

Chen, Ying; Lane, Tom; Macdonald, Stuart

Working Paper

Endogenous network formation in local public goods: An experimental analysis

CeDEx Discussion Paper Series, No. 2023-02

Provided in Cooperation with:

The University of Nottingham, Centre for Decision Research and Experimental Economics (CeDEx)

Suggested Citation: Chen, Ying; Lane, Tom; Macdonald, Stuart (2023) : Endogenous network formation in local public goods: An experimental analysis, CeDEx Discussion Paper Series, No. 2023-02, The University of Nottingham, Centre for Decision Research and Experimental Economics (CeDEx), Nottingham

This Version is available at:

<https://hdl.handle.net/10419/284277>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



CENTRE FOR DECISION RESEARCH & EXPERIMENTAL ECONOMICS



University of
Nottingham
UK | CHINA | MALAYSIA

Discussion Paper No. 2023-02

Ying Chen, Tom Lane,
Stuart McDonald

March 2023

**Endogenous Network Formation
in Local Public Goods: An
Experimental Analysis**

CeDEx Discussion Paper Series

ISSN 1749 - 3293



CENTRE FOR DECISION RESEARCH & EXPERIMENTAL ECONOMICS

The Centre for Decision Research and Experimental Economics was founded in 2000, and is based in the School of Economics at the University of Nottingham.

The focus for the Centre is research into individual and strategic decision-making using a combination of theoretical and experimental methods. On the theory side, members of the Centre investigate individual choice under uncertainty, cooperative and non-cooperative game theory, as well as theories of psychology, bounded rationality and evolutionary game theory. Members of the Centre have applied experimental methods in the fields of public economics, individual choice under risk and uncertainty, strategic interaction, and the performance of auctions, markets and other economic institutions. Much of the Centre's research involves collaborative projects with researchers from other departments in the UK and overseas.

Please visit <http://www.nottingham.ac.uk/cedex> for more information about the Centre or contact

Samantha Stapleford-Allen
Centre for Decision Research and Experimental Economics
School of Economics
University of Nottingham
University Park
Nottingham
NG7 2RD
Tel: +44 (0)115 74 86214
Samantha.Stapleford-Allen@nottingham.ac.uk

The full list of CeDEx Discussion Papers is available at

<http://www.nottingham.ac.uk/cedex/publications/discussion-papers/index.aspx>

ENDOGENOUS NETWORK FORMATION IN LOCAL PUBLIC GOODS: AN EXPERIMENTAL ANALYSIS^{*}

Ying Chen[†] Tom Lane[‡] Stuart McDonald[§]

This version: March 2, 2023

Abstract

We experimentally explore public good production levels, and the endogenous formation of network structures to facilitate output sharing, among agents with heterogeneous production costs or valuations. Results corroborate the key theoretical insights of [Kinateredder & Merlino \(2017\)](#) characterizing how agents form core-periphery networks. However, subjects often produce more and form denser networks than predicted, which sometimes reduces efficiency. There is some tendency for behaviour to converge towards the theoretical equilibrium over repeated play. Our results help us understand the emergence of the ‘law of the few’ in real-world networks, and suggest it is driven by endogenous sorting of heterogeneous agents.

Keywords: Local public goods; Network formation; Experiment; Heterogeneity.

JEL Classification: C91; D85; H41.

^{*}**Acknowledgements:** This research was made possible by financial support from the Centre for Decision Research and Experimental Economics China and the School of Economics at the University of Nottingham Ningbo China. We have also benefited from valuable suggestions and comments by Vladimir Brusic, Saileshsingh Gunessee, Martin Sefton, Shuo Xu, Haihan Yu and seminar participants at Hunan University, Zhejiang University of Finance and Economics, China, and the 2022 Conference on Mechanism and Institution Design, Singapore. Ying Chen acknowledges support from Lingbo Huang and Xueheng Li as well as their lab assistants for hosting the half of the experiment sessions in Nanjing Audit University Economics Experiment Lab. The research protocol was approved by the University of Nottingham Research Ethics Subcommittee on January 29, 2021.

[†]PhD candidate, Centre for Decision Research and Experimental Economics China; School of Economics, University of Nottingham Ningbo China. Email: ying.chen2@nottingham.edu.cn.

[‡]Assistant professor, Centre for Decision Research and Experimental Economics China; School of Economics, University of Nottingham Ningbo China. Email: tom.lane@nottingham.edu.cn.

[§]Associate professor, China Beacons Institute; School of Economics, University of Nottingham Ningbo China. Email: stuart.mcdonald@nottingham.edu.cn.

1 Introduction

A large body of literature studies the context of public good provision in which those public goods are produced and obtained through networks (see, e.g., [Jackson, 2010](#)). An oft-cited example is the production and consumption of knowledge, which can be obtained either by generating it oneself or by connecting to others in possession of it. One key observation in the literature is that the structure of such networks, in the real world, often resembles a star, consisting of one or few key contributors located in the core and lots of other agents located on the periphery (see, e.g., [Ch'ng, 2015](#); [Goyal et al., 2006](#)). Another empirical finding is that contributions to the public good often roughly follow the “80-20” rule: a large fraction of the content (e.g., 80%) is provided by a few agents (e.g., 20%) (see, e.g., [Wang et al., 2013](#); [Yang et al., 2008](#)). If we assume that these few highly productive contributors also occupy the core position of the network, these two regularities can be combined to represent the law of the few. This law, first coined by [Galeotti & Goyal \(2010\)](#), refers to the large majority of agents, positioned in the periphery, obtaining most of their consumption from a small minority located in the core.

A distinct possibility is that these network patterns occur at least partly as a result of *agent heterogeneities* – that is, some members of the network are either better than others at producing the good, or have particularly strong preferences for consuming it. In this paper we empirically explore how the structure of public good provision networks, and the contribution patterns of the individuals located within, take form in the presence of such heterogeneities in production costs and valuations. Such circumstances have been considered theoretically by [Kinaterder & Merlino \(2017\)](#) (henceforth, KM), whose model demonstrates the *law of the few* holds with agent heterogeneities and indeed is specifically shaped by them. In extending [Galeotti & Goyal](#)’s framework (which itself also predicts the endogenous emergence of the *law of the few*) to allow for agent heterogeneities, KM yielded the additional prediction that it will be those agents with lowest production costs or highest consumption valuations positioned in the core of the network.¹

¹These papers fall within a wider stream of recent theoretical literature, which has

Our paper provides a direct test of key aspects of the KM model. We present a laboratory experiment with a payoff structure based on KM, in which each subject is asked to decide how much she would like to produce, and with whom she would like to share output by initiating costly links. We test the prediction that differences in individual types lead to differences in their choices leading to network position, i.e., that economic agents tend to rely more on themselves if producing on their own is relatively low cost, or yields relatively high individual benefits. To model this, our experiment introduces two types of scenario, each of which features a different kind of heterogeneity. In scenarios with *cost heterogeneity*, we vary the cost of contributing a unit of production so that agents can be ranked in terms of their relative productive efficiency. In scenarios with *valuation heterogeneity*, we let the returns from the public good strictly decrease from the “best” to “worst” agent. In doing this, we want to understand how cost heterogeneity and valuation heterogeneity shape agents’ decisions and whether and why some group members will choose to contribute more and others less. We also aim to gain insight into why networks tend to have a “star” structure, where most individuals are peripheral to a few core members and how and why individuals are sorted into the core and periphery.

Our results confirm that participants behave differently from each other when perfect heterogeneities exist in their group. In both of our scenario types, participants who are assigned a better role (lower cost or higher benefit) decide to produce higher quantities of the public good and pay less to create links to others, while those who are assigned a worse role decide to produce little and rely on better types’ production by initiating many links. Therefore, better roles become the centre of the network and worse roles are positioned on the edge of the network. This emerges endogenously, and

made significant progress in embedding network formation into the study of public goods provision, either with exogenously imposed or endogenously formed networks. [Galeotti & Goyal \(2010\)](#) built upon [Bramoullé & Kranton \(2007\)](#), the first model to show star networks lead to specialisation in the provision of public goods. [Cho \(2010\)](#) and [Cabrales et al. \(2011\)](#) also theoretically study public good provision with endogenously formed networks. [Baetz \(2015\)](#) and [Hiller \(2017\)](#), while still studying endogenous networks, are different in that they both focus on a version of the public good game where contribution actions are strategic complements rather than strategic substitutes. In the literature on public good provision under exogenous networks, important works include [Allouch \(2015, 2017\)](#), [Boncinelli & Pin \(2012\)](#), [Bramoullé et al. \(2014\)](#), [Elliott & Golub \(2019\)](#), and [Galeotti et al. \(2010\)](#).

supports the theoretical predictions of KM. We therefore experimentally validate that the relative centrality of network members and the level of their personal contributions depend on the personal attributes of these individuals.

However, we find that participants are quite willing to pay for the costly links to build connections with each other, and thus often form denser networks than the model predicts. This result is in line with other experimental studies of endogenous network formation (Falk & Kosfeld, 2012; Goyal et al., 2017; He & Zou, 2022), while we additionally show that such over-linking behaviour depends on types and scenarios. Moreover, most types are willing to incur production costs to contribute at a level higher than predicted in KM. This excessive production and linking behaviour leads earnings under valuation heterogeneity to be less than under equilibrium. This is because both producing and linking incur costs, and participants suffer in a dense network by producing too much when they should have instead relied more on their neighbours' production. We observe, however, some tendency for behaviour to more closely approach the theoretical equilibrium as the game is played repeatedly.

Our paper builds upon earlier laboratory experimental literature which showed that contributions in local public goods games are sensitive to one's position in an *exogenously* fixed network structure (Rosenkranz & Weitzel, 2012).² Other than our paper, we are aware of only four laboratory experimental studies that allow *endogenous* network formation in such settings, and thus study both contribution levels and linking decisions.³ van Leeuwen et al. (2020) and Rong & Houser (2015) focus on identifying mechanisms that can increase the probability of star networks occurring, a matter of interest because the star network is the most efficient structure based on Galeotti & Goyal (2010)'s *law of the few*. van Leeuwen et al. (2020) find that introducing status rents, by rewarding players for receiving in-links,

²Other representative experimental studies of public goods provision under fixed networks include Choi et al. (2011), in which a binary-choice action profile is considered, while Gallo & Yan (2015) provide an extension with strategic complements. A good review is available in Choi et al. (2015).

³Here we mainly focus on experimental settings in which subjects are asked to make the two decisions simultaneously. We are aware of recent studies, such as He & Zou (2022), using two-stage games in which the first stage only consists of network formation decisions and the second stage solely of public good provision.

can facilitate the emergence of star networks because it makes the core a more attractive position. [Rong & Houser \(2015\)](#) find that more star networks are generated when each participant is restricted to either making contributions or initiating links, and when at most one player in each group can choose to contribute. [Choi et al. \(2019\)](#) focus on the effect of group size. Specifically, they examine groups with 100 agents and find that the law of the few exists in such substantial networks.

The paper most similar to ours is [Goyal et al. \(2017\)](#), which focuses on studying the effects of linking costs and contribution costs on contribution behaviour, finding it to be sensitive to both, with an increase in linking costs leading to higher contributions by the hub players and fewer links in the formed network. Like our experiment, [Goyal et al. \(2017\)](#) also allow for individual heterogeneities. They verify the proposition in [Galeotti & Goyal \(2010\)](#) that if an agent has a lower production cost than her group members, this agent is more likely to stay in the core. Our experiment is different in that we explore heterogeneities in valuations as well as costs. Furthermore, while [Goyal et al. \(2017\)](#) modelled cost heterogeneities such that costs were uniform across the network except for one low-cost agent, we follow KM in devising *perfect heterogeneities*, where all players differ from one another. Particularly since we are not only interested in who self-selects into the core but also into the periphery, this approach helps us to investigate in greater depth whether differences in individual traits contribute towards the *law of the few*. Our results suggest they do, and therefore provide a suggestive explanation for why this pattern emerges so frequently in real-world networks.

The remainder of the paper is structured as follows. In [Section 2](#), we present the experimental design. In [Section 3](#), we outline and explain our hypotheses. We then present our results and draw conclusions in [Sections 4](#) and [5](#) respectively.

2 Experimental design

2.1 The task

In our experiment, we confronted subjects with a task based closely on the setup of the local public goods game in the KM model.⁴ The task required each participant to simultaneously (1) choose her neighbours, and (2) select a level of contribution, which would yield returns for herself as well as bringing positive externalities to her neighbours. At the start of the game, participants were told that they could earn experimental currency units (ECUs) by collecting tokens, and that there were two ways they could do this: either by producing the tokens themselves or by connecting to other participants to gain access to duplicates of those produced by the others.

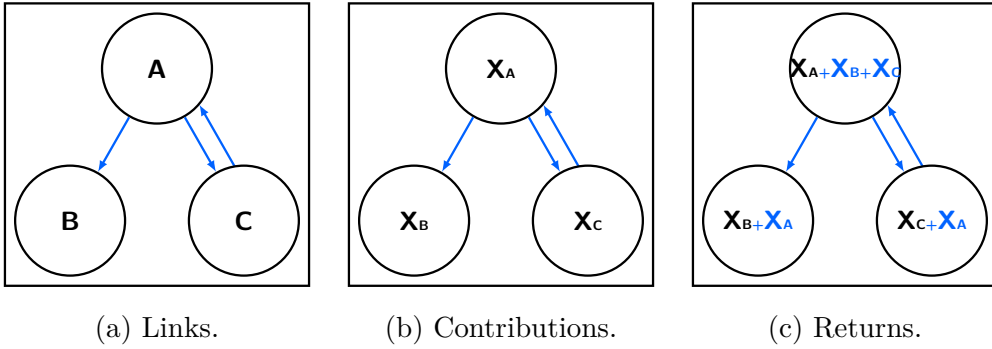


Figure 1: Simplified task example with $n = 3$.

Note: Suppose there are three agents, A , B and C . Agent A initiates a link to agent B , and agents A and C initiate links to each other (panel (a)). This results in A and B becoming neighbours, and A and C becoming neighbours. B and C are not neighbours. Simultaneously, agents A , B and C decide to produce x_A , x_B , and x_C tokens, respectively (panel (b)). Panel (c) presents the agents' consumption: each agent consumes her own production and that of her neighbours.

Figure 1 provides a simplified illustration of the game's decision and earning structures (for ease of exposition we use an example with three players, although in the experiment groups were actually of size six). Each player decides with whom to connect, as illustrated in panel (a). It depicts the case where agent A initiates a link to agent B , and agents A and C both

⁴See Appendix A1 for an overview of the model.

initiate links to each other, while there is no connection between agents B and C. Therefore, agents A and B become neighbours, as do agents A and C, while agents B and C do not. They also decide how many tokens to produce by themselves. Panel (b) shows that agent A, B and C decide to produce x_A , x_B , and x_C tokens, respectively. Agents share their tokens with their neighbours, as shown in panel (c). Note that the links have a two-way flow feature; each neighbour obtains the other's output, regardless of who initiated a link. Note also that when an agent's production x_i is shared with a neighbour, the form this takes is that both agents obtain this full amount x_i . This sharing payoff structure resembles the case for a public good such as information.

More specifically, each individual's net earnings – after the exchange of tokens – depend on her consumption resulting from her own efforts and those of her neighbours, and the costs incurred by her two decisions, as represented by the following payoff function:

$$U_i(x, g) = \underbrace{\left\{ \begin{array}{l} \underbrace{\left[V_i - \left(x_i + \sum_{j \in N_i(\bar{g})} x_j \right) \right]}_{\text{revenue}} \underbrace{\left(x_i + \sum_{j \in N_i(\bar{g})} x_j \right)}_{\text{cost of contribution}} - \underbrace{k\eta_i^{OUT}}_{\text{cost of initiating links}}, \text{ if } x_i + \sum_{j \in N_i(\bar{g})} x_j \leq \frac{V_i}{2}; \\ \frac{V_i^2}{4}, \text{ if } x_i + \sum_{j \in N_i(\bar{g})} x_j > \frac{V_i}{2}. \end{array} \right.}_{\text{net earnings}} \quad (1)$$

In this function, x_i represents each participant i 's level of production, and $\sum_{j \in N_i(\bar{g})} x_j$ represents the total production of the neighbours with whom she is linked in the network. $N_i(\bar{g})$ represents the set of neighbours of participant i , in which $\bar{g}$ is an adjacency matrix representing the undirected network formed by participant i and her neighbours. Each participant i 's revenue is therefore quadratic in the sum of her own and her neighbours' efforts, $\left[V_i - \left(x_i + \sum_{j \in N_i(\bar{g})} x_j \right) \right] \left(x_i + \sum_{j \in N_i(\bar{g})} x_j \right)$. Each participant i 's cost is linear in her own contribution, x_i , and the number of links she has initiated, η_i^{OUT} . Participants do not have to pay for links initiated to them by others. Participants may differ in the level of personal returns they derive from the public good, determined by the value of V_i , or in the marginal

cost of own contribution, c_i . The cost of sponsoring a link, k , is identical for all. A participant's net earnings from the task, $U_i(x, g)$, therefore is obtained by subtracting both kinds of cost from the revenue.

We highlight three features of this task implied by equation (1). First, this task is different from other public goods games in the sense that there is no initial endowment but rather players produce, at cost, each unit of their own output. It is important to note that there is no free lunch; if a participant chooses to produce nothing, and she does not have any connections at all, then her earnings will be zero. Additionally, each token produced by participants exerts positive externalities on their neighbours. Equation (1) tells us that the marginal revenue from own production and neighbours' production is the same; the two ways of obtaining tokens are perfect substitutes. Finally, in order to follow KM in keeping marginal revenue non-negative, we adjust the rule of calculating payoffs as follows. In equation (1), if the sum of their own effort and their neighbours' effort, $x_i + \sum_{j \in N_i(\bar{g})} x_j$, is greater than $\frac{V_i}{2}$, then the marginal revenue becomes negative. To avoid this situation, we tell participant that, once it happens, the revenue is simply fixed at $\frac{V_i^2}{4}$ (which is the revenue when $x_i + \sum_{j \in N_i(\bar{g})} x_j = \frac{V_i}{2}$). In other words, we set the marginal revenue to be zero when $x_i + \sum_{j \in N_i(\bar{g})} x_j > \frac{V_i}{2}$.

2.2 Heterogeneities and treatments

Subjects played the game in groups of six.⁵ Within each group, individuals are randomly assigned to a type, which is common knowledge to all group members. Types are unique, so that the number of types in each group is six. Types are labelled from Role A to Role F. Role A is always the “best” type and Role F the “worst”, as defined below.⁶

Roles are determined according to the source of heterogeneity employed

⁵We ran some additional treatments where the group size was instead eight. These are covered only in Appendix A2.

⁶In the experimental instructions, we use “Role + English Alphabet” to name and introduce each type. This is because in Mandarin (the language the experiment was conducted in), “Role A (角色 A)” is neutral while “Type 1 (第 1 类)” implies “the best condition”. We used “Role A” instead of “Type 1” because we wanted participants to infer the differences between types from the cost or valuation parameters associated with them, rather than from the labels themselves. In the paper, we hereon also use “Role” as a replacement for “Type”.

in the experimental treatment in question. There are two kinds of heterogeneities, of which only one features in a given treatment. Under heterogeneity in production cost, the production cost c_i of each role is given as follows: $c_A < c_B < c_C < c_D < c_E < c_F$. Other parameters are all kept identical. Therefore, Role A is the “best” role because it has the smallest cost of production, c_A . Under heterogeneity in valuation of the good, we vary V_i (but hold the production cost and other parameters constant) within each group. The “best” role has the largest marginal revenue from obtaining one extra token either by contributing herself or by obtaining linked output, i.e., $V_A > V_B > V_C > V_D > V_E > V_F$.

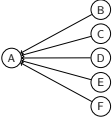
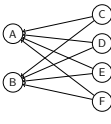
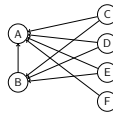
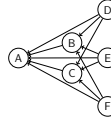
Table 1: Treatments.

		Cost (c) by role						k	V
Treatment		A	B	C	D	E	F		
Cost heterogeneity	T1	8	72	76	80	84	88	1500	240
	T2	8	80	84	88	92	96		
	T3	20	32	64	68	73	96	2000	
	T4	20	34	80	84	88	92		
	T5	34	70	74	86	90	94	1500	
	T6	34	68	72	84	88	92		
		Valuation (V) by role						k	c
Treatment		A	B	C	D	E	F		
Valuation heterogeneity	T7	252	188	184	180	176	172	300	20
	T8	252	180	176	172	168	164		
	T9	252	200	176	172	168	144	620	
	T10	252	200	172	168	164	140		

We created six treatments with cost heterogeneity and four treatments with valuation heterogeneity. The treatments, displayed in Table 1, vary according to the precise distribution of values for the variable subject to heterogeneity. An equilibrium prediction exists for each treatment, specifying the contribution level for each role, and also who initiate links to whom. Although in KM it is possible to have more than one equilibrium for a given set of parameters, the parameters selected in our design ensure that each treatment has a unique one, thus enabling the evaluation of whether our participants’ behaviour is consistent with the predictions in KM. The equilibrium of each treatment is presented in Table 2.

Note that, for each type of heterogeneity, we have some treatments

Table 2: Theoretical equilibria.

