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A comment on "Network formation and efficiency in linear-quadratic games: An experimental study"

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February 2026

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A comment on “Network formation and efficiency in linear-quadratic games: An experimental study”

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September 30, 2025

Abstract

We replicate [Horváth \(2025\)](#), experimentally studying link formation and effort in a linear-quadratic game with positive externalities. Across five treatments, subjects exert 38–97 percent more effort than the Nash benchmark yet create too few links, depressing payoffs. In groups of five, the complete network appears in roughly 25 percent of final rounds (66–76 percent if deviations of ± 2 links are allowed); in groups of nine it is almost never reached. Larger groups and lower link costs fail to improve connectivity.

Following the original procedures and analysis step-for-step, our replication reproduces the sign, magnitude, and statistical significance of every reported effect. Robustness checks—learning, benefit salience, group benchmarking, alternative clustering, and multiple link-formation specifications—confirm the core pattern: persistent over-provision of effort coupled with under-provision of links, generating substantial efficiency losses.

KEYWORDS: network formation, efficiency, linear-quadratic payoffs, experiment

JEL CODES: D85, D62, C92

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1 Introduction

Horváth (2025), henceforth (H24), conducted an experiment with endogenous link formation and effort provision in a linear-quadratic game that features positive externalities and strategic complementarities. Thirty-period online sessions pit fixed groups of $N = 5$ or $N = 9$ against five treatment combinations that vary linking costs so as to fixed equilibrium network structure. H24 found that Subjects supply between 38% and 97% more effort than the Nash benchmark in four of the five treatments, yet form only 60–80% of the links required for the complete network; pay-offs therefore reach just 34–65% of the benchmark, with larger groups being worst. Lowering link costs hardly improves connectivity, because participants preferentially attach to top-effort providers and bypass otherwise profitable links to low-effort subjects. In this replication report we evaluate H24 along three dimensions:

- Computational reproducibility. Using the authors' data and code, we exactly reproduce all published tables and figures, uncovering no material discrepancies.
- Direct replication. Implementing the same analytic procedures, we confirm the sign, magnitude, and statistical significance of every reported coefficient.
- Robustness reproduction. We probe three alternative explanations for the observed departures from equilibrium: learning across rounds, misperception of link benefits, and reluctance to reward shirkers. Combined with a battery of alternative clustering rules and link-formation specifications, we find that none meaningfully alter the qualitative conclusions of the paper.

Before proceeding, we verify study transparency. The author registered the study and obtained approval from the Institutional Review Board (IRB). The pre-analysis plan aligns with the procedures reported in the paper, particularly regarding the intervention and experimental design. The five specific treatments described in the study are clearly outlined, along with the protocol used to randomly assign participants to each treatment

Taken together, our analyses confirms H24's central message: when networks form endogenously under strategic complementarities, individuals systematically

over-provide effort yet under-connect, leading to persistent efficiency losses that neither larger group size nor cheaper links alleviate.

2 Computational Reproducibility

The raw data, alongside with cleaning and analysis code were provided in the replication package. We were able to successfully reproduced all the main results computationally (i.e., P.Tables 6, 7, 8, P.A1–A4, and P.A6–A10), with only a minor discrepancy in the reported number of observations in P.Table 8, column 4. See Table 1 for details. Note that when referring to tables from the paper, we use the prefix "P." to distinguish them from tables we include in this comment.

Table 1: Replication Package Contents and Reproducibility

Replication Package Item	Fully	Partial	No
Raw data provided	✓		
Analysis data provided	✓		
Cleaning code provided	✓		
Analysis code provided	✓		
Reproducible from raw data	✓		
Reproducible from analysis data	✓		

Notes: This table summarizes the replication package contents contained in [Horváth \(2025\)](#).

The authors registered the study and published a pre-analysis plan (PAP). After comparing the PAP with the original paper, we find that PAP specifies the exact design of the study, the exact data collection and exactly how all analyses and tests will be conducted. The paper follows the pre-registered design, data collection and it carries out and reports all analyses and tests reported in the paper exactly as specified in the PAP.

3 Robustness Reproduction

Our robustness checks reaffirm the core findings of [Horváth \(2025\)](#): subjects consistently over-exert effort while under-forming links, despite potential gains from

higher connectivity. We examine several alternative explanations for this behavior and evaluate the consistency of our findings across multiple specifications.

