Essays in Networks, Conflict and Contests

By

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ABSTRACT

My thesis has three chapters which look at: (i) the centralised network design in the presence of infiltration, (ii) an experiment, analysing the impact of voluntary disclosure of information in a model of asymmetric contests under incomplete information and, (iii) optimal contracts between a politician and agent in deciding resource allocation in a scenario of conflict. The summaries of each chapter are as follows:

Chapter 1: Terrorist organisations face a dilemma: increased connectivity can enhance their benefits but also increase the risk of infiltration. In this paper, we examine how infiltration by law enforcement authorities affects the structure of terrorist networks. We model the network structure in the presence of infiltration and solve for an efficient network. The efficient network is determined by the probability of an individual terrorist being captured through direct and indirect connections. If capturing an individual terrorist is possible through both direct and indirect connections with equal probability, the efficient structure will form of maximally connected sub-structures i.e., 'components'. If the probability of an individual terrorist getting caught through direct connections is higher than indirect connections then non-maximally connected sub-structures may arise. The efficient network can have either symmetric or asymmetric components, depending on the probability of infiltration. For some parameter values the efficient network is composed of only symmetric components.

Chapter 2: In many contest scenarios, such as space races, R&D, and military conflicts, participant's abilities are publicly known, while their costs remain private. This paper experimentally investigates the incentives for voluntarily disclosing private infor-

mation about marginal costs in an asymmetric one-shot contest. Our between-subjects experimental design with two players includes a baseline with incomplete information with no disclosure, and two treatments with incomplete information with two-sided disclosure and one-sided disclosure. Participants risk preferences were elicited during the experiment to better understand their decision-making processes. We report the findings of our experimental study on bidding behaviour (average investment levels), probabilities of winning, and expected payoffs in ex-ante asymmetric contests. We explore whether participants consistently choose to reveal their private information when given the option. Additionally, we examine how investment levels, winning probabilities, and expected payoffs vary by ability and disclosure decisions. Our results show that participants do not always reveal their private information when given the opportunity to do so, and this decision depends on their unit cost.

Chapter 3: We analyse a principal-agent model where a politically elected leader of a group (citizens) negotiates division of resources with another group (insurgents). Citizens have preferences over resources that have economic and ideological value but keeping more resources leads to more conflict with the insurgent group. Leaders differ in their ability which affects both the cost of conflict as well as the value of the resources net of costs of conflict. We illustrate when leaders of different abilities and ideologies choose to cede more or less of the resources to the insurgent group. The first best contract from the citizens point of view is characterised. We find that in the first best contract, the amount of resources ceded to the insurgent group can be non-monotonic in ability of the citizen's leader. We provide illustrations of such non monotonic contracts. We further show what the optimal choice is by the leader when he is re-elected vs replaced in the first best contract.

DEDICATION

Dedicated to Sid, Ma, Baba and Madhuparna

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Chapter One

Efficient Terrorist Networks in the Presence of Infiltration*†

1.1 Introduction

Law enforcement intelligence units often employ strategies to gather sensitive information aimed at dismantling terrorist plots. The Intelligence Handling Model (IHM), jointly developed by MI5 and Counter Terrorism (CT) policing in 2011, emphasizes gathering and analysing information to mitigate terrorist activities.[1] Using IHM, MI5 and CT policing thwarted 20 Islamist terrorist plots between 2013 and 2017. This strategy of gathering information to infiltrate is applicable to a wide range of organisations from terrorist groups to drug cartels, enabling the effective disruption of their activities through targeted intelligence gathering. In this chapter we aim to understand the efficient network structures of such organisations when law enforcement organisation can capture terrorists or other criminal networks using infiltration. For illustrative purposes we will continue

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[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664682/Attacks_in_London_and_Manchester_Open_Report.pdf

to describe these as terrorist networks but they include these wider networks of interest to law enforcement.

We ask two main questions in this chapter: Given the presence of infiltration techniques like surveillance and electronic eavesdropping, how do terrorist organisations structure themselves? How do individual terrorists undertake productive activities within such organisational structures? These questions underscore the complexities and challenges in the fight against terrorism and organised crime.

While this matter pertains to the extensive body of literature on organisational structure, it does not center on infiltration, which is the primary focus of our chapter. Some papers discuss the internal efficiency of organisations, while others focus on external considerations. Baccara and Bar-Isaac (2008) combined both internal and external efficiencies in a crime setting. Their paper discusses the trade-off between concerns to increase internal efficiency (sustaining cooperation) against the threat of greater vulnerability to an external threat (increasing the probability of indirect detection) in an organisation

Our chapter differs from Baccara and Bar-Isaac (2008) in two key aspects. Firstly, we model the importance of interactions for the purpose of production, while they focus on interactions to enforce cooperation. For example, in a terrorist organisation, effective mutual support and resource sharing for production among members increase individual and total payoffs. Secondly, we determine the efficient network structure based on the probabilities of capturing players (i.e., terrorists) through direct and indirect connections. This is influenced by the 'precision' parameter used for targeting and the path length between terrorists, and it is independent of the level of information exchange. In contrast, Baccara and Bar-Isaac (2008) base their structure on whether detection depends on cooperation levels. Our approach considers the interconnectedness of terrorists and the associated capture risks, whereas theirs focuses on cooperation's impact on detection risks.

Our study seeks to answer the following research questions: What are the effort and utility for each member of a terrorist network, given a specific structure and the probability of infiltration? Furthermore, what constitutes an efficient terrorist network structure considering a given probability of infiltration?

In this chapter, we focus on understanding the efficient structure of the terrorist network designed. Terrorist networks often design multiple sub-structures, each sub-structure undertakes production cooperatively within those structures but independent of the other sub-structures. We model this as a terrorist network comprising of 'N' terrorists. There exists a head of the network, henceforth referred to as the 'Leader', who decides on these sub-structures of the terrorist network. The leader designs these networks keeping in mind the probability that an individual terrorist is captured directly or through direct and indirect connections. In our model, we focus on understanding these sub-structures inside the terrorist network and abstract away from the links between the leader and the terrorists inside the network. This leader operates from a concealed location, and his communication with other terrorists is assumed to be undecipherable by law enforcement authorities. He is cognizant of the potential for infiltration, understanding that law enforcement authorities can randomly target a terrorist through infiltration. Given this understanding, we model this as an extensive form game which we explain below.

In our chapter we explore the trade-offs terrorist organisations face: increased connectivity yields organisational benefits but also escalates the costs posed by infiltration. By examining how organisations navigate this balance, we seek to understand the architecture of efficient networks in the presence of infiltration threats. By an efficient network, we mean a terrorist organisation that maximizes the sum of utilities of its individual terrorists. We model this as a Stackelberg structure: the terrorist leader moves first, followed by the individual terrorists. The objective of the terrorist leader is to decide on the efficient network structure, given the possibility of infiltration. The individual terrorists then choose their effort to maximize their utilities within this network structure. In our

model, the law enforcement authority is not modelled explicitly, instead, their presence is reflected in the utility functions of the individual terrorists, with each terrorist facing a random chance of being targeted. We solve this game by backward induction and solve for the Sub-game Perfect Nash Equilibrium (SPNE).

Our results show that if an individual terrorist can be captured through both direct and indirect connections with probability one if infiltration is successful, the efficient network consists of maximally connected sub-structures called 'components'. In the presence of infiltration, there is an optimal degree of separation within an efficient network depending on the probability of infiltration. Additionally, we also explore how structures within the network fluctuate with changes in infiltration probabilities. Our finding suggests that at low infiltration levels, the terrorist leader designs a single, complete structure. However, with increased infiltration risk, the network breaks down into smaller sub-structures. The components designed within these efficient networks can be either symmetric or asymmetric, depending on the probability of infiltration. For some parameter values, the efficient network consists only of symmetric components. When punishments in the form of fines are sufficiently high or when the degree of complementarity is low, we observe the emergence of symmetric components in our chapter. When an individual terrorist exerts maximal effort, even with high infiltration probability, an efficient network is not necessarily composed of empty sub-structures. We also conducted a series of comparative static analyses to understand how individual efforts and utilities vary in response to changes in key factors: the number of neighbours each terrorist has, the size of the terrorist network, the level of fine each terrorist faces, and the degree of complementarity between the efforts of terrorists. Our analysis shows that when the marginal cost of capture due to an increase in neighbours outweighs the marginal benefits from complementarity, the equilibrium effort decreases as the number of neighbours grows. The effect on equilibrium utilities is ambiguous: if the marginal change in equilibrium effort is non-positive, the marginal change in equilibrium utility is unambiguously negative. If the marginal change in equilibrium effort is positive, the effect on utilities remains

ambiguous. If equilibrium effort is non-decreasing with the number of neighbours, the marginal change in complementarity between efforts is positively correlated with utility. Otherwise, it depends on the relative strength of the marginal benefit and cost. If the marginal change in equilibrium effort with respect to complementarity is non-positive, the marginal change in utility is negative. Otherwise, it depends on whether the benefits of increased complementarity outweigh the costs. We will discuss these comparative statics in more detail later.

Next, we focus on a second formulation where a terrorist can only be captured directly and not through any of its connections being infiltrated. In this case, the efficient network consists solely of symmetric components. At the end, we considered the formulation where the probability of capturing a terrorist through direct connections is higher than through indirect ones.[2] In this case, non-maximally connected sub-structures may emerge. Here, the likelihood of capturing a terrorist is inversely proportional to the distance between them and their connections.

