left(I - \delta\widehat{G}\right)^{-1} \cdot \mathbf{1}, \tag{4}$$

agent does not know them, they are evaluated at their expected values: this is the reason we have an expectation in (2). Note moreover that ε^i is known to the agent, so it enters (2) only as a parameter.

[14] In Section 4, we apply the model to the U.S. Congress. In this case, the network has over 400 nodes per Congress (the congressmen) and thousands of links.

where $\delta < 1$ is a positive parameter that controls the rate of decay of the influence in indirect links, I is the identity matrix and $\mathbf{1}$ is a column vector of ones. The Katz-Bonacich centrality of legislator i with respect to $\widehat{G}$ and δ is the ith entry of $\mathbf{b}\left(\delta, \widehat{G}\right)$. Katz-Bonacich centralities may not exist because the matrix $I - \delta\widehat{G}$ may fail to be invertible. Invertibility is guaranteed for any $\widehat{G}$ if δ is sufficiently small. For the reminder of the paper, a condition that guarantees that the relevant Katz-Bonacich centralities exist in our environment is the following:

Assumption 2. *The matrix $I - 2\phi\Psi G$ is invertible and the associated Katz-Bonacich vector is positive:* $(I - 2\phi\Psi G)^{-1} \cdot \mathbf{1} > 0$

Note that, as for Assumption 1, this condition is satisfied if Ψ and/or ϕ is sufficiently small.[15] We assume that the relevant Katz-Bonacich centralities $(I - 2\phi\Psi G)^{-1} \cdot \mathbf{1}$ are positive for simplicity and because it appears to be the most plausible case. In the context of our model, a vector $(I - 2\phi\Psi G)^{-1} \cdot \mathbf{1}$ with negative components, i.e. a negative Katz-Bonacich centrality for some i, corresponds to the case in which some legislator i generates such negative externalities that a marginal increase in the probability that i votes for A induces a reduction in the expected plurality for A.

In general, it is difficult to compare the Katz-Bonacich centralities in networks with different n because an increase in the number of agents may completely change the topology of the network. However, the comparison is straightforward when the agents in the networks can be classified into a finite number of types, each comprising a given fraction of population. We say that two legislators i and j have the same type if they have the same preferences, $v^i = v^j$, and if they interact in the same way with the other legislators, so $g_{i,k} = g_{j,k}$ and $g_{k,i} = g_{k,j}$ for all $k = 1, ..., n$. As we formally prove in Lemma 3.1, presented in the online appendix, in this case each agent of the same type has the same centrality and, more importantly, the centralities depend only on the share of the population of each type.[16] In the following analysis we assume that there is at most

[15] If we assume a positive matrix of social interactions, i.e. $g_{i,j} > 0$ for $i, j \in N$, then a sufficient condition for Assumption 2 is the condition assumed by Ballester et al. [2006]: $\Psi < 1/(2\phi\mu_1(G))$, where $\mu_1(G)$ is the largest eigenvalue of G (see also Bramoulle et al. [2014]). This condition guarantees that $(I - 2\phi\Psi G)^{-1}$ exists and it is positive, which implies $(I - 2\phi\Psi G)^{-1} \cdot \mathbf{1} > 0$. However, Assumption 2 is weaker for two reasons: first, it does not require $g_{i,j} > 0$, allowing positive and negative social interactions; second, it only requires $(I - 2\phi\Psi G)^{-1} \cdot \mathbf{1} > 0$ and not the stronger condition that the entire matrix $(I - 2\phi\Psi G)^{-1}$ is positive.

[16] The requirement that two agents i and j of the same type have $v^i = v^j$ is irrelevant when the centrality measure is the Katz-Bonacich, since this centrality does not depend on the agents' preferences. When we have policy motivated legislators, however, the relevant centrality measure is the Modified Katz-Bonacich centrality (defined in (15)) that depends on the agents v^is.

a finite number m of types of legislators.[17]

3 Equilibrium contributions

The game described in the previous section has two stages. In the first stage, the *influence stage*, the interest groups simultaneously promise monetary contributions to the legislators contingent on their votes. In the second stage, the *voting stage*, the legislators simultaneously choose how to vote given the interest groups' promises. We can solve this game by backward induction: first, we solve the voting stage, taking as given the allocation of transfers; second, we solve the influence stage, given the continuation value for the voting stage.

3.1 The voting stage

Each legislator chooses his ballot on the basis of his preferences, the monetary promises and his expectations of the other legislators' behavior. Because of this, the voting probabilities must be jointly determined in equilibrium and no legislator can be treated in isolation. From (3) we have that the legislators' probabilities of choosing A, $\boldsymbol{\varphi}$, are characterized by the nonlinear system:

$$\begin{pmatrix} \varphi_1 \\ \\ ... \\ \\ \varphi_n \end{pmatrix} = \begin{pmatrix} 1/2 + \Psi\left(\omega(s_A^1) - \omega(s_B^1) + v^1 q^1(\boldsymbol{\varphi}) + \phi \sum_j g_{1,j}\left(2\varphi_j - 1\right)\right) \\ \\ ... \\ \\ 1/2 + \Psi\left(\omega(s_A^n) - \omega(s_B^n) + v^n q^n(\boldsymbol{\varphi}) + \phi \sum_j g_{n,j}\left(2\varphi_j - 1\right)\right) \end{pmatrix}. \tag{5}$$

For any $\mathbf{s} = \mathbf{s}_A, \mathbf{s}_B$, the system of equations (5) defines a function $T(\mathbf{s}, \boldsymbol{\varphi})$ that maps the vector of probabilities $\boldsymbol{\varphi}$ to itself. A voting equilibrium is a fixed point $\boldsymbol{\varphi}(\mathbf{s}) = T(\mathbf{s}, \boldsymbol{\varphi}(\mathbf{s}))$ of this correspondence. Since T is continuous in $\boldsymbol{\varphi}$ from $[0,1]^n$ to itself, Brouwer's fixed point theorem implies that an equilibrium exists for any pair $\mathbf{s}_A, \mathbf{s}_B$ of transfers by the interest groups.

In general, (5) may admit multiple solutions and the solution may not be well behaved in the monetary transfers (as, for example, multiplicity may induce $\boldsymbol{\varphi}$ to be discontinuous in $\mathbf{s}_A, \mathbf{s}_B$). The following result shows that, indeed, (5) admits a unique, well-behaved solution when there is sufficient uncertainty on the legislators' types.

Lemma 1. *There is a Ψ^* such that for any $\Psi \leq \Psi^*$ the vector of equilibrium probabilities $\boldsymbol{\varphi}(\mathbf{s}) = \{\varphi_1(s), ..., \varphi_n(s)\}$ solving (5) is unique. Moreover, the sum of the equilibrium probabilities*

[17] Naturally this assumption is without loss of generality if n is finite and it will play a role only when we consider sequences of economies as $n \to \infty$.

$\sum_i \varphi_i(s)$ *is increasing, differentiable in* s^i_A *(respectively decreasing and differentiable in* s^i_B*) for all* i*, and concave in* $\mathbf{s}_A$ *(respectively convex in* $\mathbf{s}_B$*).*

To see the intuition of this result, consider first the case in which legislators are office motivated (i.e. $v^j = 0$ for all j). In this case, (5) is a linear system with a unique solution $\boldsymbol{\varphi}^*$. Consider now the marginal effect of an increase in s^i_A. Differentiating (5), we obtain:

$$\partial\varphi^*_j/\partial s^i_A = \Psi\left[\omega'(s^i_A)\cdot 1_{j,i} + 2\phi\sum\nolimits_l g_{j,l}\cdot\partial\varphi^*_l/\partial s^i_A\right], \tag{6}$$

where $1_{j,i}$ is an indicator function equal to 1 when $j = i$ and 0 otherwise. The first term in the square parenthesis is the direct effect of an increase in s^i_A: it induces a marginal change in legislator j's utility of $\omega'(s^i_A)$ if $j = i$, and zero otherwise. The second term is the indirect network effect: the change in i's behavior induces a change in legislator l's behavior $\partial\varphi^*_l/\partial s^i_A$, which in turn affects j's behavior in a recursive fashion. The system of equations (6) can be rewritten in matrix form as: $D_i[\boldsymbol{\varphi}] = \Psi[D_i[\boldsymbol{\omega}] + 2\phi G\cdot D_i[\boldsymbol{\varphi}]]$, where $D_i[\boldsymbol{\varphi}]$ and $D_i[\boldsymbol{\omega}]$ are the Jacobians of, respectively, $\boldsymbol{\varphi}$ and $\boldsymbol{\omega}$ with respect to s^i_A. By Assumption 2, $[I - 2\Psi\phi\cdot G]^{-1}$ exists, so we can write

$$D_i[\boldsymbol{\varphi}] = \Psi[I - 2\Psi\phi\cdot G]^{-1} D_i[\boldsymbol{\omega}], \tag{7}$$

Since $D_i[\boldsymbol{\omega}] = (0,..0,\partial\omega(s^i_A)/\partial s^i_A,..,0)^T$, we have that:

$$\sum\nolimits_j \partial\varphi^*_j/\partial s^i_A = \sum\nolimits_j m_{j,i}\omega'(s^i_A) \text{ and } \sum\nolimits_j \partial^2\varphi^*_j(\mathbf{s})/\partial^2 s^i_A = \sum\nolimits_j m_{j,i}\omega''(s^i_A)$$

where $m_{j,i}$ is the jith element of $[I - 2\Psi\phi G]^{-1}$. As it is easy to verify, as $\Psi \to 0$ $\sum_j m_{j,i} \to 1$ for any i, so for a sufficiently small Ψ we have $\sum_j m_{j,i} > 0$, implying $\sum_j m_{j,i}\omega'(s^i_A) > 0$ and $\sum_j m_{j,i}\omega''(s^i_A) < 0$. Voting probabilities are therefore unique, increasing and concave in s^i_A for a sufficiently small Ψ.[18] A similar argument establishes the respective properties for s^i_B.

With policy motivated legislators, the analysis is slightly more complicated because we need to take into account the pivot probabilities, which are nonlinear functions in φ. Lemma 1 shows that when there is sufficiently high uncertainty on the legislators' preferences, these nonlinearities are not problematic because the pivot probabilities are sufficiently insensitive to changes in the monetary allocations.

[18] When $g_{i,j} > 0$ for all i, j, we have that $m_{i,j} > 0$ for all i, j when Ψ is sufficiently small. When $g_{i,j}$ are not necessarily all positive, we may have some $m_{i,j} < 0$: but we necessarily have $\sum_i m_{i,j} > 0$, since the elements in the diagonal converge to one and the elements off the diagonal converge to zero as $\Psi \to 0$.

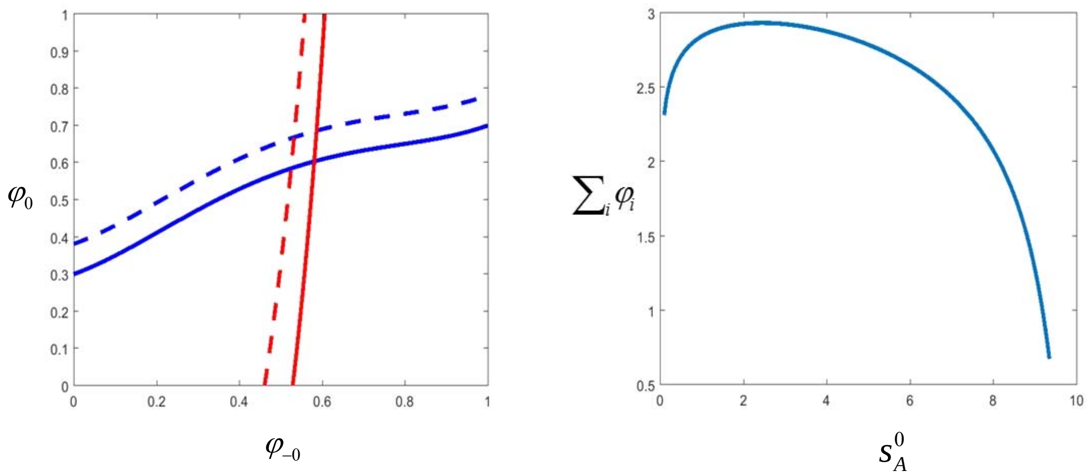

Figure 1: The flatter lines in the left panel represent the reaction function of agent 0 to φ_{-0} (i.e. the first equation in (8)). The steeper lines are the reaction functions of all the other agents to φ_0 (i.e. the second equation in (8)). The intersections of the reaction functions correspond to voting equilibria for different allocations of the campaign contributions. The right panel illustrates $\sum_j \varphi_j$ as a function of s_A^0 (adjusting s_B^{-0} to satisfy the budget condition).