	Treatment	Equilibrium contribution in tokens by role						Equilibrium graph
		A	B	C	D	E	F	
Cost heterogeneity	T1	71	13	11	8	7	5	graph (a)
	T2	66	14	11	10	8	6	
	T3	34	32	22	20	18	16	graph (b)
	T4	30	28	22	20	18	16	
	T5	23	20	18	16	14	12	graph (d)
	T6	24	20	18	16	14	12	
	Treatment	Equilibrium contribution in tokens by role						Equilibrium graph
		A	B	C	D	E	F	
Valuation heterogeneity	T7	71	13	11	9	7	6	graph (a)
	T8	66	14	12	10	8	6	
	T9	36	33	9	7	5	26	graph (c)
	T10	34	32	10	8	6	26	
Equilibrium graph								
	(a)							
	(b)							
	(c)							
	(d)							

where equilibrium play would generate a simple star network structure (graph (a)), while in other treatments it would create rather more complex linking structures. In devising multiple treatments, it is not our primary interest to compare outcomes between them by measuring treatment effects. Instead, our interest is, within each treatment, to compare the observed behaviour against the theoretical prediction. Our reason for including many different treatments is to evaluate the KM theory extensively, across a wide range of different circumstances.

2.3 Procedure

We used z-Tree to conduct the experiment (Fischbacher, 2007). In each round, subjects made their two decisions on the screen shown in Figure 2(a). All group members made their decisions simultaneously without any communication. When the whole group finished inputting its decisions, the

result was reported to all group members, as shown in Figure 2(b). We reported the following information by role: tokens produced, all connections made, tokens obtained from neighbours, revenue, total cost of contribution, total cost of initiating links, and finally the earnings which are defined by revenue minus the two kinds of cost.

(a) An example of the decision screen (Part 1 of Treatment 1).

Link result by role

```

graph LR
    A((A)) --> B((B))
    A((A)) --> C((C))
    A((A)) --> D((D))
    A((A)) --> E((E))
    A((A)) --> F((F))
    B((B)) --> C((C))
    C((C)) --> D((D))
    D((D)) --> E((E))
    E((E)) --> F((F))
    F((F)) --> A((A))
  
```

Earnings result by role

Role	Your tokens	Neighbours' tokens	Total tokens	Total paid links	Revenue	Total production cost	Total link cost	Earnings
A	80	110	190	0	14400	640	0	13760
B	48	141	189	1	14400	3456	1500	9444
C	24	128	152	2	14400	1824	3000	9576
D	12	128	140	2	14400	960	3000	10440
E	25	128	153	2	14400	2100	3000	9300
F	1	80	81	1	12879	88	1500	11291

OK

(b) An example of the result screen (Part 1 of Treatment 1).

Figure 2: z-Tree screenshot.

Note: the red English translations are overlaid above the original Mandarin text.

In addition to the experimental instructions, each participant was given a booklet, which displayed, for each role, what the payoffs would be for different combinations of possible actions. When a specific role was assigned to a participant, she could turn to the page for that role, using the listed payoffs and associated actions to help make decisions. We expected this booklet to reduce the calculation load in the experiment. The instructions in English and the corresponding payoff booklet of Treatments 1 and 7 are available in Appendix [A3](#). The experimenter read aloud the instructions and the notes on the first page of the payoff booklet introducing how to use it.

Each session had two parts. In Part 1, participants were randomly partitioned into groups and performed the task for one round. We included this one-shot game in order to be consistent with the KM model, which itself only has one round. Not until Part 2 started would the participants become informed of its content. In this part, participants performed the same task for another 19 rounds. They were told they would keep the same matching group from Part 1, while the six roles would be randomly assigned at the start of each round. Each group maintained the same treatment as in Part 1. At the end of each round, the results of the current round were reported. Our reason for including this repeated game in addition to the earlier one-shot game is to provide the KM model with a fair chance of success in reality: while repeated interactions are not technically part of the model, we considered learning effects to be an empirical possibility, which in practice could potentially push subjects either closer to or further away from equilibrium behaviour.

After we introduced the experimental instructions in Part 1, participants needed to pass tests of understanding and play a mock round of the task before starting the formal task. The aim of the tests was to train participants to familiarize themselves about how their earnings in ECUs were calculated. In each test, participants were asked to calculate the earnings of certain roles, based on the levels of production and network graph in the example given. To avoid nudging participants into particular contribution or linking behaviour, different subjects in a given session were assigned different tests, and the tests also differed across sessions. The mock round was identical in procedure to the formal task of Part 1 except participants

were told this was not a paid round. The purpose of the mock round was for participants to familiarize themselves with the screen and software.⁷

Before the start of Part 1, participants were told their final payment would consist of their show up fee and their earnings from either Part 1 or Part 2 with equal probability, to be determined at the end of the experiment. In Part 1, when the one-round task was introduced, subjects were told that if Part 1 was randomly selected to be the incentivised part, their payment from this part would comprise their earnings from its (formal) one-shot game. In Part 2, when they were introduced to the repeated task, they were told that if Part 2 was selected, then one of these 19 rounds would later be selected with equal probability to determine their earnings from this part. The show up fee was 40 Chinese Yuan per participant. This amount is higher than standard levels to avoid the possibility of any subject achieving a negative overall payoff. The ECUs earned in the task were transferred to Yuan at the exchange rate of 150 ECUs = 1 Yuan.

The experiment was conducted at the CeDEx China laboratory of the University of Nottingham Ningbo China, and the Economics Experimental Laboratory (NEXL) of Nanjing Audit University, between March and June 2021. We conducted two sessions for each treatment, one in Ningbo and the other in Nanjing. In Ningbo, participants were selected and invited at random via ORSEE (Greiner, 2015). In Nanjing, they were recruited by Sona Systems.⁸ Detailed background information on the subjects, summarised in Table 3, was collected via a post-experimental questionnaire. The majority were undergraduate students majoring in Economics and

⁷Participants received feedback on the outcome of the mock round, since we wanted to familiarize them with the way the results would be presented. In principle, one might wonder if behaviour in the formal round of Part 1 was influenced by learning effects from the mock round, but we find little evidence of this. We ran Mann-Whitney U tests to compare the production levels and number of links initiated between the mock round and formal round (of Part 1), separately for the combined data collected under cost heterogeneity and valuation heterogeneity. We find only that production behaviour under cost heterogeneity is just barely significantly different between the mock and formal rounds at the 10% level ($z = 1.667$, $p = 0.0096$). There is an insignificant difference in the number of initiated links under cost heterogeneity, and there are insignificant differences in both production levels and quantity of links under valuation heterogeneity. Assignment to groups was shuffled between the mock and formal rounds (and subjects were informed of this).

⁸Sona Systems is a cloud-based participant management platform. The functions Sona Systems has are almost the same as ORSEE. For more information, see <https://web.sona-systems.com/default.aspx>.

Business, and 75% were female. This is consistent with the gender ratios within the registered participant pools of both universities. 81.58% of the participants reported that they understood the concept of “marginal benefit”, which reflects their academic background; and 41.45% of them reported that this was their first time participating in an economics lab experiment.

Table 3: Background information about participants.

	Ningbo $N = 152$	Nanjing $N = 152$	Total $N = 304$	
Mean age	19.94	21.00	20.47	($SD = 1.66$)
Female	107	121	228	(75.00%)
UG-Year 1 to Year 4	144	134	278	(91.45%)
Area of study				
Social Science -Economics	32	35	67	(22.04%)
Social Science -Other	14	3	17	(5.59%)
Business	61	102	163	(53.62%)
Science	45	12	57	(18.75%)
Have experiment experiences	44	134	178	(58.55%)
Have ever heard of “marginal benefit”	105	144	248	(81.58%)
Mean number of friends in the lab	0.34	0.89	0.62	($SD = 1.76$)

Participants were paid at the end of the session using WeChat Pay. This type of electronic method is used for almost all payments in China nowadays, and the money transfer is immediate. Earnings per participant, including the show-up fee, took a mean value of 98.32 Yuan, with a range of 42.11-143.15. Since each session lasted for about 100 minutes, the average hourly rate in this experiment reached 58.99 Yuan (equivalent to 8.02 Euros), thus the incentive level was sufficient.⁹

3 Hypotheses

We will evaluate whether participants’ behaviour is affected by their role, and to what extent it is consistent with that predicted by the KM model. KM characterise equilibria under scenarios of cost and valuation heterogeneity in Theorem 1 and Theorem 2 of their paper, respectively. They point out that different roles have different behaviour in equilibrium, and

⁹The mean hourly earnings were three times higher than for a part-time job on either campus, e.g., working as a student administrative assistant at the front desk of the university library.

that these constitute the ‘law of the few’. Our hypotheses correspond to these theorems, and are based on predicted equilibrium behaviour in the treatments we consider (see Table 2). In both Hypothesis 1 and Hypothesis 2, we consider two things. First, we consider which roles receive relatively more or less links. In graph theory, the links received by a node are called “in-links”. We use this concept to define which role is positioned into the centre of the network.¹⁰ Secondly, we consider the relative production levels among the different roles. Hypothesis 1 below relates to the within-group differences under cost heterogeneity scenarios.

Hypothesis 1 *In scenarios of cost heterogeneity, behaviour exhibits the following two patterns:*

Hypothesis 1.1 *Any better role receives weakly more in-links than any worse role, i.e., $\eta_A^{IN}(g) \geq \eta_B^{IN}(g) \geq \eta_C^{IN}(g) \geq \eta_D^{IN}(g) \geq \eta_E^{IN}(g) \geq \eta_F^{IN}(g)$.*

Hypothesis 1.2 *Any better role produces more than any worse role, i.e., $x_A > x_B > x_C > x_D > x_E > x_F$.*

Hypothesis 2 relates to scenarios of valuation heterogeneity. Note that in these scenarios, for production behaviour the KM model only makes predictions about the roles which are positioned in the core of the network in equilibrium. Correspondingly, our Hypothesis 2.2 applies only to the core roles rather than all roles. To verify Hypothesis 2.2, we will only use Treatments 9 and 10. This is because the equilibrium graph in Treatments 7 and 8 only contains one role in the core, so there is no way to make within-core comparisons. Moreover, we will firstly need to verify that Role A and Role B are – as predicted – positioned as core players in Treatment 9 and Treatment 10, before we use their decisions to test the hypothesis.

Hypothesis 2 *In scenarios of valuation heterogeneity, behaviour exhibits the following two patterns:*

Hypothesis 2.1 *Any better role receives weakly more in-links than any worse role, i.e., $\eta_A^{IN}(g) \geq \eta_B^{IN}(g) \geq \eta_C^{IN}(g) \geq \eta_D^{IN}(g) \geq \eta_E^{IN}(g) \geq$*

¹⁰The degree centrality of a node is measured as $\frac{\text{this node's number of inlinks}}{\text{total number of nodes}-1}$, and ranges from 0 to 1. In other words, a larger number of in-links also indicates a more central position in a network. In a directed graph, we can also consider the links initiated by a node, which are called “out-links”.

$$\eta_F^{IN}(g).$$

Hypothesis 2.2 *For roles in the core, better roles produce more than worse roles, i.e., $x_A > x_B$.*

We also want to assess the extent to which the equilibrium can be reached. Since each treatment has only one equilibrium, we will evaluate whether the behaviour in each treatment is close to this predicted state. To do so, one statistic we will use is the *network density ratio*, defined as the total number of links initiated within an entire group divided by number of links of that group's equilibrium graph. If it is larger or smaller than one, it means this group forms a network which is denser or sparser than the equilibrium graph, respectively. In such cases, we can conclude the group deviates from the predicted linking behaviour. To evaluate the closeness of participants' contributions to the equilibrium level, we further define the *production ratio* of a participant as her tokens produced divided by her predicted equilibrium contribution, given her role. If this ratio is above or below one, then actual contributions exceed or fall short of the hypothesised level, respectively. Hypothesis 3 below applies both to cost and valuation heterogeneity scenarios.

Hypothesis 3 *Under both cost and valuation heterogeneity, participants' behaviour is consistent with the equilibrium predictions for their assigned roles.*

Hypothesis 3.1 *Linking behaviour is consistent with the equilibrium: the mean network density ratio is statistically indifferent from 1.*

Hypothesis 3.2 *Production behaviour is consistent with the equilibrium: the mean production ratio is statistically indifferent from 1.*

Note that, although Hypothesis 3.1 relates to the network density ratio, even if we were to identify a value equal to one, this would not necessarily indicate the emergent network is the same as the equilibrium graph. This is because, although the total number of initiated links are the same, who links with whom could be different. We will therefore also explore the extent to which the links actually initiated are the same as those predicted by the model.

4 Results

The analysis is structured in three sub-sections. We firstly discuss behaviour by role in Section 4.1, as these correspond to Hypothesis 1 and Hypothesis 2. Next, we evaluate the extent to which the results are close to the equilibrium predictions in Section 4.2, thereby testing Hypothesis 3. In Section 4.3, we consider the payoff consequences of choices in the experiment. Since we are specifically interested in the two types of scenarios considered in the experiment, we will analyse data under the cost heterogeneity and valuation heterogeneity scenarios separately. In our data set, an observation consists of one subject in one round, which means it documents a subject’s decisions about how many tokens to produce and to whom to link to in a certain round. For cost heterogeneity, we use data from Treatments 1 to 6, which consists of 2,880 observations.¹¹ For valuation heterogeneity, we use data from Treatments 7 to 10, which consists of 1,920 observations.¹²

4.1 Behaviour by role

4.1.1 Part 1 results

We first analyse behaviour under cost heterogeneity. Figure 3(a) displays the average number of links initiated by each role. A Kruskal-Wallis test confirms that the mean level of out-links differs across the six roles ($\chi^2(5) = 53.695$, $p < 0.001$). We further conduct pairwise comparisons between roles using Dunn’s test.¹³ We find the only significant difference between roles is that Role A rarely initiates links compared with the other five (largest p -value = 0.031). The average number of links received by each role are shown in Figure 3(b). We find that in-links are highly concentrated on Roles A and B, while for Roles C to F the mean number is close to zero.

¹¹2,880 observations = 6 treatments * 4 matching groups per treatment * 6 group members per matching group * 20 rounds (excluding the mock round).

¹²1,920 observations = 4 treatments * 4 matching groups per treatment * 6 group members per matching group * 20 rounds (excluding the mock round).

¹³The significance reported by a Kruskal-Wallis test only shows differences among the six roles exist, while it cannot tell which roles differ. Dunn’s test therefore is used as a post hoc procedure to determine which roles are significantly different from each other by providing pairwise analysis (Dinno, 2015).

Following a Kruskal-Wallis test confirming the significance of differences in mean number of in-links across role types ($\chi^2(5) = 110.039$, $p < 0.001$), the Dunn's test shows this number does not significantly differ between Roles A and B, while both roles receive significantly more than each of Roles D to F (largest p -value < 0.001). Number of in-links also does not significantly differ across Roles C to F (smallest p -value = 0.290).

Result 1.1 *Under cost heterogeneity, better roles receive weakly more in-links than worse roles. Hypothesis 1.1 is supported.*

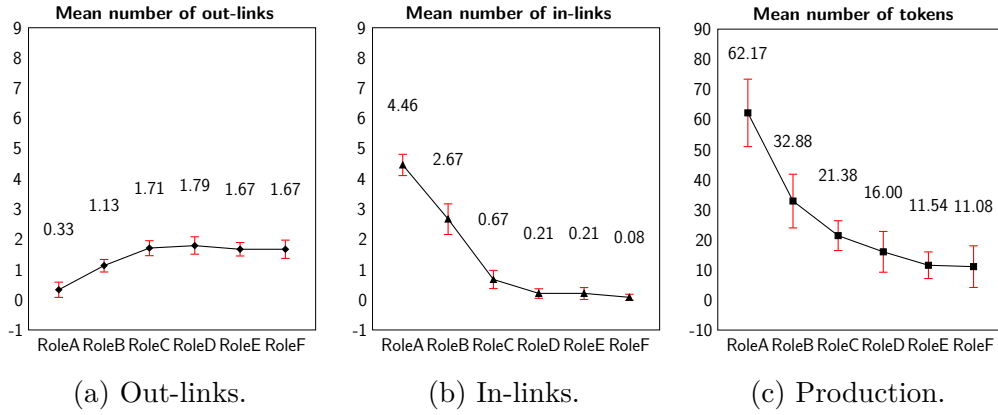


Figure 3: Behaviour by role, Part 1, Cost Heterogeneity.

Note: Error bars represent 95% confidence intervals

Figure 3(c) displays the average number of tokens produced by each role. It can be observed that the amounts decrease in the cost parameter. Again, a Kruskal-Wallis test confirms that the mean level of production differs across the six roles ($\chi^2(5) = 66.260$, $p < 0.001$). Using Dunn's tests, it is found that Role A produces significantly more than any other role (largest p -value = 0.042). Role B does not differ significantly from Role C, while it produces significantly more than each of Roles D to F (largest p -value = 0.042). Role C does not differ significantly from Role D or Role E, while it produces significantly more than Role F (p -value = 0.039). Role E to Role F cannot be distinguished (smallest p -value = 1.000). In summary, while all roles produce more than those with higher costs, the differences are not always significant. Nevertheless, results are generally consistent with our theoretical expectations.

Result 1.2 *Under cost heterogeneity, better roles produce more tokens than worse roles, although not all strict inequalities are established (because it is not the case that every pairwise comparison is significant). Hypothesis 1.2 is partially supported.*

Results 1.1 and 1.2 together show the ‘law of the few’. When we vary production costs among group members, better roles endowed with lower costs produce more by themselves and initiate less links; worse roles produce less and initiate more links. Better roles are positioned in the centre of the network by receiving more in-links from worse roles, and worse roles are positioned on the periphery of the network.

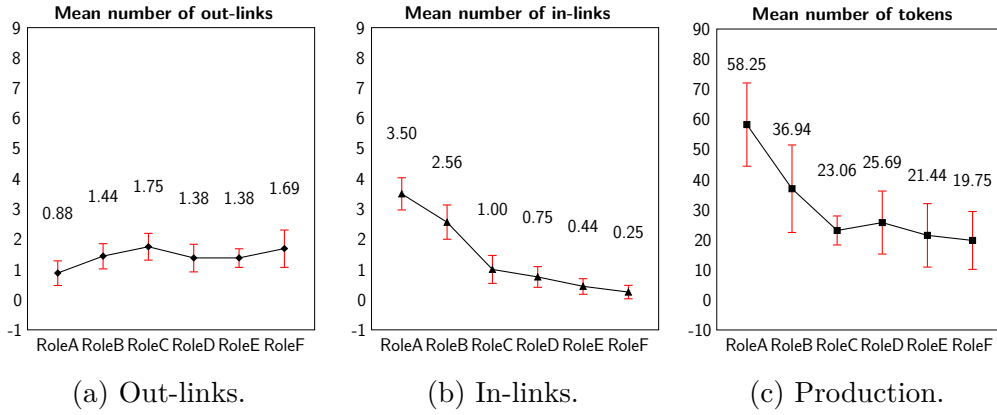


Figure 4: Behaviour by role, Part 1, Valuation Heterogeneity.
Note: Error bars represent 95% confidence intervals

Regarding scenarios of valuation heterogeneity, Figure 4(a) displays the average number of links initiated by each role. A Kruskal-Wallis test shows that there are no differences with respect to link initiating behaviour among these roles ($\chi^2(5) = 8.084$, $p = 0.152$).¹⁴ Figure 4(b) shows that in-links are concentrated on Roles A and B. A Kruskal-Wallis test finds number of in-links differs across role types ($\chi^2(5) = 62.732$, $p < 0.001$). Dunn’s tests show that Role A and Role B receive significantly more links than each of the other roles (largest p -value = 0.016), while there are no significant differences between them (p -value = 1.000). All differences among Roles C to F are also insignificant (smallest p -value = 0.316).

¹⁴We therefore do not report the results of pairwise Dunn’s tests here, since these are follow-up tests we employ only when the Kruskal-Wallis test identifies differences exist across role types.

Result 2.1 *Under valuation heterogeneity, better roles receive weakly more links than worse roles. Hypothesis 2.1 is supported.*

As discussed above, the prediction in Hypothesis 2.2 on producing behaviour is restricted to the core players in Treatments 9 and 10. Therefore, we need to show that Roles A and B are indeed core players in these two treatments, in line with our prediction. Figure 5(b) shows that similar with the whole sample under valuation heterogeneity (Treatment 7 to 10), in Treatments 9 and 10 in-links are concentrated on Roles A and B as well. Kruskal-Wallis test confirms that differences across roles exist ($\chi^2(5) = 29.417$, $p < 0.001$), and Dunn's tests show Result 2.1 satisfies this restricted sample, albeit with some differences in the precise results. Role A and Role B are not significantly different with each other (p -value = 1.000), while Role B is different from Role A in that it does not receive significantly more links than Role D (p -value = 0.104). Therefore, Roles A and B are confirmed to be positioned in the centre of the network, with Role B less central than Role A.

