# Supporting Information for:
## Complex Dependence in Foreign Direct Investment: Network Theory and Empirical Analysis

### Abstract

We develop theory that accounts for complex dependence in foreign direct investment (FDI) relationships. Conventional theories of FDI focus on firm-, country-, or dyad-level characteristics to account for cross-border capital movements. Yet, today's globalization is characterized by the increasing fragmentation and dispersion of production processes, which gives rise to complex dependence among production relationships. Consequently, FDI flows should be represented and theorized as a network. Specifically, we argue that FDI flows are reciprocal and transitive. We test these hypotheses along with conventional covariate determinants of FDI using an exponential random graph model (ERGM) for weighted networks. We find that FDI networks exhibit both reciprocity and transitivity. Our network approach to studying FDI provides new insights into global investment flows and their political and economic consequences. In addition to our substantive findings, we offer a broad methodological contribution by introducing the ERGM for count-weighted networks in political science. (150 words)
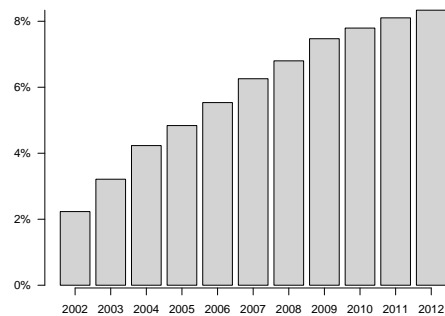
# A   Summary Statistics
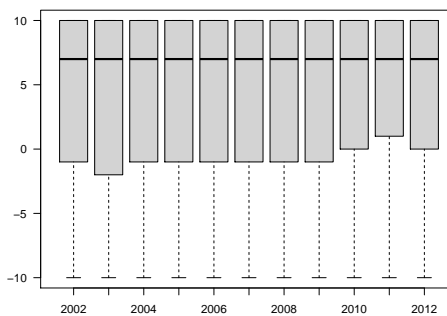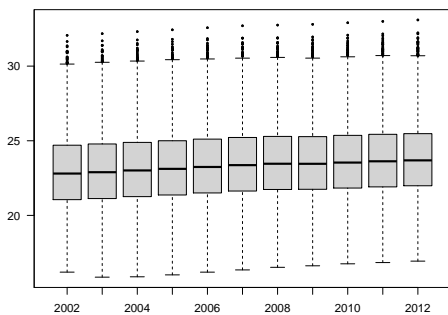
### Alliance Treaty
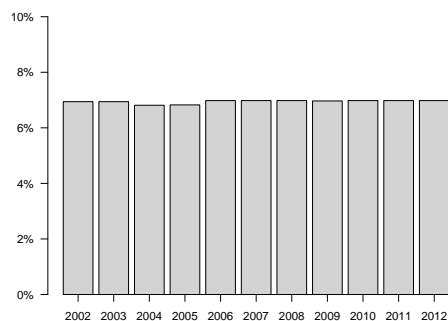


