Strategic Foreign Aid: A Structural Approach*

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Abstract

What is the effect of competition on the distribution of aid from China and the U.S. across the globe? While the literature has studied how specific factors (e.g., democracy) affect the amount of foreign aid a country receives, we still do not know whether these factors affect the preferences of the U.S. and China for giving aid directly or indirectly via competition and strategic interaction. In this paper, we answer these questions by adopting a structural approach: we construct a game-theoretic contest model of aid distribution and estimate its parameters given the observed foreign aid commitments of the two countries. Our estimates demonstrate that for a slim majority of recipient-years, donations are driven by non-strategic considerations. However, the strategic incentives to provide aid are highest when recipients have ongoing elections, and there are heterogeneous effects because strategic incentives can account for $10 million in aid to some countries. Our counterfactual experiments demonstrate that aid from the US will generally discourage aid from China, but not *vice versa*.

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Introduction

In 2013, China adopted the Belt and Road Initiative (BRI). The program has used more than a trillion dollars in aid and investment to connect China with Eurasia and Africa with enhanced physical and technological infrastructure, although China plans to invest as much as 8 trillion (Hurley, Morris and Pvortelance 2018). While such spending could be seen as a way to decrease trade costs and increase globalization (Baniya, Rocha and Ruta 2020; De Soyres et al. 2019; Mlambo 2022), several policymakers, pundits, officials, and international relation experts warned that the program was China buying economic influence and dominance (Bolton 2019; Krishnamoorthi 2023; Lake 2018; Miller 2022).[1]

Moreover, those suspicious of China's investments encouraged the US to up its foreign aid to discourage China's expanding influence. For example, Daniel Runde, senior vice president of the Center for Strategic Studies, testified to Congress in 2024 saying

> I want to make a key point: I have heard many smart people say that the DFC [US International Development and Finance Corporation] is our response to Belt and Road. The DFC did $9 billion across 130 transactions last year while China's BRI did $92 billion across about 210 deals...We likely need to spend at least another $2 billion a year in foreign aid to counter China for the next couple of decades.

In 2023, the chair of the House Committee on Strategic Competition between the US and the Chinese Communist Party wrote, "We've got to be bigger, faster, and bolder in our approach. We've got to play to win" (Krishnamoorthi 2023).

The resulting policy debate centers around several scientific questions that are central to the international relations literature, however. First, while enhanced spending and competition from the US may discourage spending and competition from China, they also can backfire and encourage even greater competition from China (Lake 2018). Indeed the encouragement and discouragement

[1] In 2017, CNN reported, "the tendrils of Chinese influence are gradually wrapping themselves around the world, upending roles and relationships that have dominated the global order for half a century" (https://www.cnn.com/interactive/2017/05/world/chinas-new-world-order/).

effects of enhanced competition are well documented theoretically and empirically in the contest literature (Chaudoin and Woon 2018; Dechenaux, Kovenock and Sheremeta 2015; Stein 2002). It is unclear which effect dominates across multiple recipient countries. Second, a key claim is that the US, unlike China, overly prioritizes reducing poverty and encouraging democratization when making aid decisions rather than focusing on strategic resources and infrastructure, such as access to minerals and ports (Runde 2024; Runde, Savoy and McKeown 2022). Nonetheless, it is not obvious how to validate such assertions empirically because observed aid allocations are determined by both strategic interactions between donors and recipient country characteristics. Likewise, we need to assess counterfactual predictions about how competition would change if the US changed its priorities to more closely match those of China.

In this paper, we tackle these questions head on by adopting the structural approach. First, we construct a game-theoretic contest model of foreign aid allocation between two donors where donors compete for a rivalrous private good linked to an aid recipient. This recipient-specific prize could represent preferential commercial deals, military cooperation in alliances, or support in international fora. Compared to standard contests, a unique feature of our model is that donors receive private returns to increase aid, which could capture altruistic benefits like reducing poverty, that do not depend on winning a contest. Second, we use the model's equilibrium conditions to derive an empirical moment condition that we use to estimate the model's unobserved parameters from observed aid allocations from the US and China. These parameters capture the two countries' preferences for aid distribution. In particular, our estimates allow us to see how important the returns of winning the contest (e.g., influence over the recipient) are relative to the intrinsic private benefits of donating (e.g., the benefit of helping a country in need) for each donor. Thus, they are per se important evidence about whether the two countries have different priorities when determining aid allocation. In doing so, we follow recent identification strategies in the applied microeconomics literature that instruments aid spending with temporary shocks to budget constraints for the two countries (Ahmed 2016; Dreher et al. 2021; Dreher and Langlotz 2020; Nunn and Qian 2014). Third, we use the fitted model to conduct counterfactual exercises that answer key questions in recent policy debates. For example, how would either donor respond to increased spending by its rival? Our framework will also allow us to make predictions about aid allocation changes of both donors after changes in democracy levels, economic growth, and other recipient characteristics.

Besides allowing us to address these important policy questions, our estimates increase our understanding of what drives the relationships between foreign aid and other variables documented elsewhere. This is because our estimates indicate how a given determinant of foreign aid affects such assistance's cost and benefits separately. For example, it has been noted that the economic development of the recipient does not appear to be as important as other factors in aid allocation for some donors like the US (e.g., Alesina and Dollar 2000; Bueno de Mesquita and Smith 2009). It is possible, however, that GDP positively affects the strategic value of influencing recipients (e.g., influencing recipients with higher GDP might be politically and economically profitable); at the same time, giving aid to a recipient with higher GDP increases the costs of the aid, as it deviates from stated foreign assistance priorities. Since higher GDP could raise benefits and costs, it might not affect final allocations. By assessing the strength of those two considerations, the model sheds light on the nature of the observed relationship between US aid and recipient's GDP.

Our preliminary analysis yields three conclusions about aid as a tool of strategic competition between the US and China. First, for the majority of recipient-years, donations are motivated by non-strategic considerations. In just over half of observations for the US and more than three-quarters for China, we estimate a precise zero for the sensitivity of the donor's utility to its rival's contributions. That said, this leaves a substantial minority of recipient-years where strategic considerations are directly impacting the level of aid. We find evidence that those considerations are highest when there are ongoing executive elections in the recipient country, indicating strategic interest in influencing the domestic politics of aid beneficiaries.

Second, among the set of recipient-years for which strategic considerations play a role, we identify critical differences between how US aid responds to Chinese aid and vice versa. Using the utility parameters that we estimate, we calculate how each major power would best-respond to a hypothetical 10% increase in its rival's aid in each recipient-year. In this counterfactual experiment, the US is much more likely to respond by increasing donations than by decreasing them, whereas China is slightly more likely to decrease aid than increase it in response to a US increase. In part this arises because US outlays are already much greater than China's, so a further disproportion only decreases China's incentive to respond in kind.

Third, in another counterfactual experiment, we are able to quantify in dollar terms the effect that these strategic incentives have on donations. We compare equilibrium behavior at the estimated utility parameters to a hypothetical scenario in which both donors are motivated purely by non-strategic considerations. There are important differences between the extensive and intensive margins here: there is less likely to be any effect on Chinese aid as China's baseline strategic parameters are already zero for most recipients, but conditional on there being an effect it is typically stronger for China. For each potential recipient in the data, the highest average change in aid due to the presence of strategic incentives is about \$10 million, which is 25% of the median annual donation by the US and more than 600% that of China. Altogether, while the effects of strategic competition are neither universal nor uniform, we identify substantial localized effects.

This paper contributes to the scholarly literature on the determinants of foreign aid allocation. Early studies found evidence in favor of foreign assistance being driven mainly by donors' interests and less so by other considerations like recipients' need (Alesina and Dollar 2000; Maizels and Nissanke 1984; McKinlay and Little 1977). Donors use aid to accomplish several goals, including, but not limited to, building support in diplomatic fora (Dreher et al. 2022), gaining market or natural resource access in receiving countries (Dang and Stone 2021), combating transnational threats like terrorism (Scott and Carter 2019), bolstering favorable regimes' electoral prospects (Faye and Niehaus 2012), and incentivizing political or economic liberalization (Wright 2009). Absent from this work, however, is the explicit consideration of competition with other donors and empirical estimates that reflect the strength of such considerations.

More closely related to our paper are studies that explore strategic interactions of donors and the effects of competitive pressures determining foreign assistance levels. Several papers have shown that competition for export markets and political influence drives foreign aid allocation, leading to fragmentation of aid and lack of coordination (Annen and Moers 2016; Barthel et al. 2014; Fuchs, Nunnenkamp and Öhler 2015; Kilama 2016). Others have shown that competitive pressure pushes donors to offer aid on more favorable terms. This includes directing funds to more politically favorable sectors like infrastructure (Zeitz 2021), or reducing the number and effective stringency of conditions (Hernandez 2017; Li 2017; Watkins 2021). There is also evidence of competition through international development organizations between major powers (Qian, Vreeland and Zhao 2023). Our framework focuses less on the rationale behind competition and cooperation, and unlike previous work, it allows us to explore how the characteristics of the recipients shape the nature of the competitive use of aid.

Finally, our paper makes a more marginal contribution to the theoretical contest literature by establishing a uniqueness result in a generalized Tullock contest with private returns to effort. Although we have two players, compared to Szidarovszky and Okuguchi (1997) and Kang (2016), we relax strict concavity assumptions on the production function and add private returns to effort. Chowdhury and Sheremeta (2011) also consider a Tullock model with private returns to effort, but they assume these private returns are linear and negatively impact a player's prize of winning. In contrast, we focus on the case where players receive private benefits to effort, but the private benefits need to have decreasing marginal returns.

Formal model

Donor countries $i, j \in \{1, 2\}$ are competing for influence across $m = 1, \ldots, M$ recipient countries at times $t = 1, \ldots, T$. In each recipient at a particular time, the donors simultaneously select how much to donate, denoted $d_{imt} \geq 0$ and $d_{jmt} \geq 0$.

A donor country's utility from donations to a particular recipient m has two components. First, there is a non-strategic component that does not depend on the other donor country's actions (e.g., altruistic motivations, or development aid that will yield trade rewards later). The baseline non-strategic utility is $u(d_{imt})$, where $u : \mathbb{R}_+ \to \mathbb{R}_+$ is twice differentiable, strictly increasing ($u' > 0$), and strictly concave ($u'' < 0$).

Second, there is a strategic component that the donor countries compete over. Specifically, there is a rivalrous private good on which each donor places a value $\Pi_{imt} \geq 0$. Preferential commercial deals, military cooperation in the form of alliances, or support in international fora could represent that prize. The subscript on Π_{imt} represents that the strategic value of aid may vary by donor i, recipient m, and time t. A contest success function $p_1 : \mathbb{R}^2_+ \to [0, 1]$ determines the share of the private good that donor 1 garners, as a function of both donors' aid.[2] We assume that the contest success function is twice differentiable, that donor 1's share strictly increases with its own donations ($\partial p_1/\partial d_1 > 0$) and strictly decreases with its rivals ($\partial p_1/\partial d_2 < 0$), and that there are weakly decreasing marginal returns to donations ($\partial^2 p_1/\partial d_1^2 \leq 0$, $\partial^2 p_1/\partial d_2^2 \geq 0$). We define $p_2 \equiv 1 - p_1$, so we may write each donor's expected utility in terms of the generic contest success function p_i.

We assume a linear cost of donations. The cost may be specific to the donor, recipient, and time, so we will denote it $C_{imt} > 0$. These costs represent the actual monetary cost of sending aid and the opportunity costs of not using the funds for other ends. In this way, they can encompass deviations from the stated donor's foreign aid goals. For example, if a donor supports a non-democratic regime despite having the promotion of democracy included as one foreign aid aim in its statutes, this will increase the marginal cost of aid targeted to this country.

Donor i's expected utility from recipient m at time t is therefore[3]

$$U_{imt}(d_{imt}, d_{jmt}) = u(d_{imt}) + \Pi_{imt} p_i(d_{imt}, d_{jmt}) - C_{imt} d_{imt}. \tag{1}$$

Because U_{imt} is continuous and strictly concave in d_{imt}, a donation $d_{imt} > 0$ is a best response if and

[2] This could also be interpreted as donor 1's probability of winning the entire prize.

[3] Equation 1 implicitly normalizes the value of the non-strategic component to each donor. Imagine a more general model where the non-strategic component is valued at $V_{imt} > 0$ by each donor, giving us the expected utility function $U_{imt}(d_{imt}, d_{jmt}) = V_{imt} u(d_{imt}) + \Pi_{imt} p_i(d_{imt}, d_{jmt}) - C_{imt} d_{imt}$. Using our utility specification in Equation 1, if we replaced Π_{imt} with Π_{imt}/V_{imt} and C_{imt} with C_{imt}/V_{imt}, best responses and equilibrium behavior would be identical to the ostensibly more general model proposed here. Consequently, we opt for the simpler specification, keeping in mind that our estimates of strategic values and marginal costs should be interpreted as the ratio relative to the non-strategic value.

only if

$$\frac{\partial U_{imt}(d_{imt}, d_{jmt})}{\partial d_{imt}} = u'(d_{imt}) + \Pi_{imt} \frac{\partial p_i(d_{imt}, d_{jmt})}{\partial d_{imt}} - C_{imt} = 0. \tag{2}$$

In Appendix F, we show the existence and uniqueness of pure-strategy equilibria when p_i is a generalized Tullock contest success function.

Structural model

Our goal is to estimate the observable determinants of marginal costs C_{imt} and strategic values Π_{imt} from data on foreign aid allocations and recipient characteristics. To this end, we place some additional structure on donor payoffs that allow us to identify these parameters in data. This entails making some specific functional form assumptions, as well as modeling the key structural parameters C_{imt} and Π_{imt} as linear functions of observable covariates.

For each donor i and recipient m at time t, let $\mathbf{x}_{imt}$ be a row vector of predetermined characteristics observed by the players and the analyst. We assume this set of characteristics consists of two distinct pieces. The first, $\tilde{\mathbf{x}}_{mt}$, is a set of (potentially time-varying) recipient characteristics that may affect both donors' payoffs. This component is common across both donors. The second, $\mathbf{z}_{imt}$, is a vector of instruments, which in this context are covariates that affect donor i's payoffs but not donor j's. We further discuss both sets of covariates below when we discuss data and estimation.