In the following, we will maintain the assumption that Ψ is sufficiently small that the properties described in Lemma 1 are satisfied:

Assumption 3. *There is sufficient uncertainty on the legislators' preferences so that $\sum_i \varphi_i(s)$ is increasing, differentiable in s_A^i (respectively decreasing and differentiable in s_B^i) for all i, and concave in $\mathbf{s}_A$ (respectively convex in $\mathbf{s}_B$).*

Figure 1 illustrates the system (5) in a simple "star" network example in which there is a central legislator, say legislator 0, who is connected to all other legislators and $n-1$ peripheral legislators $j = 1, .., 4$, who in turn are connected only to the central legislator.[19] The symmetric structure implies that the probabilities of $j = 1, .., 4$ are equal and so (5) collapses to two equations in two unknowns, φ_0 and $\varphi_j = \varphi_{-0}$ for all $j = 1, ..., 4$. Assuming that legislators have the same logarithmic utility $\omega_i(s) = \beta_0 \log(s)$, the voting probabilities are characterized by:

$$\begin{aligned} \varphi_0 &= \frac{1}{2} + \Psi \cdot \left(\log(s_A^0 / s_B^0) + 4\phi \left(2\varphi_{-0} - 1 \right) + 6\varphi_{-0}^2 (1 - \varphi_{-0})^2 \right), \qquad (8) \\ \varphi_{-0} &= \frac{1}{2} + \Psi \cdot \left(\log(s_A^{-0} / s_B^{-0}) + \phi \left(2\varphi_0 - 1 \right) + 3\varphi_0 \varphi_{-0} (1 - \varphi_{-0})^2 + 3(1 - \varphi_0)(1 - \varphi_{-0}) \varphi_{-0}^2 \right) \end{aligned}$$

[19] Formally, $g_{0,j} = g_{j,0} = 1$ for all j and $g_{i,j} = 0$ if neither i nor j is equal to zero.

where s_j^0 (respectively, s_j^{-0}) is the transfer by interest group j to legislator 0 (respectively, -0). The solid lines in the left panel of Figure 1 illustrate the legislators' reaction functions in the case in which the interest group allocates $W = 10$ evenly:[20] their intersection is a solution of (8) and a voting equilibrium. Given B's promise $\mathbf{s}_B$, interest group A can control the equilibrium probabilities by changing $\mathbf{s}_A$. The dashed lines in Figure 1 illustrate the effect of a redistribution by A of money on $\boldsymbol{\varphi} = (\varphi_0, \varphi_{-0})$ from the initial even distribution ($s^i = 2$ for all i) to a distribution that favors $i = 0$: $s_A^0 = 3$, $s_A^j = s_A^{-0} = 7/4$ for $j = 1, .., 4$. Despite the fact that each legislator does not directly care about the transfers sent to the other players, his behavior is indirectly affected by the transfers to the other legislators since these transfers affect behavior in his social network. Given the symmetry of this example, s_A^{-0} is automatically given as a function of s_A^0 by the budget condition $s_A^{-0} = \left(10 - s_A^0\right)/4$. The right panel of Figure 1 illustrates interest group A's objective function as a function of s_A^0 keeping s_B^0, s_B^{-0} constant at $(2, 2)$.[21]

3.2 The influence stage

We can now turn to the interest groups' problems in the first stage. Interest group A solves:

$$\max_{\mathbf{s}_A \in S} \left\{ \sum\nolimits_i \left[\varphi_i(\mathbf{s}_A, \mathbf{s}_B)\right] \right\} \tag{9}$$

taking $\mathbf{s}_B$ as given. Interest group B's problem is the mirror image of A's problem, as it attempts to minimize the objective function of (9) taking s_A as given.

Under Assumption 3, (9) is a standard maximization program. This implies that A's optimal choice is uniquely defined and a continuous function in s_B (and symmetrically B's reaction function is a continuous function of s_A). The Brouwer's fixed-point theorem implies that a Nash equilibrium in pure strategies exists. The equilibrium solution, moreover, must satisfy the first order condition:

$$\sum\nolimits_j \partial\varphi_j(\mathbf{s}_A, \mathbf{s}_B)/\partial s_l^i = \lambda_l \text{ and } \sum\nolimits_{j=1}^n s_l^j = W \text{ for } i = 1, ..., n, \ l = A, B \tag{10}$$

where λ_l is the Lagrangian multiplier associated with the budget constraints $\sum_i s_l^i \leq W$ in interest group l's problem. By a standard argument we can show that it must be that A and B's problems

[20] Specifically, in the example of Figure 1 we assume $\beta_0 = 1$, $\phi = 0.25$, $\Psi = 0.2$, $q = 1/2$ and $v^i = 1$ for all i.

[21] Naturally in this case $\sum_j \varphi_j$ is not monotonically increasing in s_A^0 since we are imposing the budget condition $s_A^{-0} = \left(10 - s_A^0\right)/4$.

have the same Lagrangian multipliers $\lambda_A = \lambda_B = \lambda_*$.[22]

To discuss the implications of (10) intuitively, we will first consider the case in which legislators are office motivated. We then generalize the results to the case of legislators that are policy motivated.

3.2.1 Office motivated legislators

We can rewrite the necessary and sufficient condition with respect to s_A^i (10) in matrix form as

$$D_i [\boldsymbol{\varphi}]^T \cdot \mathbf{1} = \lambda_*$$

where $D_i [\boldsymbol{\varphi}]^T = (\partial \varphi_1^* / \partial s_A^i, .., \partial \varphi_n^* / \partial s_A^i)$ and $\mathbf{1}$ is a n-dimensional column vector of ones. Using (7), we have:

$$\begin{aligned} D_i [\boldsymbol{\varphi}]^T \cdot \mathbf{1} &= \Psi \cdot D_i [\boldsymbol{\omega}]^T \cdot \left(I - \phi^* \cdot G^T \right)^{-1} \cdot \mathbf{1} = \lambda_* \\ &\Rightarrow D_i [\boldsymbol{\omega}]^T \cdot \mathbf{b} \left(\phi^*, G^T \right) = \lambda_* / \Psi \end{aligned} \tag{11}$$

where $\phi^* = 2\Psi\phi$ and for the last equality we used the definition of the vector of Katz-Bonacich centralities (4). Recall that $D_i [\boldsymbol{\omega}]$ is a vector of zeros except for its ith element that is equal to $\omega'(s_*^i)$. We can therefore write our necessary and sufficient condition (10) as:

$$b_i \left(\phi^*, G^T \right) \cdot \omega'(s_*^i) = \lambda_* \text{ for } i = 1, ..., n \tag{12}$$

where, without loss in generality, we incorporate the constant Ψ in the Lagrangian multiplier λ_*.

The necessary and sufficient condition (12) shows the determinants of the interest group's monetary allocation. The interest group chooses s_*^i to equalize the marginal cost of resources and their marginal benefit. The marginal cost is measured by the Lagrangian multiplier λ_* of (9). The marginal benefit is measured by the increase in expected votes for A. Equation (12) makes clear that, because of network effects, the direct benefit of a transfer to i is magnified by a factor that is exactly equal to $b_i \left(\phi^*, G^T \right)$, the Katz-Bonacich centrality of i in G^T with coefficient ϕ^*.

An immediate implication of (12) is the following result:

Proposition 1. *With office motivated legislators, there is a unique equilibrium in which the*

[22] As discussed in greater detail in the Proof of Proposition 1 and 2, if $\lambda_A > \lambda_B$ (resp., $\lambda_A < \lambda_B$), then (10) would imply $\omega'(s_A^i) > \omega'(s_B^i)$ (resp., $\omega'(s_A^i) < \omega'(s_B^i)$) for any i, implying $\sum s_B^i > \sum s_A^i = W$ (resp., $\sum s_A^i > \sum s_B^i = W$), a contradiction.

interest groups choose the same vector of transfers s_*. The vector s_* solves the problem:

$$\max_{\mathbf{s}\in S}\left\{\sum\nolimits_j b_j\left(\phi^*, G^T\right)\cdot\omega_j(s^j)\right\} \tag{13}$$

where $b_j\left(\phi^*, G^T\right)$ is the Katz-Bonacich centrality measure of i in G^T with coefficient $\phi^* = 2\Psi\phi$.

If we assume that the utility from money is logarithmic, then the transfer promised to legislator i is exactly proportional to his Katz-Bonacich centrality, with a factor of proportionality that depends on the inverse of the shadow cost of resources λ^*. In general, (13) shows that money is chosen in order to maximize a weighted sum of the legislators' monetary utilities, where the weights are exactly equal to the respective Katz-Bonacich centrality measures.

3.2.2 Policy motivated legislators

When legislators are not purely office motivated, the analysis is complicated by the fact that a marginal increase in a payment s_A^i has an additional effect on voting probabilities that does not exist with exclusively office motivated legislators. By affecting the voting probabilities of all players, an increase in s_A^i changes the pivot probabilities $q(\varphi) = (q^i(\varphi))_{i=1}^n$. This effect is irrelevant with office motivated legislators because they do not care about the policy outcome.

Taking this into account, the analysis proceeds in the same way as above assuming Ψ sufficiently small so that the objective function of (9) is concave. Concavity and the symmetry of the two groups' problems imply that the equilibrium is unique and symmetric with $s_{\mathbf{A}} = s_B = s_*$. Given this, (5) becomes the system:

$$\begin{pmatrix} \varphi_1^* \\ \\ ... \\ \\ \varphi_n^* \end{pmatrix} = \begin{pmatrix} 1/2 + \Psi\left(v^1 q^1(\boldsymbol{\varphi}) + \phi\sum_j g_{1,j}\left(2\varphi_j^* - 1\right)\right) \\ \\ ... \\ \\ 1/2 + \Psi\left(v^n q^n(\boldsymbol{\varphi}) + \phi\sum_j g_{n,j}\left(2\varphi_j^* - 1\right)\right) \end{pmatrix}. \tag{14}$$

This system admits a solution that depends *only* on exogenous variables ϕ, G, Ψ and $\left(v^i\right)_{i=1}^n$. The equilibrium vector $\boldsymbol{\varphi}^* = (\varphi_1^*, ..., \varphi_n^*)$ can therefore be taken as a function of only the primitives of the model.

Let $D\mathbf{q}_*$ be the Jacobian of $\mathbf{q}(\boldsymbol{\varphi}) = (q^1(\varphi)..., q^n(\varphi))^T$ evaluated at $\boldsymbol{\varphi}^*$. Moreover, let V be the diagonal matrix with ith diagonal term equal to v^i. Given this we can define the following *Modified Katz-Bonacich* centrality measure in V, G^T and coefficients Ψ and ϕ^*:

$$\mathbf{b}^{\mathcal{M}}(\phi^*, V, G^T) = \left[I - \left(\phi^* G^T + \Psi D\mathbf{q}_*^T \cdot V\right)\right]^{-1}\cdot\mathbf{1}. \tag{15}$$

This formula augments the standard Katz-Bonacich formula by incorporating information on the legislators' policy preferences and equilibrium pivot probabilities. It is easy to see that when $v^i = 0$ for all i, it coincides with (4) with $\delta = \phi^*$ and $\widehat{G} = G^T$.