### Defense Treaty
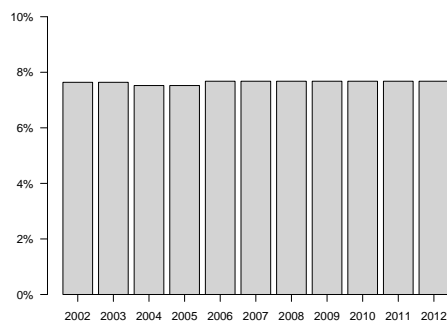


### Bilateral Investment Treaty



### Polity



### Dyad GDP Product



### Distance

## GDP per capita



## Trade as % of GDP



## Trade Volume



## FDI Stock
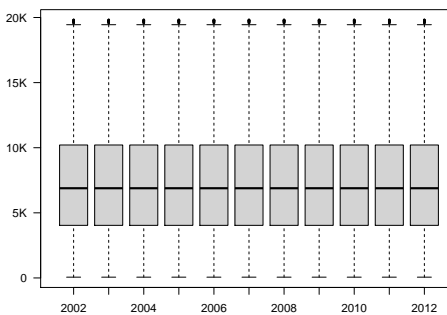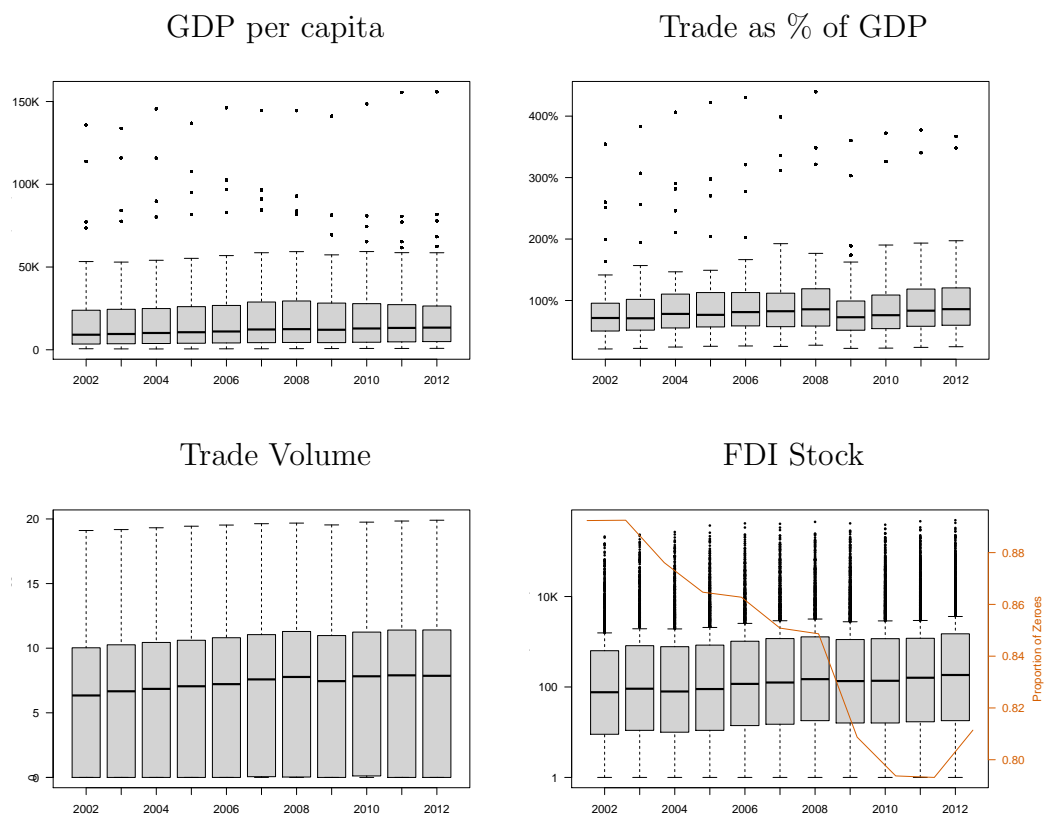


Table A:  Summary Statistics.

Table B: Correlation Matrix

|  | Mass | Distance | Polity |
|---|---|---|---|
| Mass | 1 | -0.003 | 0.091 |
| Distance (logged) | -0.003 | 1 | 0.008 |
| Polity | 0.091 | 0.008 | 1 |
| Trade Openness | -0.166 | -0.057 | -0.078 |
| BITs | 0.141 | -0.085 | 0.018 |
| Trade Volume | 0.714 | -0.215 | 0.215 |
| GDP per capita (logged) | 0.392 | -0.084 | 0.166 |
| Alliance Treaty | 0.133 | -0.348 | 0.073 |
| Defense Treaty | 0.065 | -0.391 | 0.065 |

|  | Trade Openness | BITs | Trade Volume |
|---|---|---|---|
| Mass | -0.166 | 0.141 | 0.714 |
| Distance (logged) | -0.057 | -0.085 | -0.215 |
| Polity | -0.078 | 0.018 | 0.215 |
| Trade Openness | 1 | 0.032 | -0.055 |
| BITs | 0.032 | 1 | 0.143 |
| Trade Volume | -0.055 | 0.143 | 1 |
| GDP per capita (logged) | 0.225 | 0.093 | 0.330 |
| Alliance Treaty | -0.044 | 0.021 | 0.216 |
| Defense Treaty | -0.046 | 0.010 | 0.177 |

|  | GDP per capita | Alliance Treaty | Defense Treaty |
|---|---|---|---|
| Mass | 0.392 | 0.133 | 0.065 |
| Distance | -0.084 | -0.348 | -0.391 |
| Polity | 0.166 | 0.073 | 0.065 |
| Trade Openness | 0.225 | -0.044 | -0.046 |
| BITs | 0.093 | 0.021 | 0.010 |
| Trade Volume | 0.330 | 0.216 | 0.177 |
| GDP per capita (logged) | 1 | 0.098 | 0.038 |
| Alliance Treaty | 0.098 | 1 | 0.850 |
| Defense Treaty | 0.038 | 0.850 | 1 |

**Difference Between Bilateral Totals and World Total**



N = 1368   Bandwidth = 321.7

Figure A:  Density Plot of the Difference between Total FDI stocks and Summing Bilateral FDI stocks.