We model the marginal cost of donations as a linear function of observable characteristics with an additively separable stochastic shock:

$$C_{imt} = \mathbf{x}_{imt}\boldsymbol{\beta}_i + \eta_{imt}.$$

The term $\boldsymbol{\beta}_i$ is a column vector of coefficients that we want to estimate (a separate vector for each donor). We assume the shock η_{imt} has zero mean and is independent across donors, recipients, and times. The expected marginal cost of donation for each donor-recipient-time is thus $\mathbf{x}_{imt}\boldsymbol{\beta}_i$, which we denote $\bar{C}_{imt}$ for short. We assume η_{imt} is observed by both donors, but not the analyst.[4] This allows us to build an estimator on the assumption of pure strategy Nash equilibrium play, while rationalizing deviations between predicted and observed donations.

This utility specification is particularly useful because it allows us to determine the sources of opportunity costs. Specifically, besides national security, the two stated rationales for US foreign assistance are commercial interest and humanitarian concerns (Morgenstern and Brown 2022). In particular, the US is interested in promoting economic growth, disaster relief, and governance, emphasizing democratic promotion and protection of human rights. Except for governance concerns, China shares similar goals, giving high importance to promoting economic development (The State Council Information Office of the People's Republic of China 2021).

Estimating β_i allows us to test whether sending aid to countries that might not fit the ideal recipient given their humanitarian, developmental, or governance situation (e.g., providing foreign aid assistance to a corrupt regime) increases the marginal cost of sending aid. More generally, the estimated parameters allow us to test the importance of those stated foreign aid goals. For example, given the stated concerns, we could compare the degree to which either China or the US internalizes the democracy of recipient country by including the recipient's democracy level in $\tilde{\mathbf{x}}_{mt}$. E.g., the US may face smaller opportunity costs to giving to a recipient that is democratizing whereas China may see a difference between countries that are democratizing and are backsliding democratically.

We model the strategic values as a linear function of recipient characteristics:

$$\Pi_{imt} = \tilde{\mathbf{x}}_{mt}\gamma_i,$$

where again γ_i is a column vector of coefficients to estimate. The instruments z_{imt} do not enter the strategic payoffs Π_{imt}, an assumption that can be motivated through two ways. First, if we were to include the instruments in the strategic term as well, then our identification strategy would essentially boil down to functional form assumptions about how we specify the contest success

[4] See Gordon and Hartmann (2016) for a similar structural model specification.

function p_i. Second, the literature on foreign aid generally instruments donor aid using variables that depend on temporary shocks to the donor's ability to provide aid (e.g., Dreher et al. 2021; Nunn and Qian 2014). For instance, the US might have a strong wheat harvest, or China might have a surplus of steel reducing the cost of providing foreign aid. Thus, the instruments affect the cost of giving aid rather than the strategic value of a specific recipient.

Finally, to complete the empirical counterpart of the model, we assume that $u(d_{imt}) = \log(d_{imt} + \delta)$ and

$$p_i(d_{imt}, d_{imt}) = \frac{d_{imt} + \varepsilon}{d_{imt} + d_{jmt} + 2\varepsilon},$$

where $\delta > 0$ and $\varepsilon > 0$ are constants that we calibrate to maximize model fit.[5] The log utility form of u is computationally straightforward, and the Tullock specification of the contest success function is a standard choice in the international relations literature, with normalizing assumptions chosen to ensure continuity and make implementation of our estimator easier.[6]

Estimation

We seek to derive an estimator from the assumption that observed levels of aid represent Nash equilibrium play of the underlying game form. We assume that η_{imt} is white noise error: mean zero, uncorrelated with covariates, independent across donor countries.

For each observation with positive aid, $d_{imt} > 0$, Nash equilibrium implies that the marginal benefit to the donor must equal marginal cost. Substituting the structural forms into the first-order condition in Equation 2 implies that if $d_{imt} > 0$, then

$$u'(d_{imt}) + \tilde{\mathbf{x}}_{mt}\gamma_i \frac{\partial p(d_{imt}, d_{jmt})}{\partial d_{imt}} - (\mathbf{x}_{imt}\boldsymbol{\beta}_i + \eta_{imt}) = 0.$$

To conserve notation in what follows, define the scalar $a_{imt} \equiv -u'(d_{imt})$ and the row vector $\mathbf{w}_{imt} \equiv$

[5] See Appendix A.3 for details.

[6] While arguably reasonable assumptions, both of these choices can be compared to alternative specifications in robustness checks. Indeed, in the next iteration of the analysis, we plan to compare this specification with another that allows the effectiveness of aid to be asymmetric between China and the US.

$-\tilde{\mathbf{x}}_{mt}\frac{\partial p(d_{imt},d_{jmt})}{\partial d_{imt}}$. We can then simplify the first-order condition above to

$$(3) \qquad -\eta_{imt} = a_{imt} + \mathbf{x}_{mt}\boldsymbol{\beta}_i + \mathbf{w}_{imt}\gamma_i.$$

Because $\mathbf{w}_{imt}$ is implicitly a function of (d_{1mt}, d_{2mt}) and thus of both donors' stochastic shocks, the key econometric difficulty is to identify the strategic coefficients, γ_i. We take a two-step approach to address this difficulty.

We first run a first-stage model to generate exogenous predicted spending, $\hat{d}_{imt}$ and $\hat{d}_{jmt}$. We use a pair of ridge regressions to estimate these values.[7] For this to not be purely functional form-based identification, this requires there be elements of $\mathbf{x}_{imt}$ that enter the equation for i but not for j, i.e., z_{imt}, and vice versa. We follow Nunn and Qian (2014), Ahmed (2016), Dreher and Langlotz (2020), and Dreher et al. (2021) by using as instruments the products of the recipient (invariant) propensity to receive foreign aid with time-variant determinants of the supply of aid. The recipient-specific propensity to receive aid from a given donor is the fraction of years in the period of analysis that the recipient received aid from that donor. Conditional on controls that include recipient and year-fixed effects, the first stage compares the aid received after a positive shock in the supply of resources available for foreign assistance with the aid received before that shock in countries that are likely to receive aid during the period of study relative to those that are not.

The time-variant aid supply shock variables for the US are US wheat production and US legislative fractionalization. As highlighted in Nunn and Qian (2014), most US surpluses of wheat production are used in foreign assistance, with wheat being an important component of food aid. Because we consider more than food aid, we turn to political economy determinants of foreign aid and use a polarization-augmented measure of US legislative fractionalization. The strategy builds on the well-established idea that more fragmentation leads to more government spending (e.g., Alesina and Tabellini 1990; Roubini and Sachs 1989). Fragmentation, for example, increases the costs of getting bills passed via logrolling, especially when there is polarization (Eslava and Nupia

[7] See Appendix A.1 for details.

2017; Nupia 2013).[8] Evidence of a strong link between legislative fragmentation and government spending for the US has been presented in Ahmed (2016) and cross-nationally by Alesina and Tabellini (1990), Alesina and Rosenthal (1995) and Dreher and Langlotz (2020).

The supply of aid variable used as a component of the instrument of Chinese aid is the first factor from a factor analysis of the detrended and logged production of steel, cement, iron, glass and timber (Dreher et al. 2021). As with the wheat production in the US, surpluses of these raw materials are destined to foreign aid.

Figures E8 and E9 in the Appendix show the relationships of the components of the instrument, supply of aid variables and propensities to receive aid from both countries, with average aid. We see that the relationships between government spending and aid, and polarization-augmented fractionalization and government spending are positive and strong, which is consistent with the theory that supports this choice of instruments. As expected, the relationship with wheat production is weaker than the one reported in Nunn and Qian (2014), since we consider not just food aid but total aid. Polarization augmented fragmentation, raw materials production, and propensity to receive aid, all exhibit the expected positive relationship with average aid. Below, we show that the instruments are strong predictor of aid after controlling for covariates and fixed and year effects in the estimation's first stage.

Returning to the estimator of structural parameters, we instrument $\mathbf{w}_{imt}$ with the exogenous analogue:

$$\hat{\mathbf{w}}_{imt} = -\tilde{\mathbf{x}}_{mt} \frac{\partial p(\hat{d}_{imt}, \hat{d}_{jmt})}{\partial d_{imt}}.$$

Define the vector $\mathbf{v}_{imt} = (\mathbf{x}_{mt}, \hat{\mathbf{w}}_{imt})$. Under our exogeneity assumption on the stochastic shock η_{imt}, the first-order condition of Equation 3 implies $\mathbb{E}[\mathbf{v}_{imt}\eta_{imt}] = \mathbf{0}$, where the expectation is taken over

[8] The polarization-augmented fragmentation measure is the average of $fractionalization_t \times polarization_t + fractionalization_t$ across the US Senate and House of Representatives, where $fractionalization_t$ is the likelihood that two randomly chosen legislators are from different political parties and $polarization_t$ is the polarization score from DW-NOMINATE.

the population of observations with nonzero donations. This condition is equivalent to

$$\mathbb{E}[\mathbf{v}_{imt}\,(a_{imt} + \mathbf{x}_{imt}\boldsymbol{\beta}_i + \mathbf{w}_{imt}\boldsymbol{\gamma}_i)] = \mathbf{0}.$$

The sample analogue we use for estimation, restricting ourselves to the subsample of observations in which $d_{imt} > 0$, is

$$\mathbf{V}_i'\,[\mathbf{a}_i + \mathbf{X}_i\boldsymbol{\beta}_i + \mathbf{W}_i\boldsymbol{\gamma}_i] = \mathbf{0}. \tag{4}$$

where $\mathbf{V}_i$, $\mathbf{X}_i$, and $\mathbf{W}_i$ are matrices formed by stacking the row vectors $\mathbf{v}_{imt}$, $\mathbf{x}_{imt}$, and $\mathbf{w}_{imt}$, respectively, each recipient m at time t for donor i.

Although Equation 4 admits an exact solution under standard full rank assumptions, the estimated values may violate the nonnegativity constraints on the underlying structural parameters $\bar{C}_{imt}$ and Π_{imt}. We therefore solve for the values of $\boldsymbol{\beta}_i$ and $\boldsymbol{\gamma}_i$ that come closest (in terms of squared deviations) to solving Equation 4 while ensuring that $\bar{C}_{imt} \geq 0$ and $\Pi_{imt} \geq 0$ for the full sample. See Appendix A.2 for details.

While we use the full sample to generate the first-stage predicted values $\hat{d}_{imt}$ and $\hat{d}_{jmt}$, we can only use the subsample with positive observed aid to estimate $\boldsymbol{\beta}_i$ and $\boldsymbol{\gamma}_i$ via Equation 4. That is because the first-order condition, which our estimator is derived from, only holds with equality when aid is strictly positive. In theory this may be problematic in the presence of observations with zero donation.[9] In a Monte Carlo study with simulated data where equilibrium aid was zero for a substantial portion of observations, we found no bias due to excluding these from estimation of the structural parameters. In Table D4 in the Appendix, we characterize differences between the excluded observations and those used for estimation, finding that the country-year observations in our sample tend to have lower GDP, more corruption, less civil liberties, more aid from multilateral organizations, more likely to be election years, and fewer natural resource rents than those

[9] See Gordon and Hartmann (2016). Like us, they ultimately exclude observations with zero spending from their estimator.

excluded.

Data

Our main outcome variables are the United States net commitments of official development assistance (ODA) taken from the OECD DAC3A dataset and the Chinese ODA-like aid from Aid Data (Custer et al. 2023). ODA foreign aid are flows given by official agencies of national governments to states to promote development and welfare. The projects must take place in countries that, according to the OECD, qualify for ODA based on income, and they have a grant component of at least 10%.[10] Small loans with low interest could also be classified as ODA.

The US appears to give greater amounts of aid than China. The average developing aid a country receives from the US in a given year is 149 million US (2021 constant) dollars,[11] while the figure is 52.26 million for China. The AidData data sometimes lacks all information necessary to classify Chinese projects as ODA. Development-intent loans for which borrowing terms are not available, or projects for which the flow type (e.g., loan, grant, debt forgiveness) cannot be clearly established could be ODA but might not appear as such in our data sources. With these caveats in mind, in the period of analysis and among the developing countries in our sample (154), 130 countries received aid from both donors at least one year, 13 received aid only from the U.S., 1 received aid only from China, and 10 did not receive aid from the US or China.

The nature of the aid between China and the US is also different. The US gives most of its aid via grants, while Chinas' loan aid component is more prominent (see the distribution of the proportion of loans in total aid across recipients by donor in Figures C3 and C4). While China gives loans to countries in all continents, the US loans tend to be concentrated in Africa and they still represent a smaller component of total development aid to those countries (see Figures C5 and C6). The data also show that for a given recipient, the US tends to allocate more aid to health, education, and the governance and civil society sectors than China, while China's projects are

[10] The exact grant component depends on the recipient's income level as determined by the OECD.
[11] We use constant 2021 dollars in all analyses.

mostly linked to industry, construction, and transports and storage (Figure C7).

	No Chinese aid		Chinese aid	
	Proportion	Aid value (per capita, USD)	Proportion	Aid value (per capita, USD)
No US aid	0.12	(0.00, 0.00)	0.02	(0.00, 129.86)
US aid	0.23	(90.39, 0.00)	0.63	(25.08, 19.46)

Table 1. US and Chinese foreign aid allocation. This table reports the proportion of recipient years where recipients receive aid from both donors, one donor, or no donor. It also reports the average yearly US and Chinese aid per capita for each of these configurations of aid patterns between donors. The first number in the parenthesis corresponds to average US aid, and the second to average Chinese aid. Total number of recipient-years is 3,410.

Table 1 presents a first look at the data focusing on how aid is allocated depending on whether a competitor is giving funds to a given recipient. Aid in this table is normalized by population. We see that there are more recipient-years where both China and the US are donating than where only one does so. When only one of the donors gives to a recipient, they tend to give more on average than when they both give. We also classify aid recipients according to their year-to-year changes in aid from both donors. That is, a recipient could have experienced a positive average year-to-year increase in aid from both donors in our period of analysis, increases from one but a decrease from the other, or decreases from both. This descriptive analysis, reported in Table C2, gives a first approximation to patterns of strategic responses among donors. We see that for 103 recipients (out of 154) donors tend to mimic each other by either increasing the aid when the other does so or decreasing it. The number of recipients where average positive year-to-year aid growth occurs along with decreases in aid from the other donor is smaller, with 51 recipients.

There is also a positive correlation when examining the overtime behavior of total US and China aid (see Figure C1). Although the beginning of the 2000s saw increased foreign aid from China and the US, US assistance increased dramatically early on due to the non-military component of the war on terror and the Emergency Plan for AIDS Relief in Africa. After 2005, US aid stabilized while China's kept a more moderate increase up to 2016.

In what follows, we examine whether these patterns in the data are explained by the characteristics of the recipient countries, irrespective of the other donor's actions, or by competitive pressures.