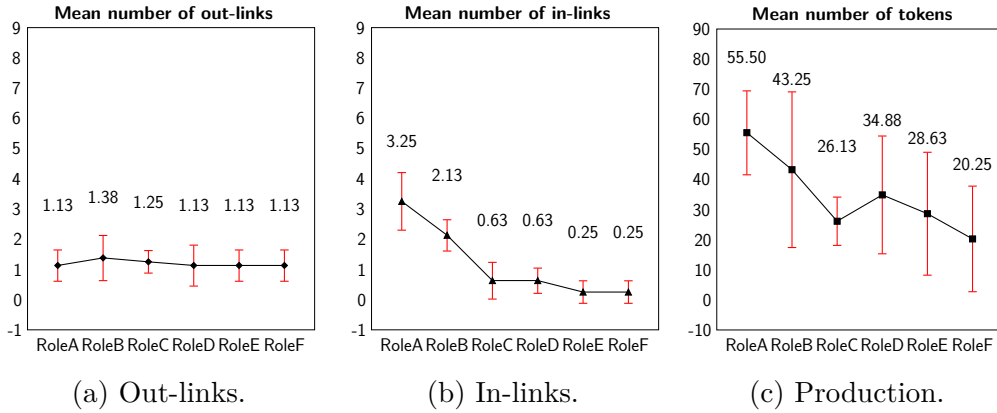


Figure 5: Behaviour by role, Part 1, Valuation Heterogeneity, Treatments 9 and 10.

Note: Error bars represent 95% confidence intervals

Therefore, we can turn to verifying Hypothesis 2.2. Figure 5(c) displays the mean amount of tokens produced by each role in Treatments 9 and 10. It shows that Role A contributes more than Role B. However, the core players Role A and Role B do not significantly differ in production levels (Kruskal-Wallis test, $\chi^2(5) = 0.625$, $p = 0.429$).

Result 2.2 *Under valuation heterogeneity, better roles produce more than worse roles, but the difference in production between players in the core is not significant. Hypothesis 2.2 is not supported.*

Result 2.2 does not necessarily mean Hypothesis 2.2 is not supported at all. We will return to this point in Section 4.1.2 when multiple-round outcomes are discussed.

Although Result 2.1 is not fully consistent with our predictions, we still argue our findings are consistent with the ‘law of the few’, at least based on a looser definition. The reason is that from the data of Treatments 7 to 10, we still can find evidence that better roles contribute more. Consider the mean amount of tokens produced by roles across Treatments 7 to 10, which is displayed in Figure 4(c). The general pattern is that the mean number of tokens produced increases in the valuation parameter, with the slight exception of Role D. A Kruskal-Wallis test shows roles are different in the level of contribution ($\chi^2(5) = 23.190$, $p < 0.001$). Dunn’s tests further tell us this is because Role A contributes significantly more than Role C to F (largest $p = 0.011$). However, there are differences in linking behaviour compared with scenarios of cost heterogeneity. Although better roles are again positioned in the centre because they receive more in-links, our evidence shows that these in-links come from both better roles and worse roles in scenarios of valuation heterogeneity.¹⁵

4.1.2 Part 2 results

In Part 2, participants performed the same task for another 19 rounds, kept in the same matching groups with roles shuffled in each round, and with feedback delivered at the end of each round. Our interest in Part 2 is in the form behaviour takes after multiple rounds have been played and subjects have had the opportunity to learn about the game. Therefore, we will focus primarily on the last round of Part 2.

Figures 6 and 7 show the mean numbers of out-links and in-links, as well as the mean production levels of the six roles, in the last round of

¹⁵In the restricted sample (Treatments 9 and 10), Figure 5(a) also shows on average each role initiates about one link. A Kruskal-Wallis test shows linking behaviour does not significantly differ across roles ($\chi^2(5) = 0.430$, $p = 0.995$). Thus, all roles initiate links.

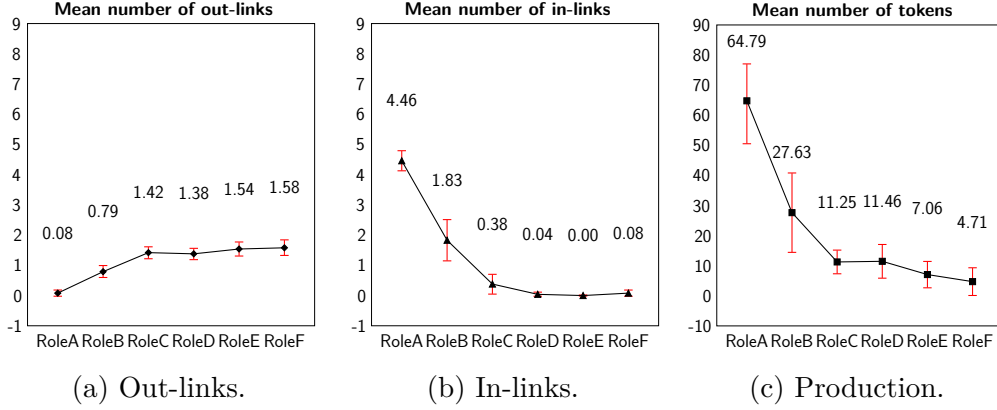


Figure 6: Behaviour by role, last round of Part 2, Cost Heterogeneity.
Note: Error bars represent 95% confidence intervals

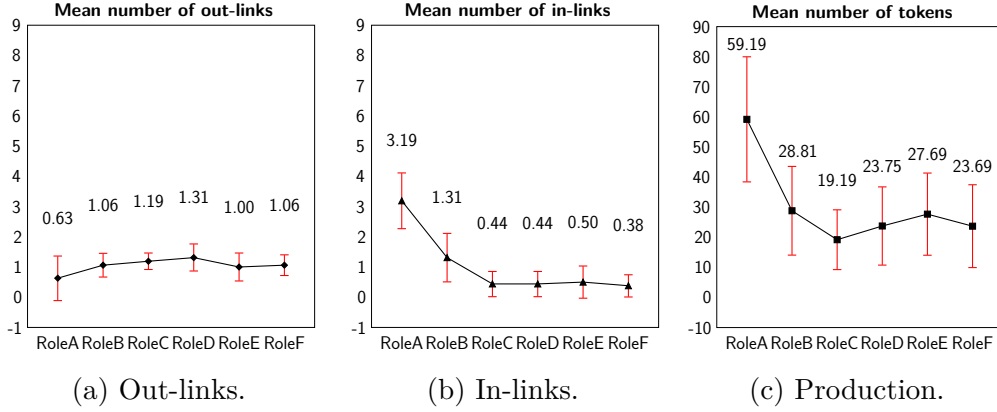


Figure 7: Behaviour by role, last round of Part 2, Valuation Heterogeneity.
Note: Error bars represent 95% confidence intervals

Part 2. From casual inspection of the graphs, it can clearly be seen that the patterns of behaviour look qualitatively similar to those from Part 1. To the data from this round, we apply the same formal methods of analysis we reported above for Part 1, to check whether the patterns of behaviour we identified there remain true. We find the results of the last round of the experiment, under both scenarios of cost and valuation heterogeneity, still generally support ‘the law of the few’, although there are some changes. The final round data still leads to Results 1.1 and 1.2 under scenarios of cost heterogeneity. There are some differences under scenarios of valuation heterogeneity. Regarding linking behaviour, in the last round, only Role A is in the core; and the production of Role A is only significantly greater than

that of Roles C, D and F. Appendix A5 contains the relevant statistical tests.

The similarity of outcomes between the first and last rounds of the experiment demonstrate the impact of heterogeneity is enduring; it was formed in Part 1 when participants performed the one-shot game and maintained in Part 2 when they played it repeatedly. In Appendix A6, we provide graphs to show the evolution of levels of production, number of out-links and number of in-links. These demonstrate that, not only was behaviour similar between the first and last rounds, but the patterns are also replicated for middle rounds. As a further exploration, we also provide, in Appendix A4, an analysis of the data combined across all 20 rounds. This takes the form of OLS regressions with categorical variables capturing the different roles, as well as dummies representing the stage of the experiment and treatment. The results yield qualitatively similar findings to those observed separately from the first or last round of the experiment.

Recall that in Section 4.1.1 we find the data cannot support Hypothesis 2.2. However, this might be due to the small amount of data under valuation heterogeneity: we only focus on Roles A and B, and each role only contains eight observations when we restrict the sample to the first round of Treatments 9 and 10. As an alternative analysis, we also run a regression analysis using all 20 rounds of Roles A and B's decisions from Treatments 9 and 10 in column (3) of Table A.1 (Appendix A4). The result shows that when there are more data points included, Role A contributes significantly more than Role B, supporting our hypothesis (the Restricted F Test of coefficient on Role A and B, $p < 0.001$).

4.2 Equilibrium analysis

In this subsection we first evaluate the extent to which behaviour is close to the equilibrium in the one-shot game. Thus, we report the results of Part 1. We then report the results of Part 2 to identify the closeness to equilibrium in a repeated game setting.

4.2.1 Part 1 results

We first check the number of participants making the equilibrium choices that are predicted given their assigned role and treatment. There are 57 participants (39.583%) participants making the linking decisions that are identical to those in their treatment’s equilibrium graph in cost heterogeneity scenarios, and 23 (23.958%) doing so under valuation heterogeneity. As each participant needs to make five linking decisions, we further check how many of these on average correspond to those in their equilibrium graph. We find that in the first round the model predicts quite well because on average each participant makes 4.115 ($SD = 1.034$) and 3.854 ($SD = 0.917$) decisions corresponding to the equilibrium prediction in scenarios of cost heterogeneity and valuation heterogeneity, respectively.¹⁶ With regards to production decisions, there are two participants (1.389%) choosing the exact equilibrium level of their assigned role as their actual production level in scenarios of cost heterogeneity, and one participant (1.042%) does so under valuation heterogeneity. We further find that no participant makes linking and production decisions which both correspond to the equilibrium behaviour. Therefore, in the one-shot game setting, the exact equilibrium does not occur. Our next step is to check how subjects deviate from it.

The mean network density ratio in scenarios of cost heterogeneity is 1.139 ($SD = 0.444$), although this is not significantly different from one (Two-tailed Wilcoxon Single Sample T-test, $z = 0.992$, $p = 0.331$). In scenarios of valuation heterogeneity, the mean network density ratio is 1.432 ($SD = 0.661$), which is significantly greater than one (Two-tailed Wilcoxon Single Sample T-test, $z = 4.741$, $p < 0.001$). Table 4 below shows on average which roles initiate more or less links than equilibrium, by subtracting their equilibrium number of out-links from their actual numbers. This table shows that in both types of scenario, this statistic is significantly positive for better roles (Role A and Role B), indicating they initiate more links than predicted by the model.¹⁷ Worse roles in general initiate insignifi-

¹⁶Details can be retrieved from Appendix A7.

¹⁷Note that the comparisons here are against zero (rather than against one, like other comparisons in this paper) since here the measurement is the actual number of out-links minus the equilibrium, rather than a division. We cannot use a division because for some roles the equilibrium number of out-links is 0.

cantly fewer links than in equilibrium in scenarios of cost heterogeneity, and do not deviate too much from equilibrium in scenarios of valuation heterogeneity.

Result 3.1 (a) *Under cost heterogeneity, in one shot games participants form a network that is equally dense as the equilibrium prediction. Under valuation heterogeneity, participants form a denser than equilibrium network in one shot games. Therefore, Hypothesis 3.1 is not fully supported for one shot games. In both type of scenarios, better roles initiate more links than predicted.*

Table 4: Average number of out-links compared to the equilibrium by role.

	Role A	Role B	Role C	Role D	Role E	Role F
Cost heterogeneity						
Round 1	0.333** (0.637)	0.458*** (0.588)	0.375** (0.770)	-0.208 (1.102)	-0.333 (0.917)	-0.333 (1.167)
Round 20	0.083 (0.282)	0.125 (0.448)	0.083 (0.584)	-0.625*** (0.770)	-0.458*** (0.721)	-0.417** (0.929)
Valuation heterogeneity						
Round 1	0.875*** (0.806)	0.938*** (0.929)	0.250 (1.238)	-0.125 (1.147)	-0.125 (0.957)	0.688** (1.195)
Round 20	0.625** (1.408)	0.563*** (0.629)	-0.313 (0.873)	-0.188 (1.223)	-0.500 (1.211)	0.063 (0.680)

Note: Standard deviation in parentheses. Two-tailed Wilcoxon Single Sample T-test against zero. Number highlighted in green and in red when it is significantly greater than and less than zero, respectively.

** $p < 0.01$, * $p < 0.05$, $p < 0.1$.

In both types of scenario, participants produce more than the predicted levels. The mean production ratio in the scenario of cost heterogeneity is 1.323 ($SD = 1.336$), which is significantly greater than one (Two-tailed Wilcoxon Single Sample T-test, $z = 1.895$, $p = 0.058$). Table 5 displays the ratio by roles. It shows that better roles produce over the predicted level and the production ratios of worse roles are either not significantly different from one or significantly less than one. In the scenario of valuation heterogeneity, the mean production ratio is 2.387 ($SD = 2.449$) and it is significantly greater than one (Two-tailed Wilcoxon Single Sample T-test, $z = 5.681$, $p < 0.001$). When the result is separated by roles in Table 5, all roles produce more than their own predicted equilibrium levels even if not

all of them pass Two-tailed Wilcoxon Single Sample T-tests (largest $p = 0.342$). Moreover, worse roles have higher production ratios than better roles. These patterns, combined with Result 3.1, show that in a one-shot game participants tend to produce more, and form a denser network, than in equilibrium.

Result 3.2 (a) *In both types of scenario, participants overproduce in one shot games. There is overproduction by better and worse roles under valuation heterogeneity, while only better roles overproduce in scenarios of cost heterogeneity. Hypothesis 3.2 is not supported for one shot games.*

Table 5: Average production ratio by role.

	Role A	Role B	Role C	Role D	Role E	Role F
Cost heterogeneity						
Round 1	1.787*** (0.959)	1.607*** (0.938)	1.267* (0.667)	1.083 (1.041)	0.920* (0.971)	1.277 (2.507)
Round 20	1.675*** (0.964)	1.135 (1.086)	0.656*** (0.550)	0.773* (0.888)	0.602*** (0.989)	0.570*** (1.424)
Valuation heterogeneity						
Round 1	1.247 (0.616)	1.789** (1.447)	2.251*** (1.035)	3.222*** (2.789)	3.707** (4.001)	2.108 (2.481)
Round 20	1.388 (1.135)	1.293 (1.065)	1.917 (1.948)	2.816** (2.862)	4.620** (4.694)	3.165 (4.644)

Note: Standard deviation in parentheses. Two-tailed Wilcoxon Single Sample T-test against one. Number highlighted in green and in red when it is significantly greater than and less than one, respectively.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.2.2 Part 2 results

In the repeated game, we again find little evidence of behaviour coming very close to the predicted equilibrium. We first summarize the results of the final round of the experiment. In scenarios of cost heterogeneity, 89 participants (61.806%) make linking decisions identical to those in their treatment's equilibrium graph, with one participant (0.694%) choosing the equilibrium amount as their production level (this participant also made equilibrium linking decisions, and therefore played perfectly in accordance to the model). In scenarios of valuation heterogeneity, 34 participants

(35.417%) make linking decisions identical to their treatment’s equilibrium graph, and no participant chooses the equilibrium amount as their production level. We find that in the last round participants on average make 4.423 ($SD = 0.993$) and 3.979 ($SD = 1.056$) predicted decisions out of the total of five linking decisions in cost heterogeneity and valuation heterogeneity scenarios, respectively. A Wilcoxon Signed-Rank test shows that participants make more predicted linking decisions in round 20 than in round 1 in scenarios of cost heterogeneity ($z = 3.231$, $p = 0.001$). Under valuation heterogeneity, a Wilcoxon Signed-Rank test shows that participants do not make more predicted linking decisions in the final round compared with round 1 ($z = 1.061$, $p = 0.290$). Therefore, while the probability of reaching the exact equilibria is still very low, there is clearly some movement towards it over the course of the experiment, at least in terms of linking behaviour.

Under cost heterogeneity, the network density ratio is 0.912 ($SD = 0.322$), which shows a significant decrease compared with Part 1 (Wilcoxon Signed-Rank test, $z = -2.465$, $p = 0.012$). While this is weakly significantly less than 1 (Two-tailed Wilcoxon Single Sample T-test, $z = -1.912$, $p = 0.055$), it is qualitatively not far away from it. Thus, participants form a slightly sparser network than the equilibrium graph after multiple rounds. The production ratio is 0.902 ($SD = 1.074$), which is significantly different from the ratio in Part 1 (Wilcoxon Signed-Rank test, $z = -3.562$, $p < 0.001$). The production ratio is also significantly less than 1 (Two-tailed Wilcoxon Single Sample T-test, $z = -3.035$, $p = 0.002$) but the value itself is not far away from 1. It indicates that in the repeated game setting, both linking decisions and production do not converge to the equilibrium, but instead to a below-equilibrium level. Tables 4 and 5 show that both declines are mainly caused by worse roles as they initiate links and contribute under the equilibrium level. For linking behaviour, Roles D, E and F have average numbers of links below the equilibrium predictions. For contribution behaviour, Role A significantly overproduces in the last round, while Roles C, D, E and F significantly underproduce. Such a decline in contributions after repeated play is consistent with experimental observations of standard public good games (see, e.g., [Chaudhuri, 2011](#)).

In the scenarios of valuation heterogeneity, the network density ratio

is 1.100 ($SD = 0.772$). It is not significantly different from 1 (Two-tailed Wilcoxon Single Sample T-test, $z = 0.078$, $p = 0.950$). A significant decrease of this ratio from Part 1 to Part 2 is detected (Wilcoxon Signed-Rank test, $z = -1.813$, $p = 0.071$). As before, better types link more than predicted. The mean production ratio in the scenarios of valuation heterogeneity is 2.533 ($SD = 3.243$), which is significantly greater than one (Two-tailed Wilcoxon Single Sample T-test, $z = 3.590$, $p < 0.001$), and not significantly different from Part 1 (Wilcoxon Signed-Rank test, $z = -0.771$, $p = 0.444$). Therefore, while linking decisions are somewhat closer to equilibrium, the general patterns from round 1 are replicated and, in particular, production levels are still a long way above equilibrium.

Result 3.1 (b) *Under cost heterogeneity, in repeated game settings, participants form a network sparser than the equilibrium prediction since worse roles initiate less links. Under valuation heterogeneity, participants form a network of equivalent density to the equilibrium, while better roles initiating more links than predicted. Hypothesis 3.1 is not fully supported for repeated games settings.*

Result 3.2 (b) *Under cost heterogeneity, in repeated game settings, participants underproduce and this is mainly caused by worse roles. Under valuation heterogeneity, participants overproduce, and all roles contribute to this even if not significantly. Hypothesis 3.2 is not supported for repeated games settings.*

Overall, although we find evidence that participants are making more predicted linking decisions in repeated game settings, there is only limited evidence that they are converging to the predicted equilibrium when we consider both linking and production behaviour. The equilibrium convergence situation also differs between cost and valuation heterogeneity scenarios. In Appendix A8, we provide graphs to show how the linking and producing behaviour converges or deviates from equilibrium across all rounds.

4.2.3 What graph emerges in the experiment?

Given that we have established above that subjects' linking decisions often deviate from the theoretical predictions, we are interested in what shape the network graphs form in reality. First, we note that the precise equilibrium graphs do occur occasionally. Recall (from Table 1.2) that, under both cost heterogeneity and valuation heterogeneity scenarios, we have pairs of treatments with different sets of parameters but the same equilibrium graph. We therefore combine each pair of treatments in our analysis. Under cost heterogeneity, aggregating across all rounds, the predicted equilibrium graph emerges 34.38% of the time in Treatments 1 and 2, 6.25% of the time in Treatments 3 and 4, but never in Treatments 5 and 6. Under valuation heterogeneity, the predicted equilibrium graph emerges in 11.88% of all rounds in Treatments 7 and 8, but never in Treatments 9 and 10. One observation arising from these results is that the equilibrium graph occurs more often when it involves simpler relationships among agents. Note that graph (a), the equilibrium graph in Treatments 1, 2, 7 and 8, is a simple "star" network, with only one agent in the core. Other equilibrium graphs have greater complexity, especially graph (d), the equilibrium from Treatments 5 and 6, which has a two-level periphery and never occurs in reality. Another observation is that graph (a) even occurs with moderate frequency in treatments where it is not the equilibrium graph. Moreover, the frequency of the appearance of graph (a) increases in later rounds. These findings are presented in more detail in Appendix A9.

In Figures 8 and 9, we present the graphs from the final round of Part 2 from all matching groups, for scenarios of cost heterogeneity and valuation heterogeneity respectively. Under cost heterogeneity, the graphs show a clear core-periphery structure, because the initiated links are mostly concentrated towards Role A or Role B. Some graphs are exactly at equilibrium, e.g., Group 1, Treatment 1, and Group 2, Treatment 3. Furthermore, other graphs are only slightly different from equilibrium, e.g., the graph of Group 1, Treatment 3, would be in equilibrium if links BC and BE were to exist. Under valuation heterogeneity, the graphs also show a clear core-periphery structure, but there are some differences from under cost heterogeneity. With valuation heterogeneity, in-links are not concentrated on

the best roles in some groups, e.g., Group 1, Treatment 8.