Our model demonstrates that within a network, although there is a degree of separation between the sub-structures but within each sub-structure individual terrorists work closely i.e., they are maximally connected. This pattern is also observed in the analysis conducted by Krebs (2002).[3] Krebs (2002) uses publicly available data to construct a partial network map centred around the 19 hijackers. Examining the 9/11 terrorist network, we observe varying degrees of connectivity among the terrorists. Some were closely linked, while others had minimal connections. The 19 hijackers were divided into four groups, each responsible for crashing a plane at different locations. Although unfamiliar with each other before the attacks, they worked seamlessly together. Figure 1.1 illustrates the network of the 19 terrorists involved in the 9/11 attack. This is derived from mapping which terrorists were in which flight and from the sequence of events occurring within each flight which indicated there was close cooperation of the terrorists within each flight

[2]previously studied by Watts (2001) and Bala and Goyal (2000)
[3]https://www.aclu.org/sites/default/files/field_document/ACLURM002810.pdf

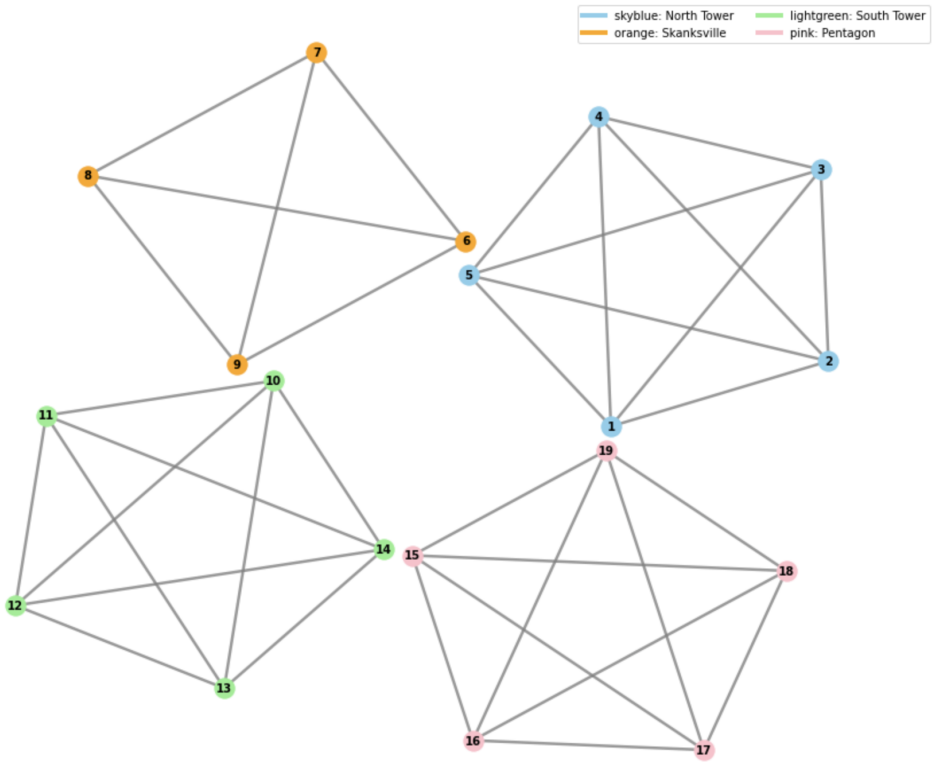

Figure 1.1 Network of 19 hijackers during execution of 9/11 attacks

but not across flights. The diagram uses colour-coded blocks to represent the terrorists associated with each plane. Three planes had five terrorists onboard, while one had four. This suggests that the terrorists on each plane worked closely together, coordinating tasks such as subduing passengers but did to have any connections across the different planes. This pattern indicates that terrorists tend to operate in cohesive groups.

Even though this chapter focuses on terrorist organisations and individual terrorists, the concepts are equally applicable to explaining financial contagion. In this context, the model can be interpreted as a central bank designing connections or linkages among individual banks to ensure the resilience of the banking system against external shocks. Just as individual terrorists operate independently while complementing the organisation's broader goals, individual banks function independently while meeting customer needs collectively. Similarly, while law enforcement might infiltrate a terrorist organisation by targeting a random individual, an external shock may impact a random bank, with the effects spreading through the network. Another interesting application of our model is

in the spread of diseases. Moreover, our findings can also offer insights into the efficient network structure in contexts involving infiltration and social networks where trust is a key factor in business proceedings. These findings will be discussed in more detail in the conclusion.

The rest of chapter 1 is organised as follows. In Section 1.2, we review the related literature, followed by the presentation of the general model in Section 1.3. In this section, we discuss the various cases of captures through connections. We characterise the equilibrium and do comparative statics of when the probability of capture through connections is 1. Finally, Section 1.4 offers conclusions and potential directions for future research.

1.2 Related Literature

Our research contributes to the economic theory of networks[4], the literature on hide-and-seek [5] and related security games [6] by utilising peer effects models (see Durlauf (2004)), with a focus on centralized network design and defence strategies against the possibility of an attack.

Our chapter specifically focuses on crime, making it essential to review the literature associated to crime economics. The individual-level analysis of crime dates back to Becker (1968), who framed crime as an economic decision-making problem and provided insights into an individual's optimal response to the expected penalty of committing crime. The subsequent literature does not focus on how crime is committed when criminals work with

[4]Network theory examines network formation, optimal structures, and the performance of social and economic networks under various conditions; see e.g., Vega-Redondo (2007); Jackson et al. (2008); Goyal (2012); Goyal (2023); Allen and Babus (2009); Cabrales et al. (2016).

[5]The first paper on hide-and-seek games was by Von Neumann (1953). Interestingly, the value of this 'hide-and-seek game' on a fixed arbitrary network can be computed using fractional graph theory, as shown by Fisher (1991).

[6]The literature on security explores the optimal allocation of limited security resources—such as guards or cybersecurity measures—to protect assets against threats (see e.g, Sinha et al. (2018), Kiekintveld et al. (2009) and Goyal and Vigier (2014)).

their accomplices as a group and how such networks can be deterred.[7] Papers by Sarnecki (2001) and Warr (2002) suggest crime often originates within social networks, with criminals frequently having accomplices. In economics, studies like Glaeser et al. (1996) propose that crime-prone neighbourhoods can induce individuals to commit more crimes. Case and Katz (1991) found a ten percent increase in neighbourhood juvenile crime rate leads to a 2.3 percent increase in individual delinquency. According to Calvó-Armengol and Zenou (2004), delinquents engage in competition with each other in criminal activities but also derive benefits from having friendships with other criminals. These connections enable them to learn and acquire valuable know-how within the criminal domain. Our chapter also focuses how the marginal utility of an individual's action is influenced by the average level of that action taken by their peers.

Notably, the works by Ballester et al. (2006, 2010), examines finite population non-cooperative games with linear-quadratic utilities, interpreting them as network games where each player's Nash equilibrium action is linked to her Bonacich centrality. It also analyses how aggregate equilibrium behavior varies with network size and density and introduces a policy for identifying and targeting the 'key-player' and 'key-group' whose removal optimally impacts aggregate activity. Their findings, when applied to the realm of crime, suggest that both a direct and an indirect effect on crime reduction. The insights gleaned from these papers can be considered as effective deterrence strategies when dealing with criminals operating as a cohesive group. Based on Ballester et al. (2006) framework, we developed a model to study the efficient structure of terrorist networks in the presence of infiltration. In contrast to property crimes, these organisations are sometimes driven by non-profit motives, such as religious extremism, political ideology, or social and economic grievances. One can thus think of a leader who shares this ideology trying to maximize the sum of utilities of the members. Terrorist networks, being vulnerable to infiltration, give rise to various structures within the network. [8] Although

[7]See Ehrlich (1975); Ehrlich (1996); Heineke (1978); Brown and Reynolds (1973); Allingham and Sandmo (1972)

[8]The survey of non-judicial publications on terrorism suggests a shift in the characteristics of modern terrorism, marked by new actors, means, and ideologies, particularly the heightened role of religious

these various structures function independently, the terrorists within each structure complement each other's roles (see e.g., Schorkopf (2003) and Baccara and Bar-Isaac (2008)) For instance, some members may specialise in bomb-making, others arrange resources, some know the right hideouts and some focus on attack preparations. This interdependence in their production and planning process creates a scenario where their efforts enhance each other's utility through collaboration. Our model suggests that different levels of infiltration, followed by appropriate punishment upon capture, can induce changes in the structure of a terrorist network. The connectivity within the structures and the number of structures varies depending on the probability of capture through direct and indirect connections. Understanding these structures is crucial for law enforcement authorities as it enables them to allocate their resources effectively, thereby enhancing their ability to combat crime more efficiently in the future.

Previous literature on centralized network design and defence often assumes homogeneity among nodes(see e.g., Bloch et al. (2020); Chen et al. (2019); Gueye et al. (2012)). Goyal et al. (2013) analysed a two-stage game where a designer selects and protects a network, and an attacker then targets nodes. They showed that optimal network formation varies with defence costs, favouring sparse networks when defence is affordable. Goyal and Vigier (2014) found that a centrally-protected star network often maximizes the designer's payoff. Cerdeiro et al. (2017) further explored decentralized defence, highlighting potential inefficiencies in security investment under this model. Stupak (2023) extends the literature on centralized network design and defence in three key directions: (1) by introducing heterogeneous vertices valued according to their degree centrality—the number of immediate neighbours a vertex has, (2) by modeling the simultaneous distribution of attacking and defensive resources by the Defender and Attacker and (3) by considering an adversary whose goal is to extract value from the network rather than merely disrupt it. They confirms that a centrally-protected star is the most secure formation, it also

fundamentalism. Fundamentalists, view the world as an eternal struggle between good and evil. Furthermore, the terrorist are now organized into small, durable cells within networks, making it more difficult for law-enforcement authorities to combat these organisations. https://www.ojp.gov/pdffiles1/nij/grants/208551.pdf

shows that it is the least efficient, appearing in equilibrium only when the cost of a single link is sufficiently high.