# B    Time-Pooled Model Results

For robustness checks, we re-estimate the count ERGM by pooling the data, which is common in the literature for regression based models. Figure B shows that after pooling, network terms remain positive and statistically significant, supporting our hypothesis that reciprocity and transitivity characterize FDI flows. The exogenous covariates from the pooled model are presented in Table C. The estimates are similar to yearly results in terms of direction and statistical significance.



Figure B: Estimates of Dependence terms in time-pooled ERGMs. Bars span 95% confidence intervals.

The results also show that ignoring network structure lead to biased estimates in several covariates. We see significant differences in the coefficients for distance, the product of dyad's GDP, the three treaty variables, as well as origin and destination's GDP per capita, Polity, and trade openness. These findings are consistent with those from the yearly models. It illustrates that failure to include network structure results in biased estimates.

## Sum

## Sum$^{(1/2)}$

## Non-Zero

## Alliance Treaty

## Bilateral Investment Treaty

## Defense Treaty

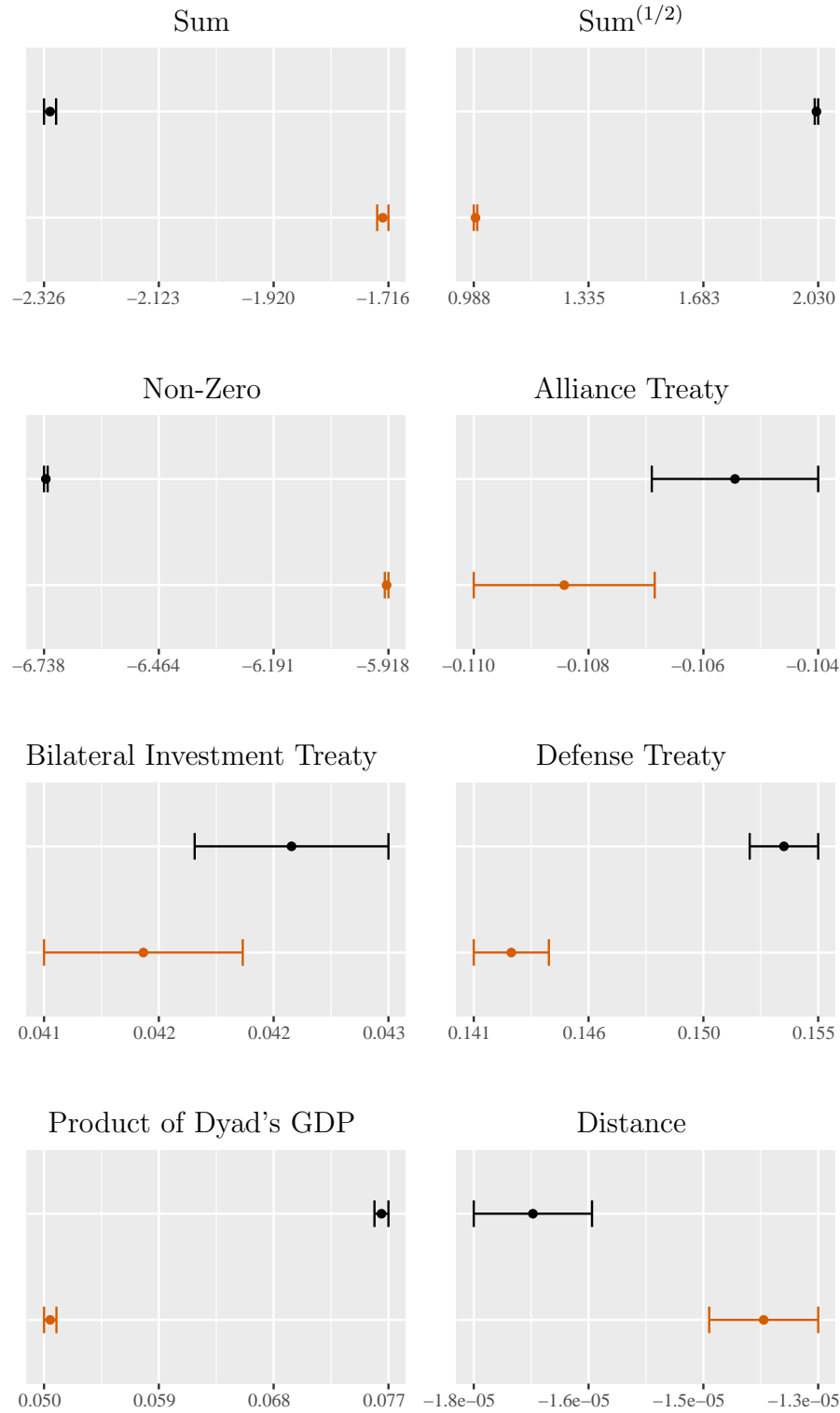## Product of Dyad's GDP

## Distance

Table C: Estimates of terms in time-pooled ERGMs. Bars span 95% confidence intervals. Black coefficient representations are from models excluding dependence terms (i.e., transitivity and reciprocity).