3.1 Why don't subjects converge to Nash equilibrium?

We consider three candidate explanations:

3.1.1 Learning over rounds: One hypothesis is that subjects may simply need more time to learn the equilibrium. We replicate [Horváth \(2025\)](#)'s block-by-block effort analysis using period partitions (1–10, 11–20, 21–30). Table 6 of our replication shows that effort declines modestly over time in some treatments (e.g., Treatment 1), but this tapering does not translate into closer alignment with equilibrium predictions. In other treatments (e.g., Treatment 5), effort increases over time. There is no consistent convergence toward either the Nash effort level or full network formation.

This mirrors [Horváth \(2025\)](#)'s P.Tables 4 and 5, where the average number of links and average effort remain stable throughout the experiment, with no clear evidence of learning-driven convergence.

3.1.2 Misperception or salience of link benefits: Another explanation is that subjects do not perceive or correctly estimate the benefits of forming additional links. To assess this, we use a series of binary logistic models predicting the probability of a link $g_{ij,t} = 1$, based on lagged decisions and effort contributions.

We estimate the following six specifications:

$$\Pr(g_{ij,t} = 1) = \text{logit}^{-1} \left(\beta_1 g_{ij,t-1} + \sum_{k=2}^5 \delta_k D_{ik} + \beta_2 x_{i,t-1} + \beta_3 x_{j,t-1} + \beta_4 \mathbf{1}\{x_{j,t-1} < \bar{x}_{-i,t-1}\} + u_i \right) \quad (1)$$

The baseline specification includes own and partner effort in previous period, $x_{i,t-1}$ and $x_{j,t-1}$ respectively, lagged link status $g_{ij,t-1}$, and an indicator for whether partner effort was below group average. Next, we add new variables that could plausibly explain the results found in the paper.

In Specification 2, we replace the median with Rank $\in \{1, 2, 3\}$, the tercile-rank

of partners j 's effort, as the potential benchmark participants could have used. This assumes that the aversion to below-median peers could be explained by their rank, and be independent of the actual effort levels.

$$\Pr(g_{ij,t} = 1) = \text{logit}^{-1} \left(\beta_1 g_{ij,t-1} + \sum_{k=2}^5 \delta_k D_{ik} + \beta_2 x_{i,t-1} + \beta_3 x_{j,t-1} + \sum_{r=2}^3 \theta_r \mathbf{1}\{\text{Rank}_{ij,t-1} = r\} + u_i \right) \quad (2)$$

Specification 3 tests a complementary predictor, the lagged effort gap between self and peer $\Delta x_{ij,t-1}$, for linking decisions in the current round. We hypothesize the potential preference for fairness as captured by the homogeneity of effort in the pair could be an important factor for links persisting across rounds.

$$\Pr(g_{ij,t} = 1) = \text{logit}^{-1} \left(\beta_1 g_{ij,t-1} + \sum_{k=2}^5 \delta_k D_{ik} + \beta_2 x_{i,t-1} + \beta_3 x_{j,t-1} + \beta_4 \mathbf{1}\{x_{j,t-1} < \bar{x}_{-i,t-1}\} + \beta_6 \Delta x_{ij,t-1} + u_i \right) \quad (3)$$

Then, we also test one specification that combines both variables (Specification 4), another that uses the absolute difference $|\Delta x_{ij,t-1}|$ as a an alternative relative performance measure (Specification 5) to account for symmetry, and the last that includes all new variables (Specification 6). In all six specifications (see Table 6), we find strong and consistent support for the following patterns:

- Past links $g_{ij,t}$ are highly predictive of current links with coefficients ≈ 2.9 across specifications all specifications (Tables 3 and 6). This is consistent in both magnitude and direction with Horváth (2025)'s P.Tables 7 and 8.
- The coefficient on group effort being above the median in the previous period is consistent across all specifications, ranging from 1.12 to 1.35. This directly corresponds to Horváth (2025)'s P.Tables 8, where it ranges from 1.15 to 1.36 across treatment groups.
- We observe the same consistency in magnitude and direction with the "Below

average” dummy. In our robustness checks, it falls from 0.63 to 0.66. This directly corresponds to Horváth (2025)’s P.Tables 8, where it hovers around 0.7 across treatment groups.