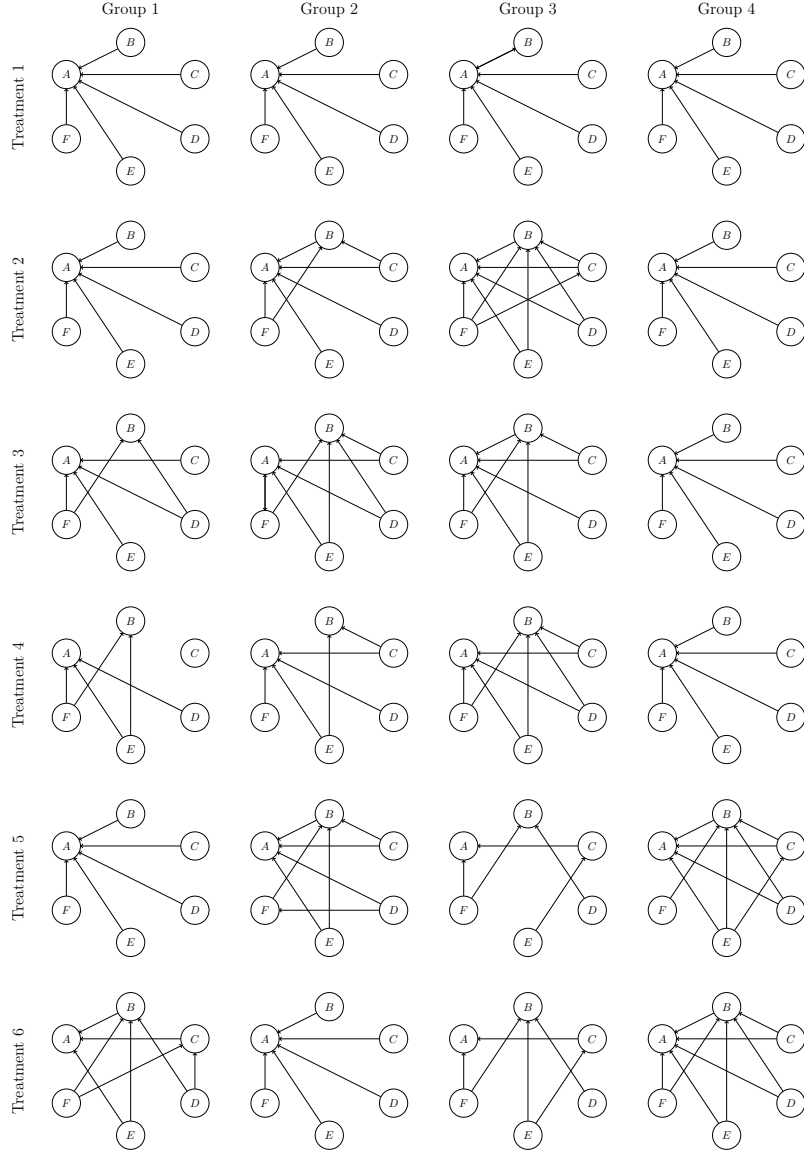


Figure 8: Graph of Round 20, Cost Heterogeneity.

Overall, we observe that participants in our experiment form networks containing core-periphery structures. While in shape they clearly do not match the exact predictions of KM, we argue that they tend to be a qualitative nature broadly consistent with the theory. We do note, however, that the observed networks do not generally belong to the two specific categories of core-periphery graph – complete multipartite graph and nested

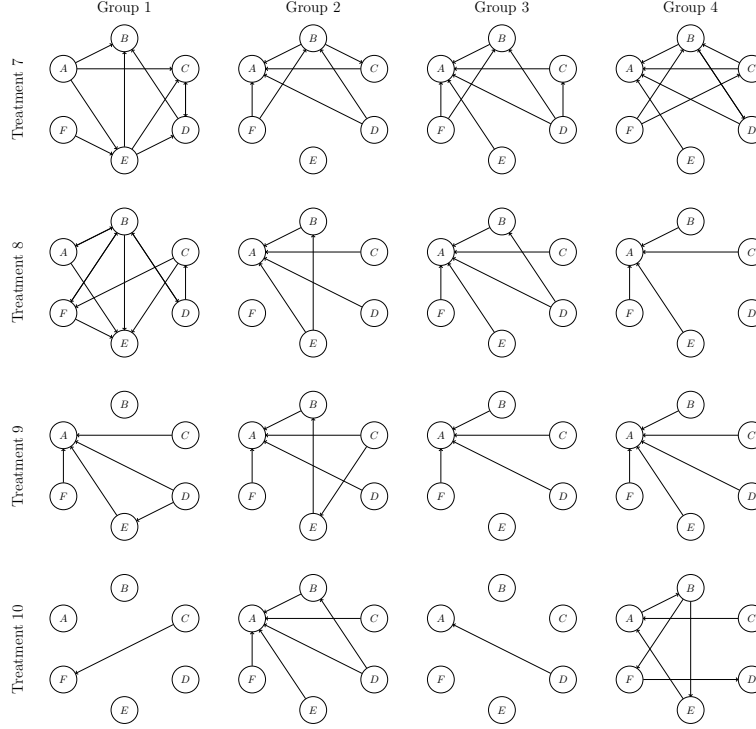


Figure 9: Graph of Round 20, Valuation Heterogeneity.

split graph – that are predicted by the KM model.¹⁸

4.3 Analysis of earnings

Finally, we consider the implications of the patterns of behaviour identified for the networks' efficiency and the payoffs accruing to their members. We present in Table 6 the ratio of each role's average earnings to the predicted equilibrium value, as well as their absolute earnings counted by ECUs. In scenarios of cost heterogeneity, aggregating across all roles, the overall mean earnings ratio is 0.999 ($SD = 0.284$) in Part 1 and 1.094 ($SD = 0.277$) in the last round of Part 2. This demonstrates the overall efficiency of networks is very similar to that predicted in theory, although the ratio is significantly greater than one in the last round (Two-tailed Wilcoxon Single

¹⁸The KM model predicts that under cost heterogeneity the network graph will be a complete multipartite graph, and under valuation heterogeneity it will be a nested split graph. These two kinds of graphs both have a core-periphery structure, but they are different in the core. In a complete multipartite graph, the core players do not connect with each other; in a nested split graph, they do. More discussion can be seen in Appendices A1.2 and A1.3.

Sample T-test, $z = 3.596$, $p < 0.001$), indicating overall payoffs are slightly better than expected.¹⁹ However, when we break down the analysis by role, we find that better roles earn significantly less than their equilibrium amounts and worse roles earn above equilibrium. This result is mainly caused by those in better roles over-producing: this increases their costs, and also benefits worse roles who link with them. As such, the networks exhibit lower inequality than predicted in theory, as the more able agents support the lesser so.

Table 6: : Average earnings (in ECUs) and average earnings ratio by role.

		Role A	Role B	Role C	Role D	Role E	Role F
Cost heterogeneity							
Round 1	average earnings	12267.17	9922.58	8595.08	8495.46	8976.67	8538.71
	average earnings ratio	0.905*** (0.114)	0.878*** (0.141)	0.939 (0.273)	1.055 (0.279)	1.128** (0.258)	1.088 (0.437)
Round 20	average earnings	12231.08	10793.17	9789.17	9617.92	9457.96	9983.67
	average earnings ratio	0.901*** (0.082)	0.962 (0.184)	1.072 (0.318)	1.189*** (0.274)	1.175*** (0.282)	1.265*** (0.277)
Valuation heterogeneity							
Round 1	average earnings	13777.94	7708.63	6122.06	6070.94	5963.75	4657.81
	average earnings ratio	0.926*** (0.065)	0.937*** (0.069)	0.905*** (0.139)	0.948** (0.120)	0.976* (0.062)	1.020 (0.267)
Round 20	average earnings	13833.50	7502.50	6572.75	6191.75	5854.19	4569.50
	average earnings ratio	0.930** (0.086)	0.916** (0.174)	0.976 (0.077)	0.970 (0.120)	0.958 (0.092)	0.965 (0.300)

Note: Standard deviation in parentheses. Two-tailed Wilcoxon Single Sample T-test against one. Number highlighted in green and in red when it is significantly greater than and less than one, respectively.

** $p < 0.01$, * $p < 0.05$, $p < 0.1$.

Under valuation heterogeneity, aggregating across roles, the mean earnings ratio is 0.976 ($SD = 0.251$) in Part 1 and 0.988 ($SD = 0.246$) in the last round of Part 2. Both values are significantly less than one (Two-tailed Wilcoxon Single Sample T-test, largest $p < 0.001$). A Wilcoxon Signed-rank test shows that the last round of Part 2 did not improve relative to Part 1 ($z = 0.862$, $p = 0.391$).²⁰ When split by roles, in Table 6 we find that almost all roles have earnings below their equilibrium level in Part 1 while this only happens for better roles in the last round of Part 2. This is because those roles over-produce and initiate excess links, both of which damage earnings as extra costs are incurred.

¹⁹A Two-tailed Wilcoxon Single Sample T-test shows that the overall mean earnings ratio is not significantly different from 1 ($z = -0.744$, $p = 0.458$). A Wilcoxon Signed-rank test shows that the last round of Part 2 is better than Part 1 ($z = 3.456$, $p < 0.001$).

²⁰Appendix A10 shows the changes of earnings ratio in all rounds.

5 Conclusion

Our experimental results show that, when heterogeneity becomes common knowledge, it determines the behaviour of network members. When heterogeneity is exogenously introduced into a group by assigning agents different roles from best to worst, these roles heavily impact their decisions about the amount to produce and to whom to link. Better roles and worse roles have different choices. The minority of relatively better roles produce the majority of output and are central to the network, with the majority of relatively worse roles forming the network’s periphery. Heterogeneity induces specializations to appear in Part 1, when participants are asked to perform the production task for only one round and when the only information they obtain about each other is their different roles. Then this specialization is sustained in later rounds even when we allow participants to observe historical levels of production and every round’s linking decisions. Therefore, as predicted in the KM model, heterogeneous costs or valuations of the public good determine an agent’s position in the network, and associated production behaviour. In general, the networks are formed with a core-periphery structure, and the ‘law of the few’ emerges. We argue that the key insights of the model are empirically supported.

The KM model, and its empirical validation provided by our experiment, can help explain features of network public goods provision observed in reality. Real networks exhibit the 80-20 rule, where a small minority of agents produce the majority of output and are linked to by the low-producing majority who lie at the periphery of the network. In reality, it is likely that there will often be substantial variation between agents in the extent to which they value and are able to easily produce output, as assumed in the KM model and implemented in our experiment. Our study validates the insight of KM that this heterogeneity contributes in a large way to the formation of the ‘law of the few’, with the network endogenously sorting itself according to the preferences and abilities its members are endowed with.

On the other hand, our experimental results also identify some systematic deviations from the model’s predictions. Participants tend to over-produce and groups tend to form networks that are denser than the equi-

librium structure, especially under conditions of valuation heterogeneity. In such treatments, the deviation of production and linking decisions from equilibrium result in aggregate efficiency losses. Under cost heterogeneity, meanwhile, deviations from predicted strategies lead if anything to efficiency gains, and a reduction in payoff inequality.

We note some tendency for outcomes to move closer to the theoretical predictions as the game is played repeatedly. Both production and initiated links decline over the course of the experiment. This may partly represent a learning effect as subjects grasp towards an understanding of the rather complex game environment. However, it may also reflect a breakdown of cooperation analogous to that observed in standard public goods games, as conditional cooperators react with disappointment to the self-regarding behaviour of others (Fischbacher et al., 2001). It is important to note, though, that in our setting, the reduction in production and linking can actually have positive aggregate effects, as levels of production and linkage fall from inefficiently high levels. A particularly interesting element of our results is that, under cost heterogeneity, the tendency for over-production and excessive link formation is specific to the low-cost players; this may be driven by the social preferences of the advantaged players, indicating their willingness to subsidise the disadvantaged. A deeper understanding of the patterns of behaviour observed is left as a promising question for future research. In particular, future designs could consider (1) re-shuffling the matching groups in each round, rather than keeping subjects in the same groups throughout, or (2) cementing the stability of groups even further than done in our experiment, by keeping each player in the same role throughout. A further interesting extension would involve replacing the perfect availability of information about other agents' parameters with a setting in which these parameters are private information which can only be deduced by interacting with one another. This would complicate the experiment and move it away from the assumptions of the KM model, but would bring the setting closer to reality.

References

- Allouch, N. (2015). On the private provision of public goods on networks. *Journal of Economic Theory*, 157, 527–552.
- Allouch, N. (2017). The cost of segregation in (social) networks. *Games and Economic Behavior*, 106, 329–342.
- Baetz, O. (2015). Social activity and network formation. *Theoretical Economics*, 10(2), 315–340.
- Boncinelli, L. & Pin, P. (2012). Stochastic stability in best shot network games. *Games and Economic Behavior*, 75(2), 538–554.
- Bramoullé, Y. & Kranton, R. (2007). Public goods in networks. *Journal of Economic theory*, 135(1), 478–494.
- Bramoullé, Y., Kranton, R., & D’amours, M. (2014). Strategic interaction and networks. *American Economic Review*, 104(3), 898–930.
- Cabrales, A., Calvó-Armengol, A., & Zenou, Y. (2011). Social interactions and spillovers. *Games and Economic Behavior*, 72(2), 339–360.
- Chaudhuri, A. (2011). Sustaining cooperation in laboratory public goods experiments: a selective survey of the literature. *Experimental economics*, 14(1), 47–83.
- Ch’ng, E. (2015). Local interactions and the emergence of a twitter small-world network. *Social Networking*, 4(2), 33–40.
- Cho, M. (2010). Endogenous formation of networks for local public goods. *International Journal of Game Theory*, 39(4), 529–562.
- Choi, S., Gale, D., Kariv, S., & Palfrey, T. (2011). Network architecture, salience and coordination. *Games and Economic Behavior*, 73(1), 76–90.
- Choi, S., Gallo, E., & Kariv, S. (2015). Networks in the laboratory. (*Cambridge Working Paper in Economics: 1551*). Cambridge-INET Institute, University of Cambridge.
- Choi, S., Goyal, S., & Moisan, F. (2019). Network formation in large groups. (*SIER Working Paper Series No.120*). Institute of Economic Research, Seoul National University.
- Dinno, A. (2015). Nonparametric pairwise multiple comparisons in independent groups using dunn’s test. *The Stata Journal*, 15(1), 292–300.

- Elliott, M. & Golub, B. (2019). A network approach to public goods. *Journal of Political Economy*, 127(2), 730–776.
- Falk, A. & Kosfeld, M. (2012). It’s all about connections: Evidence on network formation. *Review of Network Economics*, 11(3).
- Fischbacher, U. (2007). z-tree: Zurich toolbox for ready-made economic experiments. *Experimental economics*, 10(2), 171–178.
- Fischbacher, U., Gächter, S., & Fehr, E. (2001). Are people conditionally cooperative? evidence from a public goods experiment. *Economics letters*, 71(3), 397–404.
- Galeotti, A. & Goyal, S. (2010). The law of the few. *American Economic Review*, 100(4), 1468–92.
- Galeotti, A., Goyal, S., Jackson, M. O., Vega-Redondo, F., & Yariv, L. (2010). Network games. *The review of economic studies*, 77(1), 218–244.
- Gallo, E. & Yan, C. (2015). Efficiency and equilibrium in network games: An experiment. *The Review of Economics and Statistics*, 1–44.
- Goyal, S., Rosenkranz, S., Weitzel, U., & Buskens, V. (2017). Information acquisition and exchange in social networks. *The economic journal*, 127(606), 2302–2331.
- Goyal, S., Van Der Leij, M. J., & Moraga-González, J. L. (2006). Economics: An emerging small world. *Journal of political economy*, 114(2), 403–412.
- Greiner, B. (2015). Subject pool recruitment procedures: organizing experiments with orsee. *Journal of the Economic Science Association*, 1(1), 114–125.
- He, S. & Zou, X. (2022). Public goods provision in a network formation game. *Available at SSRN 4182214*.
- Hiller, T. (2017). Peer effects in endogenous networks. *Games and Economic Behavior*, 105, 349–367.
- Jackson, M. O. (2010). *Social and economic networks*. Princeton university press.
- Kinateder, M. & Merlino, L. P. (2017). Public goods in endogenous networks. *American Economic Journal: Microeconomics*, 9(3), 187–212.

- Rong, R. & Houser, D. (2015). Growing stars: A laboratory analysis of network formation. *Journal of Economic Behavior & Organization*, 117, 380–394.
- Rosenkranz, S. & Weitzel, U. (2012). Network structure and strategic investments: An experimental analysis. *Games and Economic Behavior*, 75(2), 898–920.
- van Leeuwen, B., Offerman, T., & Schram, A. (2020). Competition for status creates superstars: An experiment on public good provision and network formation. *Journal of the European Economic Association*, 18(2), 666–707.
- Wang, G., Gill, K., Mohanlal, M., Zheng, H., & Zhao, B. Y. (2013). Wisdom in the social crowd: an analysis of quora. In *Proceedings of the 22nd international conference on World Wide Web*, (pp. 1341–1352).
- Yang, J., Adamic, L. A., & Ackerman, M. S. (2008). Competing to share expertise: The taskcn knowledge sharing community. In *ICWSM*, (pp. 1–8).

Appendices

A1 Theoretical appendix

A1.1 The model in [Kinaterder & Merlino \(2017\)](#)

A1.2 A graphical example of complete multipartite graph under cost heterogeneity

A1.3 A graphical example of nested split graph under cost heterogeneity

A2 Larger group size

A3 Experimental instructions

A3.1 Treatment 1 instructions

A3.2 Treatment 7 instructions

A3.3 Treatment 1 payoff booklet

A3.4 Treatment 7 payoff booklet

A4 OLS regression results of round 1 to 20

A5 Statistical tests on each role's behaviour in round 20

A5.1 Scenarios under Cost Heterogeneity

A5.2 Scenarios under Valuation Heterogeneity

A6 Evolution of behaviour patterns

A7 Accuracy of linking predictions

A8 Changes with respect to equilibrium predictions

A9 The tendency of emergence of graph types

A10 Earnings ratio and earnings in terms of ECU

A1 Theoretical appendix

A1.1 The model of Kinatered & Merlino (2017)

There is a set of agents $N = \{i : i = 1, 2, \dots, n\}$. These agents constitute the nodes of network. Each agent has two decisions: they decide on the amount that they will contribute to the production of the public good and with whom to connect. Each agent can consume both the contribution of herself, and the contribution of her contacts within the network.

The game concerns the process of network formation in a directed network, in which the link initiator is distinguished from the link receiver. We denote the directed network by an adjacency matrix g , in which each entry g_{ij} in this matrix equals to one when i initiates a link to j and equals to zero otherwise. Let $N_i^{OUT}(g) = \{j \in N : g_{ij} = 1\}$ be the set of agents to which i links to in g , and let $\eta_i^{OUT}(g) = |N_i^{OUT}(g)|$ be the number of *out-links* that i forms.

The game concerns the exchange of contribution in an undirected network, in which who initiates the link does not affect the result of the consumption. To this purpose, we define $\bar{g}$ to be the undirected network of g , in which each entry $\bar{g}_{ij}$ equals to one once i and j are connected regardless of who is the link initiator, and equals to zero otherwise. Let $N_i(\bar{g}) = \{j \in N : \bar{g}_{ij} = 1\}$ be the set of agents to which i is connected no matter whether the links are initiated by i or not, and let $N_i(\bar{g}) = \{j \in N : \bar{g}_{ij} = 1\}$ be the number of i 's *neighbours*. We further denote i 's number of *in-links* as $\eta_i^{IN}(g)$, which is defined as the number of links directed to i .

Let $x_i \in X_i$, $X_i = [0, \infty)$ be i 's contribution and $g_i \in G_i$ be i 's link decision. Note that G_i is the set of i 's link decisions in which each $g_i = (g_{i1}, \dots, g_{ii-1}, g_{ii+1}, \dots, g_{in})$ is a vector documenting one of the possible plans about how i links to all agents except herself, thus $g_i \in G_i = \{0, 1\}^{n-1}$. Thus, i 's set of strategies is $S_i = X_i \times G_i$, in which $x_i \in X_i$ and $g_i \in G_i$. The set of all agents' strategy profiles is $S = S_1 \times \dots \times S_n$. A strategy profile is defined as $s = (x, g) \in S$, in which $x = (x_1, \dots, x_n)$ and $g = (g_1, \dots, g_n)$. Given a strategy profile $s = (x, g)$, each player gains a payoff

$$U_i(x, g) = f_i \left(x_i + \sum_{j \in N_i(\bar{g})} x_j \right) - c_i x_i - k \eta_i^{OUT}, \quad (A1)$$

which depends on the revenue, $f_i(x)$ and the two kinds of cost, $c_i x_i$ and $k \eta_i^{OUT}$. If $g_{ij} = 1$, i gets a copy of j 's contribution, x_j , to be part of her consumption, and j gets a copy of i 's contribution, while both of their initial contributions are unaffected by any copying behaviour. Therefore, the revenue depends on i 's level of consumption, consisting of her own contribution and the contribution of her neighbours. As for the cost, each unit of contribution by i costs c_i , each out-link costs k and each in-link has zero cost.