# C   Subset by Missingness Results

In the paper, we imputed missing values with zeros. In this section, we check whether our results are robust if we analyze a subset of the data set based on the level of missingness. To subset the data, we approximate total level of missingness ($q$) in the adjacency matrices by using the proportion of missing values for each node ($p$). We conduct two robustness checks: (1) when $p = 0.72$, $q \approx 0.25$ and $n = 28$; and (2) when $p = 0.86$, $q \approx 0.50$ and $n = 70$. In the first case, we include nodes that ... [please explain what p=.72 and q=.25 mean and what the sub-data sets look like]. Following our approach in the paper, we impute missing values in two sub-data sets with zeros.

Figures C and D present the results for the two robustness checks, respectively. We see that FDI networks show strong transitivity for all years, but reciprocity effects become weak and insignificant in some years. This may be because most nodes (i.e. states) in the sub-data sets are developed countries that have high two-way FDI flows between them and thus there is low variation in the level of reciprocity.
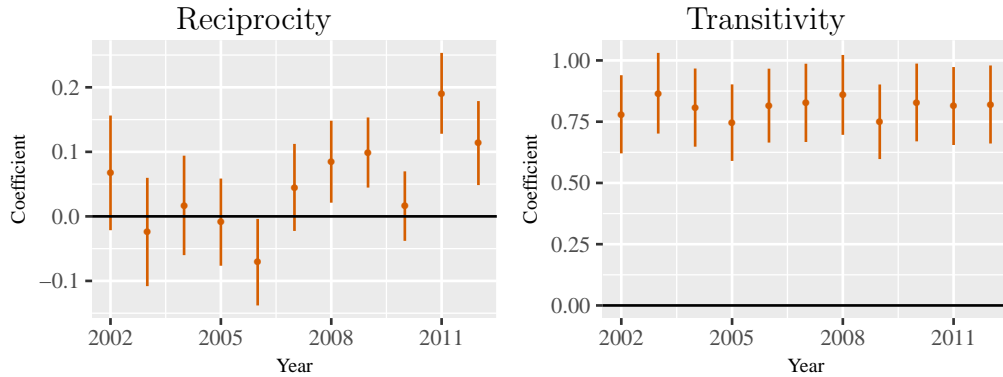
## C.1   q ≈ 0.50



Figure C:  Estimates of Dependence terms. Bars span 95% confidence intervals.
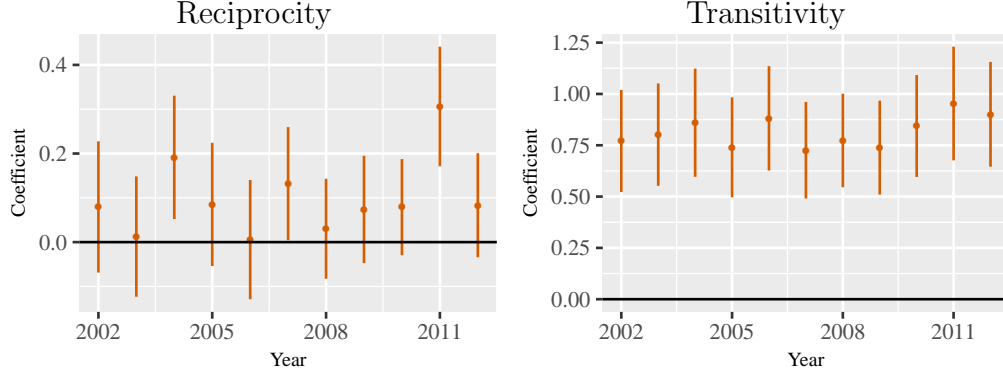
Figure D: Estimates of Dependence terms. Bars span 95% confidence intervals.