- Both own and partner’s effort in the previous period positively relate to the linking decision in about 1 to 1 ratio, as shown in Tables 2 to 6. This corresponds to the results presented in Horváth (2025) P.Table 7 and 8. Even though there is some variation in statistical significance and a potentially suspect homogeneity, we stop our analysis there. Since the coefficients cleanly map onto the results from the paper and this is not a core result, we see no benefit in additional inquiry into clarifying the source of differences.
- Our robustness checks establish the potential for the gap between effort inside each pair to be a predictor of linking behavior as seen in Table 6, coefficient on ”Own-partner effort.” The addition of this variable, however, does not result in any meaningful changes in Horváth (2025) core results.

The robustness analysis largely confirms Horváth (2025)’s interpretation as it did not identify any specifications that results in meaningful changes in coefficients of interest. Participants selectively link to top performers and avoid weaker contributors, even when additional links would be individually and collectively beneficial. Misperception of benefits is unlikely to explain under-linking, since subjects clearly react to relative effort differences, and explicitly making benefits visible (in Horváth (2025)) had no effect.

3.1.3 Benchmarking behavior: Avoiding low-effort peers The strongest support lies in the hypothesis that subjects strategically avoid linking with perceived shirkers. This behavior is consistent with a ”partner screening” heuristic: individuals reward high-effort partners and punish low-effort ones by withholding links—even when those links would increase group welfare.

We find that individuals are less likely to link with those whose effort is below the group average (Table 6, ”Dff+BelowAvg”), even if linking would benefit them. The odds ratio on the below-average dummy is consistently around 0.66 and highly significant across all specifications.

3.2 Alternatives to clustering and MHT (P.Table 6 & 7)

The results from [Horváth \(2025\)](#)'s Tables 6 and 7 reproduce with alternative software packages (`lmtree`) to a sufficient degree. For example, Table 5 reproduces Table 6 in its entirety.

3.3 Robustness to Specification

As shown in Tables 2 to 6, all of the results are robust to the following:

- use of group average vs. group median benchmarks,
- truncated measures of extreme values,
- modeling at the pair level instead of the group level,
- including or omitting treatment dummies,
- modeling differences vs. ranks vs. absolute differences.

No matter how effort comparisons are modeled, linking behavior reflects a consistent, non-Nash bias toward excluding low-effort peers. This aligns with behavioral norms of reciprocity or conditional cooperation. Across all robustness checks, we find that link under-provision can be consistently explained by the social heuristics in strategies identified by the authors. These heuristics cause avoidance of “free-riders” even when linking with them would be beneficial, rewards top contributors disproportionately, and result in prioritizing relative over absolute gains.

While there could be some alternative explanations for this pattern of behavior, e.g. bounded rationality or fairness concerns, we did not find evidence for this. Thus, we conclude that [Horváth \(2025\)](#)'s explanation is plausible, likely, and successfully explains the observed large and persistent welfare losses in the presence of strategic complementarities.

4 Conclusion

This replication confirms and reinforces the central conclusion of [Horváth \(2025\)](#): network inefficiency persists even when individuals over-contribute effort. Across

all five experimental treatments, subjects systematically exert more effort than predicted by Nash equilibrium (38%–97% above benchmark), yet form too few links—achieving only 60–80% of the complete network. As a result, payoffs are well below potential efficiency levels, particularly in larger groups.

Our robustness checks validate the original interpretation:

- Learning does not eliminate inefficiencies since behavior does not converge to equilibrium over time.
- Highlighting benefits explicitly does not meaningfully increase link formation.
- The main driver of network under-formation appears to be a strategic aversion to low-effort partners, even when such links would be beneficial.

We replicate and extend [Horváth \(2025\)](#)'s regression models of link formation. Across all specifications, subjects prefer to connect with top-tier effort providers, and are significantly less likely to form links with those below the group average or median.

This behavior, while understandable as a heuristic, leads to persistent under-connection and suboptimal group welfare. This is especially pronounced in treatments with high link cost and larger groups. Even when forming a complete network is a Nash equilibrium (e.g., Treatment 1), the network is only reached in 25% of the final rounds, or $\approx 75\%$ if two-link deviations are allowed.

In summary, strategic selectivity in partner choice undermines the formation of fully efficient networks. These findings suggest that policies or mechanisms aimed at increasing link inclusivity—perhaps through subsidies, visibility of joint surplus, or peer-matching—could improve welfare outcomes in collaborative network settings.

References

Horváth, G.: 2025, Network formation and efficiency in linear-quadratic games: An experimental study, *The Economic Journal* **135**(665), 212–234.