Drawing on prior research, our study makes three key contributions to network security models. In our chapter, we further extend the literature on centralized network design and defence by incorporating the Ballester et al. (2006) framework. Unlike previous studies on defence, our chapter does not involve the allocation of defensive resources by the designer (referred to as the leader). Instead, the designer designs the network structure such that individual nodes (referred to as terrorists) work closely within a substructure, while maintaining separation between each substructures. Specifically, we introduce decision-making by individual terrorists for production activities within a substructure. The attacker in our model (referred to as law enforcement authorities) randomly targets a terrorist for capture. The number of terrorists captured through the links of the targeted terrorist is determined by the targeting technology. As in the existing literature, the attacker's objective is to disrupt the network. The designer, on the other hand, designs the network structure with the assumption of an external threat. We consider three distinct cases in our analysis. In the first case, the probability of capture through connections is 1. In the second case, the probability of capture through connections is 0. Finally, in the third case, we examine the case where there are unequal probabilities of capture through direct and indirect connections.

Our game is a variant of the hide-and-seek game, extensively studied in economics and computer science (see e.g., Bloch et al. (2020); Crawford and Iriberri (2007); Dziubiński and Roy (2018); Fisher (2002); Waniek et al. (2017); Waniek et al. (2018)). Originating from Von Neumann (1953), these games have applications in security and auditing. While previous studies like Dziubiński and Roy (2018), Waniek et al. (2017) and Waniek et al. (2018) focused on exogenously defined resources and non-strategic seeker responses, our approach builds on Stupak (2023), where the seeker (attacker) randomly selects a node to attack. However, in our model, the attack is non-strategic. Here, an individual node

can be vulnerable both directly and through indirect connections, with vulnerability determined by exogenous probabilities of successful infiltration. The hider, aware of these vulnerabilities, designs the network structure accordingly. Within this structure, individual nodes maximize their payoffs by selecting optimal actions. Our focus is not only on network design but also on individual node decision-making within the designed network.

In addition to other strands of literature, our chapter relates to the financial contagion literature. Early models of counterparty risk, such as Rochet and Tirole (1996) and Allen and Gale (2000) explore the behaviour of banks and depositors. For instance, Allen and Gale (2000) analyses banks facing liquidity shocks, similar to the probability of infiltration in our model. To mitigate these shocks, banks can exchange deposits ex-ante. More recent studies (see e.g., Blume et al. (2013); Elliott et al. (2014); Acemoglu et al. (2015)) examine interdependencies between banks, such as lending and liquidity provision, which can help distribute shocks and reduce the likelihood of individual failures. However, large shocks can still cause failures, with interdependencies transmitting the impact more widely. The extent of contagion depends on the model and the types of contracts between institutions. Our chapter is closely related to Cabrales et al. (2017), who study optimal financial structures to minimize bank defaults. However, our research differs in three key ways: (1) we analyse the decision-making processes of individual terrorists within a predesigned network structure designed by a terrorist leader, (2) we explore various cases of capture probability through direct and indirect connections, influenced by both law enforcement's targeting parameter values and the network's design and (3) we focus on a production network, examining contagion in a criminological context. Further details of the model and results are discussed in the next section.

1.3 Model

1.3.1 Network

There are $n \geq 3$ terrorists in the model. The terrorist network $\mathcal{G}$ is the pair $(N, \mathcal{E})$ consisting of a set of terrorists $N = \{1, 2, \ldots..n\}$ and a set of links $\mathcal{E} \subseteq N^2$ between them. Terrorists i and j are connected by a link if and only if $(ij) \in \mathcal{E}$. The neighbourhood of a terrorist $i \in N$ is represented by the set $N_i = \{j \in N : (ij) \in \mathcal{E}\}$. The degree d_i, gives the number of neighbours of terrorist $i \in N$, i.e., $d_i = |N_i|$. The terrorist network is undirected $(\forall\{i, j\} : (ij) \in \mathcal{E} \Leftrightarrow (ji) \in \mathcal{E})$ and reflexive $(\forall i : (ii) \in \mathcal{E})$, implying the connections between terrorists are mutual and terrorists can have self-loops. Let, P_i^j be a path from terrorist i to j defined as a sequence of distinct links $(i_1 i_2), (i_2 i_3), ...(i_{t-1} i_t)$ such that $(i_k i_{k+1}) \in \mathcal{E}$ for each $k \in \{1, ..., t-1\}$ with $i_1 = i$ and $i_t = j$. The length of the path P_i^j is defined as the number of links in the path, denoted by $L(P_i^j)$. The distance $d(i, j)$ between terrorists i and j is defined as the minimum length of all paths from i to j. Formally, $d(i, j) = \min\{L(P_i^j) \mid P_i^j = (i_1, i_2, \ldots, i_t),\ i_1 = i,\ i_t = j,\ (i_k, i_{k+1}) \in \mathcal{E}\ \forall k \in \{1, 2, \ldots, t-1\}\}$.[9] The sequence $(i_1, i_2, \ldots, i_t)$ defines a valid path, with $i_1 = i$ and $i_t = j$, and the edge condition $(i_k, i_{k+1}) \in \mathcal{E}$ ensures that each consecutive pair of vertices is connected by an edge in $\mathcal{E}$. The set of terrorists that has a path with terrorist i is denoted as $M_i = \{j \in N : d(i, j) \neq \infty\}$. The number of all path-connected terrorists of terrorist $i \in N$ is denoted by m_i, where $m_i = |M_i|$.Component is a subset $C(\mathcal{G}) \subset N$ that is maximally connected; that is, it is, itself, connected and no $C(\mathcal{G}') \supsetneq C(\mathcal{G})$ is also connected.[10]

[9] If no path exists between terrorist i and j, then the $d(i, j) = \infty$, see Jackson et al. (2008).
[10] See Cabrales et al. (2017).

1.3.2 Individual Choices

Terrorists

Terrorist $i \in N$ choose an effort $e_i \in [0, B]$, with $B < \infty$, for conducting terrorist activities. These terrorists are both self-sufficient ($g_{ii} = 1$) as well as collaborate closely with their neighbours in the production process, and as a result, the outcome of each terrorist's output depends not only on their effort but also on the combined efforts with their neighbouring terrorists. Similar to Ballester et al. (2006), producing output collaboratively indicates 'strategic complements', where the effort of terrorist j positively influences the output of terrorist i when there is a link between i and j i.e., $g_{ij} = 1$. The degree of this complementarity between the efforts of terrorists is denoted by $\beta \geq 0$. Since terrorists operate interdependently, they may be linked to one another within the network. In our chapter, we account for various possible cases on how a terrorist can be targeted.

Leader

The leader of the organisation holds the authority to decide the efficient network structure and operates from a concealed position and is not reflected in the terrorist network. In our model the leader is assumed to have an objective function that maximises the sum of utilities of members of the network. The leader is well aware of the possibility of infiltration and, accordingly, makes decisions regarding the network structure. This includes determining both the internal connectivity within a component and the degree of separation between different sub-structures.

Law Enforcement Authorities

The law enforcement authorities does not know the terrorist network structure. Although they are not explicitly modelled, they play a role in the expected payoff function of the

terrorists and, consequently, in the decision-making process of the leader. Due to the unknown network structure, the authorities resort to random targeting of terrorists and attempt to gather evidence against them. We explain the general scenario. A terrorist denoted as i can be targeted with probability $\frac{\sum_{i\neq j,\ d(i,j)\neq\infty}\delta^{d(i,j)}+1}{n}$. This implies that out of the n possible terrorists, some terrorist i, is randomly targeted for infiltration, resulting in a targeting probability of $\frac{1}{n}$. However, terrorist i can also be targeted through its path-connected members depending on targeting technology $\delta \in [0,1]$, therefore the probability of targeting a terrorist is not just $\frac{1}{n}$ but $\frac{\sum_{i\neq j,\ d(i,j)\neq\infty}\delta^{d(i,j)}+1}{n}$. The probability of successful infiltration is denoted as $p \in [0,1]$. This can be interpreted as the likelihood of obtaining hard evidence against the terrorist after they have been randomly targeted. The probability of successful infiltration and the probability of terrorist i being targeted are considered independent events in the model. When terrorist i is targeted and the infiltration is successful, they incur a negative payoff referred to as 'fine' denoted by f, where $f \in (0,\infty)$.

1.3.3 Time-line

The game takes place sequentially and the timeline is as follows,

- At T=1, The leader decides on the network structure.[11]
- At, T=2, Individual terrorists choose efforts and maximize their own utilities given the network structure. level,
- At, T=3, The law enforcement authorities target a terrorist at random for capture.
- At, T=4, Payoffs are realised.

We analyse the above game in the next section.

[11] keeping in mind the probability of infiltration

1.3.4 Payoffs

All payoffs are realized at the end of the game. We adapted the model of Ballester et al. (2006) and used specifics from Bose (2023). The utility function for terrorist $i \in N$ is denoted as follows,

$$u_i = \Big(1 - \frac{\sum_{i\neq j,\, d(i,j)\neq\infty} \delta^{d(i,j)} + 1}{n}\Big) e_i(g_{ii} + \beta \sum_{j\in N} g_{ij}e_j) + \frac{\sum_{i\neq j,\, d(i,j)\neq\infty} \delta^{d(i,j)} + 1}{n} p(-f) + \frac{\sum_{i\neq j,\, d(i,j)\neq\infty} \delta^{d(i,j)} + 1}{n} (1-p) e_i(g_{ii} + \beta \sum_{j\in N} g_{ij}e_j) - \frac{1}{2}e_i^2 \quad (1.1)$$

Now we will delve into a detailed explanation of the right-hand side (R.H.S.) of equation 1.1. The R.H.S. comprises four terms, each representing different aspects of the utility function of terrorist i: The first term indicates the payoff for terrorist i when they are not targeted.[12] The probability of being targeted is $\frac{\sum_{i\neq j,\, d(i,j)\neq\infty} \delta^{d(i,j)}+1}{n}$, and the probability of not being targeted is $1 - \frac{\sum_{i\neq j,\, d(i,j)\neq\infty} \delta^{d(i,j)}+1}{n}$. In this case, the terrorist receives the value of the output produced through their own effort and the combined efforts of their neighbours.[13] The second and third terms together represent the expected payoff for terrorist i if they are targeted. Following targeting, with probability p, the infiltration is successful, resulting in a penalty of $-f$. With probability $1-p$, the infiltration is unsuccessful, meaning the terrorist is targeted but not captured. In this scenario, they still receive the value of the output generated by their individual effort and the joint efforts of their neighbours. Lastly, the final term highlights the disutility of effort, representing the cost of efforts or difficulty of engaging in terrorist activities. To summarise, the R.H.S. of equation 1.1 considers various factors influencing the payoffs of terrorists. It accounts for successful and unsuccessful law enforcement attempts, the collaboration between terrorists and their neighbours, the potential consequences of being targeted and captured,

[12] Note: A terrorist can only be captured if they are targeted.