There are three characteristics on this payoff function. First, the revenue function $f_i(x)$ is strictly concave and increasing at a diminishing marginal rate in x for all i , and $f'_i(0) > c_i$. Second, for any two agents i and j , their contributions x_i and x_j are perfect substitutes. Third, regarding the decision on x_i , contributing nothing neither gains revenue nor incurs cost ($c_i x_i$), and contributing something leads to a positive payoff. Furthermore, if an agent i neither initiates links to her group members nor accepts links from her group members (i.e., being isolated from the network), her optimal contribution is defined as $a_i = \arg \max_{x_i \in X_i} f_i(x_i) - c_i x_i$. We call a_i the optimal contribution in isolation.

Individual heterogeneity is embedded into this payoff function, and characterized as below. KM define the lowest index (which is $i = 1$) as the best type, the second lowest index as the second-best type, so on and so forth, and finally the highest index as the worst type among the set of agents N . Then the two kinds of *ex ante* heterogeneity are introduced as follows.

1. Differences in the cost, c_i . Given $f_i = f$, defining $c_1 < c_2 < \dots < c_n$ with strict inequality, we say that better types have higher efficiency of contributing an extra unit of the local public good than worse types.
2. Differences in the valuation of the public good, $f'_i(x)$. Given $c_i = c$, defining $f'_1(x) > f'_2(x) > \dots > f'_n(x)$ with strict inequality, we say that better types have higher marginal revenue of obtaining an extra

unit of the local public good than worse types.

The two sources of heterogeneity bring two implications. First, best types have a higher contribution to the public good. This applies to both sources of heterogeneity. This is because both the cost and valuation heterogeneity lead a_i , to decrease in i when holding everything else constant, such that $a_1 > a_2 > \dots > a_n$. Second, depending on the sources of heterogeneity, best types hold different attitudes toward initiating links. To explain this, KM defines a concept called gain from connection. Suppose i have already contributed x_i and obtained y from his or her neighbours, and now i decides whether to link to agent z whose contribution is x_z . Thus, i 's gain from a connection (henceforth CG_i) to agent z is $CG_i = [f_i(x'_i + x_z + y) - c_i x'_i] - [f_i(x_i + y) + c_i x_i]$, in which x'_i is the updated optimal contribution after her neighbours' contribution increases by x_z .²¹ The gain from a connection can be used to determine the willingness to initiate an extra link.²² It varies among types in the two sources of heterogeneity as summarized below.

1. Under cost heterogeneity, keeping f_i as constant leads the CG_i to increase in i , such that $CG_1 < CG_2 < \dots < CG_n$. Better types have lower gains from a connection than worse types.
2. Under valuation heterogeneity, keeping c_i as constant leads the CG_i to decrease in i , such that $CG_1 > CG_2 > \dots > CG_n$. Better types have higher gains from a connection than worse types.

This is a one-shot game and agents choose their actions simultaneously. The Nash equilibrium of the resulting strategic form game of complete information is defined as $s^* = (x^*, g^*)$, if for all $s_i \in S_i$ and all $i \in N$, $U_i(s^*) \geq U_i(s_i, s_{-i})$, when $U_i(\cdot, \cdot)$ is the i^{th} agent's payoff function. Perfect information is required. When playing the game, each agent knows other agents' costs and valuations. We retrieve the equilibrium analysis under both sources of heterogeneity here, and briefly explain the intuition of them. Precise mathematical proof can be retrieved from KM.

The first result in equilibrium derived by KM is about the level of contribution: $x_i^* + \sum_{j \in N_i(\bar{g})} x_j^* \geq a_i$. For active agents who contribute

²¹A mathematical definition of $x'_i = \arg \max_{x_0} f_i(x + x_z + y) - c_i x$.

²²Recall that the cost of a link to agent z is k . Therefore, $CG_i > k$ means i benefits from initiating the link to z ; $CG_i < k$ otherwise.

$x_i^* > 0$, $x_i^* + \sum_{j \in N_i(\bar{g})} x_j^* = a_i$. This means that for active agents, her optimal contribution in equilibrium, x_i^* , plus the collection from her neighbours, $\sum_{j \in N_i(\bar{g})} x_j^*$, equal to her optimal contribution in isolation, a_i . This applies under both sources of heterogeneity. Then we discuss the equilibrium in the two heterogeneity scenarios.

Theorem 1 of KM characterize the network structure of Nash equilibria under cost heterogeneity:

Theorem 1 *Under heterogeneity in the cost of producing the public good, if $k \leq f(a_1) - f(a_n) + c_n a_n$, in a strict Nash equilibrium, active players form a complete multipartite graph in which better types produce more and are in independent sets that comprise fewer players.*²³

In this scenario, better types have a higher optimal contribution level than worse types, while they gain less from a connection. It is efficient to fulfil this high level by self-contributing rather than establishing links. As a result, better types initiate few links, and contribute a lot. Worse types free ride on better types' contribution since it is inefficient to contribute by themselves. Then the network structure of *complete multipartite graph*. In the network formation process, all agents firstly link to the best type since she contributes the most, then probably links to the second-, the third- and the fourth-best type until the gains from connection are less than the linking cost. Worse types would like to initiate more links since they gain more from connections.

Theorem 2 of KM characterizes the network structure of Nash equilibria under valuation heterogeneity:

Theorem 2 *Under heterogeneity in the valuation of the public good, if $k \leq f_2(a_1) - f_2(a_2) + c a_2$, in a strict Nash equilibrium, $\bar{g}^*$ is a nested split graph in which better types have more links. Moreover, there exist $\tilde{n}_1$ and $\tilde{n}_2$, $\tilde{n}_1 < \tilde{n}_2 \leq n$, such that*

1. $\mathcal{C}(\bar{g}^*) = \{i \in n : i \leq \tilde{n}_1, x_i^* > 0\}$ is the core of active players;

²³ $k \leq f(a_1) - f(a_n) + c_n a_n$ is the upper bound of linking cost to ensure the complete multipartite graph exists. In Appendix A1.2, we provide a graphical example of a complete multipartite graph, and explain why k is bounded given the definition of a complete multipartite graph.

2. $\mathcal{P}(\bar{g}^*) = \{i \in n : \tilde{n}_1 < i \leq \tilde{n}_2\}$ is the periphery;
3. $\mathcal{I}(\bar{g}^*) = \{i \in n : \tilde{n}_2 < i\}$ is a set of isolated players.²⁴

In this scenario, better types have a higher optimal contribution level than worse types and they gain more from a connection. This motivates better types to connect with each other to satisfy this high level even if they contribute the most. These connected better types form the core of the network. Worse types contribute less, therefore cannot receive in-links and form the periphery to free ride on better types' contribution. Then the network structure of *nested split graph* emerges. Agents at the periphery firstly link to the best type in the core since she contributes the most, then probably links to the second-, the third- or the fourth- best types in the core until the gains from connection are less than the linking cost. In this scenario, worse types gain less from connections, thus they are less willing to initiate more links.

A1.2 A graphical example of complete multipartite graph under cost heterogeneity

Under heterogeneity in the production cost of the public good, active players form a *complete multipartite graph* g^* in equilibrium in which better types produce more and are in independent sets that comprise fewer players if $k \leq f(a_1) - f(a_n) + c_n a_n$. This is Theorem 1 of KM. The complete multipartite graph consists of several partitioned non-empty independent sets $\mathcal{H}_w$, $w = 1, \dots, W$, and every node connects with all nodes outside its set. Each independent set can be regarded as a tier. If this tier contains more better types, we say this tier is higher than others. It is predicted that every agent in a higher set will be of a higher type than every agent in the next set. An example can be shown in Figure A1.

In this example, we have six agents indexed from 1 to 6 in which 1 denotes the best type and 6 denotes the worst type. There are two independent sets, $\mathcal{H}_1 = \{1, 2\}$ and $\mathcal{H}_2 = \{3, 4, 5, 6\}$. $\mathcal{H}_1$ is an independent set because agents in $\mathcal{H}_1$ are unconnected with each other, the same for $\mathcal{H}_2$.

²⁴ $k \leq f_2(a_1) - f_2(a_2) + c a_2$ is the upper bound of linking cost to ensure the nested split graph exists. In appendix A1.3, we also provide a graphical example of a nested split graph as well as the reason why k is bounded by this value.

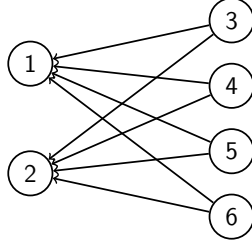


Figure A1: A complete multipartite graph.

Since 1 and 2 are better types and 4 to 6 are worse types, $\mathcal{H}_1$ is called a higher tier. Each agent in $\mathcal{H}_2$ (the lower tier) links to all agents in $\mathcal{H}_1$ (the higher tier), thus causing each agent in higher tier to be connected to by all agents in lower tier.

The condition $k \leq f(a_1) - f(a_n) + c_n a_n$ is to ensure the graph exists. We can re-arrange the condition $k \leq f(a_1) - f(a_n) + c_n a_n$ into $f(a_n) - c_n a_n \leq f(a_1) - k$, then the left-hand side $f(a_n) - c_n a_n$ represents the optimal payoff when type n is isolated, and the right-hand side represents pure free riding behaviour of type 1 with zero contribution. Therefore, $f(a_1) - f(a_n) + c_n a_n$ is the upper-bound of the link cost for a worse type (other than type 1) to link with type 1. In other words, for type n , if the link cost higher than $f(a_1) - f(a_n) + c_n a_n$, then she chooses to be isolated, because it is even unprofitable to connect with type 1. Thus, if the link cost higher than this borderline, then no agents connect with type 1, and the network does not exist.

A1.3 A graphical example of nested split graph under cost heterogeneity

Under heterogeneity in the valuation of the public good, if $k \leq f_2(a_1) - f_2(a_2) + c a_2$, g^* is a nested split graph in equilibrium in which better types have more links, as presented in Theorem 2 of KM. For the definition of the *nested split graph*, we refer to the definition of a complete core-periphery graph. In a complete core-periphery graph, there are two sets of active agents, the periphery $\mathcal{P}(\bar{g})$ and the core $\mathcal{C}(\bar{g})$. For every $i, j \in \mathcal{P}(\bar{g})$, $g_{ij} = 0$. For every $l, m \in \mathcal{C}(\bar{g})$, $g_{lm} = 1$. For any $i \in \mathcal{P}(\bar{g})$, there exists

$l \in \mathcal{C}(\bar{g})$ such that $g_{il} = 1$. The periphery and the core are connected such that each $i \in \mathcal{P}(\bar{g})$ connects all agents in $\mathcal{C}(\bar{g})$ and each $l \in \mathcal{C}(\bar{g})$ connect all agents except himself or herself. The nested split graph is a complete core-periphery graph while not all nodes in the periphery will link to every node in the core. An example is displayed in Figure A2.

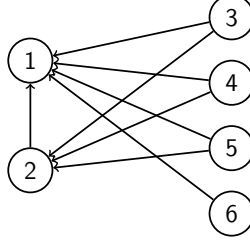


Figure A2: A nested split graph.

In this example, we have six agents indexed from 1 to 6 in which 1 denotes the best type and 6 denotes the worst type. The periphery $\mathcal{P}(\bar{g}) = \{3, 4, 5, 6\}$, which is an independent set. The core $\mathcal{C}(\bar{g}) = \{1, 2\}$, these two nodes are connected with each other. Not all nodes in $\mathcal{P}(\bar{g})$ share the same neighbours.

The condition $k \leq f_2(a_1) - f_2(a_2) + ca_2$, is to ensure the core of the nested split graph exists. We can change the $k \leq f_2(a_1) - f_2(a_2) + ca_2$ into $f_2(a_2) - ca_2 \leq f_2(a_1) - k$, then the left-hand side shows the optimal payoff of type 2 when isolated, and the right-hand side represents the payoff of an inactive type 2 when she links to type 1. Therefore, $f_2(a_1) - f_2(a_2) + ca_2$ is an upper-bound of the link cost for type 2 to link with type 1. The rationale is that, if the core has at least two agents, then type 1 and type 2 must connect with each other. This condition is a necessary requirement of the existence of a core when the core has more than 1 agent in the nested split graph.

A2 Larger group size

We additionally designed two treatments of larger group size, $n = 8$. They are denoted as Treatments 11 and 12, under scenarios of cost heterogeneity and valuation heterogeneity, respectively. In these two treatments, the eight roles are labelled as A, B, C, D, E, F, G and H, in which Role A is denoted as the best role and Role H is denoted as the worst role.

These two treatments use the payoff function in equation (1). In Treatment 11, $V = 240$ which shares the common valuation parameter with all other treatments of $n = 6$ under cost heterogeneity, and $k = 1500$ which is identical specifically with Treatments 1 and 2. The cost parameter, c_i , from Roles A to H (the best to worst) is assigned as 8, 80, 84, 88, 92, 96, 100 and 104, respectively. The predicted equilibrium is reached when (1) Roles A to H produce 67, 13, 11, 8, 7, 5, 3 and 1 tokens, respectively, and (2) the eight roles form a “star” network such that Role B to Role H each initiate one link to Role A, and Role A does not initiate any links (as shown in Figure A3). In Treatment 12, $c = 20$ which is consistent with all other treatments of $n = 6$ under valuation heterogeneity, and $k = 300$ which is identical with identical with Treatments 7 and 8. The valuation parameter, V_i , from Roles A to H (the best to worst) is assigned as 252, 180, 176, 172, 168, 164, 160 and 156, respectively. The predicted equilibrium is reached when (1) Roles A to H produce 67, 13, 11, 8, 7, 5, 3 and 1 tokens, respectively, and (2) a “star” network presented in Figure A3 is formed as well.

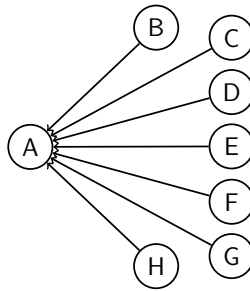


Figure A3: Equilibrium graph of Treatments 11 and 12.

Other than what is discussed above, there is no difference in the experimental designs and procedures between $n = 8$ and $n = 6$ treatments. These

two $n = 8$ treatments also share the same participant pool with all $n = 6$ treatments. We conducted two sessions for each $n = 8$ treatment, one in Ningbo (UNNC) and the other in Nanjing (NAU). Each session contains two matching groups. Therefore, each $n = 8$ treatment has 32 student subjects who play the game repeatedly for 20 rounds (excluding the mock round).

Our aim of adding one large-group size treatment under each scenario is to investigate the effect of group size on earnings. To make relatively fair comparisons, we will compare Treatment 11 ($n = 8$) with Treatments 1 and 2 ($n = 6$). This is because among all $n = 6$ treatments under cost heterogeneity, the predicted equilibria of Treatments 1 and 2 are more similar to Treatment 11 – in particular, all the three treatments contain a “star” graph. We will compare Treatment 12 with Treatments 7 and 8 due to the same reason.

We are interested in two aspects. First, we want to know whether earnings inequality within the matching group will increase in group size. We use coefficient of variance (CV) to measure differences in earnings across subjects in the matching group of each round. This measure for the dispersion of a distribution is defined as the standard deviation of earnings of the eight group members divided by the mean. Under cost heterogeneity, the overall mean $CV = 18.064$ ($SD = 16.770$) and 13.894 ($SD = 8.946$) in treatments $n = 6$ and $n = 8$, respectively. A two-sided Wilcoxon Mann-Whitney test shows that $n = 6$ and $n = 8$ are not significantly different with each other ($z = -0.791$, $p = 0.429$). Therefore, an increase in group size does not affect within-group earnings inequality in scenarios of cost heterogeneity. Under valuation heterogeneity, the overall mean $CV = 40.333$ ($SD = 15.773$) and 48.879 ($SD = 11.758$) in treatments $n = 6$ and $n = 8$, respectively. A two-sided Wilcoxon Mann-Whitney test shows that the CV of $n = 6$ is significantly less than that of $n = 8$ ($z = 8.443$, $p < 0.001$). We therefore conclude that group size has an effect on the earnings gap in the scenarios of valuation heterogeneity such that the gap increases in a larger network.

Second, motivated by KM, we are also interested in the effect of forming a network on within-group earnings inequality. KM discuss that forming a network can either increase or decrease earnings inequality. They define

such kind of inequality as “... the differences in payoffs across players in isolation versus in a network” (see, pp.199-120). If this difference is greater in isolation than in a network, then the inequality decreases when the network is formed. We apply their definition in our analysis. Specifically, for each role, in each round we define:

1. *Payoff in a network* of each role is simply their earnings in ECUs of that round; we denote it as $U_i(x, g)$.
2. *Payoff in isolation* is defined as follows. Suppose in a round, participants are not allowed to obtain tokens by forming networks. Then a natural consequence is that each participant needs to produce $x_i + \sum_{(j \in N_i(\bar{g}))} x_j$ (including $\sum_{(j \in N_i(\bar{g}))} x_j$) by herself to maintain her earnings. We define the level of production in isolation as $x_i^{iso} = x_i + \sum_{(j \in N_i(\bar{g}))} x_j$. Therefore, payoff in isolation is calculated as $\underline{U}_i = f_i(x_i^{iso}) - c_i x_i^{iso}$. Note that x_i^{iso} is not directly obtained from any of our treatments, since we do not have any treatment without network formation processes. x_i^{iso} is a hypothetical number, in line with KM, wherein we assume when initiating links is not allowed, a subject produces everything that she could have obtained via network formation.

Next, for each pair of roles i and j in a matching group (suppose i is a relatively better role):

1. We define inequality *after* forming the network as $U_i(x, g) - U_j(x, g)$.
2. We define inequality *before* forming the network as $\underline{U}_i - \underline{U}_j$.
3. Finally, following KM, we say that the inequality between any two roles i and j decreases after forming the network if $\bar{U}_{ij} = [U_i(x, g) - U_j(x, g)] - [\underline{U}_i - \underline{U}_j] < 0$.

Next, we report our data. We start from scenarios of cost heterogeneity. Over all 20 rounds, there are 83.875% pairs of roles in the $n = 6$ treatments for which we report a $\bar{U}_{ij}$ that is less than zero, and the percentage increases to 86.384% in the $n = 8$ treatments. A two-sided Wilcoxon Mann-Whitney test shows that there is a significant increase from the $n = 6$ treatments to the $n = 8$ treatments ($z = 2.403$, $p = 0.016$). Therefore, when group size

becomes larger, under cost heterogeneity, forming a network is inequality-reducing, compared to being isolated. In scenarios of valuation heterogeneity, there are 44.208% pairs of roles in the $n = 6$ treatments for which we report a $\bar{U}_{ij}$ that is less than zero, and this percentage decreases to 30.268% in the $n = 8$ treatments. A two-sided Wilcoxon Mann-Whitney test confirms such a decline ($z = -9.813$, $p < 0.001$). Therefore, contrasting with the scenarios of cost heterogeneity, when group size becomes larger, forming a network increases inequality relative to being isolated.

The above result is consistent with the Proposition 2 of KM (*pp.* 199), which I quote here:

Proposition 2 *Given any g^* and any $i < j$ which receive no in-links, as $n \rightarrow \infty$, under heterogeneity in production cost, the inequality between i and j decreases, while it increases under heterogeneity in valuation.*

However, our data above does not fully correspond to Proposition 2 for two reasons. First, in Proposition 2, inequality *after* forming the network is defined on the predicted equilibrium, i.e., $U_i(x^*, g^*) - U_j(x^*, g^*)$; while our data, as explained in the main text, to some extent deviates from x^* and g^* . Second, this proposition extends the group size to infinity; however, due to the limitation of lab size, we only extend the group size from six to eight, not to infinity. In conclusion, our data only elaborates that Proposition 2 tends to be established when increasing the group size from six to eight.

A3 Experimental instructions

We present the experimental instructions for the Treatment 1 (cost heterogeneity with group size $n = 6$) and Treatment 7 (valuation heterogeneity with group size $n = 6$) in Appendix [A3.1](#) and Appendix [A3.2](#), respectively. Treatments 1 and 7's payoff booklets are presented in Appendix [A3.3](#) and Appendix [A3.4](#), respectively. Participants receive printed copies of the instructions and payoff booklets and the experimenter read the both aloud in each session. Part 2 instruction is distributed only after the completion of Part 1 decisions.

Each payoff booklet has seven pages. Page 2 to page 7 displays payoffs of Role A, Role B, Role C, Role D, Role E and Role F, respectively. The first page is identical with page 2 while containing some explanations – it means that we use the payoff sheet of Role A as an example to assist participants to understand how to use this booklet.

A3.1 Treatment 1 instructions

Instruction

Welcome to CeDEX. This experiment will be conducted on a PC. We kindly ask you to switch off your cell phone and all other mobile devices throughout the whole experiment. During the experiment, please do not use a cell phone or any other mobile devices, please do not communicate with other participants, please do not focus on anything that is irrelevant to the experiment. Participants intentionally violating the rules will result in an immediate exclusion from the experiment without being paid. If you have any questions, please raise your hand. The experimenter will approach you to answer your questions.

The experimenter will read the instructions page by page. Please keep up with the experimenter's reading, and **do not skip any pages or turn to subsequent pages in advance!** Sufficient time will be given for familiarisation with the experimental materials and the computer interface before the experiment starts.