Contextual variables

Moving on to the contextual variables that enter the marginal cost equation in the model, these are linked to the stated goals of foreign assistance. These variables are the recipient's logged GDP per capita, logged population, V-Dem's index of Electoral Democracy, Corruption index, an index of Civil Liberties,[12] logged aid from the IMF and the World Bank, and the number of disasters from the Emergency Events dataset, all measured in $t-1$. By including pre-determined multilateral aid in the costs equation and endogenizing bilateral aid, we are able to focus on aid that is most directly linked to donor's priorities (Easterly and Pfutze 2008; Martens et al. 2002) while still accounting for the fact that multilateral aid can affect the costs of sending more aid to a given recipient.[13] In addition to these variables, we include recipient and year intercepts. Appendix B gives a description of these variables and provides a more complete justification for their inclusion.

As for the variables included in the strategic value equation, we include the recipient's logged GDP per capita, logged population, natural resource rents (which include oil, natural gas, coal, and forests), an election year dummy, membership in the UN Security Council indicator, and two dummies for being a rival of the US or China. The strategic value specification also includes year-effects. These covariates influence the competition for export foreign markets among donors, or their desire to influence the recipients' voting patterns in international fora or internal policies (e.g., Alesina and Dollar 2000; Dreher, Sturm and Vreeland 2009; Faye and Niehaus 2012; Selaya et al. 2014; Vreeland and Dreher 2014).

[12]We alter V-Dem's Civil Liberties original index by excluding the Political Civil Liberties index from its components. We do this because the Electoral Democracy index shares most of its components with the Political Civil Liberties index.

[13]Multilateral aid could also be used as a tool of the most influential members of multilateral institutions (e.g., Stone 2011) and the choice between bilateral and multilateral aid is also strategic (Milner 2006). We plan to check the robustness of our results to using multilateral aid as part of the choice variable for the US.

Results

Parameter Estimates

We run first stage models to generate exogenous predictions of aid that we plug in to form the moment conditions for the structural estimator. Table D5 in the Appendix reports the coefficient estimates from these models. This table confirms that the instrumental variables have the predicted signs and are statistically significant, even after conditioning on recipient and year fixed effects as well as the other time-varying covariates. Overall, the Spearman correlation between the predicted values from these regressions and actual aid is 0.91 for the US and 0.67 for China.[14]

Having confirmed the quality of the first stage estimates, we move on to our structural model. Table 2 reports estimates for the four equations we estimate: $\boldsymbol{\beta}_i$ determining the expected marginal cost of donation $\bar{C}_{imt}$ for the US and China, and γ_i determining the strategic spillover parameter Π_{imt} for the US and China.

In the cost equations, we find that most of the coefficients on the individual time-varying variables are imprecisely estimated. Only two terms are statistically significant, both in the US's cost equation. Corruption in the recipient country raises the US's effective cost of aid, thereby decreasing the US's propensity to donate. Meanwhile, electoral democracy has the opposite effect. This is consistent with the stated goals driving foreign assistance in the US.

We also find relatively few statistically significant covariates in the strategic spillover equations, though for slightly different reasons—most of these terms are *precise* zeros. This is in part due to our estimator's imposition of the constraint that $\Pi_{imt} \geq 0$ for all donors i, recipients m, and years t in the data. The only term with a nonzero coefficient in the strategic spillover equation is the occurrence of an executive election in the recipient country, which increases the strategic value of donation for both major donors (though is only statistically significant for the US). Though the recipient country's membership on the UN Security Council has no effect on Π_{imt} in our main estimates, we do estimate a positive effect in a substantial proportion of our bootstrap resamples

[14] See Figure E10 in the Appendix for an illustration.

Term	C_{USA}	C_{China}	Π_{USA}	Π_{China}
log(GDP per Capita)	1.58	−9.32	0.00	0.00
	(3.02)	(9.29)	(0.00)	(0.00)
log(Population)	2.44	0.68	0.00	0.00
	(5.11)	(11.23)	(0.00)	(0.00)
Electoral Democracy	$-8.47^{\dagger}$	−5.38		
	(4.96)	(18.98)		
Civil Liberties	6.98	3.37		
	(4.89)	(15.37)		
Corruption	12.46^{*}	−12.42		
	(5.76)	(18.39)		
Disaster	−0.06	0.39		
	(0.34)	(1.28)		
log(1 + World Bank Aid)	−0.18	0.47		
	(0.14)	(0.47)		
log(1 + IMF Aid)	−0.14	−0.48		
	(0.10)	(0.33)		
Pr(US Aid) × Fractionalization	−6.00			
	(10.59)			
Pr(US Aid) × Wheat Production	−3.98			
	(8.61)			
Pr(China Aid) × China Production Index		−1.43		
		(2.18)		
Executive Election			$0.16^{\dagger}$	0.16
			(0.08)	(0.22)
Resource Rents			0.00	0.00
			(0.06)	(0.00)
UNSC Membership			0.00	0.00
			(0.09)	(0.26)
Year FEs	✓	✓	✓	✓
Recipient FEs	✓		✓	
Observations (First Stage)	2795		2795	
Observations (Second Stage)	2592		1718	
Clusters	150			

Table 2. Parameter estimates for the structural model. *: $p < 0.05$, †: $p < 0.1$. Standard errors estimated by pairs cluster bootstrap, with clustering at the recipient level.

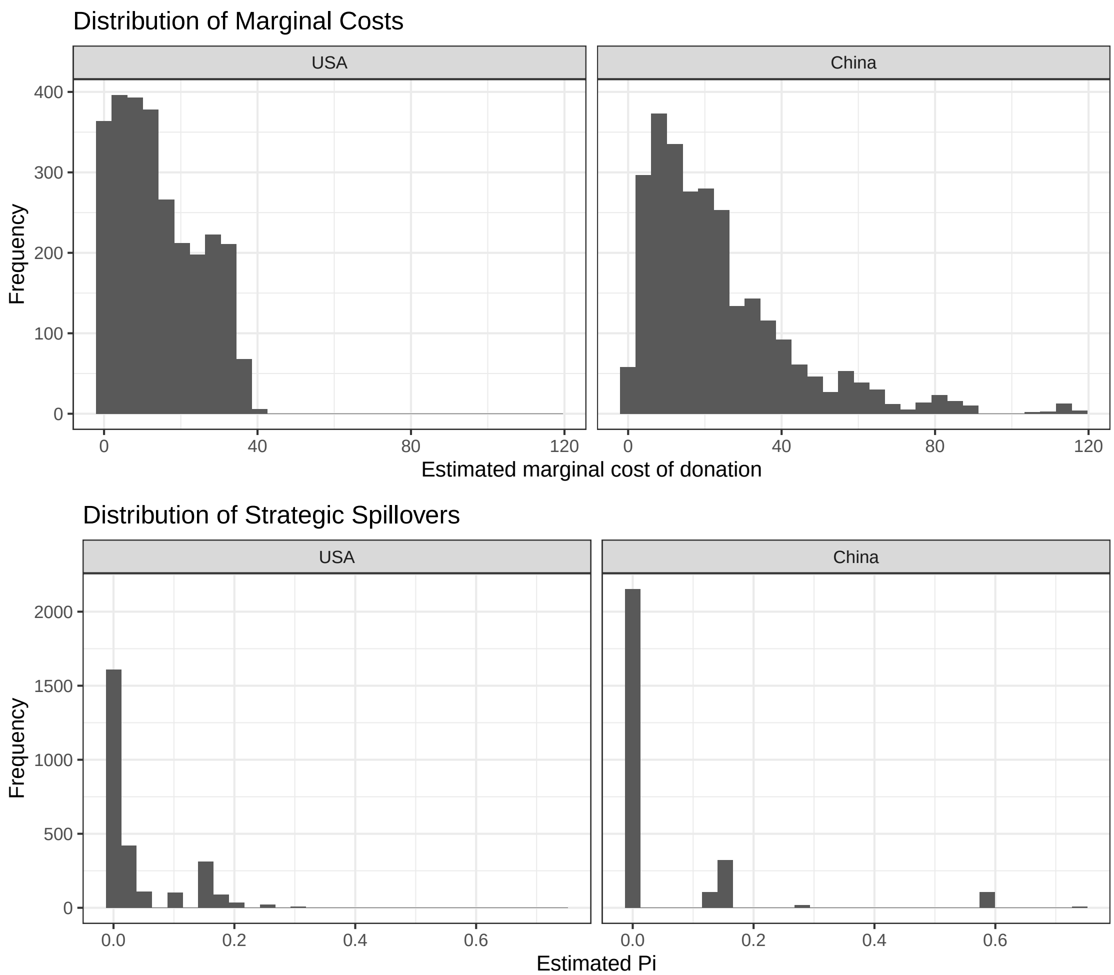

Figure 1. Distribution of estimated average marginal costs $\bar{C}_{imt}$ and strategic spillovers Π_{imt} across recipient-years for each donor.

(48% for the US and 36% for China).[15]

Because the fixed effects are omitted from Table 2, it is difficult to assess model fit from the regression table alone. As a general measure of model fit, we use our coefficient estimates to calculate $\bar{C}_{imt}$ and Π_{imt} for each donor-recipient-year in the data, then calculate the unique Nash equilibrium contributions by each donor for each observation, and finally compare those to the true observed values. The Spearman correlation between the equilibrium predictions and the observed donations is 0.88 for the US and 0.34 for China; see Figure E11 in the Appendix for an illustration. For the USA, this correlation is slightly weaker than the first stage model, though it is evident from

[15]We estimate a negative coefficient for the US in 4% of bootstrap resamples, but never for China.

comparing the x-axes of Figure E10 and Figure E11 that the structural model better captures the upper range of American donations. The fit for China, especially when compared to the first stage model, is more concerning. It is possible that the functional forms we currently assume capture the US's incentive structure better than China's, suggesting that we may need to investigate whether alternative specifications for China would yield an improvement in fit.[16]

Each pairing of donor and recipient-year is characterized by two parameters: the donor's expected marginal cost of aid $\bar{C}_{imt}$ and the donor's strategic sensitivity Π_{imt}. Figure 1 illustrates the distribution of our estimates of these key structural parameters across recipient-years in our sample. Consistent with the lower extensive and intensive margins of Chinese aid compared to American aid, we estimate greater marginal costs for China. The distributions of the strategic spillover parameters are perhaps more interesting. While we estimate zero strategic spillover for both donors in at least half of recipient-years, the proportion of zeroes is greater for China than for the US. However, conditional on a nonzero strategic spillover, the values for China tend to be greater than those for the US. Loosely speaking, there is a smaller set of recipient-years for which China cares about geopolitical competition with the US through foreign aid—but when China does care, it cares more.

Counterfactual Experiments

By modeling foreign aid as the outcome of an equilibrium interaction and estimating the utility parameters underlying that interaction, we are able to quantify counterfactual questions about how equilibrium behavior would change under various shocks to behavior or incentives. We focus on the role of strategic incentives in donations—the extent to which aid from one donor is a function of its geopolitical rival's behavior.

Experiment 1: Shocks to donations. In our first counterfactual experiment, we quantify how much more—or less—each geopolitical rival would prefer to give if the other suddenly increased

[16] It is of course also possible that our covariates fail to capture some important aspect of China's incentives, but that would not explain the loss in fidelity from the first stage based on the same covariates.

Effect of China increase on USA	Count	Percent
No spillover	921	55.7%
Strategic complement	535	32.4%
Strategic substitute	197	11.9%

Effect of USA increase on China	Count	Percent
No spillover	2103	83.7%
Strategic complement	159	6.3%
Strategic substitute	252	10%

Table 3. Categorization of the strategic effect of a 10% increase in the rival's donation for each donor-recipient-year with positive observed aid by the rival. "No spillover": no change in best response. "Strategic complement": increase in best response. "Strategic substitute": decrease in best response.

its donations to a particular recipient. We begin by calculating, for each recipient-year in the data, each donor's best response to the observed donation by their rival.[17] We then calculate the change in that best response if the rival's observed donation increased by 10%. Because we are considering the effects of a percentage shock here, we only use observations with a nonzero donation by the rival in this portion of the analysis.

To begin, we place each donor-recipient-year into one of three categories. If there is no change in the donor's best response due to a 10% increase in their rival's donation—either because $\Pi_{imt} = 0$, or because $\bar{C}_{imt}$ is so high that the best response is $d_{imt} = 0$ regardless—then we say there is "no spillover." We say the donor has a "strategic complement" if their best response increases, and a "strategic substitute" if it decreases. Table 3 displays the distribution of these categories across donor-recipient-years.

For the majority of observations, we find no strategic spillover; the donor's best response is invariant to a 10% increase in their rival's donation. This is consistent with the large number of observations for which we estimate Π_{imt} (see Figure 1 above). Nonetheless, we see important differences in the best-response behavior of the two powers. First, while there is no spillover in a

[17] These best response calculations differ from the equilibrium calculations we performed above to assess model fit. The difference is that here we are calculating each best response while taking the other donor's contribution as given at the observed value, rather than calculating the general equilibrium for both donors as a function solely of the structural parameters.

Complements for both (12): Bangladesh, Côte d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Mongolia, Pakistan, Panama, Senegal, Tajikistan, Zambia.

Complements for USA, substitutes for China (47): Angola, Armenia, Azerbaijan, Benin, Bolivia, Bosnia & Herzegovina, Botswana, Burundi, Cambodia, Central African Republic, Colombia, Congo - Kinshasa, Ethiopia, Georgia, Guinea, Haiti, Iraq, Jamaica, Jordan, Kenya, Kyrgyzstan, Lebanon, Liberia, Malawi, Mali, Moldova, Morocco, Mozambique, Namibia, Nepal, Niger, Nigeria, North Macedonia, Palestinian Territories, Peru, Philippines, Rwanda, Sierra Leone, Somalia, South Africa, Sudan, Tanzania, Thailand, Uganda, Ukraine, Vietnam, Zimbabwe.

Complements for China, substitutes for USA (27): Belarus, Burkina Faso, Cameroon, Cape Verde, Congo - Brazzaville, Costa Rica, Cuba, Equatorial Guinea, Fiji, Gabon, Ghana, Guyana, Laos, Maldives, Mauritania, Mexico, Papua New Guinea, Paraguay, Serbia, Seychelles, Sri Lanka, Suriname, Togo, Trinidad & Tobago, Turkmenistan, Uzbekistan, Vanuatu.

Substitutes for both (11): Algeria, Chad, Djibouti, Eritrea, Indonesia, Kazakhstan, Lesotho, Madagascar, Myanmar (Burma), Tunisia, Yemen.