5 Figures

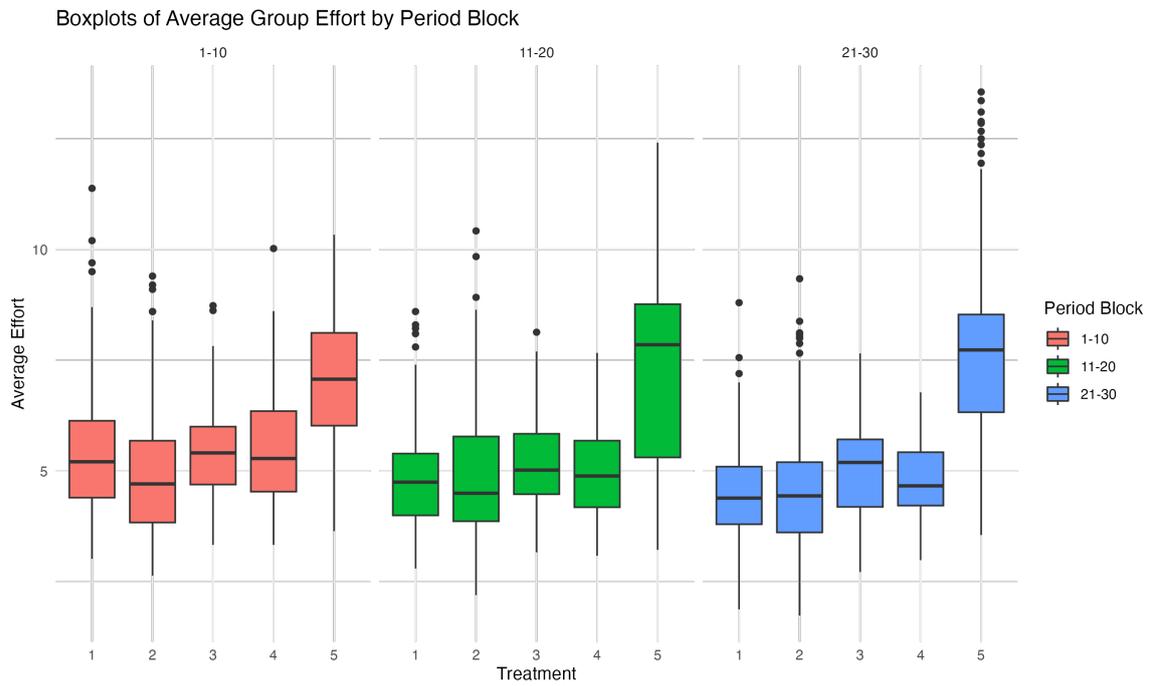


Figure 1: Boxplots of Average Effort by Period Block

Notes: This figure plots average individual effort levels across 30 periods, separately by treatment group. Despite repeated interaction, effort levels remain persistently above Nash equilibrium predictions in all treatments. There is no consistent evidence of convergence toward equilibrium, consistent with findings in [Horváth \(2025\)](#). Shaded areas or error bars (if included) represent ± 1 standard error.