Following the same steps as in the previous section, we can now characterize the equilibrium allocation solely in terms of the modified Katz-Bonacichs. We have:

Proposition 2. *With policy motivated legislators, there is a unique equilibrium in which the interest groups choose the same vector of transfers s_{**}. The vector s_{**} solves the problem:*

$$\max_{\mathbf{s} \in S} \left\{ \sum\nolimits_j b_j^{\mathcal{M}}(\phi^*, V, G^T) \cdot \omega_j(s^j) \right\} \tag{16}$$

where $b_j^{\mathcal{M}}(\phi^*, V, G^T)$ is the Modified Katz-Bonacich centrality of j in V, G^T with coefficient $\phi^* = 2\Psi\phi$.

It should be stressed that $\mathbf{b}^{\mathcal{M}}(\phi^*, V, G^T)$ can be constructed exclusively using the exogenous fundamentals of the problem q, ϕ, V, G and Ψ, so it can itself be taken as a primitive of the model. Indeed $\mathbf{b}^{\mathcal{M}}(\phi^*, V, G^T)$ and the solution $\mathbf{s}_{**}$ can be found following simple steps:

- Solve (14) to find $\boldsymbol{\varphi}^*$ as function of the primitives (that is q, ϕ, V, G and Ψ).
- Find $D\mathbf{q}_*$ exclusively as function of $\boldsymbol{\varphi}^*$.
- Compute $\mathbf{b}^{\mathcal{M}}(\phi^*, V, G^T)$ using (15) and solve (16) for $\mathbf{s}_{**}$.

A problem with Proposition 2 is that it may be laborious to compute the vector of weights $\mathbf{b}^{\mathcal{M}}(\phi^*, V, G^T)$ for large networks since the construction of the pivot probabilities is quite complicated in the presence of many heterogeneous legislators with different voting probabilities. The weights $\mathbf{b}^{\mathcal{M}}(\phi^*, V, G^T)$, moreover, do not have an immediate interpretation in terms of the standard measures of network centrality because they do not depend only on the network topology G, but on preferences and the voting rule as well.

There are two cases in which we should expect the formulas in (15) to be simple. The first is when the legislators have weak preferences for the policy outcome, so v_i is small in absolute value for all i. This is a simple implication of the fact that (15) is continuous in v_i, so the modified Katz-Bonacichs converge to the originals as $v_i \to 0$. Recalling that $\overline{v} = \max_i |v_i|$, we have:

Corollary 1. *The equilibrium allocation with policy motivated legislators converges to the allocation with office motivated legislators as $\overline{v} \to 0$.*

The second case is when the number of legislators is large. Intuitively, we should expect pivot probabilities to be quite low and irrelevant in all cases except when n is very small. In situations with a sufficiently large n we should expect the social factors described by the simple Katz-Bonacich centralities to be dominant. To formalize this point, consider a sequence of networks G_n with n legislators of m types $j = 1, ..., m$ with associated sequences of equilibria with office motivated legislators, $\mathbf{s}_*^n = (s_*^{n,1}, ..., s_*^{n,n})$, and policy motivated legislators, $\mathbf{s}_{**}^n = (s_{**}^{n,1}, ..., s_{**}^{n,n})$. In the case with policy motivated legislators, the legislators' preferences are described by some vector $\mathbf{v} = (v_1, ..., v_m)$, where v_l is the preference of a legislator of type $l = 1, ..., m$. We have:

Proposition 3. *The equilibrium allocation with policy motivated legislators converges to the allocation with office motivated legislators as* $n \to \infty$.

Proposition 3 make clear that when n is large, the main determinant of the allocation of money is effectively the centrality of the legislator as measured by the standard Katz-Bonacichs $b_j\left(\phi^*, G^T\right)$. Therefore, when studying the U.S. Congress (which has hundreds of legislators), it is essentially without loss of generality to use simple Katz-Bonacich centralities to predict how interest groups allocate resources.

4 Evidence from the U.S. Congress

4.1 Empirical model

To make the empirical predictions of the model precise, let us assume we observe data from $\bar{r}$ Congresses ($r = \{1, ..., \overline{r}\}$), each comprised of n congressmen, characterized by a network $G_r = \{g_{i,j,r}\}$. In equilibrium, each congressman j receives an offer $s_{r,A}^j$ from A and an offer $s_{r,B}^j$ from B, both equal to a common value s_r^j. Since the congressmen all vote either for A or B, the model predicts that all congressmen receive a contribution s_r^j with probability one.

Propositions 1-3 show that, in equilibrium, the contributions either solve (13) or are close to this solution. From the first order necessary and sufficient condition of this problem we have $b_j(\phi^*, G_r^T) \cdot w_j'(s_r^j) = \lambda$, where $b_j(\phi^*, G_r^T)$ is the Katz-Bonacich centrality of j in Congress r and λ is the associated Lagrangian multiplier. We now assume that legislator j's utility takes the following form:

$$\omega_j(s) = \xi_0 \log(s + x_{j,r}^T \cdot \boldsymbol{\xi}_1 + \epsilon_j) \tag{17}$$

where $x_{j,r}$ is a column vector of characteristics of j in Congress r that may affect the legislators' preferences for contributions; ξ_0, $\boldsymbol{\xi}_1$ are preference parameters; and ϵ_j is an independently drawn random variable uncorrelated with $x_{j,r}$ with mean zero, describing heterogeneity in the legislators' preferences observed by the interest groups but not by the econometrician. For example, we expect that a legislator elected in a competitive district (as measured by the margin of victory in the previous election) will have a higher marginal valuation for contributions. It may also be, for example, that seniority, gender or ideology affect a legislator's demand for contributions.[23]

Given (17), the interest groups' first order necessary and sufficient condition for optimality can be written as $s_r^j = (\xi_0/\lambda) \cdot b_j(\phi^*, G_r^T) - x_{j,r}^T \boldsymbol{\xi}_1 - \epsilon_j$. Normalizing the signs of the coefficients, this relation can be re-written in vector form:

$$\mathbf{s_r} = \alpha \cdot \mathbf{b}(\phi^*, G_r^T) + X_r^T \boldsymbol{\beta} + \boldsymbol{\epsilon}_\mathbf{r}, \tag{18}$$

where $\mathbf{s_r} = (s_{1,r}, ..., s_{n,r})^T$, $\boldsymbol{\epsilon}_\mathbf{r} = (\epsilon_{1,r}, ..., \epsilon_{n,r})^T$, $X_r = (x_{1,r}, ..., x_{n,r})$ and the coefficients α, ϕ^* and $\boldsymbol{\beta}$ are the parameters to estimate. Condition (18) makes clear that monetary contribution to j are predicted to be proportional to j's Katz-Bonacich.

For a sample with $\bar{r}$ networks, stack up the data by defining $\mathbf{s} = (s_1^T, \cdots, s_{\bar{r}}^T)^T$, $\boldsymbol{\epsilon} = (\epsilon_1^T, \cdots, \epsilon_{\bar{r}}^T)^T$, $\mathbf{b}(\phi^*) = \left(\mathbf{b}(\phi^*, G_1^T)^T, ..., \mathbf{b}(\phi^*, G_{\bar{r}}^T)^T\right)^T$, and $X = (X_1^T, ..., X_{\bar{r}}^T)^T$. For the entire sample, the model is:

$$\mathbf{s} = \alpha \cdot \mathbf{b}(\phi^*) + X^T \boldsymbol{\beta} + \boldsymbol{\epsilon}. \tag{19}$$

Model (19) cannot be estimated by simple OLS in which $\mathbf{s}$ is the dependent variables and $\mathbf{b}(\phi^*)$ and X are the independent variables because $\mathbf{b}(\phi^*)$ is a nonlinear function of a parameter to be estimated, ϕ^*. We can, however, obtain estimates for α, ϕ^* and $\boldsymbol{\beta}$ from (19) by nonlinear least squares (NLLS).

This model allows us to obtain an estimate of the impact of a congressman's social ties on the allocation of PACs' campaign contributions. Two parameters appear especially important: ϕ^* and α. Recall that $\phi^* = \Psi\phi$, where Ψ is the density of the unobserved preference parameter ε^i (see (1)) and ϕ is the parameter describing the network externality (again see (1)). Since $\Psi > 0$, the social network matters in the allocation of political contributions if and only if $\phi^* > 0$. The key hypothesis to be tested is therefore whether $\phi^* > 0$. Parameter α is important because it gives us a direct estimate of the marginal impact of an increase in a legislator's Katz-Bonacich on his received contributions.

[23] We describe the control variables in greater detail in Section 4.2.2.

In Section 4.2, we describe the construction of the networks G_r^T, the control variables $x_{j,r}$ and the data on PAC contributions used for $\mathbf{s}$. In Section 4.3, we present the empirical results.

4.2 Data description

4.2.1 The alumni network

In measuring social connections in Congress, there are two challenges. The first is the observability of the social network, since only in exceptional cases are the legislators' connections directly observable.[24] The second is the problem of endogeneity, since there could be unobserved factors that simultaneously affects interest groups' allocations and the formation of social connections. The challenge is to find a measurement of social connections that is as much as possible extraneous to these factors or that at least allows us to control for them.

To address these issues, we exploit the idea that educational institutions provide a basis for social networks (see Cohen et al. [2008], Fracassi and Tate [2012], Cohen and Malloy [2014], Do et al. [2016], among others). We therefore construct social networks using the congressmen's alumni connections: two congressmen are connected if they graduated from the same institution within a given time window. This approach gives us a network that is exogenous by construction to the political process and that, as we describe below, allows us to control for other possible confounding factors in a simple way.

To construct the network, we extract information on the educational institutions attended by the congressmen using the Biographical Directory of the United States Congress, which is available online (http://bioguide.Congress.gov/ biosearch/biosearch.asp).[25] In our baseline version, we assume that a tie exists between two congressmen if they graduated from the same institution within eight years of each other. More specifically, we set a link between two congressmen $g_{i,j}$ to be equal to the number of schools they both attended within eight years of each other; we then row normalize the social weights so that $\sum_j g_{i,j} = 1$ for any i.[26] Since many legislators hold

[24] Routt [1938] presents a quantitative analysis on the social interactions of the members of the floor of the Illinois Senate in 1937. Caldeira and Patterson [1987] analyze survey data from the 1965 Iowa legislature. Arnold et al. [2000] present evidence from a survey of the Ohio legislature in 1993.

[25] We use high schools and academic institutions attended for both undergraduate and graduate degrees. In dealing with multiple campuses, we match each satellite campus as a separate university (e.g., University of California at Los Angeles, San Diego, and Berkeley are treated as separate universities). We match specialized schools (e.g., law schools) to the larger university.

[26] In Section 5.7, we discuss alternative network constructions that use the alumni information in different ways and incorporate additional information.