Table 4. Strategic spillover effects for each donor-recipient pair, aggregated across years in the sample.

majority of cases for both donors, this categorization is much more common for China, with a 28 percentage point gap. In other words, at least at the extensive margin, the US appears to be more responsive to China's donations than vice versa. Second, in those cases where there is a spillover effect, the US is far more likely to have strategic complements than substitutes, while China is slightly more likely to have substitutes than complements. This may owe to the fact that American aid tends to be greater than Chinese aid, so an increase in American aid simply further depresses the marginal benefit of Chinese aid.

As a final step in this exercise, we aggregate these effects across years to the recipient level. Specifically, for each donor-recipient pairing, we calculate the change in the donor's best response due to a 10% increase in rival aid for each year in our data, then take the average across years. We then categorize a donor-recipient pairing as having strategic complements if the average change is positive and strategic substitutes if the average is negative. Table 4 lists the recipients by category.[18] At this level, we see about the same number of countries for which both donors have

[18]Some recipients do not appear because there is no change in best response for one or both donors in every year in the data.

strategic complements (12) as for which both have strategic substitutes (11). It is noteworthy that the category with mutual complements is comprised almost wholly of countries that border China (Mongolia, Pakistan, Tajikistan), that are in the US's historical sphere of influence in the Americas (Dominican Republic, Ecuador, El Salvador, Panama), and/or that are of strategic importance to the US in the Middle East (Egypt, Pakistan). Key global trade route centers (Panama and Egypt) and economies with a growing mining sector (Ecuador, Egypt, and Zambia) are on the strategic complements list.[19]

Meanwhile, there are almost twice as many countries for which the US has strategic complements and China has strategic substitutes (47) than for which we see the opposite pattern (27).

This classification of aid recipients differs in important ways from the one based on a simpler observed average year-to-year changes in aid by donor described earlier (see Tables C2 and C3). Focusing on the strategic complements recipients' list, we see that only Côte d'Ivoire and Senegal appear in it and also have positive average aid growth from both donors. This highlights the importance of accounting for the intrinsic benefits of sending aid to a given country to each donor and the costs of sending that aid (as in our theoretical and empirical framework) when trying to ascertain strategic responses among donors.

Experiment 2: Shocks to incentives. Next, we pursue an alternative approach to quantify the role of strategic incentives in shaping the major powers' foreign aid allocations. Unlike the previous partial equilibrium exercise which took one donor's contributions as fixed, this exercises relies on a full Nash equilibrium computation for each observation. Specifically, we calculate equilibrium donations in each recipient-year under the estimated structural parameters, then compare those to equilibrium donations if there were no strategic spillover incentives ($\Pi_{imt} = 0$ for all i, m and t's). Figure 2 illustrates the distribution of differences in equilibrium contributions across recipient-years for each of the two major-power donors.

Because the baseline estimated value of Π_{imt} is 0 for the majority of donor-recipient-years (see Figure 1 above), we naturally find no difference in this counterfactual scenario for a majority of

[19] Other major mining-oriented economies like Chile or Australia are more clearly aligned with the US.

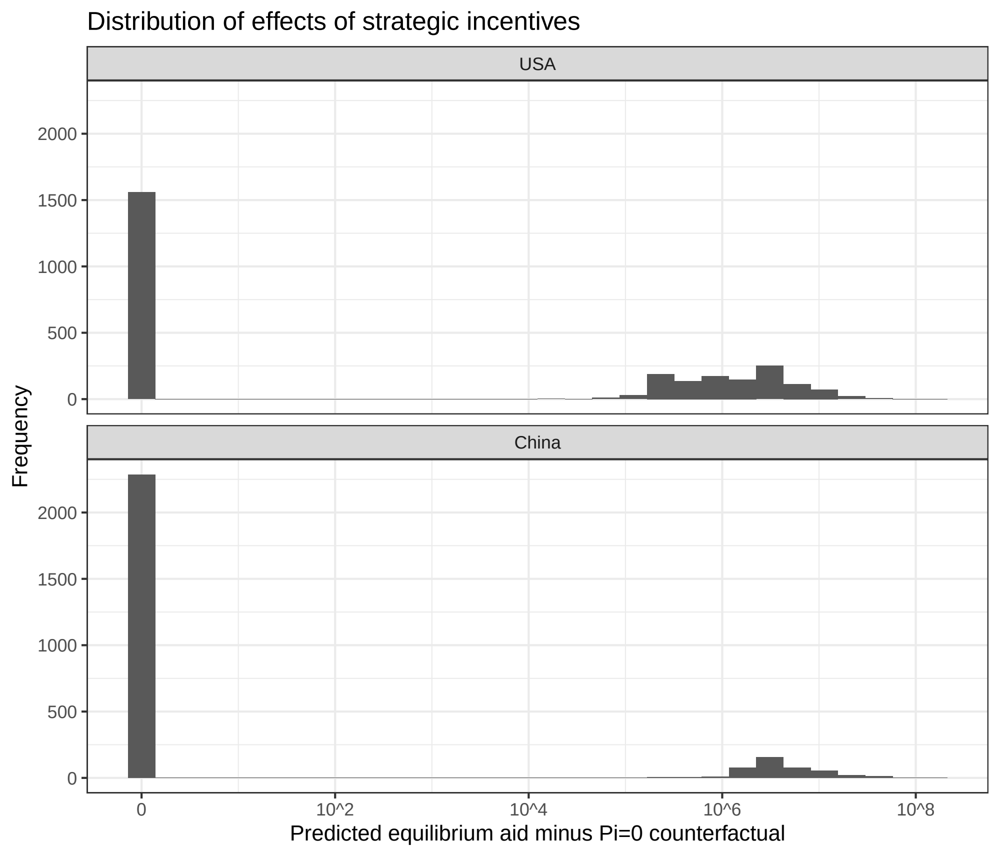

Figure 2. Distribution of differences in estimated aid between equilibrium at estimated parameters, versus equilibrium holding each $\bar{C}_{imt}$ at estimated value while setting $\Pi_{imt} = 0$.

observations. For the United States, there is no effect in just over half of recipient-years. Among those for which there is an effect, the change in equilibrium aid is less than $1,000,000 about half of the time. On the other hand, for China, while there is no effect of zeroing out strategic incentives in about 80% of recipient years, among the remaining 20% of cases the effect is virtually always at least $1,000,000. In short, strategic incentives make more difference to American aid at the extensive margin, but more difference to Chinese aid at the intensive margin.

To further illustrate the substantive significance of these effects, Table 5 displays for each donor, the ten recipients to which aid would decrease most on average in the absence of a strategic motivation. These range from $4–10M for the US and $3–10M for China. The median annual contribution in the sample is $40M for the US and $1.5M for China, so these are substantial effects, particularly for China. Additionally, there is substantial overlap in the recipients most sensitive to

Recipient	Change in Eqm. Aid
Haiti	\$10.2M
South Sudan	\$9.5M
Kenya	\$7.1M
Egypt	\$6.5M
Colombia	\$5.3M
Tanzania	\$5.3M
Sudan	\$5.2M
Zambia	\$5M
Ghana	\$4.1M
Mexico	\$4.1M

(a) Aid from USA.

Recipient	Change in Eqm. Aid
El Salvador	\$9.8M
Bangladesh	\$6.5M
Zambia	\$6.3M
Dominican Republic	\$4.2M
Jordan	\$4.1M
Sri Lanka	\$3.9M
Ghana	\$3.7M
Kenya	\$3.4M
Burkina Faso	\$3.3M
Mexico	\$3.2M

(b) Aid from China.

Table 5. For each donor, the ten recipients with the largest average decrease in equilibrium aid comparing estimated parameters to setting $\Pi_{imt} = 0$.

these strategic effects, with Ghana, Kenya, Mexico, and Zambia on both lists.

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Appendix to "Strategic Foreign Aid: A Structural Approach"

A Estimation details

A.1 First stage

For each donor i, we generate exogenous aid predictions $\hat{d}_{imt}$ with a pair of ridge regressions. First, we run a linear probability model of the form

$$\mathbf{1}\{d_{imt} > 0\} = \mathbf{x}_{imt}\alpha_i + \xi_{imt}$$

on the full sample. Then, using the subsample of observations with strictly positive aid, we run a log-linear model of the form

$$\log(d_{imt}) = \mathbf{x}_{imt}\lambda_i + \nu_{imt}.$$

We estimate both models with a ridge regression where the regularization parameter is selected through 10-fold cross-validation, via the `glmnet` R package. We exclude the intercept, as well as coefficients on the instruments $\mathbf{z}_{imt}$, from the ridge penalty in both equations. Finally, we generate the aid predictions $\hat{d}_{imt}$ using the predicted values from the linear model, trimming the predictions from the first model to ensure that they are nondegenerate probabilities:

$$\hat{d}_{imt} = \begin{cases} 0.01 \cdot \exp(\mathbf{x}_{imt}\hat{\lambda}_i) & \text{if } \mathbf{x}_{imt}\hat{\alpha}_i < 0.01, \\ \mathbf{x}_{imt}\hat{\alpha}_i \cdot \exp(\mathbf{x}_{imt}\hat{\lambda}_i) & \text{if } 0.01 \leq \mathbf{x}_{imt}\hat{\alpha}_i \leq 0.99, \\ 0.99 \cdot \exp(\mathbf{x}_{imt}\hat{\lambda}_i) & \text{if } \mathbf{x}_{imt}\hat{\alpha}_i > 0.99. \end{cases}$$

A.2 Constrained estimation

As noted in the main text, the solution to Equation 4 may sometimes result in estimates of the structural parameters that violate the nonnegativity constraints in the underlying model. This creates complications for assessing model fit and performing counterfactual experiments, so we employ a constrained estimator that ensures valid values of the structural parameters. Specifically, we solve the quadratic program

$$\begin{aligned} \min_{\beta_i,\gamma_i} \quad & [\mathbf{a}_i + \mathbf{X}_i\boldsymbol{\beta}_i + \mathbf{W}_i\gamma_i]'\mathbf{V}_i\mathbf{V}_i'[\mathbf{a}_i + \mathbf{X}_i\boldsymbol{\beta}_i + \mathbf{W}_i\gamma_i] \\ \text{s.t.} \quad & \mathbf{X}_i^{\text{full}}\boldsymbol{\beta}_i \geq \mathbf{0}, \\ & \tilde{\mathbf{X}}_i^{\text{full}}\gamma_i \geq \mathbf{0}. \end{aligned} \tag{A1}$$

The two sets of constraints encode the nonnegativity restrictions on the cost and strategic spillover parameter for each observation in the full data (not just the subsample of observations with positive aid used to evaluate the objective function). We implement this estimator via the —quadprog— function in R.

A.3 Selection of normalizing constants

Recall that we employ the functional forms $u(d_{imt}) = \log(d_{imt} + \delta)$ for the non-strategic benefit of aid and

$$p_i(d_{imt}, d_{jmt}) = \frac{d_{imt} + \varepsilon}{d_{imt} + d_{jmt} + 2\varepsilon}$$

for the contest success function in the strategic benefit. The constants $\delta > 0$ and $\varepsilon > 0$ ensure that each donor's expected utility is twice continuously differentiable at all feasible values of (d_{imt}, d_{jmt}), even when one or both components are zero. To select these constants, we:

1. Generate a grid of candidate values.

2. Estimate the model by solving Equation A1 at each candidate pair of δ and ε.[20]

3. Using the results of each estimated model, calculate fitted equilibrium spending for each observation in the full sample of data and compare it to the observed values.

4. Select the pair of δ and ε that yield the lowest median absolute deviation between the fitted equilibrium values and the observed values.

We ultimately select $\delta = 0.035$ and $\varepsilon = 0.02$.

B Contextual variables

We now describe the variables that enter into the strategic value, Π_{imt} and marginal cost terms C_{imt}. This section also gives a brief rationale for their inclusion in each equation. Overall, the variables in the strategic value increase benefits to the donor by attaining the target country's favor, which cannot be enjoyed at the same level by the other donor. Preferential commercial deals, military cooperation, or support in international fora could represent that prize. The marginal costs will include factors that are part of the explicit goals of foreign aid. Donor governments that deviate from previously stated foreign aid goals will incur higher marginal costs.

B.1 Strategic value variables

1. GDP per capita: winning the support of a richer recipient is more beneficial to the donor. For example, a richer new commercial partner offers donors a larger market for its products. This variable is taken from the World Development Indicators (World Bank 2024).

2. Population: a larger population in a recipient country could represent a larger demand for the donor's products. This variable is taken from the World Development Indicators (World Bank 2024).

3. Elections: the variable takes the value of one in years of executive elections. The recipient's electoral cycle might alter the incentives to donate (Faye and Niehaus 2012). If the target's incumbent gets a boost (via aid) in the electoral cycle and he/she wins, the election winner might reciprocate. The variable is taken from NELDA (Hyde and Marinov 2012).

[20] We use the same first stage values $\hat{d}_{imt}$ throughout this process, as their calculation does not depend on the normalizing constants.

4. Natural resource rents: Indicator taken from the World Development Indicators (World Bank 2024). It captures the differences between the price of commodities and the average cost of producing them. These differences are then multiplied by quantities of the commodity and are expressed as percentages of GDP. The commodities included are oil, natural gas, coal, mineral, and forest. It is expected that countries with more resource rents are more attractive to have as allies

5. Temporary membership in the UN Security Council: the dummy variable takes the value of one if the country is on the UN Security Council Dreher et al. (2022). Data was updated by the authors. Donors are interested in buying support from council members to ensure their future support in this council (Dreher, Sturm and Vreeland 2009).

B.2 Instruments

Two variables allow us to create instruments for US aid based on previous work:

- Nunn and Qian (2014) use wheat production to create an instrument for US food aid in civil conflict onset and duration models. The intuition is that most US food aid is wheat and that one of the functions of US food aid is to distribute US agricultural production surpluses (p. 1636). As in the original paper, we lag wheat production by one year. To construct the instrument, we interact the (lagged) US wheat production with a given recipient's (time-invariant) probability of receiving food aid from the US in a given year. This probability comes from dividing the years in which the recipient received US food aid by the total number of years in the analysis period.

- As in Ahmed (2016), we use US legislative fractionalization to build an instrument for US aid. The intuition is that legislative fractionalization tends to increase budgets, including foreign aid budgets because it leads politicians to provide program benefits to voters and incentivizes legislative logrolling (p. 10). Unlike the main specification of Ahmed (2016), we use the average fragmentation of both legislative chambers, and we augment the index by accounting for polarization. This is important, as in a context with no policy disagreements across parties, buying legislative support (which induces greater spending) is no longer necessary (Nupia 2013). We need a fractionalization component and a polarization one to create our instrument. The fractionalization component is calculated as 1 minus the absolute difference in the number of Democrats and Republicans divided by the number of legislators in the chamber, multiplied by 100. The polarization component is the distance between the average DW nominate scores of democrats and republicans in the chamber normalized by 2 (the maximum distance) and multiplied by 100. Finally, we add the fractionalization component to the product of fractionalization and polarization. With the average of these indexes (across chambers) in hand, we interact with the fixed probability that a given country receives aid in a given year.