[13] In essence, the terrorist exerts some effort on their own for production or planning, and there is additional collaborative input from their connected neighbours.

and the disutility of efforts.

Terrorists maximize their individual utilities by choosing their effort level given a network design. The leader of the terrorist network, who operates from a hidden position and whose communication is encrypted[14], then decides on the network structure given the probability of infiltration. The leader must decide both on the internal connectivity of components and the optimal degree of each component beyond which it is efficient to separate the components. The total welfare, denoted by W, is the summation of the utilities of individual terrorists. For a given p, the efficient terrorist network structure is the structure with maximized joint payoffs. The welfare function is defined as follows:

$$\max_{\mathcal{G}} W = \sum_{i=1}^{n} u_i \tag{1.2}$$

Moreover, the leader's decision problem revolves around deciding on a network structure that maximizes the collective utilities of the terrorists while minimising the cost of infiltration and disruption by law enforcement authorities. This approach ensures that terrorists operate as efficiently and covertly as possible, working together to achieve their objectives while evading detection and maximizing their individual utilities. The careful balance of network connectivity and the optimization of component degrees contribute to the creation of an effective and resilient terrorist network under the leader's direction.

For tractability reasons, we will focus for now on the scenario where the targeting technology parameter $\delta = 1$. This setting signifies that a terrorist can be targeted both directly and through all path-connected terrorists with certainty, i.e., with probability 1. Subsequently, in our chapter, we delve into scenarios where $\delta = 0$ and $\delta \in (0, 1)$ and examine the efficient network structures associated with different levels of infiltration.

[14]This is not explicitly modelled but assumed to justify why the leader is never captured.

1.3.5 Case 1: Probability of Capture through connections is One

With the targeting technology parameter $\delta = 1$ the utility of individual terrorist i can be written as,

$$u_i = (1 - \frac{m_i + 1}{n})e_i(g_{ii} + \beta \sum_{j \in N} g_{ij}e_j) + \frac{m_i + 1}{n}p(-f) + \frac{m_i + 1}{n}(1 - p)e_i(g_{ii} + \beta \sum_{j \in N} g_{ij}e_j) - \frac{1}{2}e_i^2 \quad (1.3)$$

Note the leader welfare function is represented by equation 1.2. We denote the above game, as $\Gamma = \langle N, (e_i)_{i \in N}, (u_i(E, \mathcal{G})_{i \in N}) \rangle$, where $E = \times_{i \in N} e_i$. We solve the game using backward induction.

Before we proceed to the existence of a Nash Equilibrium, we rearrange the utility function of terrorist i as,

$$u_i = (1 - p\frac{m_i + 1}{n})e_i(1 + \beta \sum_{j \in N} g_{ij}e_j) - p\frac{m_i + 1}{n}f - \frac{1}{2}e_i^2 \quad (1.4)$$

for the convenience of demonstrating the existence of the Nash equilibrium in the strategic game.

Lemma 1: The game Γ admits a Nash equilibrium, if the following conditions for each terrorist $i \in N$ are satisfied,

- e_i is a nonempty compact and convex subset of the Euclidean space.
- u_i is continuous in e_{-i}.
- u_i is continuous and concave in e_i,

Proof of Lemma 1: See the detailed proof in Appendix A.1.1. We used Debreu-Fan-

Glicksberg Theorem [15] to show the existence of the equilibrium.

In a network, if any two terrorists are connected by a path, they share the same set of path-connected terrorists excluding the end node. When we examine the cardinality of these sets, we find that the number of path-connected terrorists is the same for both individuals. The cardinality solely considers the size or magnitude of the sets in a network. Therefore, regardless of which terrorist pair we consider, as long as there is a path connecting them, the number of path-connected terrorists will be the same. This observation highlights the symmetric aspect of indirect connections when any two terrorists are involved through the paths.

Lemma 2: For all $i \neq q \in N$, if a path P_i^q exists between terrorist i and q, then they have the same number of path-connected terrorists, i.e., $m_i = m_q$.

Proof of Lemma 2: Refer to Appendix A.1.2. We explain the intuition here below, with the help of an example.

Example 1: Consider two triads connected by a line as represented by Figure 1.2. Now, consider terrorist 2 and terrorist 5 where a path P_2^5 exists. The set of path-connected terrorists of terrorist 2 is denoted as $M_2 = \{3, 1, 5, 6, 4\}$, and the set of path-connected terrorists of terrorist 5 is denoted as $M_5 = \{3, 2, 1, 6, 4\}$. We observe that $M_2 \cap M_5 = \{1, 3, 6, 4\}$, and the only elements different in the sets are the nodes itself i.e., 2 in M_2 and 5 in M_5. However, when we look at the cardinality of the sets, then $m_2 = |M_2| = |M_5| = m_5$. Therefore, it can be said that when a path connects two terrorists, although the sets themselves are different, they have the same number of path-connected terrorists, i.e., the cardinality is the same. Generalizing to all $i \neq q \in N$, we explain Lemma 2.

[15] See Debreu (1952), Fan (1952), and Glicksberg (1952).

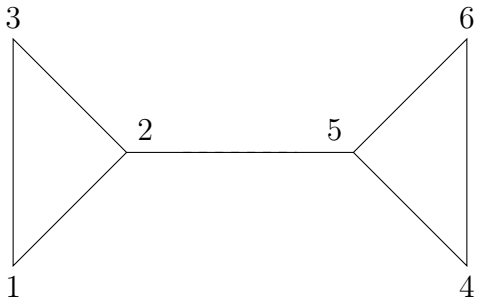

Figure 1.2 Two Connected Triads

In the presence of infiltration, the leader of the organisation design components (sub-networks) within the network. These components can vary from being a single complete structure to all empty sub-structures. However, specific properties of these components emerge due to certain conditions in our model. In this case, we have mentioned the use of targeting technology $\delta = 1$, that ensures if one terrorist is targeted, all the terrorists path-connected to them are also targeted.[16] This assumption enables law enforcement authorities to target terrorists not only directly but also through the targeting of their path-connected members with probability 1. Using this property, law enforcement can effectively disrupt the network operations. In Proposition 1, below we will elaborate on the connectivity in a network structure as a consequence of the assumption of the model.

Proposition 1: An efficient network is composed of components $C(\mathcal{G})$, where $d_i = m_i$ where d_i is the degree of i and m_i is the cardinality of path-connected members of i.

[16] Alternatively, this can be explained as a terrorist being targeted directly and through all of their path-connected terrorists.

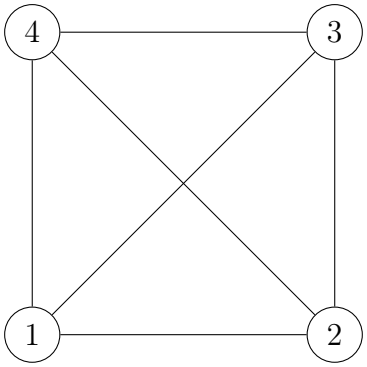

Figure 1.3 Complete Component

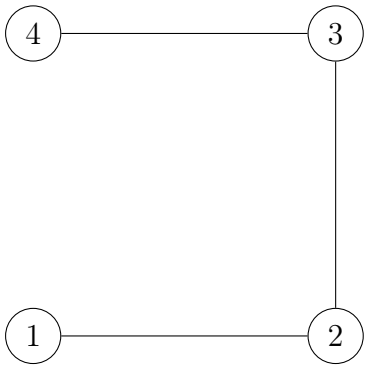

Figure 1.4 Line Component

Proof of Proposition 1: Please refer to Appendix A.1.3 for the proof.

This result highlights the strategic behaviour of the leader in designing maximally connected sub-structures i.e., components within the terrorist network. Within the designed component, individual terrorists maximize their own utilities by choosing their effort level for their illegal activities.

Discussion: To explain the rationale, we present two Figures (1.3 and 1.4), and use a proof by contradiction to demonstrate why Figure 1.3 represents the efficient network, as opposed to Figure 1.4.

Suppose the scenario where Figure 1.4 is regarded as the efficient network. In this case, terrorist 1 can be targeted in four different ways. They can be directly targeted, or through targeting terrorists 2, 3, and 4, as terrorist 1 is path-connected to all three of them. However, terrorist 1 receives benefits only from their direct connection, which, in this case, is terrorist 2. Now, if the leader had designed the network differently, such that terrorist 1 is connected to both terrorists 2 and 3, 1's benefits would have increased due to the additional neighbour, terrorist 3, while the risk of infiltration remains unchanged. Similarly, following the addition of a link with terrorist 3, if the leader had designed further a new structure structure where a link is present between terrorist 1 and terrorist 4, then terrorist 1's benefits would have been further enhanced while the cost

from infiltration remains unchanged. The same intuition applies to other terrorists in the network. Having a terrorist located outside the direct neighbourhood but still within the component of the said terrorist only raises the cost of capture through infiltration. Thus, it is rational from the leader's point of view that in a component, all terrorists will have only neighbours and no non-neighbours, i.e., there will be no terrorist located outside the direct neighbourhood of any terrorist. This observation indicates that Figure 1.4 cannot be the efficient network. Therefore, we can conclude that in efficient networks, terrorists are maximally connected within their components. Thus, Figure 1.4 represents the efficient network.