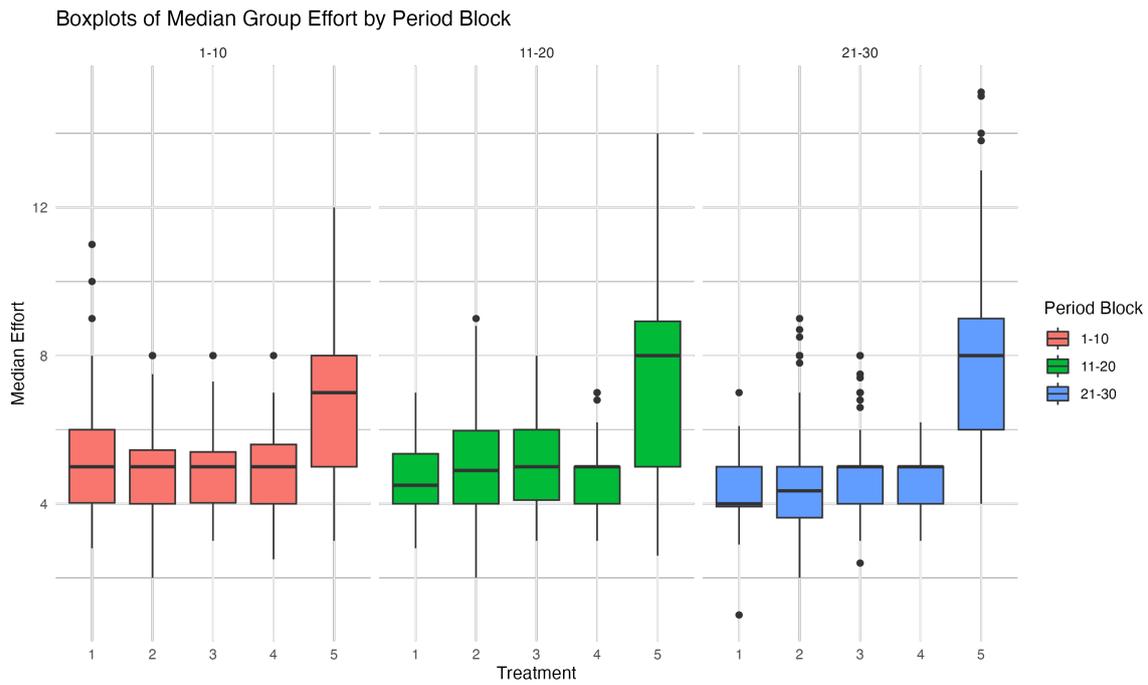


Figure 2: Boxplots of Median Effort by Period Block

Notes: This graph shows the evolution of average link formation across treatments. While some growth in network density occurs early on, most groups stabilize well below the fully connected equilibrium. Treatments with lower link costs or smaller group sizes tend to form more links, but even in these settings, under-connection persists throughout the session.

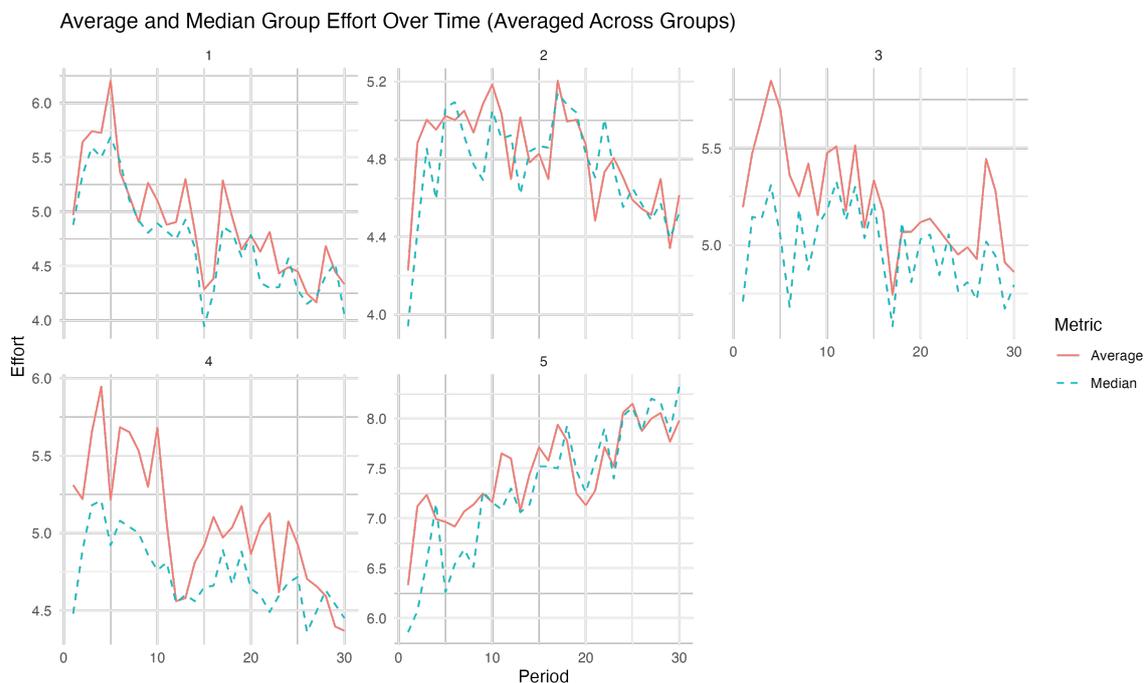


Figure 3: Average and Median Effort by Period Block

Notes: Kernel density plots of individual effort contributions pooled by treatment. All treatments display positively skewed distributions with mass concentrated above Nash equilibrium levels. This reflects systematic over-provision of effort, consistent with the findings of Horváth (2025) and our replication analysis.