As for the instrument for Chinese aid, we follow Dreher et al. (2021), by using the production of steel, cement, iron, glass, and timber. As with the wheat instrument, production surpluses are often used for foreign aid. We use the first factor from a factor analysis of the detrended and logged production figures. We interact it with the probability of receiving Chinese development finance.

B.3 Marginal costs variables

1. GDP per capita: recipient need is a key determinant of aid allocation for the United States. Bilateral development assistance and humanitarian assistance accounted for more than half of the aid given by the US in 2019 (Congressional Research Service 2022).

2. Democracy levels: the US explicitly uses foreign aid to promote democracy (Finkel, Pérez-Liñán and Seligson 2007), and the literature emphasizes how the democratic institutions of the recipient moderate the effectiveness of foreign aid in supporting economic development. We use the Electoral democracy index from V-Dem. The index captures the freedom of political and civil organizations, clean elections, freedom of expression, and institutional checks and balances (Coppedge et al. 2021).

3. Civil liberties. We modify V-Dem's Civil Liberties original index by excluding the Political Civil Liberties index from its components. We do this because the Electoral Democracy Index shares most of its components with the Political Civil Liberties Index, which is part of the Electoral Democracy Index (also included in the value equation) (Coppedge et al. 2021). The index is increasing in greater civil liberties.

4. Corruption: To promote good governance, the US seeks not to send aid to corrupt regimes. We use V-Dem's Political Corruption Index, which captures corruption from the three branches of government and other public sector institutions (Coppedge et al. 2021). The index is increasing in greater corruption.

5. World bank foreign aid: it might be easier to donate to a recipient that has not been previously supported by multilateral organizations. The variable is the World Bank ODA aid received in millions of constant US dollars. This variable is taken from OECD.

6. IMF foreign aid: IMF ODA aid received in millions of constant US dollars. This variable is taken from OECD.

C Summary Statistics

Variable	Mean	Median	SD	Min	Max
Panel A: Aid Commitments					
US commitments (millions USD)	148.99	32.08	454.63	0.00	13133.30
China commitments (millions USD)	52.26	0.54	261.86	0.00	9331.27
Panel B: Covariates					
GDP per capita (thousands USD)	5.77	3.19	8.28	0.25	73.49
Electoral democracy	0.44	0.43	0.23	0.01	0.91
Civil liberties	0.63	0.68	0.24	0.02	0.96
Corruption	0.62	0.67	0.24	0.04	0.97
World Bank aid (millions USD)	55.10	0.00	160.62	0.00	2167.08
IMF aid (millions USD)	9.01	0.00	43.03	0.00	964.83
Natural disaster dummy	0.63	1.00	0.48	0.00	1.00
Population (millions)	38.09	7.61	147.92	0.01	1411.10
Election dummy	0.11	0.00	0.32	0.00	1.00
Natural resource rents (pct. GDP)	8.75	3.53	11.95	0.00	88.59
Member, UN Security Council	0.06	0.00	0.24	0.00	1.00

Table C1. Summary Statistics.

	Negative avg. growth in Chinese aid	Positive avg. growth in Chinese aid
Negative avg. growth in US aid	76 (-0.98, -0.30)	15 (-0.63, 1.73)
Positive avg. growth in US aid	36 (2.79, -0.90)	27 (0.75, 0.37)

Table C2. Year-to-year average change in aid. Recipients are categorized according to whether the average increase in aid was positive or negative. The first number indicates the number of recipients in each category, and, in parentheses, the average change of aid normalized by population dollars for the US and China, respectively.

	Negative avg. growth in Chinese aid	Positive avg. growth in Chinese aid
Negative avg. growth in US aid	Albania, Antigua and Barb., Armenia, Azerbaijan, Bahamas, Bahrain, Barbados, Belarus, Bosnia and Herz., Botswana, Brunei, Bulgaria, Colombia, Comoros, Congo, Cuba, Dem. Rep. Congo, Dominica, Ecuador, El Salvador, Eq. Guinea, Eritrea, Gambia, Georgia, Grenada, Guatemala, Guinea, Haiti, Hungary, India, Indonesia, Iraq, Jamaica, Jordan, Kazakhstan, Kenya, Kiribati, Kuwait, Libya, Maldives, Marshall Is., Mongolia, Montenegro, Morocco, Nauru, North Korea, North Macedonia, Oman, Pakistan, Palau, Palestine, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Qatar, Romania, Russia, S. Sudan, Saudi Arabia, Serbia, Seychelles, Sierra Leone, Solomon Is., Sri Lanka, St. Kitts and Nevis, St. Vin. and Gren., São Tomé and Principe, Trinidad and Tobago, Tuvalu, United Arab Emirates, Uruguay, Venezuela, Zambia	Angola, Benin, Bolivia, Egypt, Gabon, Ghana, Kyrgyzstan, Mauritania, Mauritius, Moldova, Samoa, Tajikistan, Timor-Leste, Uzbekistan, Vanuatu
Positive avg. growth in US aid	Algeria, Argentina, Belize, Bhutan, Brazil, Burkina Faso, Chad, Chile, Costa Rica, Dominican Rep., Guinea-Bissau, Guyana, Honduras, Iran, Laos, Lebanon, Madagascar, Malaysia, Mexico, Nicaragua, Niger, Nigeria, Rwanda, Saint Lucia, South Africa, Sudan, Syria, Thailand, Togo, Tonga, Tunisia, Turkey, Turkmenistan, Uganda, Vietnam, eSwatini	Afghanistan, Bangladesh, Burundi, Cabo Verde, Cambodia, Cameroon, Central African Rep., Côte d'Ivoire, Djibouti, Ethiopia, Fiji, Lesotho, Liberia, Malawi, Mali, Micronesia, Mozambique, Myanmar, Namibia, Nepal, Senegal, Somalia, Suriname, Tanzania, Ukraine, Yemen, Zimbabwe

Table C3. Recipients and year-to-year growth in aid. Countries are categorized according to whether the average increase in aid was positive or negative.

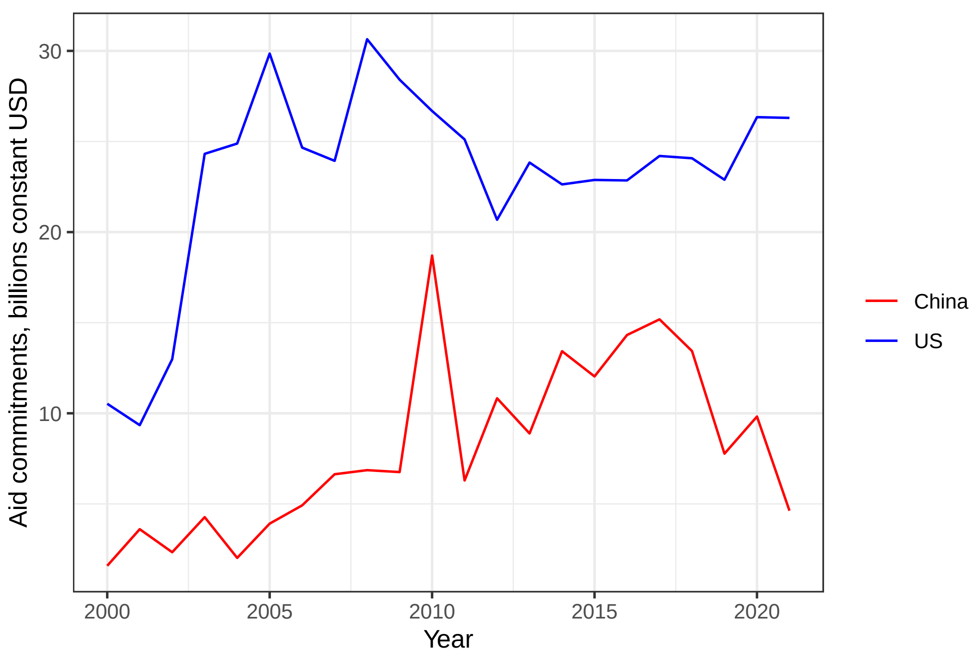

Figure C1. US and China's total development aid 2000-2021.

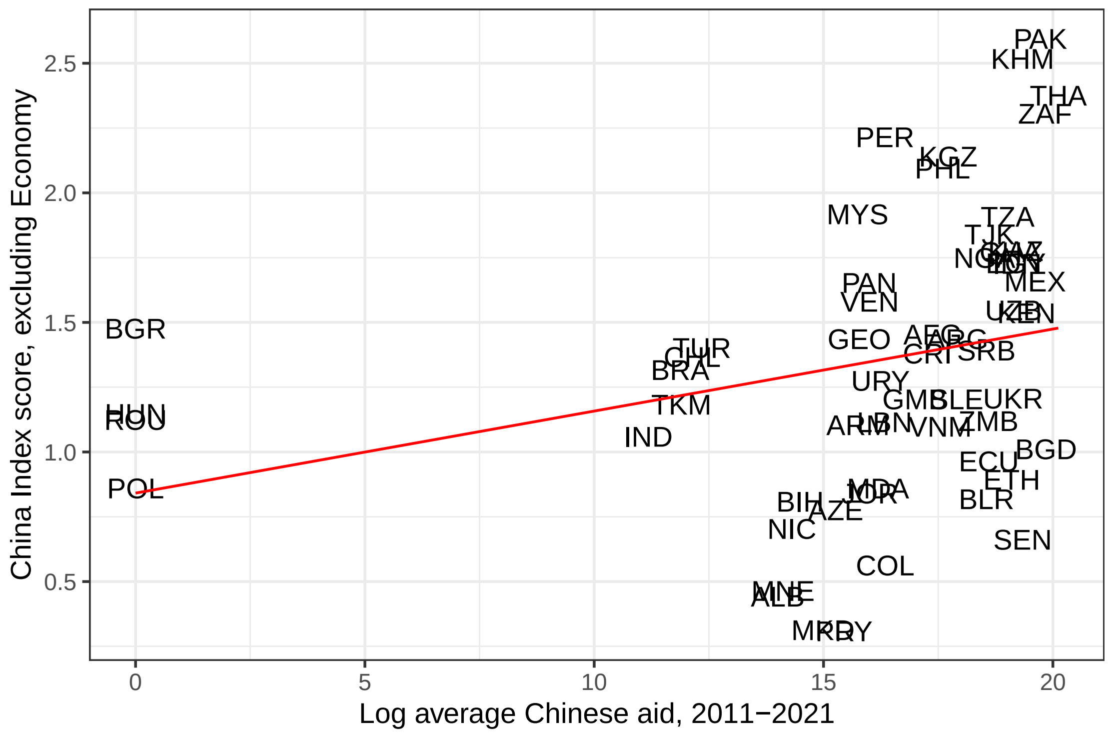

Figure C2. Chinese aid and China Index score (excluding economy component).

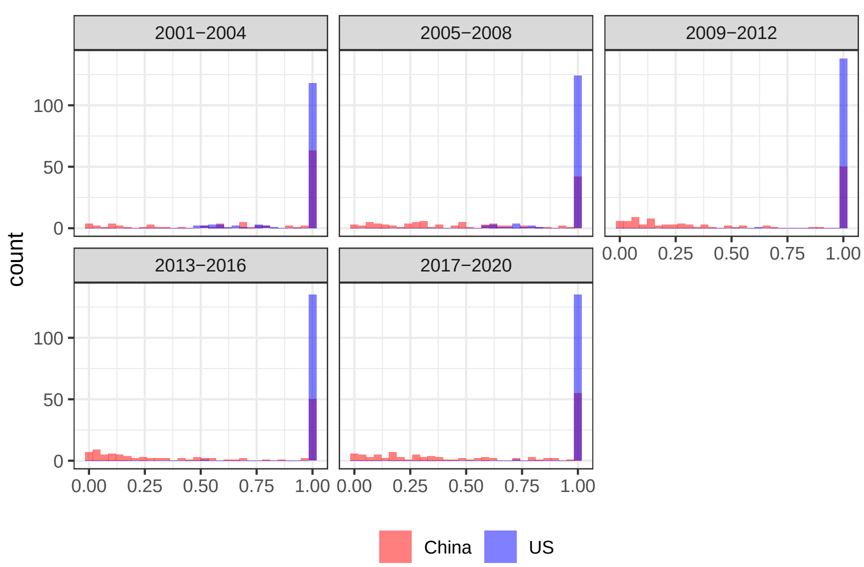

Figure C3. Distribution of proportion of grants by donor by period.

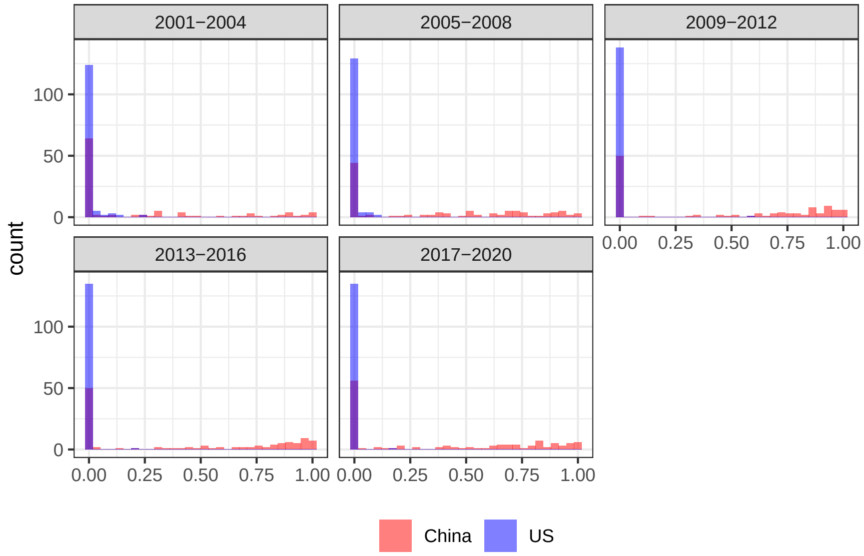

Figure C4. Distribution of proportion of loans by donor by period.