By ensuring maximal connectivity within the components, the leader of the organisation efficiently designs the network structure to enhance benefits and reduce risks.

Lemma 3: Terrorists in a component have the same degree.

Proof of Lemma 3: From Lemma 2, we have shown that if a path P_i^q exists between terrorist i and q, then they share the same number of path-connected terrorists, denoted as $m_i = m_q$. Additionally, Proposition 1 indicates that due to $\delta = 1$, targeting a terrorist leads to the capture of all their path-connected terrorists if infiltration is successful. From the perspective of the leader, it is efficient to be maximally connected within a component, as this allows for the most complete utilisation of connections. As a direct consequence of proposition 1, for every terrorist in the network, the number of path-connected terrorists is equal to the number of neighbours, denoted as $m_i = d_i$. Otherwise, the benefits from connections would not be maximized, while cost from infiltration $p\frac{m_i+1}{n}$, are identical in both situations where $m_i > d_i^{'}$ and $m_i = d_i$.

Combining Lemma 2 and Proposition 1, we deduce that $d_i = d_q$. Looking at Figure 1.3 above, we can observe that all terrorists have the same degree inside the component. This implies that the terrorists in the efficient network, represented by Figure 1.3, are

equally and maximally connected i.e., have components.

Equilibrium Characterization

Lemma 4: Terrorists in a component have same cardinality of path-connected terrorists and same degrees i.e., $m_i = m_j = d_i = d_j = \overline{d}\ \forall\ i \neq j \in C(\mathcal{G})$.

We formally combine, Proposition 1, Lemma 2 and 3 and present in Lemma 4. This emphasises the importance of the leader's decision-making regarding the maximal connectivity within a sub-structure (or structure) to design an efficient terrorist network.

Now we formalise the equilibrium characterisation of the model. Revisiting equation 1.4 for convenience,

$$u_i = \Big(1 - p\frac{m_i + 1}{n}\Big)e_i\Big(1 + \beta\sum_{j\in N} g_{ij}e_j\Big) - p\frac{m_i + 1}{n}f - \frac{1}{2}e_i^2$$

Using Lemma 4, equation 1.4 can be written as,

$$u_i = \Big(1 - p\frac{\overline{d} + 1}{n}\Big)e_i\Big(1 + \beta\overline{d}e_j\Big) - p\frac{\overline{d} + 1}{n}f - \frac{1}{2}e_i^2 \tag{1.5}$$

Assuming an interior solution, we maximize u_i with respect e_i and set it equal to 0:

$$\frac{\partial u_i}{\partial e_i} = \left(1 - p\frac{\overline{d} + 1}{n}\right)\left(1 + \beta\overline{d}e_j\right) - e_i = 0 \tag{1.6}$$

The F.O.C. of equation 1.6 can be re-written as,

$$e_i^* = \Big(1 - p\frac{\overline{d} + 1}{n}\Big)\Big(1 + \beta\overline{d}e_j^*\Big) \tag{1.7}$$

From Lemma 4, we know $m_i = m_j = d_i = d_j = \overline{d}$, therefore we can say it is an isomorphic decision problem and hence we are focusing on symmetric equilibrium, where $e_i = e_j = \overline{e}\ \forall\ i \neq j \in C(\mathcal{G})$.

Plugging $e_i = e_j = \overline{e}$ in equation 1.7, we can write, the interior equilibrium efforts as,

$$\overline{e^*} = \frac{n - p(\overline{d}+1)}{n - \beta\overline{d}[n - p(\overline{d}+1)]} \tag{1.8}$$

Plugging equilibrium efforts $\overline{e^*}$ from equation 1.8 in equation 1.5, we get the interior equilibrium utilities as,

$$\overline{u^*} = \frac{1}{2}\Big(\frac{n - p(\overline{d}+1)}{n - \beta\overline{d}n + p\beta\overline{d}(\overline{d}+1)}\Big)^2 - \frac{\overline{d}+1}{n}pf \tag{1.9}$$

Proposition 2: There exists an interior Nash Equilibrium to the strategic game Γ.

For proving proposition 2 we need to prove the following Lemmas,

- The strategic form game Γ admits a Nash Equilibrium.
- There is an interior solution to the strategic game

The existence of the game Γ is proved using Debreu-Fan-Glicksberg Theorem. Refer to Lemma 1 in Appendix A.1.1.

Lemma 5: There is an interior solution to the strategic game Γ.

Proof of Lemma 5: Revisiting equation 1.8, we have:

$$\overline{e^*} = \frac{n - p(\overline{d}+1)}{n - \beta\overline{d}[n - p(\overline{d}+1)]}$$

To ensure that the denominator $n - \beta\overline{d}[n - p(\overline{d}+1)] > 0$, we restrict the degree of complementarity between terrorist's efforts $\beta \in \big(0, \frac{1}{n-1}\big)$, ensuring that $\overline{e^*}$ remains finite. Henceforth in this chaper, we focus on $\beta \in \big(0, \frac{1}{n-1}\big)$ to do our analysis. Now, consider the

scenario where individual terrorists exert zero effort. In this case, equation 1.5 becomes,

$$u_i = -\frac{\overline{d}+1}{n} f \tag{1.10}$$

With equation 1.10 confirming $u_i < 0; \forall i \in N$, it can be deduced that terrorists will exert strictly positive effort i.e., $\boldsymbol{e} >> 0$. We considered $n \geq 3$ in our model, to rule out non-trivial component structure transition. Thus, provided the parameters β, p and $n \geq 3$, if $\overline{e^*} < B < \infty$, an interior solution to the game Γ is feasible.

Nevertheless, it is important to note that the strategic game can also give rise to a corner solution. A comprehensive overview of the equilibrium individual efforts, utilities, and the overall welfare of the network structure can be summarised through the following corollaries.

Corollary 1: Terrorists maximally connected in a component have the following equilibrium efforts and utilities,

$$\begin{aligned}
\overline{e^*} &= \begin{cases} \frac{n-p(\overline{d}+1)}{n-\beta\overline{d}[n-p(\overline{d}+1)]} & \text{if } \overline{e^*} < B \\ B & \text{otherwise} \end{cases} \\
\overline{u^*} &= \begin{cases} \frac{1}{2}\left(\frac{n-p(\overline{d}+1)}{n-\beta\overline{d}n+p\beta\overline{d}(\overline{d}+1)}\right)^2 - \left(\frac{\overline{d}+1}{n}\right)pf & \text{if } \overline{e^*} < B \\ (1-p\frac{\overline{d}+1}{n})B(1+\beta\overline{d}B) - \left(\frac{\overline{d}+1}{n}\right)pf - \frac{1}{2}B^2 & \text{otherwise} \end{cases}
\end{aligned} \tag{1.11}$$

Proof of Corollary 1: The calculations are shown in the Appendix A.1.4.

Referring to equation 1.8 and equation 1.9, we determine the interior equilibrium efforts and utilities. The equilibrium can also admit a corner solution when $e^* = B$. Similarly, the equilibrium utilities involving a corner solution, can be represented as $\overline{u^*} = (1-p\frac{\overline{d}+1}{n})B(1+\beta\overline{d}B) - \left(\frac{\overline{d}+1}{n}\right)pf - \frac{1}{2}B^2$, as provided by equation 1.11. The utility equilibrium at a given corner is negatively influenced by the probability of infiltration,

the number of neighbours for each terrorist, and the fine faced upon capture, assuming all other parameters remain constant. On the other hand, it is directly proportional to the total size of the terrorist organisation.

Before delving into the comparative statics of the equilibrium conditions, directing our attention to the network's welfare becomes crucial. Examining welfare is of paramount importance as it offers insights into the network structures that emerge in respond to various levels of infiltration.

Corollary 2: The equilibrium welfare for the efficient network can be written as follows,

$$\overline{W^*} = \begin{cases} \sum_{k=1}^{K}\left(\overline{d_k}+1\right)\left[\frac{1}{2}\left(\frac{n-p(\overline{d_k}+1)}{n-\beta\overline{d_k}n+p\beta\overline{d_k}(\overline{d_k}+1)}\right)^2-\left(\frac{\overline{d_k}+1}{n}\right)pf\right] & \text{if } \overline{e^*} < B \\ \sum_{k=1}^{K}\left(\overline{d_k}+1\right)\left[(1-p\frac{\overline{d_k}+1}{n})B(1+\beta\overline{d_k}B)-\left(\frac{\overline{d_k}+1}{n}\right)pf-\frac{1}{2}B^2\right] & \text{otherwise} \end{cases} \tag{1.12}$$

$\overline{d_k}$ is the degree of each terrorist in component k. Since all terrorists in a component have the same degree, it is denoted by an $\overline{d}$. K is the total number of components in an efficient Network. If $\overline{d_k} = d\ \forall k$, then components are symmetric and welfare can be written as,

$$\overline{W^*} = \begin{cases} \frac{n}{2}\left(\frac{n-p(\overline{d}+1)}{n-\beta\overline{d}n+p\beta\overline{d}(\overline{d}+1)}\right)^2-(\overline{d}+1)pf & \text{if } \overline{e^*} < B \\ n\left(1-p\frac{\overline{d}+1}{n}\right)B(1+\beta\overline{d}B)-(\overline{d}+1)pf-\frac{n}{2}B^2 & \text{otherwise} \end{cases} \tag{1.13}$$

Proof of Corollary 2: The mathematical proof is shown in Appendix A.1.5.