## C.2 q ≈ 0.25

# D Multiple Imputations with Amelia Results

In this section, we utilize R Amelia to impute the missing values in the full data set and when $q \approx 0.05$ (Honaker, King, Blackwell et al., 2011; King, Honaker, Joseph and Scheve, 2002). Figures E and F show the results. We see that transitivity effects are significant in all years and reciprocity effects are also significant in most years. Together together, the results in Sections C and D give us confidence that our findings regarding the reciprocity and transitivity of FDI are not a result of the pattern of missingness in the data set.

## D.1 Full



Figure E: Estimates of Dependence terms Bars span 95% confidence intervals.
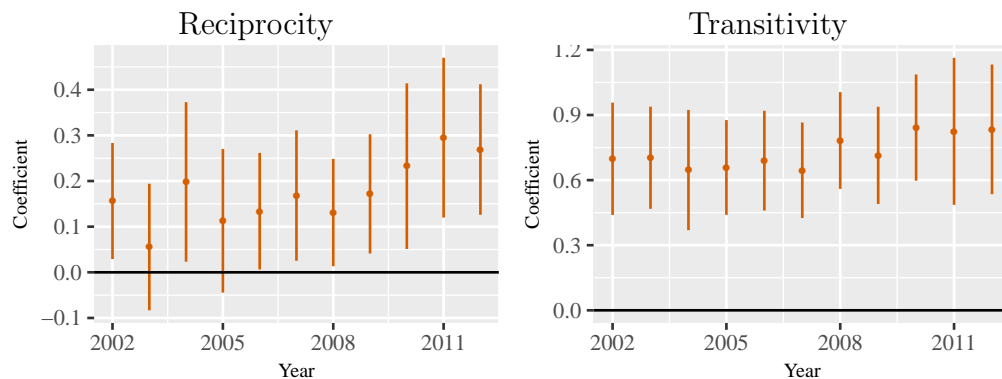
## D.2    q ≈ 0.50



Figure F: Estimates of Dependence terms in time-pooled ERGMs. Bars span 95% confidence intervals.
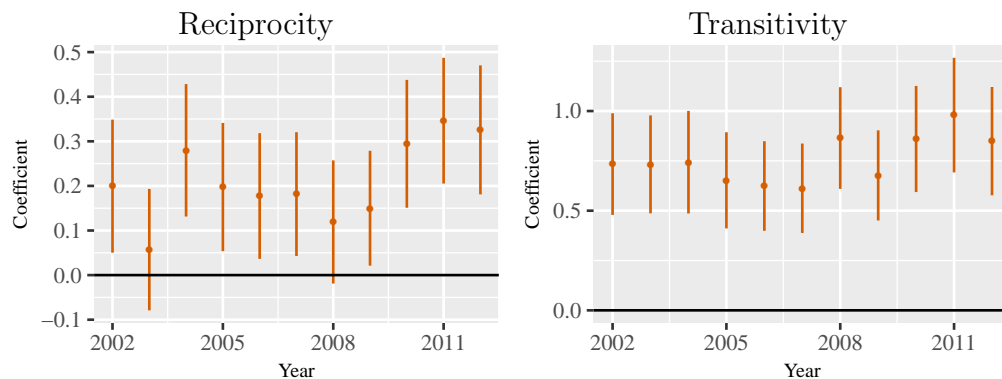
## D.3    q ≈ 0.25



Figure G: Estimates of Dependence terms in time-pooled ERGMs. Bars span 95% confidence intervals.

# E    Independent Covariate Interpretation

For the Poisson-reference ERGM these covariate estimates are usually interpreted by exponentiating Euler's constant to the power of the coefficient times the number of unit changes in the covariate to get the expected change in the tie weight (Krivitsky and Butts, 2013).