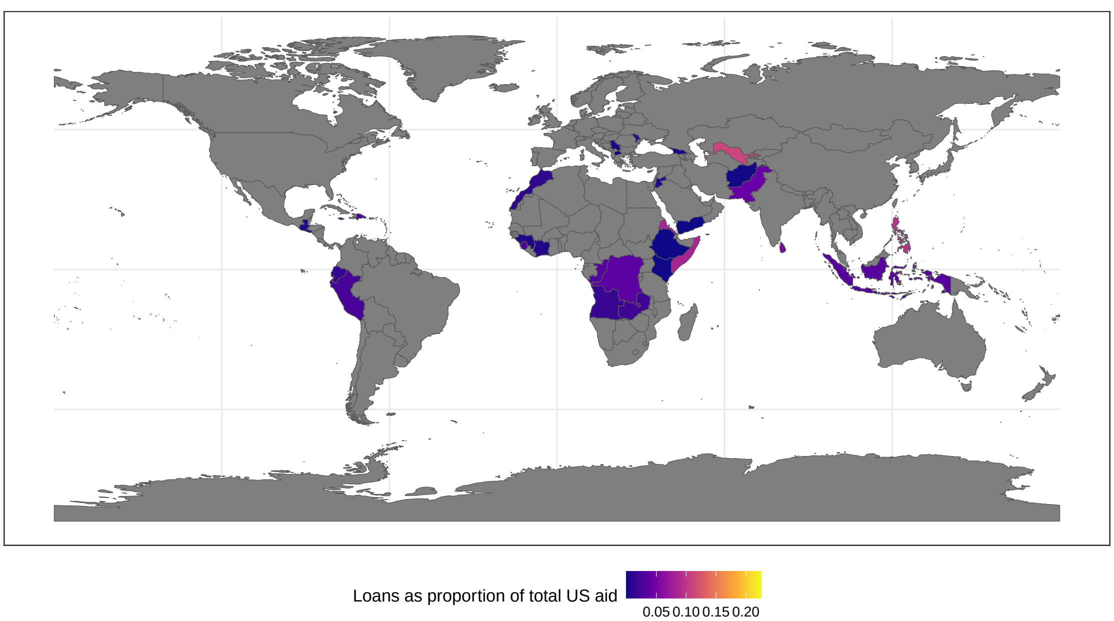

Figure C5. US loan recipients since 2000.

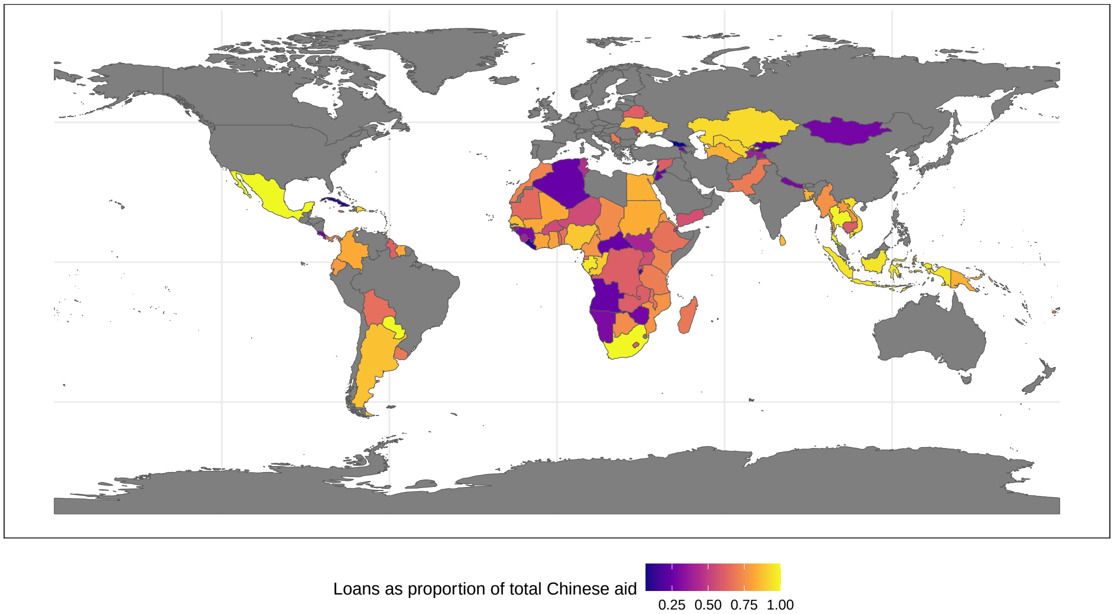

Figure C6. Chinese loan recipients since 2000.

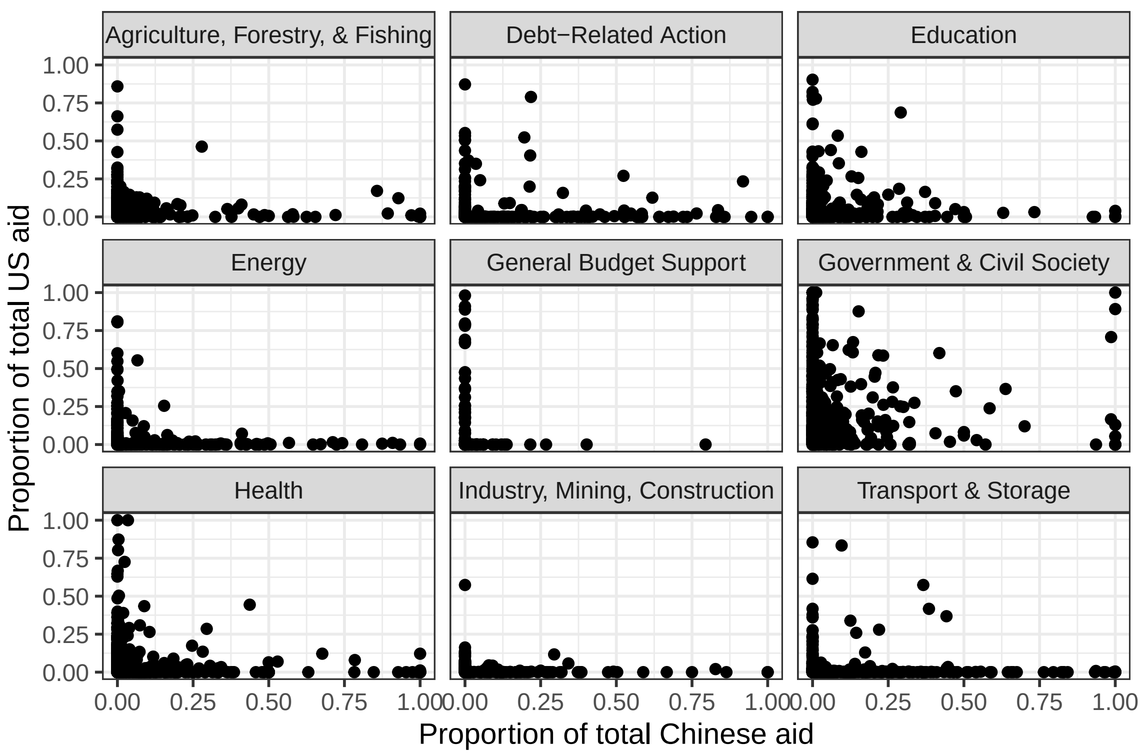

Figure C7. Proportion of sector-specific aid in total aid. Each dot represents a recipient-period.

D Other Tables

Variable	Aid from US and/or China	No aid	t	p value
GDP per capita (log)	7.80	9.43	33.04	<0.001
Electoral democracy	0.44	0.41	-1.35	0.18
Civil liberties	0.63	0.68	3.75	<0.001
Corruption	0.64	0.41	-15.67	<0.001
World Bank aid (log)	1.76	0.15	-32.98	<0.001
IMF aid (log)	0.59	0.01	-22.12	<0.001
Natural disaster dummy	0.67	0.37	-12.48	<0.001
Population (log)	15.69	14.28	-10.93	<0.001
Election dummy	0.12	0.06	-4.75	<0.001
Natural resource rents (pct. GDP)	8.25	12.23	5.02	<0.001
Member, UN Security Council	0.06	0.08	1.54	0.12

Table D4. Difference in means by donor mix. This table reports differences in means test of covariates. The tests assumes different variances across groups. No aid indicates that the country in that year is receiving aid from the US or China. There are 2,970 observations where the developing country receives aid from at least one of the donors and 440 observations where the developing country does not.

Term	$\Pr(d_{\text{USA}} > 0)$	$E[\log(d_{\text{USA}})]$	$\Pr(d_{\text{China}} > 0)$	$E[\log(d_{\text{China}})]$
log(GDP per Capita)	0.000	−0.299**	−0.052**	−0.083**
	(0.000)	(0.108)	(0.009)	(0.024)
log(Population)	0.000	0.306**	−0.002	0.030*
	(0.000)	(0.046)	(0.007)	(0.015)
Electoral Democracy	0.000	0.617†	0.012	−0.163†
	(0.003)	(0.327)	(0.040)	(0.088)
Civil Liberties	0.000	−0.334	−0.019	−0.228**
	(0.001)	(0.252)	(0.040)	(0.085)
Corruption	0.000	0.173	0.040	0.079
	(0.001)	(0.368)	(0.043)	(0.084)
Disaster	0.000	0.148**	0.009	0.027
	(0.001)	(0.055)	(0.013)	(0.039)
log(1 + World Bank Aid)	0.000	0.089**	0.011**	0.032**
	(0.000)	(0.018)	(0.003)	(0.010)
log(1 + IMF Aid)	0.000	0.046**	0.013**	0.034**
	(0.000)	(0.014)	(0.004)	(0.010)
Pr(US Aid) × Fractionalization	0.206**	1.896**		
	(0.011)	(0.301)		
Pr(US Aid) × Wheat Production	0.217**	0.591†		
	(0.017)	(0.337)		
Pr(China Aid) × China Production Index			0.055**	0.086*
			(0.007)	(0.043)
Year FEs	✓	✓	✓	✓
Recipient FEs	✓	✓	✓	✓
Observations	2795	2592	2795	1718
Clusters	150	150	150	150

Table D5. Coefficient estimates for the first stage models. All are linear models estimated via ridge regression, with the ridge penalty parameter selected by 10-fold cross-validation. The instrumental variables are excluded from the ridge penalty. Standard errors are estimated by pairs cluster bootstrap, with clustering at the recipient level.

E Other Figures

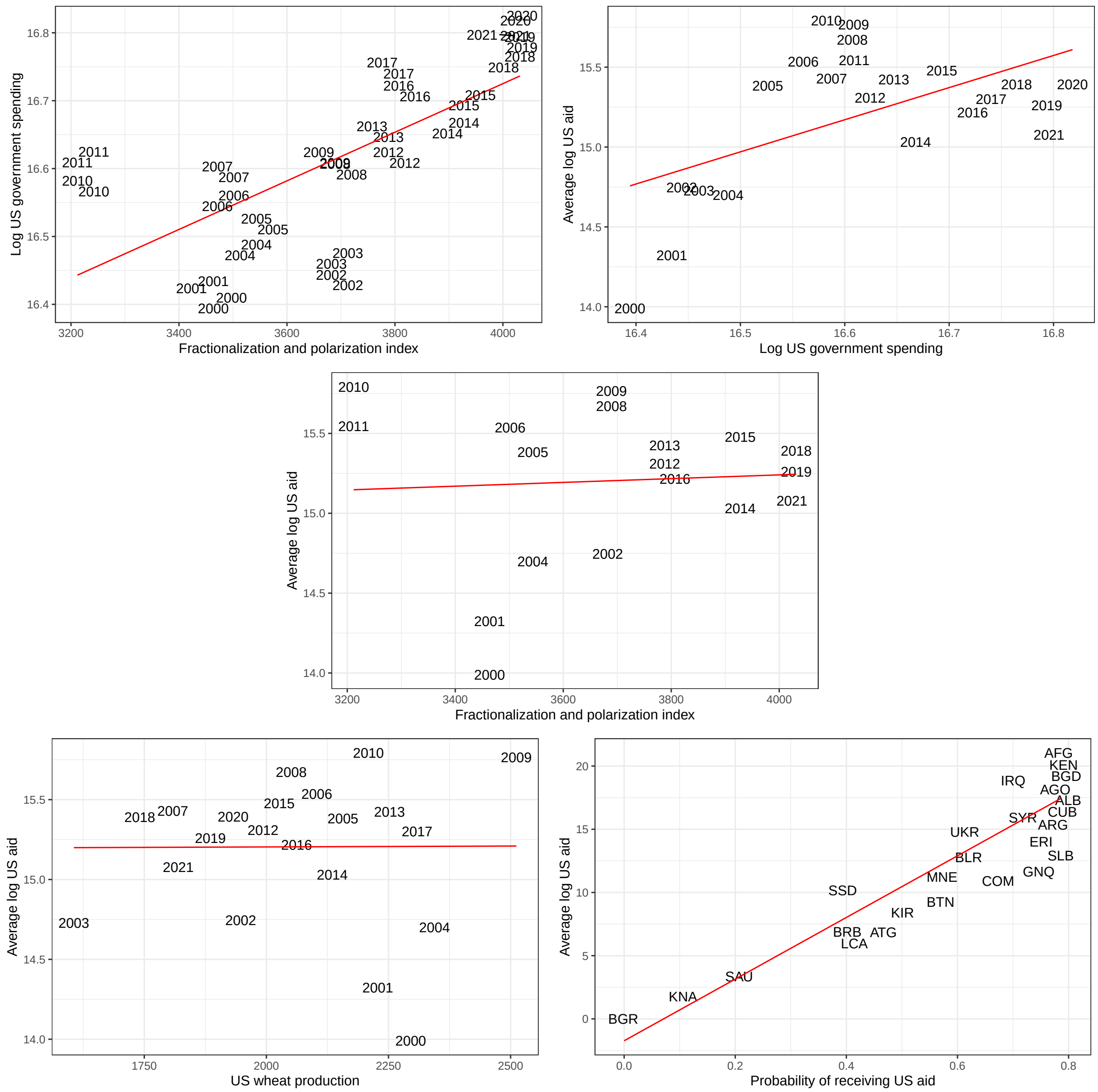

Figure E8. US aid, legislative fragmentation, government expenditures, wheat production, and propensity to receive aid from the US