The welfare of an efficient network can be determined by substituting the equilibrium utilities from equation 1.11 in terrorist leader problem i.e., equation 1.2. Upon examining these equilibrium welfare values, the leader designs the efficient network for a given probability of infiltration.

However, we focus on efficient networks, a common question emerges – whether the components within any efficient network exhibit symmetry or asymmetry. While equation 1.12 outlines the general welfare equation of an efficient network, equation 1.13 addresses the specific case of an efficient network with symmetric components. The subsequent section will delve into this topic, explaining that the presence of symmetric or asymmetric components in an efficient network depends on the probability of infiltration, the degree of complementarity between terrorists efforts, fine and organisation size.

Characterisation of the Shapes and Sizes of Components: The efficient network may have symmetric or asymmetric components, depending on the value of p, n, β and f. We will demonstrate this, with the help of few examples.

Example 1: Consider a network comprising of 6 terrorists. In this context, the degree of complementarity characterising the synergy between the terrorist's efforts is denoted as $\beta = 0.19$, while the imposed fine is set at $f = 2$. The primary objective of this example is to highlight the potential for efficient networks to exhibit either symmetric or asymmetric components. To this end, two specific efficient network designs are of interest: one featuring all 6 terrorists in a complete component, and the other involving a configuration where 5 terrorists are in fully connected while one terrorist remains isolated.

Although various other efficient network arrangements are possible, it is worth noting that the leader of the organisation designs the network that yields the highest welfare for a given probability of infiltration. This decision ensures that the organisation's leader aims to maximize the network's overall efficiency while considering the potential risks associated with infiltration.

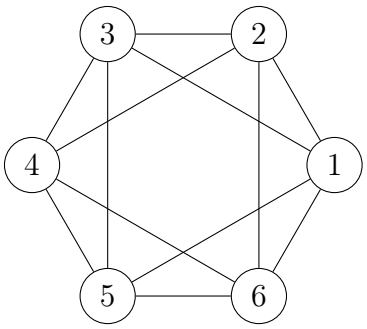

Figure 1.5 S.C. Efficient Network

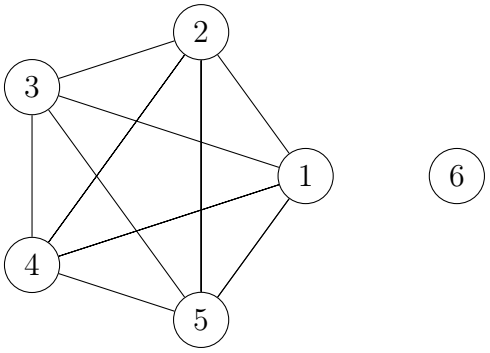

Figure 1.6 A.C. Efficient Network

The analysis was particularly focused on two levels of infiltration probability, specifically $p = 0.38$ and $p = 0.39$. The results revealed that at the infiltration probability of $p = 0.38$, the efficient network, depicted as Figure 1.5, showcases a single symmetric component. Conversely, at an infiltration probability of $p = 0.39$, the efficient network, illustrated as Figure 1.6, features asymmetric components. Notably, at this higher infiltration probability of $p = 0.39$, the leader opts to partition the network into two distinct components. This strategic decision is motivated by the intention to minimise the impact of infiltration-related costs.

As previously discussed in the chapter, the apprehension of terrorists leads to the capture of their path-connected terrorists. Consequently, as the level of infiltration probability escalates, these associated costs also increase gradually. In this context, the division of the network into separate components emerges as one among several efficient strategies to enhance the network's resilience against such escalating costs.

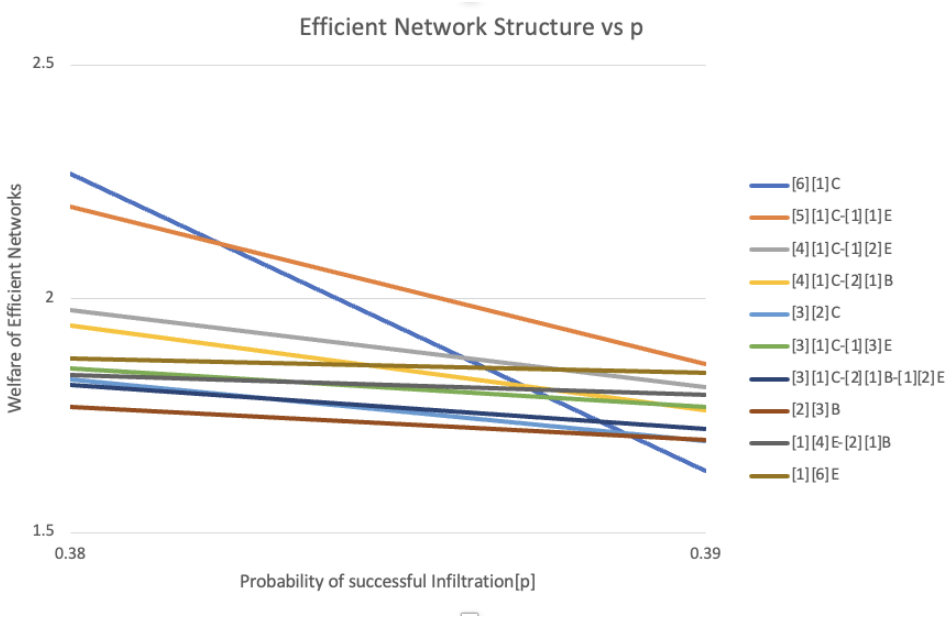

Figure 1.7 Transition of efficient Network with variation of p at $\beta = 0.19$ and $f = 2$

[17]

The scenario outlined in example 1 can be effectively depicted using figure 1.7. This visual aid captures the dynamic shift in the efficient network's structure – a transition occurring from a complete component consisting of all 6 terrorists to a new configuration featuring a complete component involving only 5 terrorists, with an accompanying empty component. This transition occurs within a specific range of infiltration probability, specifically between the values of 0.38 and 0.39. Within this range, the organisation's leader is tasked with making a strategic decision. The leader designs one of these two efficient network configurations based on a comparative assessment of their respective welfare values. The ultimate choice hinges upon identifying which among the two efficient networks offers greater welfare, given the specified parametric values.

Example 2: In a manner akin to example 1, a comparative analysis is conducted across four distinct efficient networks, considering varying values of the parameter p. The specific values chosen for this analysis are $\beta = 0.12$ and $f = 1$.

[17][4][1]C-[2][1]B reads as 4 nodes comprising 1 complete component and 2 nodes comprising of 1 binary component.

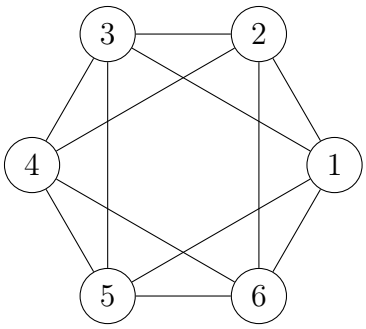

Figure 1.8 S.C. Efficient Network

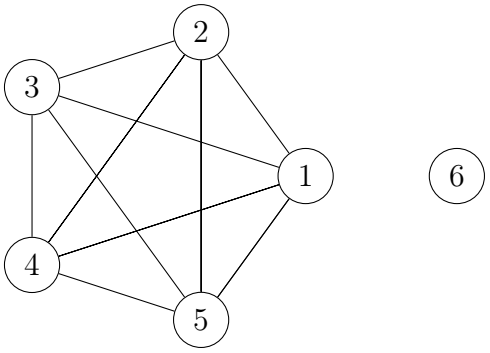

Figure 1.9 A.C. Efficient Network

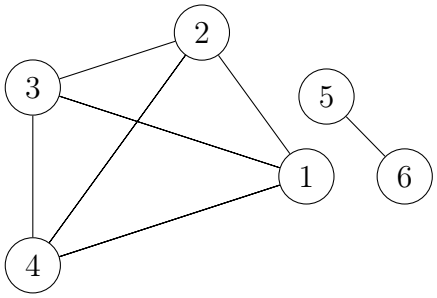

Figure 1.10 A.C. Efficient Network

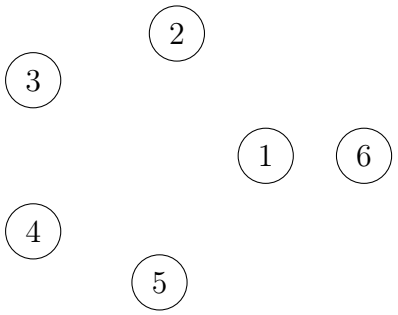

Figure 1.11 S.C. Efficient Network

Now consider a specific infiltration probability of $p = 0.29$. At this particular infiltration level, the efficient network that maximizes welfare is the one depicted in Figure 1.8. Upon increasing the infiltration probability by an increment of 0.1, a significant shift is observed in the nature of the efficient network. This transition is evident as the network transforms from having symmetric components, as shown in Figure 1.8, to possessing asymmetric components, which is represented in Figure 1.9. Continuing this analysis, at a slightly higher infiltration probability of $p = 0.31$, the efficient network maintains its configuration with asymmetric components. However, the relative sizes of these components experience alteration, leading to the arrangement depicted in Figure 1.10. Subsequently, when the infiltration probability reaches $p = 0.32$, a noteworthy change occurs. The efficient network undergoes disintegration, resulting in empty networks as illustrated in Figure 1.11. Consequently, the network once again exhibits symmetric components due to this breakdown.