Taking Polity, in-degree for example, if the FDI destination had a Polity score of 10 in 2002, we would expect the value of logged FDI being sent to be 1.27 times more than a destination that had a Polity score of -10. In the model with network terms this expected increase is only 1.17 times higher. Another possibility to interpret independent terms in the model is to simulate networks using the estimated coefficients while fixing all other independent terms at the mean value and then comparing changes in the average edge value to the range of values of the covariate. We present a plot of this for Polity, in-degree below in Figure H.
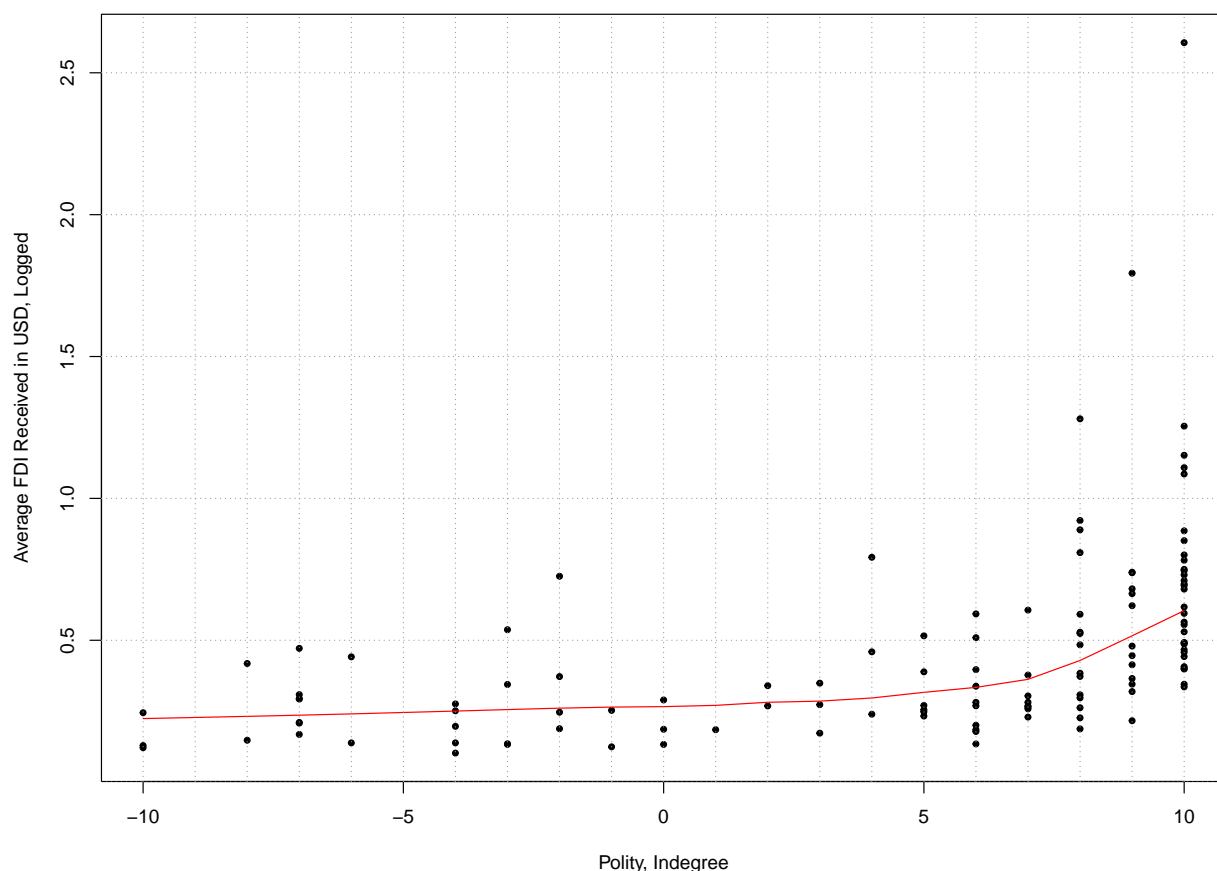


Figure H: Results from simulation exercise investigating the effects of Polity, in-degree for year 2002. These results are from 500 simulations. The line in red is the Loess curve.

# References

Honaker, James, Gary King, Matthew Blackwell et al. 2011. "Amelia II: A program for missing data." *Journal of statistical software* 45(7):1–47.

King, Gary, James Honaker, Anne Joseph and Kenneth Scheve. 2002. "Analyzing Incomplete Political Science Data: An Alternative Algorithm for Multiple Imputation." *American Political Science Review* 95(1):49–69.

Krivitsky, Pavel N and Carter T Butts. 2013. "Modeling valued networks with statnet." *The Statnet Development Team* p. 2013.