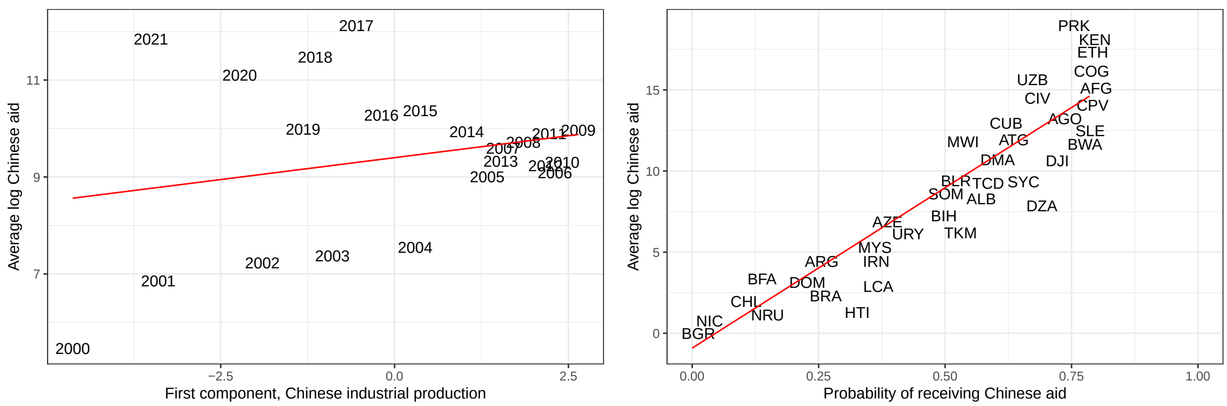

Figure E9. China aid, raw materials production, and propensity to receive aid from China

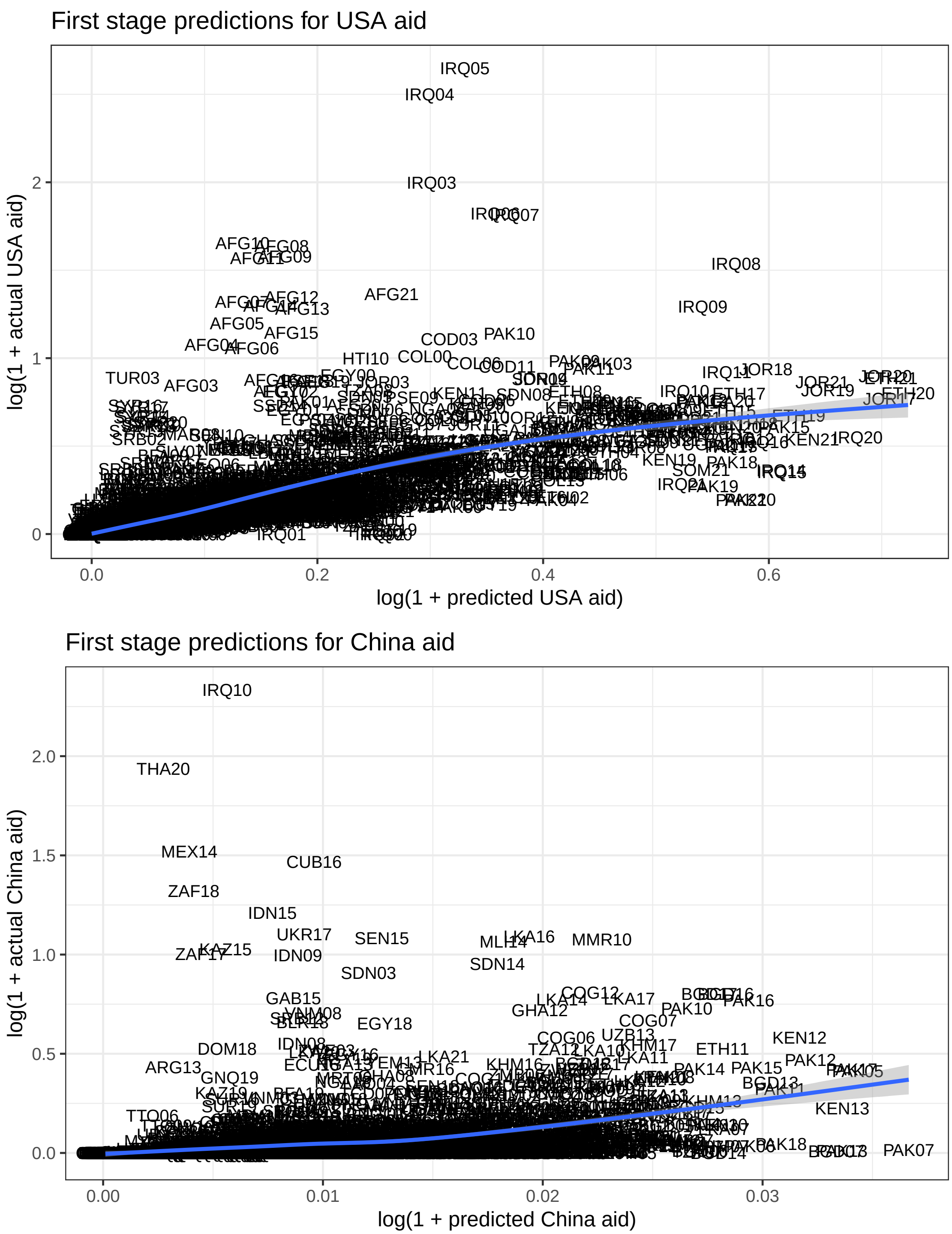

Figure E10. Predicted values from the first stage model (used in moment conditions of the structural model) versus actual aid for each donor.

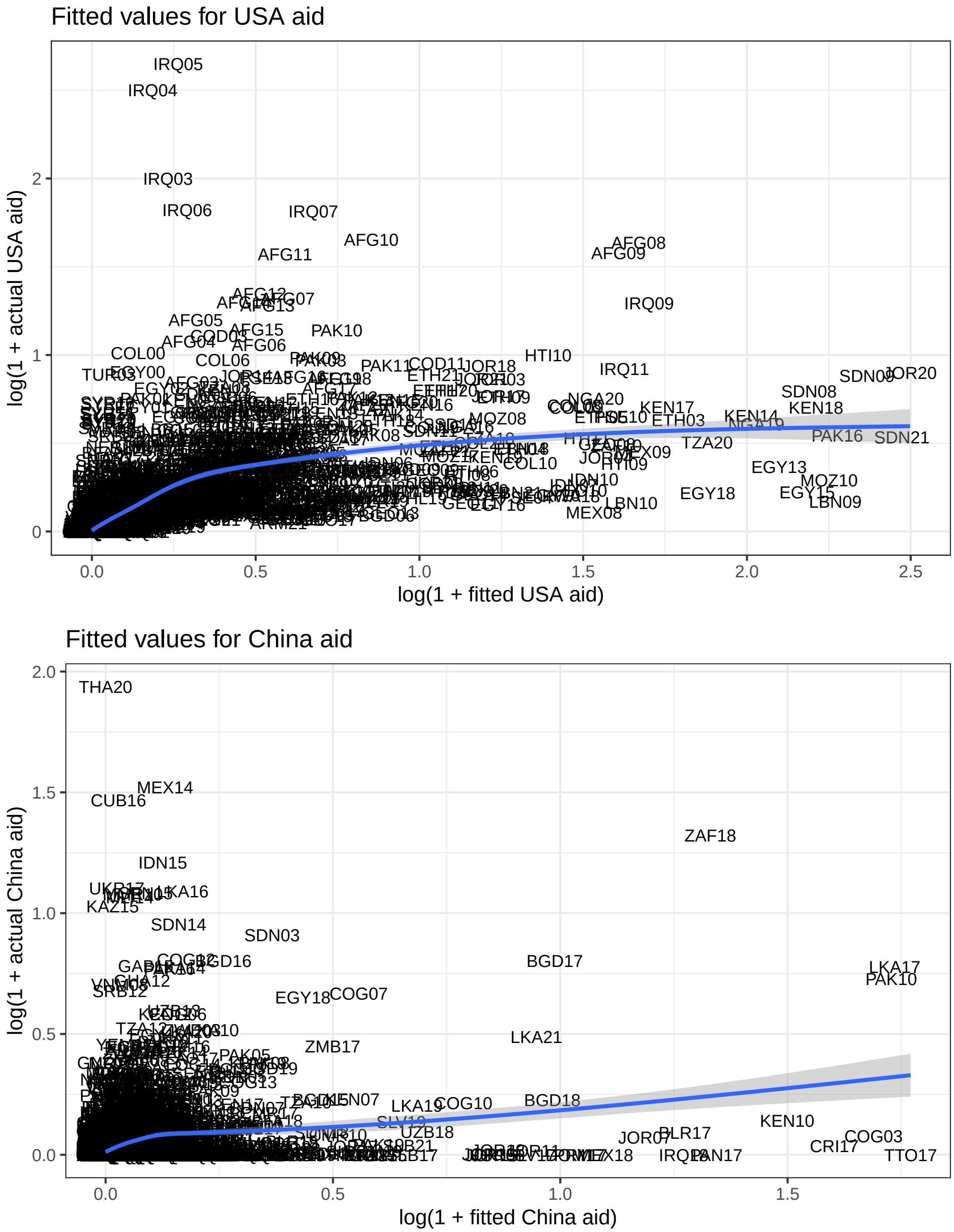

Figure E11. Predicted values from the structural model, calculated by deriving the Nash equilibrium allocations for each recipient-year, versus actual aid for each donor.

F Existence and Uniqueness

Focus on the simple game. We have players 1 and 2 who simultaneously choose $d_1, d_2 \in [0, \infty)$. With a generalized Tullock contest success function, the payoffs are

$$U_i(d_i, d_j) = u_i(d_i) + \Pi_i \frac{f_i(d_i)}{f_i(d_i) + f_j(d_j)} - c_i(d_i) \tag{A1}$$

Our first assumption is $\Pi_i > 0$. We will assume the following:

A1) $u_i'' < 0$, u_i'' is continuous, and $\lim_{x\to\infty} u_i'(x) \leq 0$

A2) $f_i > 0$, $f_i' > 0$, $f_i'' \leq 0$, and f_i'' is continuous

A3) $c_i(0) = 0$, $c_i' > 0$, $c_i'' \geq 0$, and c_i'' is continuous

Remark 1. *Szidarovszky and Okuguchi (1997) have a different uniqueness proof in which $u(d_i) = 0$, $c_i(d_i) = d_i$, and f_i satisfies A2 and is* strictly *concave.*

Remark 2. *We can accommodate $\Pi_i \geq 0$ and keep A1-A3 without changing the existence and uniqueness results. We can also drop $f_i > 0$, but the assumption matches our implementation and allows us to side step U_i being undefined.*

We will need to work with first and second derivatives of U_i. Specifically,

$$\begin{aligned}
\frac{\partial U_i}{\partial d_i} &= u_i'(d_i) + \Pi_i \frac{f_i'(d_i) f_j(d_j)}{(f_i(d_i) + f_j(d_j))^2} - c_i'(d_i), \\
\frac{\partial^2 U_i}{\partial d_i^2} &= u_i''(d_i) + \Pi_i \frac{\left(f_i''(d_i)(f_j(d_j) + f_i(d_i)) - 2 f_i'(d_i)^2\right) f_j(d_j)}{(f_i(d_i) + f_j(d_j))^3} - c_i''(d_i), \text{ and} \\
\frac{\partial^2 U_i}{\partial d_i \partial d_j} &= \Pi_i \frac{(f_i(d_i) - f_j(d_j)) f_i'(d_i) f_j'(d_j)}{(f_i(d_i) + f_j(d_j))^3}.
\end{aligned}$$

Notice $\frac{\partial^2 U_i}{\partial d_i^2} < 0$, so U_i is strictly concave in d_i. In addition, $\frac{\partial^2 U_i}{\partial d_i \partial d_j} > 0$ if and only if $f_i(d_i) > f_j(d_j)$, and $\frac{\partial^2 U_i}{\partial d_i \partial d_j} = 0$ if and only if $f_i(d_i) = f_j(d_j)$

We want to study best responses so we can prove existence and uniqueness of pure-strategy equilibria. In fact, because U_i is strictly concave in d_i, it is with out loss of generality to focus on pure-strategy equilibria, so we will just call them equilibria hereafter. Best responses are defined as:

$$BR_i(d_j) = \underset{d_i \in [0,\infty)}{\arg\max}\, U_i(d_i, d_j).$$

The next Lemma is a useful preliminary result to be invoked later.

Lemma 1. *The function $D_i(x) \equiv u_i'(x) + \Pi_i \frac{f_i'(x)}{4 f_i(x)} - c_i'(x)$ satisfies the following properties: (i) it is continuous and strictly decreasing, and (ii) $\lim_{x\to\infty} D_i(x) < 0$.*

Proof. First, by A1-A3, D_i is differentiable, where

$$D_i'(x) = u_i''(x) + \frac{\Pi_i}{4}\left(\frac{-(f_i'(x))^2 + f_i''(x)f_i(x)}{(f_i(x))^2}\right) - c_i''(x),$$

and $D_i'(x) < 0$. Second, we want to sign

$$\lim_{x\to\infty} D_i(x) = \lim_{x\to\infty} u_i'(x) + \Pi_i \lim_{x\to\infty} \frac{f_i'(x)}{4f_i(x)} - \lim_{x\to\infty} c_i'(x).$$

By A1, $\lim_{x\to\infty} u_i'(x) \leq 0$. By A3, c' is positive and weakly increasing. So $-\lim_{x\to\infty} c_i'(x)$ is either a negative number or negative infinity. Thus, a sufficient condition for $\lim_{x\to\infty} D_i(x) < 0$ is that $\lim_{x\to\infty} \frac{f_i'(x)}{4f_i(x)} = 0$.

To argue this, note that $f_i'(x)$ is weakly decreasing and $f_i'(x) > 0$ (by A2). Thus, $\lim_{x\to\infty} f_i'(x)$ exists and is nonnegative. Call this limit $L_1 = \lim_{x\to\infty} f_i'(x)$. Because f_i is strictly increasing, we have two cases.