Overview

The aim of this experiment is to study how individuals make decisions in certain contexts. You will first receive the instructions for **Part 1** of the experiment, after which you will receive the instructions for **Part 2**. In the end, you will finish a questionnaire and then claim the payment.

Payment

If you follow the instructions carefully, you will earn a non-negligible amount of experimental payment. **Your experimental payment depends on both Part 1 and Part 2: there will be a 50% of the chance that you are paid according to your performance in Part 1, and a 50% of the chance that you are paid according to your performance in Part 2.** The computer will determine which part will be paid at the end of the experiment. Therefore, Part 1 and Part 2 should be regarded as of the same importance during the experiment.

During the experiment, your payment will be accounted in ECUs (Experimental Currency Units). At the end of the experiment, the total number of ECUs that you earn will be exchanged at the rate of **150 ECUs = 1 Yuan**.

Your show up fee is 40 Yuan. Your final payment is a sum of the show up fee and the experimental payment. Your payment will remain anonymous, as nobody will know other participants' payments.

Note: Your final payment will necessarily be positive.

Part 1

1. In this room, there are 12 participants (including yourself). You will be randomly divided into 2 groups, **Group 1** and **Group 2**, each group has 6 group members. Note that each participant is equally likely to be in your group, and you will not know the identities of any of your group members. Your group number (Group 1 or Group 2) will be shown on the computer screen.
2. Once the group is assigned, you (and your group members) are randomly assigned to a role: **A, B, C, D, E or F**. The assignment process is random: You are equally likely to be allocated to each of the 6 roles. You will be informed of your role (A, B, C, D, E or F) on the computer screen.
3. Knowing your roles, you will make decisions to earn ECUs. Your group members will be asked to make the same decisions as well. All of you have to input your choices into the computer screen. You have no chance to discuss with your group members. Once all of you are done, the computer screen will display all choices and earnings by role.
4. **Your earnings in this part depend on both your and your group members' decisions.**
(*Note:* Your experimental payment will be determined by either part with equal chance, which means that there is a 50% chance that your earnings in this part will be your payment.)

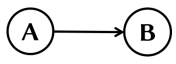
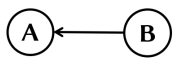
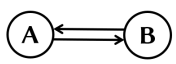
The Decision You Need to Make.

You and your 5 group members are asked to contribute units in this task. However, your units of production in the end depend on your own contribution and **the contributions of your neighbours**. Your group members **are not necessarily** your neighbours. In detail:

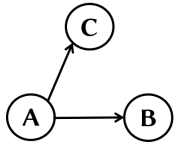
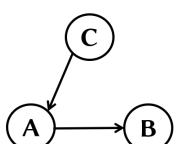
1. You can make your own contribution. For this, you have to decide a number of units to contribute. This can be any integer between 1 and 120. Your minimum contribution is 1 unit.
2. You can access the contributions of your neighbours. To become neighbours, you can initiate links to connect with one or more of your group members, or they can initiate links to you. Then, you can access your neighbours' units of contributions, and they can access your contribution as well. Here are 3 clarifications:
 - (a) Once a link is established between 2 neighbours, they both access each other's contributions, regardless of who initiated the link.
 - (b) Accessing a neighbour's contribution does not decrease their own contributions (and vice versa).
 - (c) If the link is initiated by both of them, the outcome is the same as if only one of them initiated it.

The examples then help to illustrate the above points.

Example 1 Suppose A's contribution is 5 units and B's contribution is 10 units.

	(1) If A and B do not connect with each other: A's units of production are 5, B's units of production are 10.
	(2) If A connects with B: A's units of production are 15, B's units of production are 15.
	(3) If B connects with A: A's units of production are 15, B's units of production are 15.
	(4) If A and B both connect with each other: A's units of production are 15, B's units of production are 15.

Example 2 Suppose A's contribution is 5 units, B's contribution is 10 units, and C's contribution is 1 unit.

	(1) If A connects with B and C, others do not initiate links: A's units of production are 16, B's units of production are 15, C's units of production are 6.
	(2) If A connects with B, B does not initiate links, C connects with A : A's units of production are 16, B's units of production are 15, C's units of production are 6.

The Revenue.

Your units of production (i.e., your contribution plus your neighbours' contributions) determine the revenue you can earn. **Revenue is accounted in ECUs.** Here is a brief overview:

units of production	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Revenue (in ECUs)	239	476	711	944	1175	1404	1631	1856	2079	2300	2519	2736	2951	3164	3375	3584	3791	3996	4199	4400
con't.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
	4599	4796	4991	5184	5375	5564	5751	5936	6119	6300	6479	6656	6831	7004	7175	7344	7511	7676	7839	8000
con't.	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	8159	8316	8471	8624	8775	8924	9071	9216	9359	9500	9639	9776	9911	10044	10175	10304	10431	10556	10679	10800
con't.	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
	10919	11036	11151	11264	11375	11484	11591	11696	11799	11900	11999	12096	12191	12284	12375	12464	12551	12636	12719	12800
con't.	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
	12879	12956	13031	13104	13175	13244	13311	13376	13439	13500	13559	13616	13671	13724	13775	13824	13871	13916	13959	14000
con't.	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
	14039	14076	14111	14144	14175	14204	14231	14256	14279	14300	14319	14336	14351	14364	14375	14384	14391	14396	14399	14400
con't.	121	122	123	124	124	126	...													
	14400	14400	14400	14400	14400	14400	14400													

You do not have to take any actions so far. Because we will provide you with payoff sheets to minimize your calculation load in the experiment. The above table is only for you to preview the revenues. There are 3 highlights in this table:

1. The higher the units of production, the higher the revenue. For example, if your units of production are 1, your revenue is 239 ECUs; if your units of production are 2, your revenue is 476 ECUs.
2. The higher the units of production, the lower is revenue earned from an additional unit of production. For example, if your units of production are increased from 1 to 2, your revenue is increased by 237 ECUs; if your units of production are increased from 119 to 120, your revenue is increased by 1 ECU.
3. If your units of production > 120 units, your revenue will be fixed at 14400 ECUs.

The Cost.

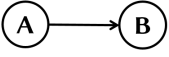
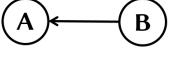
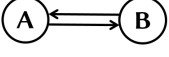
However, there are costs. **Costs are accounted in ECUs.** Although you can get revenue by accumulating units of production, some ECUs will be deducted from this amount, depending on the two types of decisions you make:

1. For contributions you make by yourself: every unit you contribute will cost you a given number of ECUs; this depends on your role.
 - For role A, it costs you 8 ECUs for 1 unit of contribution.
 - For role B, it costs you 72 ECUs for 1 unit of contribution.
 - For role C, it costs you 76 ECUs for 1 unit of contribution.
 - For role D, it costs you 80 ECUs for 1 unit of contribution.
 - For role E, it costs you 84 ECUs for 1 unit of contribution.
 - For role F, it costs you 88 ECUs for 1 unit of contribution.

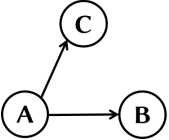
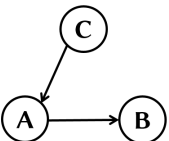
2. For links you choose to initiate: every connection that you initiated yourself costs 1500 ECUs.
3. You do not have to pay for the links between you and others that are initiated by others. If both you and another group member initiate links to each other, both of you only pay for the link that is initiated by yourself.

The examples then help to illustrate those points.

Example 3

	(1) If A and B do not connect with each other: Both A and B do not have to pay for the linking cost.
	(2) If A connects with B: A has to pay for the cost of linking with B, A has to pay for 1 link. B does not have to pay for links.
	(3) If B connects with A: B has to pay for the cost of linking with A, B has to pay for 1 link. A does not have to pay for links.
	(4) If A and B both connect with each other: A has to pay for the cost of linking with B, A has to pay for 1 link. B has to pay for the cost of linking with A, B has to pay for 1 link.

Example 4

	(1) If A connects with B and C, others do not initiate links: A has to pay for the cost of linking with B and C, A has to pay for 2 links. B and C do not have to pay for links.
	(2) If A connects with B, B does not initiate links, C connects with A : A has to pay for the cost of linking with B, A has to pay for 1 link. B does not have to pay for links. C has to pay for the cost of linking with A, C has to pay for 1 link.

The Earnings and payoff sheets.

Your earnings equal to your revenue minus the cost, **which are accounted in ECU**:

Your earnings (in ECUs)	=	the revenue
	<i>minus</i>	the cost of your own contributions (=number of units you contribute yourself × cost per unit (which depends on your role))
	<i>minus</i>	the cost of initiating links (= number of links you initiated × 1500 ECUs)

We have prepared a payoff sheet, which displays each role's earnings **except the linking cost** (i.e., **the revenue - the cost of your own contributions**). During the experiment, you will use these sheets to make decisions. Please open the attachment, let us go over each of them to see how to use these sheets.

(See attachments.)

Here are some examples on the computer screen. Could you please make use of these payoff sheets to find how many ECUs each role can earn in these examples, and answer all the questions on the screen?

(See the computer screen.)

Now, we are going to perform the task on the screen. In order to let you to understand the task better, we firstly conduct a mock task. The outcome of this mock task will not be counted for experimental payment. After that we will conduct the formal task. The outcome of the formal task will be your earnings in this part of the experiment.

Note: Please turn to the payoff sheet that represents your role, this shows how your earnings are determined.

Note: The two decisions, i.e. how many units to contribute, and to whom to link, have to be inputted into the screen together. It means that you cannot make your decisions after seeing the decisions of your other group members.

(See the mock task.)

Now we are going to perform the formal task of Part 1.

Note: In the formal task, you will be asked to answer some questions. The answer of these questions will not affect your earnings of this part.

Note: Please raise your hand to confirm with the experimenter if your computer screen has display errors.

Part 2

1. You have already been assigned into a group in Part 1 (Group 1 or Group 2). Now in Part 2, you will be kept in this same group until the end of the experiment. It means that, although you do not know who your group members are, they will be your group members until the end of the experiment.
2. Your group of 6 will perform the same task for another 19 rounds.
3. At the beginning of each round, you (and your group members) will be randomly assigned one role: either A, B, C, D, E or F. The assignment process is random: You are equally likely to be allocated to each of the 6 roles. Therefore, you are very likely to get different roles in each round. And in each round, it is very likely that your group members are assigned different roles.
At the beginning of each round, your role of this round will be displayed on the screen, thus:
 - Please turn to payoff sheet that represents your current role, this shows how your earnings are determined in this round.
 - This is really important in helping you make decisions, as the costs of contribution are different for each role.
4. Knowing your roles, you will make decisions to earn ECUs. The two decisions are the same as before. Your group members will be asked to make the same decisions as well. All of you have to input your choices into the computer screen. You have no chance to discuss with your group members. Once all of you are done, the computer screen will display all choices and earnings of the current round by role. Then the next round starts.
5. The 19 rounds are independent of each other. Your earnings in each round are **solely** determined by your and your group members' decisions **in this round**. Your earnings in this round will not affect your earnings in the next round.
6. Your earnings in Part 2 depends on both you and your group members' decisions, **and some chance**. **When Part 2 is finished, 1 round of the 19 rounds will be randomly selected, the earnings of which become your earnings in Part 2. Each round will be selected with equal chance.** (*Note: Your experimental payment will be determined by either part with equal chance, which means that there is a 50% chance that your earnings of the selected round in this part will be your experimental payment.*)

Now we are going to perform the Part 2.

A3.2 Treatment 7 instructions

Instruction

Welcome to CeDEX. This experiment will be conducted on a PC. We kindly ask you to switch off your cell phone and all other mobile devices throughout the whole experiment. During the experiment, please do not use a cell phone or any other mobile devices, please do not communicate with other participants, please do not focus on anything that is irrelevant to the experiment. Participants intentionally violating the rules will result in an immediate exclusion from the experiment without being paid. If you have any questions, please raise your hand. The experimenter will approach you to answer your questions.

The experimenter will read the instructions page by page. Please keep up with the experimenter's reading, and **do not skip any pages or turn to subsequent pages in advance!** Sufficient time will be given for familiarisation with the experimental materials and the computer interface before the experiment starts.

Overview

The aim of this experiment is to study how individuals make decisions in certain contexts. You will first receive the instructions for **Part 1** of the experiment, after which you will receive the instructions for **Part 2**. In the end, you will finish a questionnaire and then claim the payment.

Payment

If you follow the instructions carefully, you will earn a non-negligible amount of experimental payment. **Your experimental payment depends on both Part 1 and Part 2: there will be a 50% of the chance that you are paid according to your performance in Part 1, and a 50% of the chance that you are paid according to your performance in Part 2.** The computer will determine which part will be paid at the end of the experiment. Therefore, Part 1 and Part 2 should be regarded as of the same importance during the experiment.

During the experiment, your payment will be accounted in ECUs (Experimental Currency Units). At the end of the experiment, the total number of ECUs that you earn will be exchanged at the rate of **150 ECUs = 1 Yuan**.

Your show up fee is 40 Yuan. Your final payment is a sum of the show up fee and the experimental payment. Your payment will remain anonymous, as nobody will know other participants' payments.

Note: Your final payment will necessarily be positive.

Part 1

1. In this room, there are 12 participants (including yourself). You will be randomly divided into 2 groups, **Group 1** and **Group 2**, each group has 6 group members. Note that each participant is equally likely to be in your group, and you will not know the identities of any of your group members. Your group number (Group 1 or Group 2) will be shown on the computer screen.
2. Once the group is assigned, you (and your group members) are randomly assigned to a role: **A, B, C, D, E or F**. The assignment process is random: You are equally likely to be allocated to each of the 6 roles. You will be informed of your role (A, B, C, D, E or F) on the computer screen.
3. Knowing your roles, you will make decisions to earn ECUs. Your group members will be asked to make the same decisions as well. All of you have to input your choices into the computer screen. You have no chance to discuss with your group members. Once all of you are done, the computer screen will display all choices and earnings by role.
4. **Your earnings in this part depend on both your and your group members' decisions.**
(*Note:* Your experimental payment will be determined by either part with equal chance, which means that there is a 50% chance that your earnings in this part will be your payment.)

The Decision You Need to Make.

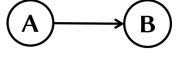
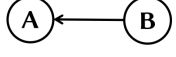
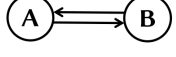
You and your 5 group members are asked to contribute units in this task. However, your units of production in the end depend on your own contribution and **the contributions of your neighbours**. Your group members **are not necessarily** your neighbours. In detail:

1. You can make your own contribution. For this, you have to decide a number of units to contribute. Your minimum contribution is 1 unit. The maximum units that you can contribute depends on your role, which decreases from Role A to Role F:
 - For role A, you can contribute any integer between 1 and 126 units.
 - For role B, you can contribute any integer between 1 and 94 units.
 - For role C, you can contribute any integer between 1 and 92 units.
 - For role D, you can contribute any integer between 1 and 90 units.
 - For role E, you can contribute any integer between 1 and 88 units.
 - For role F, you can contribute any integer between 1 and 86 units.
2. You can access the contributions of your neighbours. To become neighbours, you can initiate links to connect with one or more of your group members, or they can initiate links to you. Then, you can access your neighbours' units of contributions, and they can access your contribution as well. Here are 3 clarifications:
 - (a) Once a link is established between 2 neighbours, they both access each other's contributions, regardless of who initiated the link.

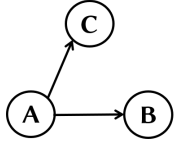
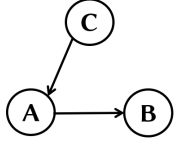
- (b) Accessing a neighbour's contribution does not decrease their own contributions (and vice versa).
- (c) If the link is initiated by both of them, the outcome is the same as if only one of them initiated it.

The examples then help to illustrate the above points.

Example 1 Suppose A's contribution is 5 units and B's contribution is 10 units.

	(1) If A and B do not connect with each other: A's units of production are 5, B's units of production are 10.
	(2) If A connects with B: A's units of production are 15, B's units of production are 15.
	(3) If B connects with A: A's units of production are 15, B's units of production are 15.
	(4) If A and B both connect with each other: A's units of production are 15, B's units of production are 15.

Example 2 Suppose A's contribution is 5 units, B's contribution is 10 units, and C's contribution is 1 unit.

	(1) If A connects with B and C, others do not initiate links: A's units of production are 16, B's units of production are 15, C's units of production are 6.
	(2) If A connects with B, B does not initiate links, C connects with A: A's units of production are 16, B's units of production are 15, C's units of production are 6.

The Revenue.

Your units of production (i.e., your contribution plus your neighbours' contributions) determine the revenue you can earn. **Revenue is accounted in ECUs.** Here is a brief overview:

The revenue of Role A is:

units of production	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Revenue (in ECUs)	251	500	747	992	1235	1476	1715	1952	2187	2420	2651	2880	3107	3332	3555	3776	3995	4212	4427	4640
con't	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
	4851	5060	5267	5472	5675	5876	6075	6272	6467	6660	6851	7040	7227	7412	7595	7776	7955	8132	8307	8480
con't	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	8651	8820	8987	9152	9315	9476	9635	9792	9947	10100	10251	10400	10547	10692	10835	10976	11115	11252	11387	11520
con't	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
	11651	11780	11907	12032	12155	12276	12395	12512	12627	12740	12851	12960	13067	13172	13275	13376	13475	13572	13667	13760
con't	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
	13851	13940	14027	14112	14195	14276	14355	14432	14507	14580	14651	14720	14787	14852	14915	14976	15035	15092	15147	15200
con't	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
	15251	15300	15347	15392	15435	15476	15515	15552	15587	15620	15651	15680	15707	15732	15755	15776	15795	15812	15827	15840
con't	121	122	123	124	125	126	...													
	15851	15860	15867	15872	15875	15876	15876													

The revenue of Role B is:

units of production	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Revenue (in ECUs)	187	372	555	736	915	1092	1267	1440	1611	1780	1947	2112	2275	2436	2595	2752	2907	3060	3211	3360
con't	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
	3507	3652	3795	3936	4075	4212	4347	4480	4611	4740	4867	4992	5115	5236	5355	5472	5587	5700	5811	5920
con't	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	6027	6132	6235	6336	6435	6532	6627	6720	6811	6900	6987	7072	7155	7236	7315	7392	7467	7540	7611	7680
con't	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
	7747	7812	7875	7936	7995	8052	8107	8160	8211	8260	8307	8352	8395	8436	8475	8512	8547	8580	8611	8640
con't	81	82	83	84	85	86	87	88	89	90	91	92	93	94	...					
	8667	8692	8715	8736	8755	8772	8787	8800	8811	8820	8827	8832	8835	8836						

The revenue of Role C is:

units of production	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Revenue (in ECUs)	183	364	543	720	895	1068	1239	1408	1575	1740	1903	2064	2223	2380	2535	2688	2839	2988	3135	3280
con't	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
	3423	3564	3703	3840	3975	4108	4239	4368	4495	4620	4743	4864	4983	5100	5215	5328	5439	5548	5655	5760
con't	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	5863	5964	6063	6160	6255	6348	6439	6528	6615	6700	6783	6864	6943	7020	7095	7168	7239	7308	7375	7440
con't	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
	7503	7564	7623	7680	7735	7788	7839	7888	7935	7980	8023	8064	8103	8140	8175	8208	8239	8268	8295	8320
con't	81	82	83	84	85	86	87	88	89	90	91	92	...							
	8343	8364	8383	8400	8415	8428	8439	8448	8455	8460	8463	8464	8464							

The revenue of Role D is:

units of production	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Revenue (in ECUs)	179	356	531	704	875	1044	1211	1376	1539	1700	1859	2016	2171	2324	2475	2624	2771	2916	3059	3200
con't	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
	3339	3476	3611	3744	3875	4004	4131	4256	4379	4500	4619	4736	4851	4964	5075	5184	5291	5396	5499	5600
con't	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
	5699	5796	5891	5984	6075	6164	6251	6336	6419	6500	6579	6656	6731	6804	6875	6944	7011	7076	7139	7200
con't	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
	7259	7316	7371	7424	7475	7524	7571	7616	7659	7700	7739	7776	7811	7844	7875	7904	7931	7956	7979	8000
con't	81	82	83	84	85	86	87	88	89	90	...									
	8019	8036	8051	8064	8075	8084	8091	8096	8099	8100	8100									

The revenue of Role E is:

units of production	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Revenue (in ECUs)	175	348	519	688	855	1020	1183	1344	1503	1660	1815	1968	2119	2268	2415	2560	2703	2844	2983	3120
con't	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
con't	3255	3388	3519	3648	3775	3900	4023	4144	4263	4380	4495	4608	4719	4828	4935	5040	5143	5244	5343	5440
con't	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
con't	5535	5628	5719	5808	5895	5980	6063	6144	6223	6300	6375	6448	6519	6588	6655	6720	6783	6844	6903	6960
con't	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
con't	7015	7068	7119	7168	7215	7260	7303	7344	7383	7420	7455	7488	7519	7548	7575	7600	7623	7644	7663	7680
con't	81	82	83	84	85	86	87	88	...											
	7695	7708	7719	7728	7735	7740	7743	7744	7744											

The revenue of Role F is:

units of production	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Revenue (in ECUs)	171	340	507	672	835	996	1155	1312	1467	1620	1771	1920	2067	2212	2355	2496	2635	2772	2907	3040
con't	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
con't	3171	3300	3427	3552	3675	3796	3915	4032	4147	4260	4371	4480	4587	4692	4795	4896	4995	5092	5187	5280
con't	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
con't	5371	5460	5547	5632	5715	5796	5875	5952	6027	6100	6171	6240	6307	6372	6435	6496	6555	6612	6667	6720
con't	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
con't	6771	6820	6867	6912	6955	6996	7035	7072	7107	7140	7171	7200	7227	7252	7275	7296	7315	7332	7347	7360
con't	81	82	83	84	85	86	...													
	7371	7380	7387	7392	7395	7396	7396													

You do not have to take any actions so far. Because we will provide you with payoff sheets to minimize your calculation load in the experiment. The above table is only for you to preview the revenues. There are 4 highlights in this table:

1. The revenue is highest for Role A and decreases from Role A to Role F. For example, if the units of production are 1, Role A's revenue is 251 ECUs, Role B's revenue is 187 ECUs, Role C's revenue is 183ECUs, Role D's revenue is 179 ECUs, Role E's revenue is 175 ECUs, Role F's revenue is 171 ECUs.
2. For each role, the higher the units of production, the higher the revenue. For example, for Role F, if your units of production are 1, your revenue is 171 ECUs; if your units of production are 2, your revenue is 340 ECUs. So on and so forth for other roles.
3. For each role, the higher the units of production, the lower are revenue earned from an additional unit of production. For example, for Role F, if your units of production are increased from 1 to 2, your revenue is increased by 169 ECUs; if your units of production are increased from 85 to 86, your revenue is increased by 1 ECU. So on and so forth for other roles.
4. For each role:
 - For Role A, if your units of production > 126 units, your revenue will be fixed at 15876 ECUs.
 - For Role B, if your units of production > 94 units, your revenue will be fixed at 8836 ECUs.
 - For Role C, if your units of production > 92 units, your revenue will be fixed at 8464 ECUs.
 - For Role D, if your units of production > 90 units, your revenue will be fixed at 8100 ECUs.
 - For Role E, if your units of production > 88 units, your revenue will be fixed at 7744 ECUs.
 - For Role F, if your units of production > 86 units, your revenue will be fixed at 7396 ECUs.