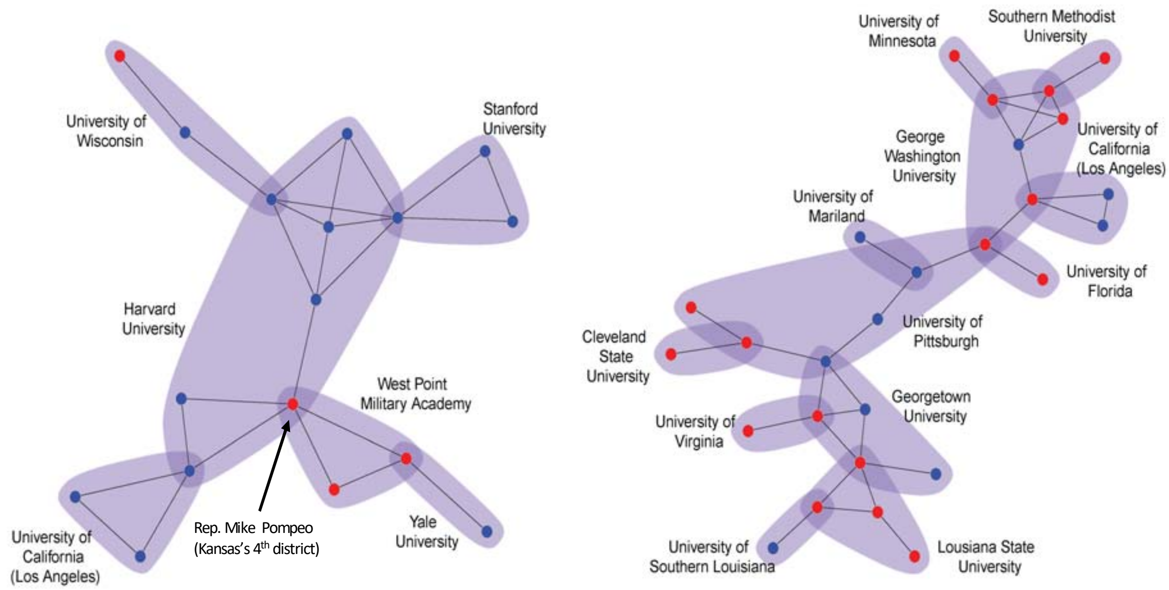

Figure 2: The figure illustrates the largest component of the 113th (left) and 109th (right) U.S. Congresses. Nodes represented by a blue (resp., red) dot correspond to Democrats (resp., Republicans). Clouds connect alumni from the same university. The legislator that links the Harvard network to the West Point Military Academy is Representative Mike Pompeo.

a primary and a secondary degree (typically a JD or an MBA), this construction gives us a rich network of direct and indirect links.

By construction, the network (N, g) described above can naturally be partitioned in multiple disconnected clusters of alumni (the network components, $(N_\theta, g_\theta)_{\theta=1}^{J}$).[27] A component may comprise only alumni from one university in overlapping cohorts, if none of them attended any other school contemporaneously to other legislators; or it may comprise multiple universities, when alumni with multiple degrees are linked to alumni of different institutions. For example, Figure 2 shows the largest components of the first (109th) and last (113th) Congresses in our sample.[28] The figure shows that the components are the result of many overlapping peer groups (the shaded and labelled "clouds" around the nodes), where we define *peer groups* as groups of legislators who

[27] A network matrix G defines a network (N, g) with $|N|$ legislators and links $g = (g_{i,j})_{i,j \in N}$. The components $(N_\theta, g_\theta)_{\theta=1}^{J}$ of (N, g) are the distinct maximal connected subgraphs of (N, g).

[28] The layout of the graph has been produced using the force-directed graph drawing algorithm by Kamada and Kawai (Kamada and Kawai [1989]).

attended the same institution within eight years of each other. The intersections between peer groups are induced by alumni with multiple degrees. The link between Harvard and West Point in the left panel of Figure 2, for example, is established by Representative Mike Pompeo (R) from Kansas's 4th district (2011-2017) who attended the U.S. Military Academy at West Point and completed a JD at Harvard. In general, the number of components per Congress ranges from 34 in the 109th Congress to 42 in the 112th Congress, and they range in size from a minimum of 2 for the smallest peer groups (comprising only two alumni and one university), to 29 legislators for the maximal component in the 111th Congress.

Table A.2 in the appendix presents the rankings of the top 30 legislators by centralities in the alumni network of the 109th Congress. From these rankings one can see that there are many legislators for whom the centrality measures are quite correlated: Rep. Ben Cardin (D), Rep. Chet Edwards (D), Rep. Jeff Fortenberry (R) are all examples of notable legislators whose centralities are generally high (and who have all received above the mean contributions).[29] (Rep. Mike Pompeo cited above is not among them because he was elected in the 112th Congress: unsurprisingly, given the position in Figure 2, he has also been ranked at the very top for most centralities since then).

It is however not difficult to find examples of prominent legislators for whom the different measures give quite different results. Rep. Mike Oxley (R), for example, who served as chairman of the Committee on Financial Services and was House sponsor of the eponymous Sarbanes–Oxley Act of 2002, was 10th in terms of Katz-Bonacich centrality in our alumni network: he, however, was not even represented in the top 30 list in terms of degree, betweenness, closeness and eigenvector. Similarly, Rep. Debbie Wassermann Schultz (D), who later served as chairperson of the Democratic National Committee from 2011 to 2016, was the 6th highest in terms of Katz-Bonacich centrality in the alumni network of the 109th Congress: but, again, she was not even represented in the top 30 list in terms of degree, betweenness, closeness and eigenvector centralities. On the opposite spectrum, Rep. Donna Christian-Christensen (D), member of the U.S. House of Representatives for the Virgin Islands' at-large district, was in the top 10 in terms of degree, betweenness and closeness centralities, but she was not even represented in the top 30 list in terms

[29] Ben Cardin (D) served in many House Committees including Ways and Means and was subsequently elected to the U.S. Senate in 2006; Chet Edwards (D) was shortlisted in 2008 as Barach Obama's Vice president; Jeff Fortenberry (R) served in the Committee on Foreign Affairs and was listed in 2010 by the magazine *Foreign Policy* among the "foreign-policy power brokers."

of Katz-Bonacich centrality.[30]

Before using the network described above, we need to address two preliminary questions regarding our approach. The first question is whether the alumni network is still relevant many years after the congressmen attended school. The second question relates to the possible presence of other confounding factors associated with school quality that may affect the parameter estimates in (19).

Consider first the issue of relevance of the alumni network. To address it, we examine two distinct sources of information on legislative activity: data on cosponsorships and data on voting behavior.[31] In Table 1, we estimate a dyadic regression model where links between legislator i and j in the alumni network, $g^A_{i,j}$, and differences in terms of the legislators' characteristics are used as explanatory variables for cosponsorship activities in Congress.[32] Cosponsorship activity is measured by directional links $g^L_{i,j}$ equal to the number of bills by j that i has cosponsored.[33] We thus run the following OLS regression:

$$g^L_{i,j} = \gamma_0 + \gamma_1 g^A_{i,j} + \sum\nolimits_l \gamma_l |x^l_i - x^l_j| + e_{i,j}, \tag{20}$$

where $e_{i,j}$ denotes an error term. Panel (a) of Table 1 shows that two politicians who attended the same school at the same time are more likely to cosponsor a piece of legislation than two politicians who did not, holding constant similarities in observed characteristics.

We next look at the relationship between the alumni network and legislative voting.[34] In panel (b) of Table 1 we show the results for the estimation of model (20) where the links $g^L_{i,j}$ is now the fraction of roll calls where i and j casted the same vote. The set of control variables is unchanged. The estimation results show that two politicians who attended the same school at the

[30] Similar examples can be easily found for the other Congresses in our sample.

[31] We look at data on cosponsorships because it has been extensively used to study social networks in Congress starting from Fowler [2006]. The link between peer connections and voting behavior in legislatures has instead been recently studied by Cohen and Malloy [2014] for the U.S. Senate and by Harmon et al. [2017] for the European Parliament.

[32] For each Congress, we control for legislators' similarities in terms of gender, party, and state (i.e. a dummy variable equal to one if they represent districts in the same state and zero otherwise). We also include school and Congress fixed effects.

[33] To construct the cosponsorship networks, we collect all pieces of legislation proposed in the U.S. House from the 109th-113th Congresses from the Library of Congress data information system, THOMAS (http://thomas.loc.gov).

[34] If we assume that G has all positive elements (as we do in our baseline network), then legislators i and j are more likely to vote together if they are linked in the network. This prediction, however, may fail to be true if G has negative components.

same time are more likely to cast similar votes on a given proposal than those who did not.[35]

Consider now the second issue regarding potential confounding effects. Although the alumni network is by construction extraneous to the political process, it may be that some educational institutions attract students with similar characteristics, or that the type of education provided by some institutions is pivotal in forming successful politicians or lobbyists. To control for these school effects, in all our regressions we include dummies for all the educational institutions (high schools, undergraduate, postgraduate) with at least 5 alumni in Congress (we report the top 50 educational institutions in terms of number of alumni in our sample in Table A.3 in the online appendix). Many universities (such as Harvard, Cornell, Duke, Stanford, Yale, and UCLA among many others) serve as hubs to multiple peer groups in our sample.[36] By including school dummies, we exploit variations in network centrality and contributions across alumni of the same school who belong to different cohorts.

4.2.2 Control variables

The vector of variables $x_{i,r}$ (and the associated matrix X) measures the susceptibility of a congressman to PAC contributions. The classic variables used to explain campaign contributions to legislators in the literature are the degree of electoral competition, measures of members' relative "power" inside the house and indicators of a congressman's ideology, political party, gender and seniority in his current Committee.[37]

Information on politicians' characteristics including gender and party of affiliation is provided by *GovTrack*. Charles Stewart and Jonathon Woon's website is used to obtain information on Committee appointments, seniority and chairmanship.[38] For each congressman, electoral com-

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[35] Data on all votes in the 109th-113th Congresses can be accessed from voteview.com. More than 7,500 proposals were proposed. For each pair of congressmen in our network, we considered the proposals where both were present and voted. Delegates are excluded, since they do not vote from the House floor.

[36] As defined before, a peer group is defined as a group of congressmen who attended the same institution in overlapping periods of time.

[37] For electoral competitiveness, the idea is that a close race increases an incumbent's demand for PAC contributions, producing an exogenous shift in contributions via an increase in the propensity to "sell" services, including roll call votes. For the "power" of a member, the argument is that groups give more to powerful members because their support is especially valuable. The inclusion of the politicians' ideologies captures the fact that congressmen with more extreme ideologies may be more or less susceptible to persuasion. The inclusion of these variables can also help control for other factors affecting the extensive margin (who is elected to Congress) that may be relevant for interest groups.

[38] See http://web.mit.edu/17.251/www/data_page.html#2. This website does not contain information for the 113th Congress. We extract the House of Representative committee roster for the 113th Congress from the website http://media.cq.com/pub/committees/index.php.

petition is measured by the margin of victory.[39] Each candidate's margin of victory is derived from the FEC's Federal Elections publications. These publications provide statistics on candidates' vote shares. Since the publications often omit special election results, we supplement the FEC reports with information from individual state agencies. The ideologies of the congressmen are measured using the first dimension of the dw-nominate score (McCarty et al. [1997]).[40] The "power" of the congressman is measured by three variables. First, we have a dummy variable indicating whether the member is a Committee chair.[41] Secondly, we have a dummy variable indicating that the member belongs to the party which has the majority in the House. Finally, we include a dummy variable indicating whether the politician is on one of the powerful Committees (Ways and Means, Energy and Commerce, Appropriations, Rules or Financial services), in which an individual is likely to receive greater PAC contributions (see Grier and Munger [1991], [1993] and Romer and Snyder [1994]).

To control for electoral cycle fixed effects, we include in our analysis four election cycle dummies (associated with each Congress). These are intended to control for changes in the number of PACs over time and changes in nominal and real PAC budgets, as well as for Congress-specific factors affecting PAC contributions.

Finally, we add a dummy variable taking value of one if the congressman did not graduate from the same institution within eight years with any other congressman to control for unobserved differences between connected and unconnected congressmen. Table A.1 contains a detailed description of our data, as well as summary statistics for our sample.

4.2.3 Campaign contributions data

Campaign contributions data from the Federal Election Commission (FEC) files are collected and aggregated by the Center for Responsive Politics (CRP). The CRP provides details on the date, type, industry with which the PAC is associated and recipient of each contribution. We consider the total amount of contributions from PACs and reduce the effect of possible outliers by trimming

[39] Margin of victory as a measure of electoral competition is used by Poole, Romer and Rosenthal [1987], Grier and Munger [1991] and Romer and Snyder [1994], among others.

[40] To isolate this index for one Congress at a time, we used the modified DW-Nominate coordinates developed by Nokken and Poole [2004]. Data are available at http://voteview.com.

[41] A dummy variable for Commitee leadership is used in Romer and Snyder [1994].

the distribution at the 1st and 99th percentiles.[42] In our data, the money spent by PACs for a given candidate ranges from \$10,750 to \$10,789,346, whereas total spending ranges from \$334 million for the 109th Congress to \$419 million for the 113th Congress.