Case 1: $\lim_{x\to\infty} f_i(x) = \infty$. In this case, $\lim_{x\to 0} \frac{1}{4f_i(x)} = 0$. Because $L_1 \in [0, \infty)$,

$$\lim_{x\to\infty} \frac{f_i'(x)}{4f_i(x)} = \lim_{x\to\infty} f_i'(x) \lim_{x\to 0} \frac{1}{4f_i(x)} = L_1 0 = 0.$$

Case 2: $\lim_{x\to\infty} f_i(x) = K$ for some $K \in [0, \infty)$. In fact, $K > 0$ because $f_i(0) > 0$ and f_i is increasing. We claim that $L_1 = \lim_{x\to\infty} f_i'(x) = 0$. To see this, suppose not, i.e., $L_1 > 0$. Pick $x > 0$ and $y > 0$. By concavity we have

$$f(x) - f(x+y) \leq f'(x+y)(x - x - y) \iff \frac{f(x) - f(x+y)}{y} + f'(x+y) \leq 0.$$

We want to take the limit of the left-hand side as $y \to \infty$. To do this, note that $\lim_{y\to\infty} \frac{1}{y} = 0$, and $\lim_{y\to\infty} f(x+y) = K$. Both of these are finite. Thus,

$$\lim_{y\to\infty} \frac{f(x) - f(x+y)}{y} + \lim_{y\to\infty} f'(x+y) = 0 + L_1 > 0,$$

which contradicts $\frac{f(x)-f(x+y)}{y} + f'(x+y) \leq 0$ for all $x, y > 0$. Thus $L_1 = 0$, and $\lim_{x\to\infty} \frac{f_i'(x)}{4f_i(x)} = \frac{L_1}{4K} = 0$. □

Lemma 2. *There exists a cutpoint $d_i^+ \in [0, \infty)$ such that, for all d_j, $BR_i(d_j) \leq d_i^+$. Moreover, $BR_i(d_j)$ is nonempty and a singleton.*

Proof. First, note that, for all d_i and d_j,

$$\begin{aligned}\frac{\partial U_i}{\partial d_i}(d_i, d_j) &= u_i'(d_i) + \Pi_i \frac{f_i'(d_i) f_j(d_j)}{(f_i(d_i) + f_j(d_j))^2} - c_i'(d_i) \\ &\leq u_i'(d_i) + \Pi_i \frac{f_i'(d_i) f_i(d_i)}{(f_i(d_i) + f_i(d_i))^2} - c_i'(d_i) \\ &= u_i'(d_i) + \Pi_i \frac{f_i'(d_i)}{4 f_i(d_i)} - c_i'(d_i) = D_i(d_i)\end{aligned}$$

By Lemma 1, there exists d_i^+ such that, for all $d_i > d_i^+$ and all d_j

$$0 > D_i(d_i) \geq \frac{\partial U_i}{\partial d_i}(d_i, d_j).$$

Thus, any $d_i > d_i^+$ cannot be a best response for every d_j. Hence, we can rewrite i's best response as $BR_i(d_j) = \arg\max_{d_i \in [0, d_i^+]} U_i(d_i, d_j)$, which is non-empty because U_i is continuous and $[0, d_i^+]$ is compact. Finally, $BR_i(d_j)$ must be unique because U_i is strictly concave. □

Theorem 1. *An equilibrium exists.*

Proof. By Lemma 2, we can write i's strategy space as $[0, d_i^+]$ because any $d_i > d_i^+$ can never be a best response to any d_j, which means d_i can never be a strategy in an equilibrium. Because U_i is concave in d_i and continuous in d_j, existence follows immediately from Debreu, Glicksberg, and Fan's Theorem. □

Definition 1. *A profile $d = (d_1, d_2)$ is* interior *if $d_1 > 0$ and $d_2 > 0$. A profile is a* corner *profile if it is not interior.*

Lemma 3. *If d^* and $d^\dagger$ are two equilibria such that $d^* \neq d^\dagger$, then $d_i^* \neq d_i^\dagger$ for both $i = 1, 2$.*

Proof. Suppose not. Thus, there exists i such that $d_i^\dagger \neq d_i^*$ and $j \neq i$ such that $d_j^* = d_j^\dagger$. But that means both $d_i^\dagger$ and d_i^* are best responses to $d_j = d_j^* = d_j^\dagger$, which contradicts U_i being strictly concave in d_i. □

Lemma 4. *If d^* is a corner equilibrium, then it is the unique corner equilibrium.*

Proof. Suppose not. Then there are two corner equilibria: d^* and $d^\dagger$. Notice that Lemma 3 implies that if $(0, 0)$ is an equilibrium, it must be unique in the class of corner equilibria. Thus, we can relabel the equilibria such that $d_i^* = d_j^\dagger = 0$, $d_j^* > 0$, $d_i^\dagger > 0$, and $f_i(d_i^\dagger) \geq f_j(d_j^*)$.

Because $d_i^\dagger > 0$, i's FOC must be satisfied:

$$\begin{aligned}0 &= \frac{\partial U_i}{\partial d_i}(d_i^\dagger, d_j^\dagger) \\ &= \frac{\partial U_i}{\partial d_i}(d_i^\dagger, 0) \\ &< \frac{\partial U_i}{\partial d_i}(d_i^\dagger, d_j^*) \\ &< \frac{\partial U_i}{\partial d_i}(0, d_j^*).\end{aligned}$$

The first inequality follows, because $\frac{\partial U_i}{\partial d_i}(d_i^\dagger, d_j)$ is strictly increasing in d_j for $d_j \in [0, d_j^*)$. To see why note that $\frac{\partial^2 U_i}{\partial d_i \partial d_j} > 0$ iff $f_j(d_j) < f_i(d_i)$, and we have assumed $f_i(d_i^\dagger) \geq f_j(d_j^*)$, $d_j^* > 0$, and f_j is strictly increasing. In addition, at $d_j = d_j^*$, $\frac{\partial^2 U_i}{\partial d_i \partial d_j} \geq 0$. The second inequality follows because U_i is strictly concave in d_i. Thus, $0 < \frac{\partial U_i}{\partial d_i}(0, d_j^*)$, but this means $d_i^* = 0$ cannot be a best response to d_j^*, a contradiction. □

Lemma 5. *If d^* is an interior equilibrium, then it is the unique interior equilibrium.*

Proof. Because U_i is strictly concave, interior equilibria will solve the necessary and sufficient FOC for each i. Define $d = (d_1, d_2)$ and $F : (0, \infty)^2 \to \mathbb{R}^2$ as

(A2)
$$F(d) = \begin{pmatrix} c_1'(d) - u_1'(d) - \Pi_1 \frac{f_1'(d_1) f_2(d_2)}{(f_1(d_1)+f_2(d_2))^2} \\ c_2'(d) - u_2'(d) - \Pi_2 \frac{f_2'(d_2) f_1(d_1)}{(f_2(d_2)+f_1(d_1))^2} \end{pmatrix}$$

Because d^* is an interior equilibrium, $F(d^*) = 0$. Our goal is to show that there is at most one solution to $F(d) = 0$.

To do this, notice F is $C1$: its second derivatives exist and are continuous by assumption. Let $JF(d)$ denote the Jacobian of F given profile d. This means

$$JF(d) = \begin{pmatrix} c_1'' - u_1'' - \Pi_1 \frac{(f_1''(\sum_i f_i) - 2(f_1')^2) f_2}{(\sum_i f_i)^3} & \Pi_2 \frac{(f_1 - f_2) f_2' f_1'}{(\sum_i f_i)^3} \\ \Pi_1 \frac{(f_2 - f_1) f_1' f_2'}{(\sum_i f_i)^3} & c_2'' - u_2'' - \Pi_2 \frac{(f_2''(\sum_i f_i) - 2(f_2')^2) f_1}{(\sum_i f_i)^3} \end{pmatrix}.$$

In the expression for $JF(d)$, we drop the dependence on d_i to aid in presentation.

We claim that $JF(d)$ is a P-matrix. Recall that a matrix is a P-matrix if all of its principal minors (determinants of a principal submatrix) are positive. To see $JF(d)$ is a P-matrix, note that the diagonal elements of $JF(d)$ are positive for all $d \in [0, \infty)^2$: we have assumed $c_1'' \leq 0$, $u_1'' < 0$, $f_i > 0$, $f_i' > 0$, and $f_i'' \leq 0$. Thus, we only need to show that the determinant of $JF(d)$ is positive:

$$\begin{aligned} |JF(d)| = &\left(c_1'' - u_1'' - \Pi_1 \frac{\left(f_1''\left(\sum_i f_i\right) - 2(f_1')^2\right) f_2}{\left(\sum_i f_i\right)^3} \right)\left(c_2'' - u_2'' - \Pi_2 \frac{\left(f_2''\left(\sum_i f_i\right) - 2(f_2')^2\right) f_1}{\left(\sum_i f_i\right)^3} \right) \\ &- \left(\Pi_2 \frac{(f_1 - f_2) f_2' f_1'}{\left(\sum_i f_i\right)^3} \right)\left(\Pi_1 \frac{(f_2 - f_1) f_1' f_2'}{\left(\sum_i f_i\right)^3} \right) \end{aligned}$$

The first expression on the right-hand side of the equality is clearly positive because we have already argued that the two diagonal elements of $JF(d)$ are positive. The second expresssion will be negative because $(f_1 - f_2)(f_2 - f_1) \leq 0$. Thus, $|JF(d)| > 0$ for any $d \in [0, \infty)$, and $JF(d)$ is a P-matrix.

Recall that by Lemma 2, we know that if d^* is an interior equilibrium, then $d_i^* \in [0, d_i^+]$ for all i. Moreover, if d_i^* is an interior equilibrium, then $F(d^*) = 0$. Because F is $C1$ and any solution must reside in set that can be written as the Cartesian product of intervals (i.e., $[0, d_1^+] \times [0, d_2^+]$), we can invoke Gale and Nikaido's (1965) Theorem 3 and conclude that d^* is the unique interior equilibrium □

Theorem 2. *There is a unique equilibrium.*

Proof. By Lemmas 4 and 5, if d^* and $d^\dagger$ are equilibria, one of them must be a corner equilibrium and another must be an interior equilibria. As such, label the equilibria and actors such that $d_i^* = 0$ and $d_i^\dagger > 0$. Note that Lemma 3 rules out the possibility that $d_j^* = d_j^\dagger$. Consider four cases.

- *Case 1:* $d_j^* > d_j^\dagger$ and $f_i(d_i^\dagger) \geq f_j(d_j^*)$. So we also have $f_i(d_i^\dagger) > f_j(d_j^\dagger)$ because f_j is strictly increasing. Because $d_i^\dagger > 0$ in the interior equilibrium $d^\dagger$, i's FOC must hold:

$$\begin{aligned} 0 &= \frac{\partial U_i}{\partial d_i}(d_i^\dagger, d_j^\dagger) \\ &< \frac{\partial U_i}{\partial d_i}(d_i^\dagger, d_j^*) \\ &< \frac{\partial U_i}{\partial d_i}(0, d_j^*) \end{aligned}$$

  The first inequality follows because $f_i(d_i^\dagger) \geq f_j(d_j^*) > f_j(d_j^\dagger)$, which implies $\frac{\partial U_i}{\partial d_i \partial d_j}(d_i^\dagger, d_j) > 0$ for all $d_j \in [d_j^\dagger, d_j^*)$ and $\frac{\partial U_i}{\partial d_i \partial d_j}(d_i^\dagger, d_j^*) \geq 0$. The second inequality follows because U_i is strictly concave and $d_i^* = 0 < d_i^\dagger$. Hence, $0 < \frac{\partial U_i}{\partial d_i}(0, d_j^*)$, which implies $d_i^* 0$ cannot be a best response to d_j^*.

- *Case 2:* $d_j^* > d_j^\dagger$ and $f_i(d_i^\dagger) < f_j(d_j^*)$. First note that $f_i(0) < f_i(d_i^\dagger) < f_j(d_j^*)$. This means $\frac{\partial^2 U_j}{\partial d_j \partial d_i}(d_j^*, d_i) > 0$ for all $d_i \in [0, d_i^\dagger]$. Now the proof proceeds along similar lines. Because $d_j^* > d_j^\dagger$, we know $d_j^* > 0$ in equilibrium. As such, j's FOC must hold:

$$\begin{aligned} 0 &= \frac{\partial U_j}{\partial d_j}(d_j^*, d_i^*) \\ &= \frac{\partial U_j}{\partial d_j}(d_j^*, 0) \\ &< \frac{\partial U_j}{\partial d_j}(d_j^*, d_i^\dagger) \\ &< \frac{\partial U_j}{\partial d_j}(d_j^\dagger, d_i^\dagger). \end{aligned}$$

  Above, the last inequality follows becuase $d_j^\dagger < d_j^*$ and U_j is strictly concave in d_j.

- *Case 3:* $d_j^* < d_j^\dagger$ and $f_j(d_j^*) \geq f_i(d_i^*)$. First, note that $d_j^* < d_j^\dagger$ implies $f_j(d_j^*) < f_j(d_j^\dagger)$ because f_j is strictly increasing. Putting everything together, we have

$$f_i(d_i^*) \leq f_j(d_j^*) < f_j(d_j^\dagger).$$

  Hence, $\frac{\partial^2 U_i}{\partial d_i \partial d_j}(d_i^*, d_j) < 0$ for all $d_j \in (d_j^*, d_j^\dagger]$, and $\frac{\partial U_i}{\partial d_i}(d_i^*, d_j^*) \leq 0$. This means $\frac{\partial U_i}{\partial d_i}$ is strictly decreasing in d_j in the interval $[d_j^*, d_i^\dagger]$. Now the proof proceeds along similar lines. In equilibrium, $d_i^* = 0$, so we know that:

$$\begin{aligned} 0 &\geq \frac{\partial U_i}{\partial d_i}(d_i^*, d_j^*) \\ &> \frac{\partial U_i}{\partial d_i}(d_i^*, d_j^\dagger) \\ &> \frac{\partial U_i}{\partial d_i}(d_i^\dagger, d_j^\dagger). \end{aligned}$$

The second strict inequality follows because U_i is strictly concave, so $\frac{\partial U_i}{\partial d_i}$ is strictly decreasing in d_i. Hence, $0 > \frac{\partial U_i}{\partial d_i}(d_j^\dagger, d_j^\dagger)$, but this means $d_i^\dagger > 0$ cannot be a best response to $d_j^\dagger$.

- *Case 4:* $d_j^* < d_j^\dagger$ and $f_j(d_j^*) < f_i(d_i^*)$. Because $d^\dagger$ is the interior equilibrium, we know that j's FOC must hold:

$$\begin{aligned} 0 &= \frac{\partial U_j}{\partial d_j}(d_j^\dagger, d_i^\dagger) \\ &< \frac{\partial U_j}{\partial d_j}(d_j^*, d_i^\dagger) \\ &< \frac{\partial U_j}{\partial d_j}(d_j^*, d_i^*) \end{aligned}$$

  Above, the first strict inequality follows because U_j is strictly concave in d_j and $d_j^* < d_j^\dagger$. To see why the first strict inequality follows, note that because $d_i^* = 0 < d_i^\dagger$, we have $f_j(d_j^*) < f_i(d_i^*) < f_i(d_i^\dagger)$. Thus, $\frac{\partial U_j}{\partial d_j \partial d_i}(d_j^*, d_i) < 0$ for $d_i \in [d_i^*, d_i^\dagger]$, so $\frac{\partial U_j}{\partial d_j}(d_j^*, d_i)$ is strictly decreasing in d_i in the interval $[d_i^*, d_i^\dagger]$. Thus, $0 < \frac{\partial U_j}{\partial d_j}(d_j^*, d_i^*)$, but that means $d_j^* \geq 0$ cannot be a best response to d_i^*. □