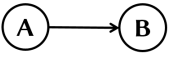
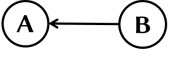
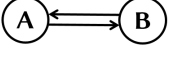
The Cost.

However, there are costs. **Costs are accounted in ECUs.** Although you can get revenue by accumulating units of production, some ECUs will be deducted from this amount, depending on the two types of decisions you make:

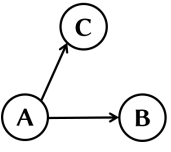
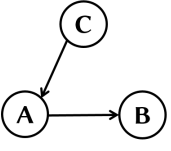
1. For contributions you make by yourself: every unit of contribution will cost you 20 ECUs.
2. For links you choose to initiate: every connection that you initiated yourself costs 300 ECUs.
3. You do not have to pay for the links between you and others that are initiated by others. If both you and another group member initiate links to each other, both of you only pay for the link that is initiated by yourself.

The examples then help to illustrate those points.

Example 3

	(1) If A and B do not connect with each other: Both A and B do not have to pay for the linking cost.
	(2) If A connects with B: A has to pay for the cost of linking with B, A has to pay for 1 link. B does not have to pay for links.
	(3) If B connects with A: B has to pay for the cost of linking with A, B has to pay for 1 link. A does not have to pay for links.
	(4) If A and B both connect with each other: A has to pay for the cost of linking with B, A has to pay for 1 link. B has to pay for the cost of linking with A, B has to pay for 1 link.

Example 4

	(1) If A connects with B and C, others do not initiate links: A has to pay for the cost of linking with B and C, A has to pay for 2 links. B and C do not have to pay for links.
	(2) If A connects with B, B does not initiate links, C connects with A : A has to pay for the cost of linking with B, A has to pay for 1 link. B does not have to pay for links. C has to pay for the cost of linking with A, C has to pay for 1 link.

The Earnings and payoff sheets.

Your earnings equal to your revenue minus the cost, **which are accounted in ECU**:

Your earnings (in ECUs)	=	the revenue
	<i>minus</i>	the cost of your own contributions (=number of units you contribute yourself × cost per unit)
	<i>minus</i>	the cost of initiating links (= number of links you initiated × 300 ECUs)

We have prepared a payoff sheet, which displays each role's earnings **except the linking cost** (i.e., **the revenue - the cost of your own contributions**). During the experiment, you will use these sheets to make decisions. Please open the attachment, let us go over each of them to see how to use these sheets.

(See attachments.)

Here are some examples on the computer screen. Could you please make use of these payoff sheets to find how many ECUs each role can earn in these examples, and answer all the questions on the screen?

(See the computer screen.)

Now, we are going to perform the task on the screen. In order to let you to understand the task better, we firstly conduct a mock task. The outcome of this mock task will not be counted for experimental payment. After that we will conduct the formal task. The outcome of the formal task will be your earnings in this part of the experiment.

Note: Please turn to the payoff sheet that represents your role, this shows how your earnings are determined.

Note: The two decisions, i.e. how many units to contribute, and to whom to link, have to be inputted into the screen together. It means that you cannot make your decisions after seeing the decisions of your other group members.

(See the mock task.)

Now we are going to perform the formal task of Part 1.

Note: In the formal task, you will be asked to answer some questions. The answer of these questions will not affect your earnings of this part.

Note: Please raise your hand to confirm with the experimenter if your computer screen has display errors.

Part 2

1. You have already been assigned into a group in Part 1 (Group 1 or Group 2). Now in Part 2, you will be kept in this same group until the end of the experiment. It means that, although you do not know who your group members are, they will be your group members until the end of the experiment.
2. Your group of 6 will perform the same task for another 19 rounds.
3. At the beginning of each round, you (and your group members) will be randomly assigned one role: either A, B, C, D, E or F. The assignment process is random: You are equally likely to be allocated to each of the 6 roles. Therefore, you are very likely to get different roles in each round. And in each round, it is very likely that your group members are assigned different roles.
At the beginning of each round, your role of this round will be displayed on the screen, thus:
 - Please turn to payoff sheet that represents your current role, this shows how your earnings are determined in this round.
 - This is really important in helping you make decisions, as the costs of contribution are different for each role.
4. Knowing your roles, you will make decisions to earn ECUs. The two decisions are the same as before. Your group members will be asked to make the same decisions as well. All of you have to input your choices into the computer screen. You have no chance to discuss with your group members. Once all of you are done, the computer screen will display all choices and earnings of the current round by role. Then the next round starts.
5. The 19 rounds are independent of each other. Your earnings in each round are **solely** determined by your and your group members' decisions **in this round**. Your earnings in this round will not affect your earnings in the next round.
6. Your earnings in Part 2 depends on both you and your group members' decisions, **and some chance**. **When Part 2 is finished, 1 round of the 19 rounds will be randomly selected, the earnings of which become your earnings in Part 2. Each round will be selected with equal chance.** (*Note: Your experimental payment will be determined by either part with equal chance, which means that there is a 50% chance that your earnings of the selected round in this part will be your experimental payment.*)

Now we are going to perform the Part 2.

A3.3 Treatment 1 payoff booklet

Example payoff sheet (Rate Role A is an example)

Linking cost = 1500 GCU x number of links you initiated

Rate Role A

Rate Role B

Rate Role C

Rate Role D

Rate Role E

Rate Role F

Rate Role G

Rate Role H

Rate Role I

Rate Role J

Rate Role K

Rate Role L

Rate Role M

Rate Role N

Rate Role O

Rate Role P

Rate Role Q

Rate Role R

Rate Role S

Rate Role T

Rate Role U

Rate Role V

Rate Role W

Rate Role X

Rate Role Y

Rate Role Z

Rate Role AA

Rate Role AB

Rate Role AC

Rate Role AD

Rate Role AE

Rate Role AF

Rate Role AG

Rate Role AH

Rate Role AI

Rate Role AJ

Rate Role AK

Rate Role AL

Rate Role AM

Rate Role AN

Rate Role AO

Rate Role AP

Rate Role AQ

Rate Role AR

Rate Role AS

Rate Role AT

Rate Role AU

	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	10

ROLE A

Linking cost = **1500 ECU** x number of links you initiated

* This is the payoff sheet of Role A. Please make sure that you are assigned as Role A.

* Your earnings (ECU) = the ECU amount on this sheet (ECU) — linking cost (ECU)

[illegible]

E ROLE **E** $\text{Linking cost} = 1500 \text{ ECU} \times \text{number of links you initiated}$

* This is the payoff sheet of Role E. Please make sure that you are assigned as Role E.

* Your earnings (ECU) = the ECU amount on this sheet (ECU) — linking cost (ECU)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97</																							

ROLE F

Linking cost = **1500 ECU** × number of links you initiated

* This is the payoff sheet of Role F. Please make sure that you are assigned as Role F.

* Your earnings (ECU) = the ECU amount on this sheet (ECU) — linking cost (ECU)

	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120																																																																																																																																																																																																																																																				
0	300	392	465	515	548	568	580	585	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640																																																																																																																																																																																																																																																		
1	700	102	124	136	145	151	155	158	161	164	167	170	173	176	179	182	185	188	191	194	197	200	203	206	209	212	215	218	221	224	226	229	232	235	238	241	244	247	250	253	256	259	262	265	268	271	274	277	280	283	286	289	292	295	298	301	304	307	310	313	316	319	322	325	328	331	334	337	340																																																																																																																																																																																																																																											
2	340	432	482	515	535	550	561	569	575	580	584	588	591	594	597	600	603	606	609	612	615	618	621	624	627	630	633	636	639	642	645	648	651	654	657	660	663	666	669	672	675	678	681	684	687	690	693	696	699	702	705	708	711	714	717	720	723	726	729	732	735	738	741	744	747	750	753	756	759	762	765	768	771	774	777	780	783	786	789	792	795	798	801	804	807	810	813	816	819	822	825	828	831	834	837	840	843	846	849	852	855	858	861	864	867	870	873	876	879	882	885	888	891	894	897	900	903	906	909	912	915	918	921	924	927	930	933	936	939	942	945	948	951	954	957	960	963	966	969	972	975	978	981	984	987	990	993	996	999	1002	1005	1008	1011	1014	1017	1020	1023	1026	1029	1032	1035	1038	1041	1044	1047	1050	1053	1056	1059	1062	1065	1068	1071	1074	1077	1080	1083	1086	1089	1092	1095	1098	1101	1104	1107	1110	1113	1116	1119	1122	1125	1128	1131	1134	1137	1140	1143	1146	1149	1152	1155	1158	1161	1164	1167	1170	1173	1176	1179	1182	1185	1188	1191	1194	1197	1200	1203	1206	1209	1212	1215	1218	1221	1224	1227	1230	1233	1236	1239	1242	1245	1248	1251	1254	1257	1260	1263	1266	1269	1272	1275	1278	1281	1284	1287	1290	1293	1296	1299	1302	1305	1308	1311	1314	1317	1320	1323	1326	1329	1332	1335	1338	1341	1344	1347	1350	1353	1356	1359	1362	1365	1368	1371	1374	1377	1380	1383	1386	1389	1392	1395	1398	1401	1404	1407	1410	1413	1416	1419	1422	1425	1428	1431	1434	1437	1440	1443	1446	1449	1452	1455	1458	1461	146

A3.4 Treatment 7 payoff booklet

[illegible]

Role A

Linking cost = 300 ECU × number of links you initiated

* This is the payoff sheet of Role A. Please make sure that you are assigned as Role A.

* Your revenue (ECU) = the ECU amount on this sheet (ECU) — linking cost (ECU)

Year	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	2979	2980	2981	2982	2983	2984	2985	2986	2987	2988	2989	2990	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000
------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

F Role

Linking cost = 300 ECU × number of links you initiated

* This is the payoff sheet of Role F. Please make sure that you are assigned as Role F.

* Your revenue (ECU) = the ECU amount on this sheet (ECU) — linking cost (ECU)

[illegible]

A4 OLS regression results of round 1 to 20

To better understand the two decisions when heterogeneity is assigned, we apply OLS regressions with categorical variables capturing the different roles, as well as part dummies and treatment dummies. We use the data of all 20 rounds. `Creftab:ols` lists the regression results. In scenarios of cost heterogeneity, the relationship between roles and the amount of production shows that participants produce 57 tokens and 20 tokens more when they are assigned as Role A and Role B, respectively, than when they are assigned Role F (the omitted category). For the number of in-links, column (4) shows that Role A and Role B receive almost all in-links. Role C and Role D have significant coefficients while the number is less than one. In scenarios of valuation heterogeneity, column (2) shows that Role A and Role B produce 38 tokens and 14 tokens more than Role F, respectively. In-links are concentrated on Role A and Role B as well which is displayed in column (5).

Column (3) and Column (6) restrict the sample of valuation heterogeneity to Treatments 9 and 10. Column (6) shows that Role A and Role B are in the core of the network, therefore Result 2.1 is still established even if we use data of all 20 rounds. For producing behaviour, column (3) shows that for the two core roles, Role A contributes significantly more than Role B (the Restricted F Test of coefficient on Role A and B, $p < 0.001$). Therefore, when we include data from all rounds of Treatments 9 and 10, the result supports Hypothesis 2.2.

All regressions in Table [A1](#) reject the null hypothesis of a global F-test ($p < 0.001$). The regressions here further confirm that, in both scenarios, the better roles who produce more and collect most of the in-links are Role A as well as Role B; they comprise the minority of the group but are the main contributing force to the public good.

Table A1: OLS regression results.

Dependent var.	Number of tokens			Number of in-links		
	Cost		Valuation	Cost		Valuation
	Heterogeneity		Heterogeneity	Heterogeneity		Heterogeneity
	T1-T6	T7-T10	T9-T10	T1-T6	T7-T10	T9-T10
	(1)	(2)	(3)	(4)	(5)	(6)
Role A	57.706*** (4.940)	38.278*** (6.209)	41.550*** (6.835)	4.502*** (0.120)	3.269*** (0.355)	3.263*** (0.316)
Role B	20.400*** (3.389)	14.269*** (2.485)	20.394*** (2.807)	1.994*** (0.231)	1.356*** (0.260)	0.944*** (0.183)
Role C	7.083*** (1.071)	4.272** (1.690)	6.963** (2.214)	0.363*** (0.091)	0.250** (0.096)	0.119 (0.089)
Role D	3.933*** (0.935)	5.041*** (1.356)	9.281*** (1.207)	0.077** (0.033)	0.047 (0.050)	0.025 (0.063)
Role E	1.063* (0.612)	3.291** (1.412)	6.563*** (1.801)	0.019 (0.018)	-0.009 (0.040)	0.031 (0.047)
Part dum.	Yes	Yes	Yes	Yes	Yes	Yes
Treatment dum.	Yes	Yes	No	Yes	Yes	No
Constant	4.747*** (0.950)	11.551*** (1.792)	18.630*** (2.493)	-0.152*** (0.092)	0.861*** (0.134)	0.153* (0.068)
# of Obs.	2,880	1,920	960	2,880	1,920	960
# of Clusters	24	16	8	24	16	8
F	108.90	13.63	34.85	266.12	83.59	467.96
R2 (adj.)	0.575	0.305	0.257	0.818	0.611	0.686
Prob.>F	0.000	0.000	0.000	0.000	0.000	0.000

Note: Multiple linear regression with role as categorical variable. Dependent variable are the number of produced tokens and the number of links received by each observation. Role F is the reference group. Indicator variables for the remaining roles are coded 1 for participants who are assigned that role, and all others are coded 0.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A5 Statistical tests on each role's behaviour in round 20

A5.1 Scenarios under Cost Heterogeneity

Table A2 and Table A3 report statistical test results about out-link decisions and centrality, respectively, in the last round of Part 2. Table A3 shows that Result 1.1 still holds. It shows Role A receives significantly more links than Role B. Both Role A and B receive significantly more links than each of Roles C to F. Number of in-links also does not significantly differ across Roles C to F.

Table A2: Test results of out-link behaviour by role, Cost Heterogeneity, T1-6, r20.

Kruskal-Wallis equality-of-populations rank test: $\chi^2(5) = 63.151$ ($p < 0.001$)						
	A	B	C	D	E	F
Rank sum	448.00	1304.50	2113.00	2056.50	2248.00	2270.00
Obs.	24	24	24	24	24	24
Dunn's Pairwise Comparison of units by role (Bonferroni)						
Col Mean - Row Mean	A	B	C	D	E	
B	-3.225** (0.010)					
C	-6.269*** (0.000)	-3.044** (0.018)				
D	-6.056*** (0.000)	-2.831** (0.035)	0.213 (1.000)			
E	-6.777*** (0.000)	-3.552*** (0.003)	-0.508 (1.000)	-0.721 (1.000)		
F	-6.860*** (0.000)	-3.635*** (0.002)	-0.591 (1.000)	-0.804 (1.000)	-0.083 (1.000)	

Note: p -values in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A3: Test results of in-link behaviour by role, Cost Heterogeneity, T1-6, r20.

Kruskal-Wallis equality-of-populations rank test: $\chi^2(5) = 71.603$ ($p < 0.001$)						
	A	B	C	D	E	F
Rank sum	3134.00	2161.00	1461.00	1228.00	1176.00	1280.00
Obs.	24	24	24	24	24	24
Dunn's Pairwise Comparison of units by role (Bonferroni)						
Col Mean - Row Mean	A	B	C	D	E	
B	4.046*** (0.000)					
C	6.957*** (0.000)	2.911** (0.027)				
D	7.923*** (0.000)	3.880*** (0.001)	0.969 (1.000)			
E	8.142*** (0.000)	4.096*** (0.000)	1.185 (1.000)	0.216 (1.000)		
F	7.710*** (0.000)	3.664*** (0.002)	0.753 (1.000)	-0.216 (1.000)	-0.432 (1.000)	

Note: p -values in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A4 shows that Hypothesis 1.1 is partially supported in round 20 – the same result as in round 1. It reports statistical test results on levels of contribution in the last round of Part 2. It confirms that Result 1.2 still holds. Dunn's tests point out Role A's contribution is significantly greater than all other roles. Level of contribution does not significantly

differ between Role B and C, while Role B contributes significantly more than Role E and F. Role C's contribution is not significantly different from Role D and Role E, while it is significantly different from Role F. Role D, E and F cannot be distinguished with each other.

Table A4: Test results of producing behaviour by role, Cost Heterogeneity, T1-6, r20.

Kruskal-Wallis equality-of-populations rank test: $\chi^2(5) = 57.473$ ($p < 0.001$)						
	A	B	C	D	E	F
Rank sum	2903.50	2065.50	1646.50	1655.00	1266.00	903.50
Obs.	24	24	24	24	24	24
Dunn's Pairwise Comparison of units by role (Bonferroni)						
Col Mean - Row Mean	A	B	C	D	E	
B	2.949** (0.023)					
C	4.424*** (0.000)	1.475 (1.000)				
D	4.394*** (0.000)	1.445 (1.000)	-0.030 (1.000)			
E	5.763*** (0.000)	2.814** (0.037)	1.339 (1.000)	1.369 (1.000)		
F	7.039*** (0.000)	4.090*** (0.000)	2.615* (0.067)	2.645 (0.061)	1.276 (1.000)	

Note: p -values in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A5.2 Scenarios under Valuation Heterogeneity

Table A5 and Table A6 report statistical test results about out-link decisions and centrality, respectively, in the last round of Part 2. Table A6 shows that only Role A receives significantly more links than other roles, and all other roles are not significantly different from each other. This is different from Result 2.1, however, Hypothesis 2.1 is still holds.

Table A5: Test results of out-link behaviour by role, Valuation Heterogeneity, T7-10, r20.

Kruskal-Wallis equality-of-populations rank test: $\chi^2(5) = 10.854$ ($p = 0.054$)						
	A	B	C	D	E	F
Rank sum	463.00	812.00	885.00	923.50	757.50	815.00
Obs.	16	16	16	16	16	16
Dunn's Pairwise Comparison of units by role (Bonferroni)						
Col Mean - Row Mean	A	B	C	D	E	
B	-2.362 (0.137)					
C	-2.856** (0.032)	-0.494 (1.000)				
D	-3.116** (0.014)	-0.754 (1.000)	-0.261 (1.000)			
E	-1.993 (0.347)	0.369 (1.000)	0.863 (1.000)	1.123 (1.000)		
F	-2.382 (0.129)	-0.020 (1.000)	0.474 (1.000)	0.734 (1.000)	-0.389(1.000)	

Note: p -values in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A6: Test results of in-link behaviour by role, Valuation Heterogeneity, T7-10, r20.