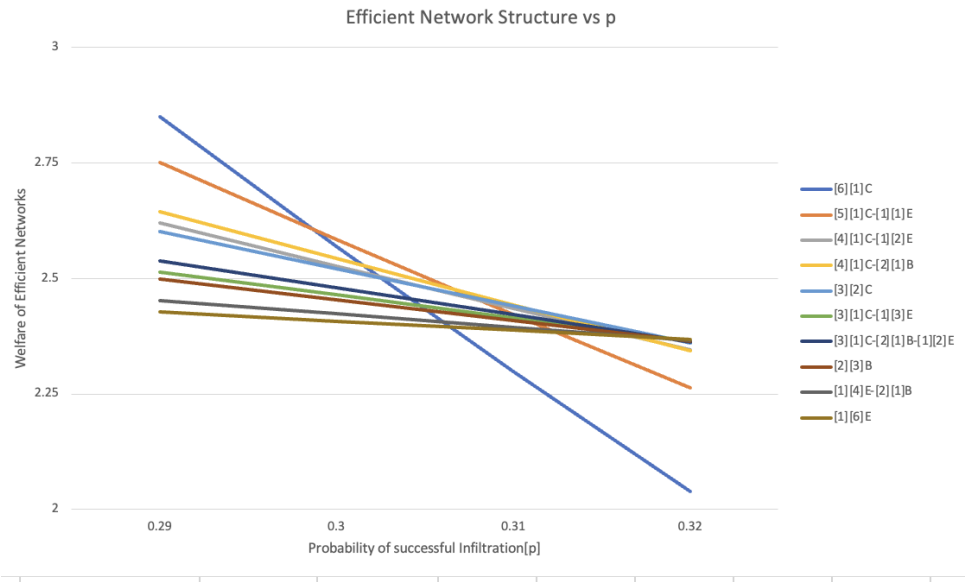

Figure 1.12 Transition of efficient Network with variation of p at $\beta = 0.12$ and $f = 1$

The sequence of network transitions is visually depicted in the figure 1.12 above. The corresponding welfare values associated with Figures 1.8,1.9, 1.10, and 1.11 are as follows: 2.85, 2.58, 2.44, and 2.37. Crucially, the leader of the organisation strategically design these specific network structures at different values of p, as indicated earlier. This decision is rooted in the fact that these chosen network configurations offer the highest possible welfare for the respective values of p.

So far, we have shown that efficient network may comprise of both sysmmetric and asymmetric components for small network size. However, in Example 3 we show this for larger network size.

Example 3: Our analysis is for a network size of $n = 100$. Due to the impracticality of comparing all possible network structures individually, particularly with larger network sizes, we aimed to discern the optimal component size for the given $n = 100$. In our investigation, we set parameters $\beta = 0.01$ and $f = 1$. We systematically varied p from 0 to 1 with increments of 0.01 and similarly varied $\overline{d}$ with increments of 1. Our objective was to determine, for each p value, the $\overline{d}$ that gives the maximum utility u for a terrorist i. We observed that for $p \in [0, 0.36]$, the u_i is maximized when $\overline{d}$ equals 99, indicating

the efficient network structure is comprised of a single complete component. However, for $p \in [0.37, 0.49]$, the efficient network comprises of asymmetric components. Notably, the optimal $\overline{d}$ is no longer 99 but begins to decrease, suggesting an inverse relationship between $\overline{d}$ and p. Finally, for $p \in [0.5, 1]$, the efficient network once again comprises of symmetric components, specifically, empty sub-structures are designed. Refer to the Table in Appendix A.2.1.

We now demonstrate that efficient networks is composed of symmetric components for some parameter values of fine.

Example 4: Our analysis focused on a network size of $n = 100$. As mentioned earlier, comparing all possible network structures individually is not feasible, especially with larger network sizes. Therefore, we aimed to discern the optimal neighbours for a terrorist for the given $n = 100$. In our investigation, we set the parameters $\beta = 0.01$ and $f = 4$. We systematically varied p from 0 to 1 with increments of 0.001 and similarly varied $\overline{d}$ with increments of 1. Our objective was to determine, for each p value, the $\overline{d}$ that gives the maximum utility u for a terrorist i.

We observed that for $p \in [0, 0.338]$, the u_i is maximized when $\overline{d}$ equals 99, indicating that each terrorist's utility is highest when the efficient network structure is a single complete component. Therefore, it is in the best interest of the leader to design an efficient network with a single complete component. However, for $p \in [0.339, 1]$, the optimal $\overline{d}$ is no longer 99 but drops down to 0. In this scenario, the efficient network comprises symmetric components, specifically, empty sub-structures are designed. In this case, no efficient networks are designed with asymmetric components.Refer to the Table in Appendix A.2.2.

Note that in the Table of Appendix A.2.2, we show a small range of p, where the transition from a single complete component to empty components occurs. We omitted the p

values outside this range because for $p \in [0, 0.328]$, the efficient network is always a single complete component, and for $p \in [0.347, 1]$, the efficient network is always designed of only empty components.

Example 5: For $\beta = 0$, the efficient network is comprised of symmetric components.

For $\beta = 0$, the utility of an individual terrorist i can be written as below,

$$u_i = \frac{1}{2}\Big(\frac{n - p(\overline{d}+1)}{n - \beta\overline{d}(n - p(\overline{d}+1))}\Big)^2 - \Big(\frac{\overline{d}+1}{n}\Big)pf$$

$$= \frac{1}{2}\Big(\frac{n - p(\overline{d}+1)}{n}\Big)^2 - \Big(\frac{\overline{d}+1}{n}\Big)pf \tag{1.14}$$

From the above equation 1.14 we see that u_i has an inverse relationship with $\overline{d}$ for $p \in (0, 1]$. Hence, the efficient network is composed of only empty components. Therefore we can say the efficient network will be designed of symmetric components.

Now, we aim to explore the range of values for p where the network transitions from a single, fully-connected structure (i.e., component) to efficient networks with component sizes strictly smaller than a single complete component, yet strictly larger than empty components, and eventually to efficient networks composed entirely of empty components. Two threshold values of p, p^* and p^{**}, were obtained. Specifically, $\forall p \in [0, p^*]$, the efficient network consists of a single component. Conversely, $\forall p \in [p^{**}, 1]$, the network is designed with only empty components. Between these bounds, i.e., $\forall p \in (p^*, p^{**})$, various other efficient network designs may emerge. We will discuss this now with the help of some lemmas and propositions.

Lemma 6A: At $p = 0$, the efficient network structure is a complete component.

Proof of Lemma 6A: After substituting $p = 0$, in the interior equilibrium utility

represented by equation 1.9 we get the following equation below,

$$\overline{u^*} = \frac{1}{2}\Big(\frac{1}{1-\beta d}\Big)^2 \tag{1.15}$$

Upon examining the individual interior equilibrium utility, it becomes evident that a positive relationship exists between the utility and the number of neighbours a terrorist possesses. Consequently, when considering a degree denoted as d', where $d' < n-1$ (with n representing the total number of terrorists), the resulting utility is lower than that derived from the utility equation 1.15 i.e., $u^{'} < u^*$.

Similarly, by substituting $p = 0$ into the corner equilibrium utility, as described in equation 1.11, we obtain the following equation:

$$\overline{u^*} = B(1 + \beta\overline{d}B) - \frac{1}{2}B^2 \tag{1.16}$$

As evident from the above equation, when we set $\overline{d} = n-1$, the value of $\overline{u^*}$ is maximum.

This analysis prompts the conclusion that when the infiltration probability is set at $p = 0$, the optimal course of action for the leader is to design a single complete component as the efficient network.

Lemma 6B: At $p = 1$, the efficient network may not always comprise empty components.

1. When efforts exerted are non-maximal, the efficient network is always comprised of empty components at $p = 1$.

2. When efforts exerted are maximal, the efficient network is comprised of empty components if $e = B \leq B^*$, otherwise, it may be composed of some non-empty components.

Proof of Lemma 6B: At $p = 1$, the equilibrium utility can be written as,

$$\overline{u^*} = \frac{1}{2}\Big(\frac{n-(\overline{d}+1)}{n-\beta\overline{d}n+\beta\overline{d}(\overline{d}+1)}\Big)^2 - \frac{\overline{d}+1}{n}f \tag{1.17}$$

Differentiating equation 1.17, with respect to $\overline{d}$ and simplifying we get,

$$\frac{\partial\overline{u^*}}{\partial\overline{d}} = \frac{n-(\overline{d}+1)}{n-\beta\overline{d}n+\beta\overline{d}(\overline{d}+1)}\Big[\frac{-n+\beta(n-\overline{d}-1)^2}{(n-\beta\overline{d}n+\beta\overline{d}(\overline{d}+1))^2}\Big] - \frac{1}{n}f$$

Given that the degree of complementarity between terrorist's efforts, denoted as β, is constrained by an upper limit of $\frac{1}{n-1}$, it follows that the term $-n+\beta(n-\overline{d}-1)^2$ is inherently negative. As a result, $\frac{\partial\overline{u^*}}{\partial\overline{d}} < 0$, which signifies that when $p = 1$, the leader of the organisation deems it advantageous to design empty components inside the network

We will now demonstrate that similar empty components also arise in the corner utility function, when certain conditions on the corner effort are met. When setting $p = 1$ for the corner utility, the equation can be expressed as follows: $\overline{u^*} = \Big(1-\frac{\overline{d}+1}{n}\Big)B(1+\beta\overline{d}B) - \frac{\overline{d}+1}{n}f - \frac{1}{2}B^2$. Now, at $p = 1$, the utility associated with empty components is: $\overline{u^*} = \big(1-\frac{1}{n}\big)B - \frac{1}{n}f - \frac{1}{2}B^2$. Now, we will consider a scenario where the leader intends to design one binary component while keeping $n-2$ empty components. The utility of the terrorist within the binary component can be written as: $\overline{u'} = \big(1-\frac{2}{n}\big)B(1+\beta B) - \frac{2}{n}f - \frac{1}{2}B^2$. Comparing the $\overline{u'}$ and $\overline{u^*}$, if $B^* = \frac{1+\sqrt{1+4\beta f(n-2)}}{2\beta(n-2)} \geq B$ then at $p = 1$, the leader will design an efficient network with only empty components. Otherwise, an efficient network with some non-empty components will be designed.