4.3 Empirical findings

Table 2 presents the estimates of our model (equation (19)), with an increasing set of controls. The two key parameters to estimate are ϕ^*, which measures the network externality in the model; and α, which measures the impact of a marginal increase in the Katz-Bonacich centrality of a legislator on the associated interest groups' contributions. Both parameters are predicted to be positive. As it can be seen from columns 1-4 of Table 2, the estimates reveal a positive and statistically significant estimate of both ϕ^* and α for all sets of controls. We estimate that a one standard deviation increase in a legislator's Katz-Bonacich centrality induces an increase of about \$16,000 in interest group's contributions. To put this in context, it roughly corresponds to the increase that a legislator achieves by being a member of the majority party.

It is interesting to note that we find the effects of the *Margin of Victory*, *Chair*, and *Majority Party* all to be significant and with the expected sign. A positive effect of *Chair* confirms the fact that congressmen in positions of leadership receive more attention from interest groups. Members of the majority party receive more contributions than members of the opposition party (in our sample, Republicans had the majority in all Congresses we consider except for the first two). The estimated effect of the *Margin of Victory* coefficient suggests that congressmen who face tight elections have higher needs for campaign finance, are more susceptible to interest groups' influence, and therefore receive more money. Being female is associated with receiving less contributions. The negative effect of *Seniority* is consistent with the results in Grier and Munger [1986]. A positive and statistically significant effect of *DW ideology* indicates that politicians with more extreme ideologies receive more money. The estimated effect of sitting on a *Relevant Committee* is not statistically different from zero.

The findings discussed above should be contrasted with two benchmarks: the OLS estimates ignoring the network effects; and estimates using other standard measures of centrality that do not have a theoretical foundation. With respect to the first benchmark, the last column of

[42] This data has been extensively used in the literature on economics and politics, following Poole and Rosenthal [1997].

Table 2 reports the OLS estimates of the traditional model where campaign contributions are explained using legislators' characteristics and school and Congress fixed effects, ignoring the fact that congressmen are connected. The important observation is that the inclusion of network effects significantly improves the fit of the model. We formally test the fit increase of our model with network externalities compared to the traditional linear regression with $\phi^* = 0$ using a partial F-test.[43] The F-test rejects the hypothesis that the model with $\phi^* \neq 0$ does not provide a significantly better fit than the model with $\phi^* = 0$ ($p < 0.001$).

With respect to the second benchmark, we compare the predictions of our model with the predictions obtained using other standard measures of network centrality (which are not supported by a theoretical analysis). Table 3 presents OLS estimates of the relationship between PAC electoral contributions and degree, betweenness, closeness, and eigenvalue centralities.[44] As it can be seen from columns 1 and 4, the effects of degree and eigenvalue centralities are not significantly different from zero. Column 2 shows that the effect of betweenness is statistically significant, but insignificant in magnitude and negative; and column 3 shows that closeness centrality has a positive and statistically significant effect. The magnitude of its impact in terms of money is, however, about one-fourth of the estimated impact of Katz-Bonacich centrality in Table 2 (column 4). All the control variables have the expected signs, the same as in the estimates of Table 2. The important observation is that when those centrality measures are included in a regression model together with Katz-Bonacich centrality (column 5), the effect of Katz-Bonacich is the *only* one to remain strong and statistically significant. Betweenness shows an effect at the edge of the statistical significance, but that is less than half the impact of the Katz-Bonacich in terms of point estimate; whereas the effects of all the other centrality measures cannot be distinguished from zero.

[43] Let RRS_1 define the residual sum of squares of the unrestricted model (column 4) and p_1 the number of parameters. Let RRS_2 the residual sum of squares of the restricted model (column 5), and p_2 the number of parameters. The partial F-test statistic $F = \left[(RRS_1 - RRS_2)/p_1 - p_2\right] / (RRS_1)/n - p_1$ will have an F distribution with $(p_1 - p_2, n - p_1)$ degree of freedom.

[44] Degree centrality counts the total number of direct connections. Closeness centrality measures the length of the average shortest path passing between a node and each other node. Betweenness is equal to the number of shortest paths from all nodes to each other that passes through that node. Eigenvalue centrality of node i is the ith component of the eigenvector associated to the highest eigenvalue of G. See Jackson [2008] for an introduction and detailed description of these measures.

5 Discussions and extensions

5.1 Heterogeneous social spillovers

In (1), we assumed that the parameter directly associated with network externalities, i.e. ϕ, is constant across legislators. Depending on personal characteristics, however, legislators may be more or less susceptible to social spillovers. Spillovers, for example, may depend on whether legislators belong to the majority or not, or on their gender; spillovers, moreover, may be different for legislators in very dense network components. When we allow for heterogeneous spillovers we have:

$$U^i(p) = \omega\left(s^i(p)\right) + \phi_i \sum\nolimits_j g_{i,j}\chi_j(p) + \varepsilon_p^i \tag{21}$$

where ϕ_i now depends on i's characteristics. The model with these preferences can be analyzed similarly to the previous models. Let us assume for simplicity that legislators are office motivated (the analysis can be easily extended to policy motivated legislators). Using (21) and differentiating the voting probabilities in a way similar to (7), we obtain: $D_i\left[\boldsymbol{\varphi}\right] = \Psi\left[I - \Lambda \cdot G\right]^{-1} D_i\left[\boldsymbol{\omega}\right]$, where Λ is a diagonal matrix with ith diagonal element equal to $2\Psi\phi_i$.[45] Substituting in the first order necessary and sufficient condition as in (11) we obtain:

$$D_i\left[\boldsymbol{\varphi}\right]^T \cdot \mathbf{1} = \lambda_* \Rightarrow \Psi \cdot D_i\left[\boldsymbol{\omega}\right]^T \cdot \left(I - G^T \cdot \Lambda\right)^{-1} \cdot \mathbf{1} = \lambda_*. \tag{22}$$

Let us define $\mathbf{b}^{\mathcal{H}}\left(G^T, \Lambda\right) = (b_i^{\mathcal{H}}\left(G^T, \Lambda\right), ..., b_i^{\mathcal{H}}\left(G^T, \Lambda\right))^T$ as

$$\mathbf{b}^{\mathcal{H}}\left(G^T, \Lambda\right) = \left(I - G^T \cdot \Lambda\right)^{-1} \cdot \mathbf{1}.$$

The vector $\mathbf{b}^{\mathcal{H}}\left(G^T, \Lambda\right)$ is a straightforward generalization of the standard Katz-Bonacich centrality measure, in which the decay factors can be heterogeneous and are given by the diagonal elements of Λ. Condition (22) can now be written as: $b_i^{\mathcal{H}}\left(G^T, \Lambda\right) \cdot \omega'(s_*^i) = \lambda_*$ for $i = 1, ..., n$. When we allow for heterogeneous spillovers, the model predicts that the interest moneys should be allocated in a way that is proportional to the heterogeneous centrality measure $\mathbf{b}^{\mathcal{H}}\left(G^T, \Lambda\right)$.

Our new equilibrium condition can be easily brought to the data. To this goal, let us assume: $\phi_i = (\theta_0 + z_i^T \boldsymbol{\theta}_1)$, where $z_i = (z_i^1, , ..., z_i^q)^T$ is a q dimensional column vector of i' characteristics relevant for ϕ_i, and $\boldsymbol{\theta} = (\theta_0, \theta_1^1, , ..., \theta_1^q)$ are underlying parameters to estimate. Using (17), we

[45] Note that when $\phi_i = \phi$ for all i, then the expression for $D_i\left[\boldsymbol{\varphi}\right]$ presented above collapses to (7).

can write the equilibrium condition as:

$$\mathbf{s} = \alpha \cdot \mathbf{b}^{\mathcal{H}}\left(G^T, \Lambda(\theta, Z)\right) + X^T\boldsymbol{\beta} + \boldsymbol{\epsilon}, \tag{23}$$

where $\Lambda(\theta, Z)$ is a diagonal matrix with the ith element equal to $2\Psi(\theta_0 + z_i^T\theta_1)$. The parameters of (23) can now be estimated with a nonlinear least squares approach similar to the estimation of (19).

As a first look into the issue of heterogeneity for network spillovers, in column 1 of Table 4 we present the estimation of (23) where we allow ϕ_i to depend on i's gender and on whether i belongs to the majority party by adding *Gender* and *Majority Party* in the Z variables. In column 2 of Table 4 we investigate whether network effects are different for legislators who are in dense components by adding a dummy variable taking a value 1 if the politician belongs to a network component with density in the top quartile (the 75th percentile in our sample is equal to 0.57). The estimation results show that, while the personal characteristics are significant in shaping spillover effects, the density of the associated network component does not seem to be relevant.

5.2 Multiple interest groups

In the preceding analysis, we maintained the assumption of two interest groups, one for A and one for B. It is natural to extend the results to the case in which we have K interest groups for A and K for B, each endowed with a budget W. Let $s^i_{j,A}$ be the contribution promised by the jth interest group for A to the ith legislator with $\mathbf{s}_{j,A} = (s^1_{j,A}, .., s^n_{j,A})$ and $\mathbf{s}_A = (\mathbf{s}_{1,A}, .., \mathbf{s}_{K,A})$. The problem faced by an interest group j of type A is similar to (9), with the only difference being that now both $\mathbf{s}_{-j,A}$, the choice of all other $K-1$ interest groups supporting A, and $\mathbf{s}_B$, the choice of all K interest groups supporting B, are taken as given.

Following the same steps as above, we can show that, if legislators are office motivated or if they are policy motivated and there is sufficient uncertainty on their preferences, there is a unique equilibrium in which all interest groups commit to the same transfer $s^i_{j,A} = s^i_{k,B} = s^i_*$ for any j, k and i. This implies that the voting probabilities are derived exactly as in Section 3.2. The analysis is unaffected by the size of K because the marginal effect of a contribution on the voting probabilities is independent of the contributions of other interest groups.[46] Assuming, as in Section 4.1, that the monetary utility is as in (17), we have that the total contribution received

[46] This can be seen from (6) with office motivated and (27) with office and policy motivated legislators.

for voting A in Congress r is just K times the formula in (18). Since these values differ from the previous analysis only by a factor of proportionality, there is no qualitative change in the result and its implications for the empirical analysis.

5.3 Asymmetric interest groups

In the previous analysis we assume that the two interest groups are symmetric, i.e. they have the same budgets and the same preferences. In this case we have $s_A = s_B$, so these expressions disappear from (5): this implies that the interest groups offset each other and, in equilibrium, they have no effect on voting probabilities (which are determined only by the legislators' preferences and the network). In our model, however, the analysis can be extended to the case of asymmetric interest groups with minimal complications. Consider first the case with office motivated legislators and assume A has a larger budget than B: $W_A > W_B$. Because (5) is linear in s_A and s_B when $v_j = 0$ $j = A, B$, the first order necessary and sufficient conditions (10) remain unchanged, except that now the Lagrangian multipliers are different and so $s_A^i > s_B^i$. The qualitative prediction of the model, however, remains identical to the previous analysis: the contribution to legislator i by interest group j is proportional to i's Katz-Bonacich centrality. The factor of proportionality now can be different between interest groups.