Kruskal-Wallis equality-of-populations rank test: $\chi^2(5) = 25.621$ ($p < 0.001$)						
	A	B	C	D	E	F
Rank sum	1250.50	875.50	645.00	645.00	626.00	614.00
Obs.	16	16	16	16	16	16
Dunn's Pairwise Comparison of units by role (Bonferroni)						
Col Mean - Row Mean	A	B	C	D	E	
B	2.652* (0.060)					
C	4.282*** (0.000)	1.629 (0.773)				
D	4.282*** (0.000)	1.630 (0.773)	0.000 (1.000)			
E	4.416*** (0.000)	1.764 (0.583)	0.134 (1.000)	0.134 (1.000)		
F	4.501*** (0.000)	1.849 (0.483)	0.219 (1.000)	0.219 (1.000)	0.085 (1.000)	

Note: p -values in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Similarly in Table A7, when we restrict our sample down Treatments 9 and 10, only Role A in the core in the last round 20, Role B now is not a core player.

Table A7: Test results of in-link behaviour by role, Valuation Heterogeneity, T9-10, r20.

Kruskal-Wallis equality-of-populations rank test: $\chi^2(5) = 14.273$ ($p = 0.014$)						
	A	B	C	D	E	F
Rank sum	328.00	185.50	140.00	181.00	160.50	181.00
Obs.	8	8	8	8	8	8
Dunn's Pairwise Comparison of units by role (Bonferroni)						
Col Mean - Row Mean	A	B	C	D	E	
B	3.178** (0.011)					
C	4.193*** (0.000)	1.015 (1.000)				
D	3.278*** (0.008)	0.100 (1.000)	-0.914 (1.000)			
E	3.736*** (0.001)	0.558 (1.000)	-0.457 (1.000)	0.457 (1.000)		
F	3.278*** (0.008)	0.100 (1.000)	-0.914 (1.000)	0.000 (1.000)	-0.457 (1.000)	

Note: p -values in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

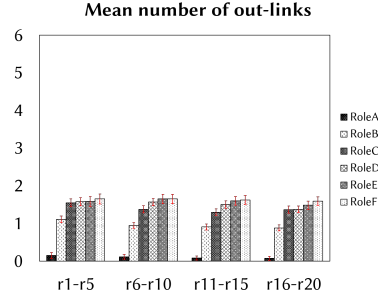
Since in round 20 only Role A is a core player, we do not provide test results to Hypothesis 2.2 using Treatments 9 and 10. We check producing behaviour patterns using Treatments 7 to 10. Table A8 shows that only Role A (the core role in round 20) behaves significantly different from some of the other roles. This is different from round 1, while still roughly confirming the ‘law of the few’.

Table A8: Test results of in-link behaviour by role, Valuation
Heterogeneity, **T9-10**, r20

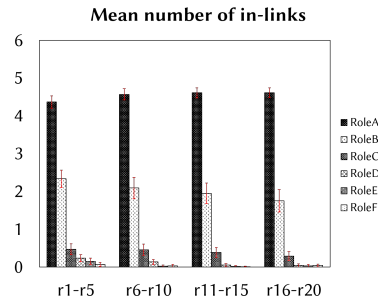
Kruskal-Wallis equality-of-populations rank test: $\chi^2(5) = 12.854$ ($p = 0.025$)						
	A	B	C	D	E	F
Rank sum	1127.00	777.00	643.00	684.00	745.50	679.50
Obs.	16	16	16	16	16	16
Dunn's Pairwise Comparison of units by role (Bonferroni)						
Col Mean - Row Mean	A	B	C	D	E	
B	2.227 (0.195)					
C	3.079** (0.016)	0.853 (1.000)				
D	2.819** (0.036)	0.592 (1.000)	-0.261 (1.000)			
E	2.427 (0.114)	0.200 (1.000)	-0.652 (1.000)	-0.391 (1.000)		
F	2.847** (0.033)	0.620 (1.000)	-0.232 (1.000)	0.029 (1.000)	0.420 (1.000)	

Note: p -values in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

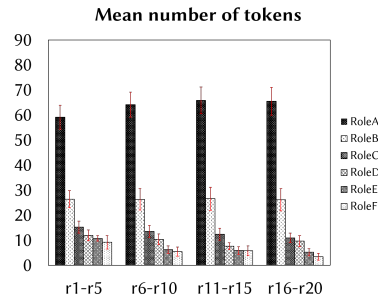
A6 Evolution of behaviour patterns



(a) Out-links.



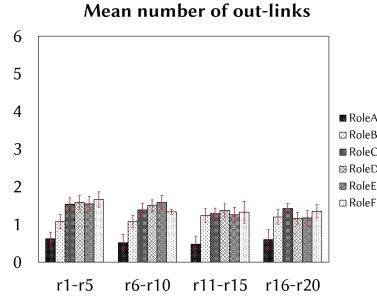
(b) In-links.



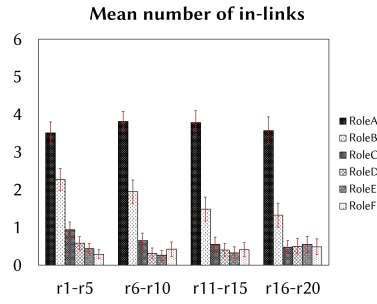
(c) Production.

Figure A4: Average performance by role at round 1 to 5, round 6 to 10, round 11 to 15 and round 16 to 20, Cost Heterogeneity.

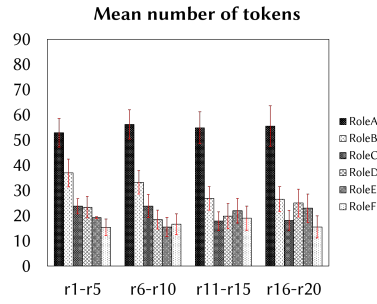
Note: In each panel, a column represents corresponding average performance of one of the six roles in every continuous five rounds. Error bars represent 95% confidence intervals.



(a) Out-links.



(b) In-links.



(c) Production.

Figure A5: Average performance by role at round 1 to 5, round 6 to 10, round 11 to 15 and round 16 to 20, Valuation Heterogeneity.

Note: In each panel, a column represents corresponding average performance of one of the six roles in every continuous five rounds. Error bars represent 95% confidence intervals.

A7 Accuracy of linking predictions

We further define the link prediction rate as the proportion of a given role's five linking decisions the model accurately predicts. For example, Role A needs to decide whether initiate links to Role B, Role C, Role D, Role E and Role F. If in Treatment 1, this Role A initiates one link to Role B and does not link to other roles, then the model gets a prediction rate as 80% because it predicts that Role A does not initiate any links.

In both scenarios, participants perform quite well in line with the model when they make linking decisions. In round 1, the mean link prediction rate in scenarios of cost heterogeneity is 82.361% ($SD = 0.207$), which means that on average participants make between four and five predicted linking decisions in the total five of them. This number is significantly different from 0.5 (Two-tailed Wilcoxon Single Sample T-test, $z = 9.650$, $p < 0.001$). Under valuation heterogeneity, the mean link prediction rate is 77.083% ($SD = 0.183$), which is significantly different from 0.5 as well (Two-tailed Wilcoxon Single Sample T-test, $z = 8.384$, $p < 0.001$). Therefore, the model predicts much better than random. Table A9 shows the mean rate separated by role. For all roles in both scenarios, the model exhibits a prediction rate which is significantly higher than 0.5 (Two-tailed Wilcoxon Single Sample T-test, largest $p = 0.059$), however, better roles have higher prediction rates than worse roles.

Table A9: Average prediction rate by role.

	Role A	Role B	Role C	Role D	Role E	Role F
Cost heterogeneity						
Round 1	0.933*** (0.127)	0.875*** (0.115)	0.858*** (0.125)	0.808*** (0.182)	0.833*** (0.174)	0.633* (0.321)
Round 20	0.983*** (0.056)	0.958** (0.083)	0.933*** (0.096)	0.841*** (0.167)	0.891*** (0.132)	0.700** (0.353)
Valuation heterogeneity						
Round 1	0.825*** (0.161)	0.813*** (0.171)	0.700*** (0.207)	0.800*** (0.146)	0.800*** (0.126)	0.688*** (0.242)
Round 20	0.875** (0.282)	0.838*** (0.196)	0.763*** (0.196)	0.738*** (0.175)	0.750*** (0.186)	0.813*** (0.213)

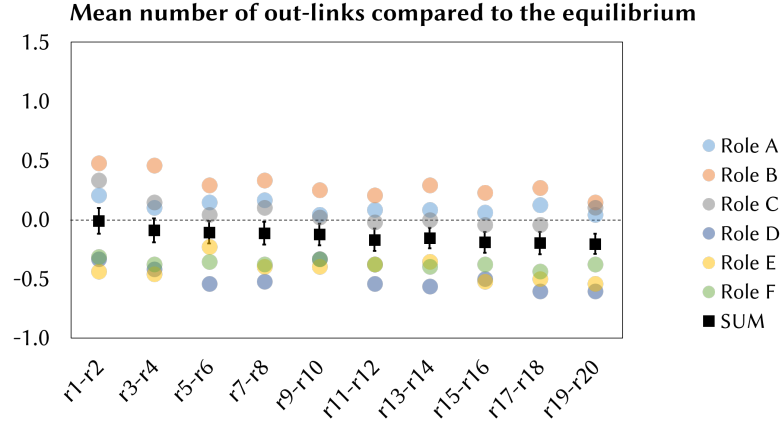
Note: Standard deviation in parentheses. Two-tailed Wilcoxon Single Sample T-test against 0.5.

** $p < 0.01$, * $p < 0.05$, $p < 0.1$.

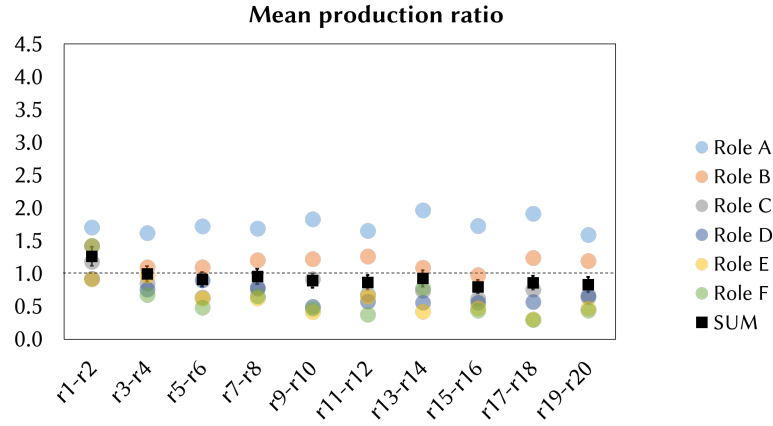
In round 20, the mean prediction rate in scenarios of cost heterogeneity

is 88.472% ($SD = 0.198$). This is still significantly different from 0.5 (Two-tailed Wilcoxon Single Sample T-test, $z = 9.993$, $p < 0.001$), and there is a significant increase compared with round 1 (Wilcoxon rank sum test, $z = 3.231$, $p = 0.001$). Table A9 shows the prediction rate increases for all roles (but only Role B, Role C and Role F pass Wilcoxon Rank-sum test, largest $p = 0.072$). In summary, playing for multiple rounds increases the consistency of linking decisions with the model’s predictions in the scenario of cost heterogeneity. Under valuation heterogeneity, in round 20, the mean prediction rate is 79.583% ($SD = 0.211$), which is significantly different from 0.5 (Two-tailed Wilcoxon Single Sample T-test, $z = 8.101$, $p < 0.001$). We do not find a significant increase compared with round 1 using a Wilcoxon Rank-sum test ($z = 1.061$, $p = 0.290$).

A8 Changes with respect to equilibrium predictions



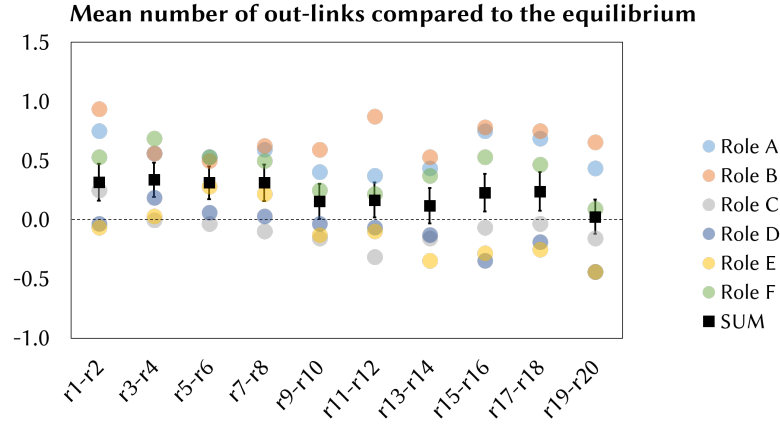
(a) Out-links compared to the equilibrium.



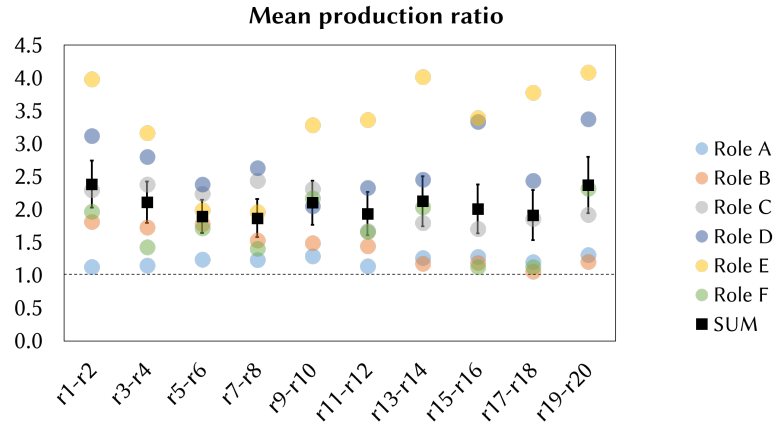
(b) Production ratio.

Figure A6: Cost Heterogeneity.

Note: In each panel, a coloured dot represents corresponding average performance of one of the six roles in every continuous two rounds. Each black squared dot represents average performance of all six roles in every continuous two rounds, on which the error bar represents 95% confidence intervals. The dotted line marks where the equilibrium lies.



(a) Out-links compared to the equilibrium.



(b) Production ratio.

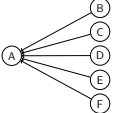
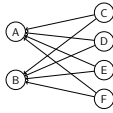
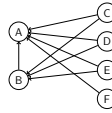
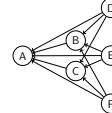
Figure A7: Valuation Heterogeneity.

Note: In each panel, a coloured dot represents corresponding average performance of one of the six roles in every continuous two rounds. Each black squared dot represents average performance of all six roles in every continuous two rounds, on which the error bar represents 95% confidence intervals. The dotted line marks where the equilibrium lies.

A9 The tendency of emergence of graph types

Table A10 shows how many times these specified graphs emerge (as a percentage) in the different treatments over all 20 rounds. The superscript* denotes the frequency of emergence of the equilibrium graph in corresponding treatments. We therefore have two findings. First, frequency of emergence of the equilibrium graph decreases in the complexity of the graph. We argue that graph (d) is more complex than graph (b) and (c), as well as graph (a), because graph (d) contains more links and more hierarchies. Therefore, for example, the frequency of emergence of the equilibrium graph in Treatments 1 and 2 (34.375%) is higher than in Treatments 5 and 6 (0.000%), with the former containing a simple equilibrium graph. Second, even though graph (a) is not the equilibrium graph in Treatments 3 and 4, Treatments 5 and 6, or Treatments 9 and 10, it also appears in these treatments.

Table A10: The tendency of emergence of graphs.

					
		graph (a)	graph (b)	graph (c)	graph (d)
Cost Heterogeneity	T1&2	34.375%*	0.000%	2.500%	0.000%
	T3&4	16.250%	6.250%*	3.125%	0.000%
	T5&6	6.875%	0.000%	0.625%	0.000%*
Valuation Heterogeneity	T7&8	11.875%*	0.625%	1.875%	0.000%
	T9&10	10.625%	0.000%	0.000%*	0.000%

Note: The superscript * denotes the equilibrium graph of that treatment(s).

The other finding about graph (a) is that it appears more frequently when more rounds were played, which can be shown in Figure A8.

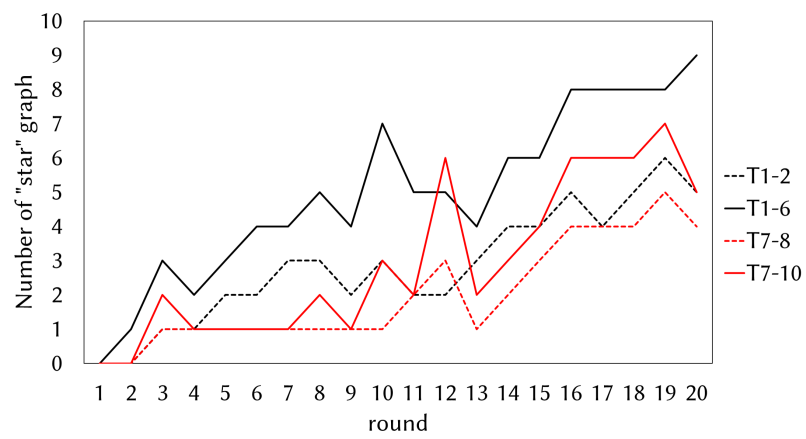


Figure A8: Frequency by rounds.

A10 Earnings ratio and earnings in terms of ECU

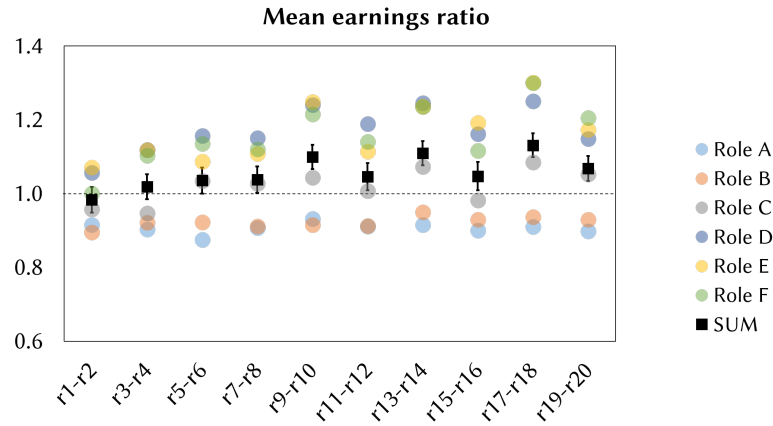


Figure A9: Mean earnings ratio, Cost Heterogeneity.

Note: Each coloured dot represents corresponding average earnings ratio of one of the six roles in every continuous two rounds. Each black squared dot represents average earnings ratio of all six roles in every continuous two rounds, on which the error bar represents 95% confidence intervals.

The dotted line marks where the equilibrium lies.

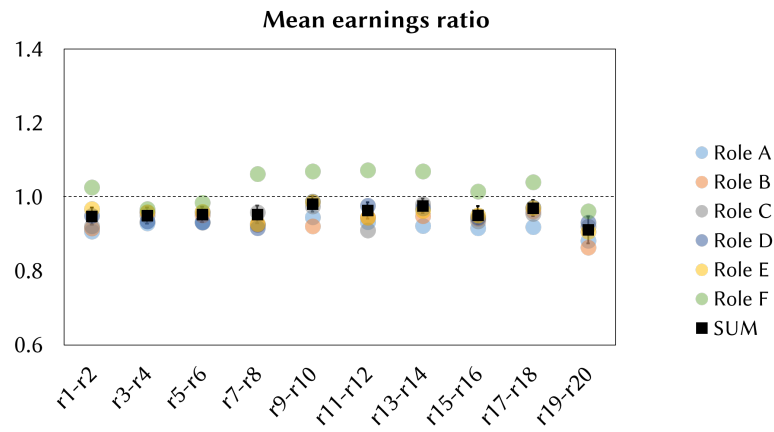


Figure A10: Mean earnings ratio, Valuation Heterogeneity.

Note: Each coloured dot represents corresponding average earnings ratio of one of the six roles in every continuous two rounds. Each black squared dot represents average earnings ratio of all six roles in every continuous two rounds, on which the error bar represents 95% confidence intervals. The dotted line marks where the equilibrium lies.

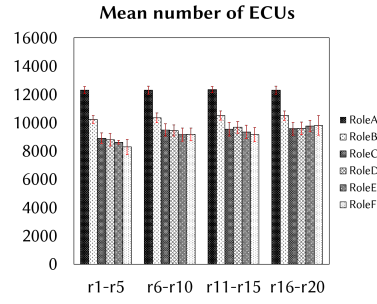


Figure A11: Mean number of ECUs at round 1 to 5, round 6 to 10, round 11 to 15 and round 16 to 20, Cost Heterogeneity.

Note: In each panel, a column represents corresponding average performance of one of the six roles in every continuous five rounds. Error bars represent 95% confidence intervals.

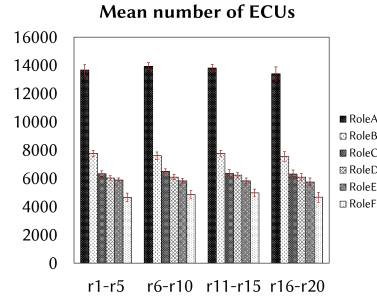


Figure A12: Mean number of ECUs at round 1 to 5, round 6 to 10, round 11 to 15 and round 16 to 20, Valuation Heterogeneity.

Note: In each panel, a column represents corresponding average performance of one of the six roles in every continuous five rounds. Error bars represent 95% confidence intervals.