6 Tables

Table 2: Odds Ratios for Link Formation Models (manual exponentiation)

	Group Avg Effort	Group Median Effort
Intercept	0.82 (0.11)	0.78* (0.11)
Lagged link $g_{ij,t-1}$	2.93*** (0.05)	2.92*** (0.05)
Treatment 2	0.81 (0.15)	0.81 (0.15)
Treatment 3	0.53*** (0.09)	0.53*** (0.09)
Treatment 4	0.40*** (0.07)	0.40*** (0.07)
Treatment 5	0.74* (0.13)	0.72* (0.13)
Lagged partner effort $x_{j,t-1}$	0.99*** (0.00)	0.99*** (0.00)
Lagged own effort $x_{i,t-1}$	0.99** (0.00)	0.99** (0.00)
Lagged group avg effort $\bar{x}_{-i,t-1}$	1.05*** (0.01)	
Lagged group med effort $\tilde{x}_{-i,t-1}$		1.06*** (0.01)
AIC	84356.49	84339.70
BIC	84449.11	84432.32
Log Likelihood	-42168.25	-42159.85
Num. obs.	77778	77778
Num. groups: indID	429	429
Var: indID (Intercept)	1.22	1.21

Notes: This table reports odds ratios from logistic regression models estimating the probability that individual i forms a link to individual j in period t . Models include lagged link status, own and partner effort, and group-level effort benchmarks (mean or median). Treatment dummies account for experimental variations. Standard errors clustered at the individual level. Asterisks indicate statistical significance: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 3: Odds Ratios for Difference-in-Lag Models (manual exponentiation)

	Avg Effort Diff	Median Effort Diff
Intercept	0.66*** (0.04)	0.66*** (0.04)
Lagged link $g_{ij,t-1}$	2.94*** (0.05)	2.94*** (0.05)
Lagged partner effort $x_{j,t-1}$	0.99 (0.00)	0.99 (0.00)
Lagged own effort $x_{i,t-1}$	1.00 (0.00)	0.99 (0.00)
Δ Group avg effort	1.00 (0.01)	
Δ Group med effort		1.01 (0.01)
AIC	81068.11	81066.18
BIC	81123.47	81121.54
Log Likelihood	-40528.05	-40527.09
Num. obs.	75096	75096
Num. groups: indID	429	429
Var: indID (Intercept)	1.44	1.44

Notes: Logistic regressions predicting link formation using the lagged difference in effort between the individual and the group. "Δ Group avg effort" and "Δ Group med effort" represent changes in group effort benchmarks across periods. Results test for dynamic adaptation to group performance trends. Standard errors clustered at the individual level. Asterisks indicate statistical significance: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 4: Odds Ratios for Difference + Dummy Models (pooled manual)

	(1)Orig	(2)Rank	(3)Diff+BelowAvg	(4)Diff+Rank	(5)DiffAbs+BelowAvg	(6)DiffAbs+Rank
Intercept	1.24 (0.17)	0.75** (0.11)	1.19 (0.16)	0.84 (0.12)	1.21 (0.17)	0.81 (0.12)
Lagged link $g_{ij,t-1}$	2.87*** (0.05)	2.95*** (0.05)	2.87*** (0.05)	2.92*** (0.05)	2.87*** (0.05)	2.92*** (0.05)
Treatment 2	0.79 (0.15)	0.80 (0.15)	0.79 (0.15)	0.80 (0.15)	0.79 (0.15)	0.80 (0.15)
Treatment 3	0.53*** (0.09)	0.53*** (0.09)	0.53*** (0.09)	0.53*** (0.09)	0.53*** (0.09)	0.52*** (0.09)
Treatment 4	0.40*** (0.07)	0.39*** (0.07)	0.39*** (0.07)	0.39*** (0.07)	0.39*** (0.07)	0.39*** (0.07)
Treatment 5	0.79 (0.14)	0.80 (0.14)	0.79 (0.14)	0.78 (0.14)	0.78 (0.14)	0.77 (0.14)
Lagged partner effort $x_{j,t-1}$	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
Lagged own effort $x_{i,t-1}$	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.01** (0.00)	1.00 (0.00)	1.01 (0.00)
Own-partner effort			0.99*** (0.00)	0.96*** (0.00)		0.96*** (0.00)
Below-avg dummy	0.63*** (0.01)		0.66*** (0.01)		0.63*** (0.01)	
Rank level 3 (Above Median)		1.35*** (0.05)		1.12*** (0.04)		1.15*** (0.04)
AIC	83658.83	81807.77	83638.53	81516.10	83645.44	81501.90
BIC	83751.45	81900.10	83740.41	81617.67	83747.31	81612.71
Log Likelihood	-41819.42	-40893.88	-41808.27	-40747.05	-41811.72	-40738.95
Num. obs.	77778	75611	77778	75611	77778	75611
Num. groups: indID	429	429	429	429	429	429
Var: indID (Intercept)	1.27	1.26	1.28	1.29	1.28	1.30