Consider the case with policy motivated legislators. The first order necessary and sufficient conditions of (16) are:

$$b_j^{\mathcal{M}}(\phi^*, V, G^T) \cdot \omega_j'(s_l^j) = \lambda_l \quad \forall j \in N \tag{24}$$

and the voting probabilities are determined by the system of equations:

$$\begin{pmatrix} \varphi_1^* \\ ... \\ \varphi_n^* \end{pmatrix} = \begin{pmatrix} 1/2 + \Psi\left(\omega(s_A^1) - \omega(s_B^1) + v^1 q^1(\boldsymbol{\varphi}) + \phi \sum_j g_{1,j}\left(2\varphi_j^* - 1\right)\right) \\ ... \\ 1/2 + \Psi\left(\omega(s_A^n) - \omega(s_B^n) + v^n q^n(\boldsymbol{\varphi}) + \phi \sum_j g_{n,j}\left(2\varphi_j^* - 1\right)\right) \end{pmatrix} \tag{25}$$

Conditions (24) and (25) can not be considered independently: since the modified Katz-Bonacichs centralities in (24) depend on the voting probabilities, the voting probabilities depend on $s_{\mathbf{A}}$ and $s_{\mathbf{B}}$. The equilibrium monetary transfers and voting probabilities must be found as the joint solution of (24) and (25). As in the previous analysis, however, monetary transfers to legislator i remain proportional to i's modified Katz-Bonacich centrality. Moreover, as $n \to \infty$ the codependence between (24) and (25) becomes irrelevant since (by exactly the same argument as in

Proposition 3) the modified Katz-Bonacich centralities converges to the standard Katz-Bonacich centralities that are independent of the voting probabilities.

5.4 Alternative objective functions

In the analysis presented above, we assume that interest groups maximize the expected number of supporters. This objective function is typically assumed in probabilistic models of electoral competition (see Lindbeck and Weibull [1987]). There are, however, environments in which interest groups care about legislators' votes only to the extent that it allows them to reach a given threshold of support (such as a majority). The analysis presented above easily extends to these cases.

To extend the analysis, let us now assume that the interest groups' preferences are represented by a sequence of thresholds $(z_j, u_j)_{j=0}^{J}$ for some finite J with $z_0 = 0$ and $u_0 > 0$ and $z_j < z_{j+1}$ and $u_j < u_{j+1}$ for all $j = 0, ..., J-1$, such that A's utility can be written as a step function: $u_A(\sum_i \chi_i(p)) = u_j$ if $\sum_i \chi_i(p) \in (z_j, z_{j+1}]$ for $j \leq J-1$ and u_J for $\sum_i \chi_i(p) > z_J$. A special example of these preferences is when interest groups care only about obtaining a majority. In this case, the utility is characterized by just one threshold and $z_1 = \frac{n-1}{2}$ for n odd or $z_1 = \frac{n}{2}$ for n even and utility level $u_1 > u_0$.

Following the same steps as above, it is straightforward to verify that, when legislators are office motivated or when they are policy motivated and there is sufficient uncertainty on their preferences, we have a unique equilibrium in which interest groups offer the same monetary contributions $\mathbf{s}_A = \mathbf{s}_B = \mathbf{s}_{**}$. Also, as before, $\mathbf{s}_{**}$ is characterized as the maximization of a weighted sum of the monetary utilities:

$$\max_{\mathbf{s}\in S} \left\{ \sum\nolimits_j b_j^{\mathbf{z},\mathbf{u}}(\phi^*, V, G^T) \cdot \omega_j(s^j) \right\},$$

where $\mathbf{b}^{\mathbf{z},\mathbf{u}}(\phi^*, V, G^T) = \left(b_j^{\mathbf{z},\mathbf{u}}(\phi^*, V, G^T)\right)_{j=1}^{n}$ are weights that depend on ϕ^*, V, G^T and on the thresholds $\mathbf{z}, \mathbf{u} = (z_j, u_j)_{j=0}^{J}$ (a formal derivation of these weights is presented in Section 5 in the online appendix). The key observation is that the importance of the thresholds vanishes as $n \to \infty$. Indeed, as we formally prove in Section 4 in the online appendix, for any $\mathbf{z}, \mathbf{u}$ we have $b_j^{\mathbf{z},\mathbf{u}}(\phi^*, V, G^T) \to \mathbf{b}\left(\boldsymbol{\phi}^*, \mathbf{G}^T\right)$. In this case too, therefore, the equilibrium allocation of transfers depends only on the Katz-Bonacich centralities for large n.

5.5 Heterogeneous policies

Another assumption we made in the previous analysis is that legislators vote only on one policy. In reality, legislators vote on many policies that could be very different and attract the attention of different sets of interest groups (defense, agriculture, trade, etc.). In these cases, we might have a set $H = \{1, ..., h\}$ of different votes, with policy $j = 1, .., h$ associated with N_j interest groups in favor and N_j against, and a per interest group budget W_j.

Once again, the analysis is quite similar to the analysis presented above. Assuming preferences as in (17), it is easy to see that in this environment each interest group interested in policy $j \in H$ in Congress r makes a transfer $\mathbf{s}_r^j = (\alpha_{r,j}) \cdot b(\phi^* G_r^T) + X_r^T \boldsymbol{\xi}_1 + \epsilon_{r,j}$ and so the total vector of contributions can be estimated as $\mathbf{S}^r = \sum_j \mathbf{s}_r^j = \left[\sum_j N_j \alpha_{r,j}\right] \cdot b(\phi^* G_r^T) + \left(\sum_j N_j\right) \cdot X_r^T \boldsymbol{\xi}_1 + \epsilon_r$, that is proportional to $b(\phi^* G_r^T)$ as in Section 4.1.

5.6 Abstention

In the previous analysis we have assumed that legislators can either vote for A or for B, but they cannot abstain. It can be argued, however, that one of the ways in which interest groups exert influence in Congress is by encouraging participation. This may be especially true in a polarized Congress in which a legislator would never vote for a bill that he does not find "ideologically compatible" (for example, a gun control bill for a very conservative Republican). There are multiple ways to extend the model presented above to reflect these issues. We propose here an especially simple way. Assume that legislators can be partitioned into two groups. Group G_A comprises legislators who would never vote for B: they may vote for A or abstain. Similarly, group G_B comprises legislators that would either vote for B or abstain.[47] A legislator i of type G_A, would vote for A if:

$$\omega\left(s_A^i\right) + \phi\left[\sum_{z \in A,B} \eta_{i,z} \sum_{j \in G_z} g_{i,j}\chi_j\right] + v^i q^i(\boldsymbol{\varphi}) \geq \omega\left(s_B^i\right) + \phi\left[\sum_{z \in A,B} \eta_{i,z} \sum_{j \in G_z} g_{i,j}\left(1 - \chi_j\right)\right] + \varepsilon^i \quad (26)$$

where s_A^i and s_B^i are the contributions received, respectively, from interest group A for voting A, and from interest group B for abstaining. If $j \in G_A$, χ_j is 1 if j votes for A and zero otherwise and if $j \in G_B$, χ_j is 1 if j abstains and zero otherwise; $\eta_{i,z}$ for $z = A, B$ are preference parameters; ε^i is a preference shock, as in the previous analysis. As before, $q^i(\varphi)$ is the pivot probability of

[47] We could also easily add a group of "non-partisans" that would vote for A or for B, but we ignore this complication for simplicity.

legislator i as a function of the voting probabilities: now φ_j is the probability of voting for A for $j \in G_A$ and of abstaining if $j \in G_B$. In (26), we are assuming that $i \in G_A$ likes voting for A (resp. abstain) more if other connected legislators in G_A vote for A (resp. abstain) and/or other legislators in G_B abstain (resp. vote for B). In (26), a legislator may value the opinion of other legislators according to their groups: for example, $i \in G_A$ is influenced more by other legislators in G_A than by other legislators in G_B if we assume that $\eta_A > \eta_B$.

Given (26), the probability φ_i that $i \in G_A$ votes for A, is:

$$\varphi_i = 1/2 + \Psi\left(\omega(s_A^i) - \omega(s_\emptyset^i) + v^i q^i(\boldsymbol{\varphi}) + \phi\left[\sum_{z \in A,B} \eta_{i,z} \sum\nolimits_{j \in G_z} g_{i,j}\,(2\varphi_j - 1)\right]\right)$$

An analogous expression can be derived for an agent $k \in G_B$. These characterizations of the voting probabilities can be easily reconstructed to resemble the model described in the previous sections if we modify the network links to incorporate the party affiliations. Let us define $\widehat{g}_{i,l} = \eta_{i,A} g_{i,l}$ if $l \in G_A$ and $\widehat{g}_{i,l} = \eta_{i,B} g_{i,l}$ if $i \in G_B$. Then we have

$$\varphi_i = 1/2 + \Psi\left(\omega(s_A^i) - \omega(s_B^i) + v^i q^i(\boldsymbol{\varphi}) + \phi\left[\sum\nolimits_j \widehat{g}_{i,j}\,(2\varphi_j - 1)\right]\right),$$

which is is exactly equivalent to (5) when we adopt the network matrix $\widehat{G} = (\widehat{g}_{i,j})_{i,j}$, and we interpret φ_j as the probability of voting for the alternative associated to j's types instead of abstaining. Given this, the analysis is exactly equivalent as the analysis presented before and leads to a prediction that monetary transfers are proportional to the legislators' centralities computed using $\widehat{G}$.

5.7 Alternative network definitions

To check for robustness, the last two columns of Table 4 collect the nonlinear least squares estimations of (19) for alternative network constructions. In column 3, we use a version of the alumni network which is not row normalized, so the link $g_{i,j}$ between two congressmen i and j is set equal to the number of schools they both attended in overlapping periods. In column 4, the alumni network is enriched with information on party affiliation. More specifically, the intensity of the i, j link is -0.5 if they are not alumni of the same school and belong to a different party; it is 0.5 if they are alumni of the same school but of different parties; it is 0 if of the same party but not alumni of the same school; and, finally, it is 1 if i, j attended the same school and are of the same party. This specification reflects the fact that two congressmen from the same party have more opportunities to form a social bond and influence each other, and that congressman of different party may be penalized. It also allows for negative spillovers between legislators with no social connections and different party affiliations. Table 4 shows that the results of the previous sections are robust to the use of these network definitions. Looking at the residual sum of squares (RSS), moreover, we see no evidence that these alternative models provide a better fit of the data than the baseline model presented in the previous sections.[48]

6 Conclusions

In this paper, we present a new theory of competitive vote-buying to study campaign contributions when legislators care about the behavior of other legislators to whom they are socially connected. The theory predicts that campaign contributions are increasing in the legislators' Katz-Bonacich centralities, a standard measure of centrality in networks.

As a first attempt to bring these predictions to the data, we estimate the model with data on PAC contributions in the last five Congresses (the 109th-113th). To measure the legislators' social network and control for endogeneity, we exploit the insight that educational institutions provide a basis for social networks. We therefore construct the social network using the congressmen's alumni connections: two congressmen are connected if they graduated from the same institution within a given time window. This approach provides a network that is exogenous by construction to interest groups' activities. To control for unobserved factors associated with school quality, we include school fixed effects in the regression model. By doing so we exploit variations in network centrality and contributions across alumni of the same school who belong to different cohorts.

As predicted by the theory, legislators' Katz-Bonacich centralities significantly impact campaign contributions. The results are robust to the inclusion of established determinants of PAC contributions used in previous literature. Adding information on the topology of the legislators' social network significantly improves the fit of the model compared with alternative specifications that ignore this information.

We believe there is significant room for further analysis on the impact of legislators' social

[48] The RSS of the baseline model is 2439.94, the RSS of the model in columns 3 and 4 of Table 4 are, respectively, 2488.86 and 2489.04. Since the three models are not nested and they employ different data sets (i.e. different network constructions), standard measures of the goodness of fit such as the Akaike information criterion are not valid (Brunham and Andreson [2002]). The comparisons between the residual sum of squares should therefore be seen as an informal way to compare their fit.

networks on interest groups' campaign contributions and other influence activities. While our analysis has focused on monetary contributions, it would be interesting to extend the basic theory to situations in which interest groups offer other types of valuable resources, including expertise and contacts with other legislators. It would be particularly interesting to allow the interest groups to affect the network topology by establishing links between legislators, blending our analysis with Ballester, Calvo-Armengol and Zenou [2006]'s analysis of key players. This would improve understanding of the extent to which legislators' social networks affect the activities of lobbyists, who provide campaign contributions, services and networking resources in the U.S. Congress.

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7 Appendix

7.1 Proof of Lemma 1

The proof for the case with office motivated legislators is presented in Section 3.1. For the case with policy motivated legislators, see the online appendix.

7.2 Proof of Propositions 1-2

We prove the result for general $v = \left(v^1, ..., v^n\right)$. This allows us to prove Proposition 2 and then Proposition 1 as a special case of Proposition 2. Following the same steps as in Section 3.2.1**,** we can derive:

$$D_i\left[\boldsymbol{\varphi}\right] = \Psi(I - \Psi\left(V \cdot D\mathbf{q}_* + 2\phi G\right))^{-1} \cdot D_i\left[\boldsymbol{\omega}\right], \tag{27}$$

where V is the n-dimensional diagonal matrix with ith diagonal entry equal to v^i, $D\mathbf{q}_*$ is the n-dimensional matrix with generic i,j element equal to q_j^i as defined in Section 3.2.2. The first order necessary and sufficient condition of the problem solved by interest group l can be written in matrix form as $D_i\left[\boldsymbol{\varphi}\right]^T \cdot \mathbf{1} = \lambda_l$, where λ_l is the Lagrangian multiplier of interest group l's program. Using (27), we have:

$$\begin{aligned} D_i\left[\boldsymbol{\varphi}\right]^T \cdot \mathbf{1} &= \left[\Psi(I - \Psi\left(V \cdot D\mathbf{q} + 2\phi G\right))^{-1} \cdot D_i\left[\boldsymbol{\omega}\right]\right]^T \cdot \mathbf{1} \\ &= \Psi \cdot D_i\left[\boldsymbol{\omega}\right]^T \left(I - \left(\phi^* G^T + \Psi D\mathbf{q}_*^T V\right)\right)^{-1} \cdot \mathbf{1} = \lambda_l \\ &\Rightarrow D_i\left[\boldsymbol{\omega}\right]^T \cdot \mathbf{b}^{\mathcal{M}}(\phi^*, V, G^T) = \lambda_l / \Psi \end{aligned} \tag{28}$$

for $l = A, B$**,** where for the last equality we used (15) and $\phi^* = 2\phi\Psi$. Note that $D_i\left[\boldsymbol{\omega}\right]$ is a vector of zeros except for its ith element that is equal to $\omega'(s_*^i)$. We can therefore write our necessary and sufficient conditions (10) as:

$$b_i^{\mathcal{M}}(\phi^*, V, G^T) \cdot \omega'(s_A^i) = \lambda_A \tag{29}$$

$$b_i^{\mathcal{M}}(\phi^*, V, G^T) \cdot \omega'(s_B^i) = \lambda_B \tag{30}$$

where, without loss of generality, we have incorporated the constant Ψ in the Lagrangian multipliers. If $\lambda_A > \lambda_B$ (resp., $\lambda_A < \lambda_B$), then by (10) we would have:

$$\omega'(s_A^i) = \lambda_A / b_i^{\mathcal{M}}(\phi^*, V, G^T) < \lambda_B / b_i^{\mathcal{M}}(\phi^*, V, G^T) = \omega'(s_B^i),$$

implying $\omega'(s^i_A) > \omega'(s^i_B)$ (resp., $\omega'(s^i_A) < \omega'(s^i_B)$) for any i, and so $\sum s^i_B > \sum s^i_A = W$ (resp., $\sum s^i_A > \sum s^i_B = W$), a contradiction. We conclude that $\lambda_A = \lambda_B = \lambda_*$ for some $\lambda_* > 0$, implying that there is a unique solution $(\lambda_*, \mathbf{s}_*)$ such that $\lambda_i = \lambda_*$ and $\mathbf{s}_i = \mathbf{s}_*$ for $i = A, B$. ■

7.3 Proof of Proposition 3

Let $\iota(\cdot)$ be a function that maps agents to their respective groups and let H be the $m \times m$ matrix describing the relationships between the types, so that $g_{ij} = h_{\iota(i),\iota(j)}$. We start with two preliminary results. The first result shows that, when we have a finite number of types, the Katz-Bonacich centralities are well-defined functions of only the shares of the types $\boldsymbol{\alpha}$ and of the matrix H describing the relationships between the types. We have:

Lemma 3.1. *For any $i = 1, ..., n$, $b_i(\phi^*, G^T)$ is equal to $\overline{b}_{\iota(i)}(H, \boldsymbol{\alpha})$ defined by:*

$$\overline{\mathbf{b}}(H, \boldsymbol{\alpha}) = \left[I + \phi^* \widetilde{H}^T\right]^{-1} \cdot \mathbf{1}, \tag{31}$$

where $\overline{\mathbf{b}}(H, \boldsymbol{\alpha}) = (\overline{b}_1(H, \boldsymbol{\alpha}), ..., \overline{b}_m(H, \boldsymbol{\alpha}))^T$ and $\widetilde{H}$ is the $m \times m$ matrix with element i, j equal to $\widetilde{h}_{i,j} = \alpha_i h_{i,j} / (\sum_l h_{i,l})$.

Proof. See the online appendix. ■

Note that $\widetilde{H}$ is a $m \times m$ matrix with bounded elements since $\widetilde{h}_{i,j} \leq \sum_i \widetilde{h}_{i,j} \leq \sum_i g_{i,j} \leq \overline{g}$.

The second preliminary result shows that as $n \to \infty$, the equilibrium pivot probabilities and the sum of their derivatives converges to zero. For a sequence of equilibria $(\varphi^n_l)_l$, let q^i_n be the associated pivot probability of legislator i, and $q^i_{n,j}$ be the derivative of q^i_n with respect to φ^n_j. We have:

Lemma 3.2. $\lim_{n\to\infty} q^i_n = 0$, $\lim_{n\to\infty} \sum_{j=1}^n \left|q^i_{n,j}\right| = 0$, *for any i, j.*

Proof. See the online appendix. ■

To complete the proof, consider a sequence of populations of size $n \to \infty$ in which the network is G_n and the share of type j is $\alpha^j_n \to \alpha^j$. We need to show that $b^{\mathcal{M}}_i(\phi^*, V, G^T_n) \to \overline{b}_{\iota(i)}(H, \alpha)$ for all i as $n \to \infty$. To keep the notation simple, let $\widetilde{b}^n_j$ be the modified Katz-Bonacich of an agent of type j. We can write:

$$\widetilde{b}^n_{\iota(i)} = 1 + \phi \textstyle\sum_{l=1}^m \widetilde{h}^n_{l,\iota(i)} \widetilde{b}^n_l + v_{\iota(i)} \sum_{l=1}^m n_l \widetilde{q}^{\,\iota(i)}_{n,l} \widetilde{b}^n_l \tag{32}$$

where $\widetilde{h}_{i,j} = n_i h_{i,j}$ and $\widetilde{q}_{n,l}^{\,\iota(i)}$ is the derivative of the pivot probability of an agent of type $\iota(i)$ with respect to the voting probability of a type l. Note that $\left| n_l \widetilde{q}_{n,l}^{\,\iota(i)} \right| \leq \sum_{j=1}^{n} \left| q_{n,j}^{i} \right|$ and, by Lemma 3.2, $\sum_{j=1}^{n} \left| q_{n,j}^{i} \right| \to 0$ as $n \to \infty$. It follows that we can write $\widetilde{\mathbf{b}}^n = \Psi \cdot \left[I + \phi^* \left[\widetilde{H}^n \right]^T + O(n) \right]^{-1} \cdot \mathbf{1}$, where $\widetilde{\mathbf{b}}^n = (\widetilde{b}_1^n, .., \widetilde{b}_m^n)^T$, $\widetilde{H}^n$ is the $m \times m$ matrix with element i, j equal to $\widetilde{h}_{i,j} = n_i h_{i,j}$ and $O(n)$ is a $m \times m$ matrix with all terms converging to zero as $n \to \infty$. Note that $\widetilde{h}_{i,j} \leq \sum_{i=1}^{m} n_i h_{i,j} = \sum_{l=1}^{n} g_{l,j} \leq \overline{g}$, so $\widetilde{H}^n$ converges to a positive and bounded $m \times m$ matrix $\widetilde{H}$. Taking the limit as $n \to \infty$, we obtain: $\lim_{n \to \infty} \widetilde{\mathbf{b}}^n = \Psi \left[I + \phi^* \widetilde{H}^T \right]^{-1} \cdot \mathbf{1}$. It follows that $b_i^{\mathcal{M}}(\phi^*, V, G_n^T) \to \overline{b}_{\iota(i)}(H, \boldsymbol{\alpha})$ for all i as $n \to \infty$ as requested. ■

TABLE 1. Predictive power of alumni network for cosponsorships and voting behavior

Dep. var:.	Same cosponsorship activity		Same voting behavior	
	(1)	**(2)**	**(3)**	**(4)**
Link in alumni network (1= yes)	0.1441*** (0.0122)	0.0399*** (0.0117)	0.0113** (0.005)	0.0118** (0.0051)
	0.2974*** (0.0027)	0.2914*** (0.0027)	0.4322*** (0.0011)	0.4316*** (0.0011)
Same party (1= yes)		0.0015 (0.0029)		0.0238*** (0.0013)
Same gender (1= yes)		0.3266*** (0.0054)		0.0006 (0.0026)
Same state (1= yes)	0.1441*** (0.0122)	0.0399*** (0.0117)	0.0113** (0.005)	0.0118** (0.0051)
Congress fixed effects	Yes	Yes	Yes	Yes
R2	0.1016	0.1267	0.7872	0.7891
N. Obs.	116,846	116,846	114,148	114,148

Notes. OLS estimated coefficients are reported. An intercept is included. Standard errors (in parentheses) are clustered by dyad. *, **, *** indicate statistical significance at the 10, 5 and 1 percent levels.

TABLE 2. Main estimation results

	Dep. var.: PAC contributions ($mil)				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Network effects (Φ)	0.0268**	0.0265**	0.0352**	0.0352***	
	(0.0098)	(0.0131)	(0.0107)	(0.0106)	
Katz-Bonacich (α)	1.2536***	1.1735***	0.8775***	0.8794***	
	(0.1041)	(0.1121)	(0.1241)	(0.1258)	
Unconnected	-0.1294**	-0.1243*	-0.1056*	-0.1054*	-0.1157*
	(0.0633)	(0.0706)	(0.0632)	(0.0631)	(0.0632)
Party (1=Democrat)	-0.1365**	-0.1131**	0.0213	0.0214	0.0205
	(0.0432)	(0.0382)	(0.0493)	(0.0493)	(0.0491)
Gender (1=Female)	-0.6145***	-0.5969***	-0.4946***	-0.4956***	-0.4685***
	(0.0342)	(0.0302)	(0.0422)	(0.0439)	(0.0418)
Chair (1=Yes)	0.3986***	0.4098***	0.349***	0.3494***	0.3353***
	(0.093)	(0.0939)	(0.0943)	(0.0944)	(0.0906)
Seniority	-0.0185***	-0.0166***	-0.0139***	-0.0141***	-0.0058***
	(0.0027)	(0.0026)	(0.0026)	(0.0029)	(0.0017)
Margin of victory (1= Less than 5%)		0.0942***	0.9691***	0.9683***	1.0027***
		(0.0969)	(0.1559)	(0.1562)	(0.1601)
DW ideology			0.3042***	0.305***	0.3739***
			(0.0859)	(0.0855)	(0.085)
Majority party (1 = Yes)			0.1135***	0.1137***	0.0488*
			(0.0278)	(0.028)	(0.0261)
Relevant committee (1=Yes)				-0.0038	0.0416*
				(0.029)	(0.0252)
School fixed effects	Yes	Yes	Yes	Yes	Yes
Congress fixed effects	Yes	Yes	Yes	Yes	Yes
Partial F test (ϕ=0)					5.9204***
p-value					[0.000]]
N. Obs.	2,125	2,125	2,125	2,125	2,125

Notes. NLLS estimated coefficients are reported in columns (1)-(4). OLS estimated coefficients are reported in column (5). An intercept is included. Robust standard errors are in parentheses. A precise definition of control variables can be found in Table A.1. *, **, *** indicate statistical significance at the 10, 5 and 1 percent levels.