Notes: This table presents results from multiple logistic regression models of link formation, incorporating effort differences (Δ), rank-based indicators, and below-average effort dummies. Each model pools data across treatments and periods. All regressions control for prior link status and treatment fixed effects. Odds ratios are shown; standard errors clustered at the individual level. Asterisks indicate statistical significance: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 5: Replication of Table 6

	Dependent variable:				
	Own effort $x_{i,t}$				
	(1)	(2)	(3)	(4)	(5)
Lagged own effort $x_{i,t-1}$	0.061*** (0.021)	0.153*** (0.021)	0.101*** (0.018)	0.297*** (0.018)	0.342*** (0.018)
<i>BR</i>	1.029*** (0.033)	0.943*** (0.038)	0.941*** (0.039)	0.757*** (0.032)	0.610*** (0.023)
$\sum_{k \neq i} x_{k,t-1}$	0.095*** (0.011)	0.050*** (0.010)	0.037*** (0.005)	0.028*** (0.004)	0.038*** (0.005)
Observations	2,175	2,175	2,871	2,610	2,610
Akaike Inf. Crit.	9,587.096	9,291.635	12,318.500	11,823.920	12,526.780
Bayesian Inf. Crit.	9,621.204	9,325.744	12,354.280	11,859.120	12,561.980

Notes: This table replicates Table 6 from the paper. Linear regressions estimating current effort levels as a function of lagged individual effort, best-response predictions (BR), and non-neighbor group effort. These models assess effort dynamics and behavioral updating. Results indicate persistence in effort and partial adjustment toward theoretical best responses. Asterisks indicate statistical significance: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 6: Summary Statistics and Pairwise Tests of Group Effort by Period Block

treatment	period block	Avg effort \bar{x}_i	Median effort	p : Avg (10vs.20)	p : Avg (20vs.30)	p : Med (10vs.20)	p : Med (20vs.30)
1	1-10	5.41 (1.48)	5.22 (1.39)	0.00	0.01	0.00	0.03
1	11-20	4.83 (1.17)	4.64 (1.10)	0.00	0.01	0.00	0.03
1	21-30	4.47 (1.00)	4.32 (0.92)	0.00	0.01	0.00	0.03
2	1-10	4.93 (1.48)	4.74 (1.24)	0.88	0.13	0.66	0.06
2	11-20	4.91 (1.52)	4.91 (1.50)	0.88	0.13	0.66	0.06
2	21-30	4.60 (1.34)	4.62 (1.46)	0.88	0.13	0.66	0.06
3	1-10	5.45 (1.13)	5.04 (1.07)	0.06	0.48	0.98	0.14
3	11-20	5.18 (1.06)	5.05 (1.10)	0.06	0.48	0.98	0.14
3	21-30	5.06 (1.11)	4.87 (1.09)	0.06	0.48	0.98	0.14
4	1-10	5.52 (1.36)	4.94 (1.04)	0.00	0.35	0.10	0.36
4	11-20	4.91 (1.06)	4.69 (1.01)	0.00	0.35	0.10	0.36
4	21-30	4.75 (0.86)	4.56 (0.84)	0.00	0.35	0.10	0.36
5	1-10	7.02 (1.53)	6.61 (1.98)	0.11	0.65	0.04	0.37
5	11-20	7.52 (2.48)	7.38 (2.64)	0.11	0.65	0.04	0.37
5	21-30	7.84 (2.50)	7.94 (2.80)	0.11	0.65	0.04	0.37

Notes: Summary statistics of average and median effort levels by treatment and period block (1–10, 11–20, 21–30). Standard deviations are shown in parentheses. Paired t-tests compare adjacent blocks to evaluate learning or convergence, for which p -values are reported in the table. No consistent trends are observed.