TABLE 3. Explicative power of traditional network measures

	Dep. var.: PAC contributions ($mil)				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Centrality measures					
Degree	-0.0039 (0.0087)				-0.0457 (0.0385)
Betweenness		-0.0098** (0.0048)			0.0510* (0.0298)
Closeness			0.8827*** (0.3473)		0.8716 (1.7437)
Eigenvector				-0.4820 (0.3355)	0.0924 (0.5587)
Φ					0.0877** (0.0352)
Katz-Bonacich (α)					0.8813*** (0.1311)
Unconnected	-0.1208* (0.0647)	-0.1189* (0.0632)	-0.0968 (0.0629)	-0.1248* (0.0642)	-0.1018 (0.0705)
Party (1= Democrat)	0.0199 (0.0492)	0.0198 (0.0491)	0.0206 (0.0491)	0.0222 (0.0491)	0.0203 (0.0495)
Gender (1=Female)	-0.4694*** (0.0421)	-0.4706*** (0.0419)	-0.472*** (0.042)	-0.4686*** (0.0418)	-0.4957*** (0.044)
Chair (1=Yes)	0.3373*** (0.091)	0.3392*** (0.0908)	0.3422*** (0.0909)	0.3381*** (0.0907)	0.3493*** (0.0943)
Seniority	-0.0061** (0.0021)	-0.0065*** (0.0017)	-0.0068*** (0.0018)	-0.0058*** (0.0017)	-0.0145*** (0.0029)
DW ideology	0.3712*** (0.0856)	0.3695*** (0.0849)	0.3707*** (0.085)	0.3739*** (0.085)	0.2971*** (0.0851)
Majority party (1 = Yes)	0.0489* (0.0261)	0.0497* (0.0265)	0.0497* (0.0265)	0.0487* (0.0261)	0.1098*** (0.0282)
Margin of victory (1= Less than 5%)	1.002*** (0.1601)	1.0004*** (0.1598)	0.9978*** (0.1596)	1.0032*** (0.1599)	0.9722*** (0.1557)
Relevant committee (1 = Yes)	0.0413 (0.0254)	0.0391 (0.0264)	0.0352 (0.0267)	0.0421* (0.0252)	-0.0069 (0.0287)
School fixed effects	Yes	Yes	Yes	Yes	Yes
Congress fixed effects	Yes	Yes	Yes	Yes	Yes
N. Obs.	2,125	2,125	2,125	2,125	2,125

Notes. NLLS estimates are reported in column (5). OLS estimates are reported in columns (1)-(4). An intercept is included. Robust standard errors are reported in parentheses. A precise definition of control variables can be found in Table A.1. *, **, *** indicate statistical significance at the 10, 5 and 1 percent levels.

TABLE 4. Additional results

	Dep. var.: PAC contributions ($mil)			
	(1)	**(2)**	**(3)**	**(4)**
Network effects (Φ)	0.0004**	0.0293***	0.4975***	0.4977***
	(0.0001)	(0.0100)	(0.0002)	(0.0004)
Katz-Bonacich (α)	0.7826***	0.9261***	0.0025***	0.6652***
	(0.0707)	(0.1279))	(0.0007)	(0.1908)
Network effects * Majority party (1 = Yes)	0.2318***			
	(0.0730)			
Network effects *Gender (1 = Female)	0.1876***			
	(0.0662)			
Network effects *Network density (1 = Higher than the 75th percentile)		-0.0088		
		(0.1264)		
Network density (1 = Higher than the 75th percentile)		-0.1650		
		(0.1176))		
Unconnected	-0.0101	-0.1447**	0.1550***	0.1537***
	(0.6701)	(0.0651))	(0.0520)	(0.0521)
Party (1= Democrat)	0.3564***	0.0167	0.1728***	0.1760***
	(0.0396)	(0.0497)	(0.0447)	(0.0447)
Gender (1=Female)	-0.3064***	-0.4958***	-0.4130***	-0.4135***
	(0.0343)	(0.0438))	(0.0416)	(0.0416)
Chair (1=Yes)	0.3559***	0.3647***	0.3508***	0.3513***
	(0.0984)	(0.0945)	(0.0909)	(0.0909)
Seniority	-0.0033	-0.0155***	-0.0095***	-0.0097***
	(0.0025)	(0.0029)	(0.0027)	(0.0027)
DW ideology	0.8374***	0.2661***	0.5701***	0.5666***
	(0.0562)	(0.0855)	(0.0726)	(0.0725)
Majority party (1 = Yes)	0.1469***	0.1051***	0.1293***	0.1285***
	(0.0326)	(0.0281)	(0.0287)	(0.0287)
Margin of victory (1= Less than 5%)	1.1438***	0.9651***	1.0350***	1.0250***
	(0.1605)	(0.1556)	(0.1579)	(0.1586)
Relevant committee (1 = Yes)	0.1054	0.0073	0.0219	0.0219
	(0.02706)	(0.02794)	(0.0278)	(0.0278)
School fixed effects	Yes	Yes	Yes	Yes
Congress fixed effects	Yes	Yes	Yes	Yes
N. Obs	2,125	2,125	2,125	2,125

Notes. NLLS estimated coefficients and robust standard errors (in parentheses) are reported. A precise definition of control variables can be found in Table A.1. *, **, *** indicate statistical significance at the 10, 5 and 1 percent levels. Columns (1) and (2) include interaction terms with personal and network characteristics according to the theoretical equation (23). In column (3), the alumni network is not row-normalized. In column (4), it is weighted by party affiliation. Weights take values of 1 if the linked congressmen have the same school and party, 0.5 if they have the same school and a different party, 0 if they have a different school and the same party, and -0.5 if they have a different school and a different party.

Table A.1. Summary statistics

	Variable definition	Mean	St. Dev
PAC contributions ($mil)	PAC Contributions to a member of Congress, source: http://opensecrets.org.	922,104	1,092.194
Party	Dummy variable taking value of one if the congressman is Democrat	0.508	0.500
Gender	Dummy variable taking value of one if the congressman is female	0.174	0.379
Chair	Dummy variable taking value of one if the congressman is a chair of at least one committee	0.046	0.209
Seniority	Maximum consecutive years in the same committee	7.549	6.241
Margin of victory	Dummy variable taking value one if the election margin of victory is less than 5%	0.050	0.218
Majority party	Dummy variable taking value of one if the congressman is member of the majority party in the House of Representatives	0.553	0.497
DW ideology	Distance to the center in terms of ideology measured using the absolute value of the first dimension of the dw-nominate score created by McCarty et al. (1997)	0.502	0.221
Relevant committee	Dummy variable taking value of one if the congressman is member of a powerful committee (Appropriations, Budget, Rules and Ways and Means)	0.386	0.486
Unconnected	Dummy variable taking value of one if the congressman did not graduate from the same institution within four years with any other congressman	0.640	0.480
N. Obs.		2,125	2,125

Table A.2 Contributions to top 30 politicians by measure of centrality
109th Congress

Bonacich		Degree		Betweenness		Closeness		Eigenvector	
Name	**PAC**	**Name**	**PAC**	**Name**	**PAC**	**Name**	**PAC**	**Name**	**PAC**
John Carter	393,840	Susan Davis	146,585	Albert Wynn	492,181	Jim Moran	465,242	Susan Davis	146,585
Susan Davis	146,585	Eni Faleomavaega	26,000	Ben Cardin	4,744,816	Albert Wynn	492,181	Doris Matsui	778,752
Eni Faleomavaega	26,000	Jeff Fortenberry	668,558	Michael Bilirakis	68,714	Ben Cardin	4,744,816	Mel Watt	451,839
Jeff Fortenberry	668,558	John Carter	393,840	Jim Moran	465,242	Michael Bilirakis	68,714	Pete Stark	313,163
Timothy F. Murphy	763,567	Adam Schiff	481,354	Cliff Stearns	507,819	Luis Fortuno	22,241	Jim Cooper	262,010
Debbie Wasserman Schultz	539,707	Donna Christian-Christensen	91,150	Jeff Fortenberry	668,558	Pete Visclosky	475,823	Vernon Ehlers	178,355
Vic Snyder	232,319	Chet Edwards	1,707,420	Donna Christian-Christensen	91,150	Cliff Stearns	507,819	Virginia Foxx	496,488
James Kolbe	111,901	Doris Matsui	778,752	Luis Fortuno	22,241	Timothy F. Murphy	763,567	Eni Faleomavaega	26,000
Michael Oxley	362,528	Ed Royce	503,070	Chet Edwards	1,707,420	Jeff Fortenberry	668,558	Howard Coble	361,910
Daniel Lungren	469,713	Jeb Hensarling	578,255	Adam Schiff	481,354	Steny Hoyer	1,697,123	Thomas DeLay	1,354,126
Bob Goodlatte	687,653	Jim Cooper	262,010	Jeb Hensarling	578,255	Donna Christian-Christensen	91,150	Mark Andrew Green	11,128
Sam Johnson	653,799	Jim Costa	490,066	Pete Visclosky	475,823	Ander Crenshaw	246,556	John Olver	298,820
Jim Ramstad	607,794	Maxine Waters	164,135	Timothy F. Murphy	763,567	Randy Forbes	240,680	Heather Wilson	5,540,104
Ben Cardin	4,744,816	Mel Watt	451,839	Susan Davis	146,585	Henry Waxman	499,683	Barbara Lee	225,262
Luis Fortuno	22,241	Sam Johnson	653,799	John Carter	393,840	Howard Berman	277,827	Tom Price	1,020,468
Jim Cooper	262,010	Tom Price	1,020,468	Eni Faleomavaega	26,000	Charles Boustany	779,656	Pete Hoekstra	325,531
Pete Stark	313,163	Joe Baca	372,619	Dan Lipinski	181,528	Jim McCrery	1,799,658	Carolyn Kilpatrick	331,971
Cliff Stearns	507,819	Pete Hoekstra	325,531	Sam Johnson	653,799	Tom Feeney	726,479	Marcy Kaptur	282,648
Michael Bilirakis	68,714	Carolyn Kilpatrick	331,971	Jim Ramstad	607,794	Steve LaTourette	783,320	Mark Kennedy	2,663,873
David Wu	391,209	Jim Ramstad	607,794	Charles Boustany	779,656	Sam Johnson	653,799	Ed Royce	503,070
Charles Boustany	779,656	Pete Stark	313,163	Jim McCrery	1,799,658	Jim Ramstad	607,794	Jim Costa	490,066
Jim McCrery	1,799,658	Cliff Stearns	507,819	Michael C. Burgess	565,562	Stephanie H. Sandlin	972,412	Maxine Waters	164,135
Ginny Brown-Waite	459,188	Albert Wynn	492,181	Henry Bonilla	3,076,115	Jimmy Duncan	434,947	Joe Baca	372,619
Dave Weldon	268,814	Luis Fortuno	22,241	David Wu	391,209	Richard Baker	823,253	Lucille Roybal-Allard	285,718
Mike Thompson	699,895	Ben Cardin	4,744,816	Rahm Emanuel	636,309	Charlie Melancon	1,416,246	Mike Thompson	699,895
Lucille R-Allard	285,718	Charles Boustany	779,656	Jim Cooper	262,010	Ralph Hall	461,201	Don Young	688,592
Albert Wynn	492,181	Dan Lipinski	181,528	Pete Stark	313,163	John Linder	340,560	Juanita M-McDonald	234,787
Chet Edwards	1,707,420	Lucille Roybal-Allard	539,707	Doris Matsui	778,752	Chet Edwards	1,707,420	Donna Christian-Christensen	91,150
Rahm Emanuel	636,309	Jimmy Duncan	434,947	Lucille Roybal-Allard	285,718	Jeb Hensarling	578,255	Sam Johnson	653,799
Adam Schiff	481,354	Joe Barton	1,827,856	Mike Thompson	699,895	Adam Schiff	481,354	Jim Ramstad	607,794