We intuitively explain the above results. In the absence of infiltration risks, the lack of capture costs allows the terrorist leader to maximize welfare by designing a fully connected network. However, when the infiltration probability reaches 100 percent, the cost associated with infiltration surpasses the benefits gained from connections. Consequently, the terrorist networks become constituted solely of empty components.

However, when effort of terrorists exerts maximal effort, one can observe if B is smaller than B^*, then all components will be empty in the efficient network. However when B is greater than B^*, one can think that the benefits from connections (βB) is significantly higher as to allow non-empty components arising even when probability of infiltration is 1.

Drawing insights from Lemma $6A$ and $6B$ mentioned earlier, an inverse correlation between p and $\overline{d}$ becomes evident. The underlying logic is intuitive: as p rises, it becomes advantageous for the leader to refrain from increasing the number of neighbours of any terrorist, as doing so heightens the risk of infiltration. The mathematical analysis supporting this conclusion is relatively straightforward. By taking the derivative of equation 1.9 with respect to p, we arrive at the following result:

$$\frac{\partial u^*}{\partial p} = \frac{1}{2}\frac{[n - p(\overline{d}+1)]}{[n - \beta\overline{d}(n - p(\overline{d}+1)]}\frac{-n(\overline{d}+1)}{[n - \beta\overline{d}(n - p(\overline{d}+1)]^2} - \frac{\overline{d}+1}{n}f \tag{1.18}$$

Examining equation 1.18, we observe that the sign of $\frac{\partial u^*}{\partial p}$ is negative. This is evident as, $[n-p(\overline{d}+1)]$, $[n-\beta\overline{d}(n-p(\overline{d}+1)]$, $n(\overline{d}+1)$ and $\frac{\overline{d}+1}{n}f$ is strictly positive. Delving into the marginal change in utility of any terrorist with respect to p, we see if the leader intends to augment the number of neighbours of a terrorist $\overline{d}$, it becomes evident that the utility of the terrorist diminishes even further. Consequently, it is not in the leader's best interest to increase the neighbours of any terrorist inside the network when the probability of infiltration rises. This establishes a clear monotonic non-increasing relationship between p and $\overline{d}$.

Proposition 3: There exists a lower bound p^* such that $\forall\ p \in [0, p^*]$, the efficient network is composed of a single complete component and an upper bound p^{**} such that $\forall\ p \in [p^{**}, 1]$, the efficient network may not always composed of all empty components.

For proving proposition 3 we need to prove the following lemmas,

1. **Lemma 7A**: There exists a value p^* such that for $\forall\ p \in [0, p^*]$, the efficient network

is composed of a single complete component.

2. **Lemma 7B**: There exists a value p^{**} such that for $\forall\ p \in [p^{**}, 1]$, the efficient network may not necessarily be composed of empty components.

The proof of Lemma 7A and Lemma 7B is in the Appendix A.1.6.

We have proved Lemma 7A and Lemma 7B with the help of Bolzano's Theorem [18]. In Appendix A.1.6, we prove Proposition 3 under the assumption that terrorist's effort admits an interior equilibrium. A similar proof holds when the effort admits a corner solution. Since the proof is identical for both interior and corner solutions, we have omitted the latter. Here, we will discuss the implications.

From Lemma 6A and Lemma 6B, we observe that at $p = 0$, the efficient network is a single complete component regardless of whether the effort exerted is maximal or non-maximal. However, at $p = 1$, the efficient network may be composed of only empty components. This depends on the nature of the solution and other parameter values such as f, β, and n of the model.

By applying Bolzano's theorem in Lemma 7A and Lemma 7B, we show that there exist two probabilities of infiltration threshold values p^* and p^{**}, where for $p \in [0, p^*]$, the efficient network is composed of a single complete component. This is because the benefits of connections are higher than the cost of infiltration. However, for $p \in [p^{**}, 1]$, the efficient network associated with non-maximal effort is always composed of empty components. When terrorists exert maximal effort, depending on the level of this maximal effort, the efficient network may have all or some empty components. This indicates that even at high levels of infiltration, if the benefits of connections are sufficiently high, the network does not necessarily disintegrate into all empty components, but some non-empty components may still exist.

[18] See Apostol (1991).

In the next section, we discuss the comparative statics of the model and examine how the equilibrium efforts and utilities vary with respect to network size, the degree of complementarity between the efforts of terrorists, the fines faced by terrorists, and the probability of infiltration.

Comparative Statics

In conducting comparative statics in this chapter, we restrict our attention to interior equilibrium efforts and utilities. Our focus is on understanding how these efforts and utilities change with variations in parametric values such as $\overline{d}$, n, p, f, and β. Although we recognise that $\overline{d}$ and n are discrete values, our primary interest lies in the signs of the comparative statics rather than their exact values. For convenience, we treat these parameters as continuous.

Variation with respect to $\overline{d}$: Upon calculating the derivative of equilibrium efforts (equation 1.8) with respect to $\overline{d}$, followed by simplifying the result, the resulting equation is as follows:

$$\frac{d\overline{e^*}}{d\overline{d}} = \frac{-np + \beta[n - p(\overline{d}+1)]^2}{[n - \beta\overline{d}[n - p(\overline{d}+1)]]^2} \tag{1.19}$$

Given that the denominator of equation 1.19 is always positive, the direction of the sign of $\frac{d\overline{e^*}}{d\overline{d}}$ can be understood by focusing on the numerator.

$$\frac{d\overline{e^*}}{d\overline{d}} \begin{cases} \geq 0 & \text{if } -np + \beta[n - p(\overline{d}+1)]^2 \geq 0 \\ < 0 & \text{otherwise} \end{cases} \tag{1.20}$$

The term present in equation 1.20, namely $-np + \beta[n - p(\overline{d}+1)]^2$, can be rewritten as $-\frac{p}{n} + \beta[1 - p(\frac{\overline{d}+1}{n})]^2$. The transformed expression can be explained in the following manner: When the number of neighbours for a terrorist increase, the marginal cost of getting captured increases by $\frac{p}{n}$. However, the marginal benefits will also rise due to the

degree of complementarity β, provided the terrorist remains uncaptured with probability $\left(1 - \frac{p(d+1)}{n}\right)$. If the marginal cost of getting captured outweighs the marginal benefits from complementarity, given that the terrorist remains uncaptured, the equilibrium effort decreases as the number of neighbours increases.

Consider the scenario, where the probability of successful infiltration $p = 1$, the number of nodes $n = 4$ and the degree of complementarity between the efforts of terrorists $\beta = 0.001$. In this context, the expression $-\frac{p}{n} + \beta[1 - p(\frac{\overline{d}+1}{n})]^2$ yields a negative value, as the cost of getting captured is higher than benefits of not getting captured. Conversely, when $p = 0$, the expression becomes positive. Thus, the sign of $\frac{d\overline{e^*}}{d\overline{d}}$ can be influenced by the specific values of the parameters. Consequently, in principle, the sign becomes uncertain due to the variability of these parameter values.

The equilibrium utility (equation 1.9) can be reformulated as:

$$\overline{u^*} = \frac{1}{2}\overline{e^*}^2 - \frac{\overline{d}+1}{n}pf \tag{1.21}$$

Upon calculating the derivative of equation 1.21 with respect to $\overline{d}$ and further simplifying, the result is as follows:

$$\frac{d\overline{u^*}}{d\overline{d}} = \overline{e^*}\frac{d\overline{e^*}}{d\overline{d}} - \frac{1}{n}pf \tag{1.22}$$

When the number of neighbours of a terrorist increase, the effect on their equilibrium utilities is ambiguous. If the marginal change in equilibrium effort is non-positive with respect to the number of neighbours $\overline{d}$, then the marginal change in equilibrium utility is unambiguously negative, as evident from the expression above. However, when the marginal change in equilibrium effort is strictly positive, the marginal effect on equilibrium utilities is ambiguous. If the increase in the marginal effort of a terrorist with respect to $\overline{d}$ is greater than or equal to the marginal cost of capture and subsequent fines, then the equilibrium utilities increase or remain constant, otherwise they decrease.

Variation with respect to n: Applying a similar approach as mentioned above, by calculating the derivative of equation 1.8 in relation to the size of the terrorist network n and then simplifying the outcome, the resulting equation is as follows:

$$\frac{d\overline{e^*}}{dn} = \frac{\frac{d\overline{d}}{dn}[-np + \beta(n - p(\overline{d}+1))^2] + \frac{d\beta}{dn}\overline{d}(n - p(\overline{d}+1))^2 + p(\overline{d}+1)}{[n - \beta\overline{d}(n - p(\overline{d}+1))]^2} \tag{1.23}$$

We know from the above expression that the denominator is strictly positive, so the sign of $\frac{de}{dn}$ depends on the sign of the numerator. In our chapter, we considered that the sign of $\frac{d\beta}{dn}$ is negative. This implies that with a greater number of terrorists, the marginal increase in complementarity decreases. However, the number of neighbours for a terrorist can increase or decrease with the size of the network. If the marginal benefit of an increase in effort with an increase in $\overline{d}$ is positive, then $\frac{d\overline{d}}{dn}$ is positive otherwise it is negative. Therefore, the sign of $\frac{de}{dn}$ is the interplay of these forces mentioned above. If the marginal benefit from increasing network size is greater than the marginal cost, then $\frac{de}{dn} > 0$, otherwise it can remain constant or decrease as well.

Using equation 1.21 and taking derivative with respect to n, we get,

$$\frac{d\overline{u^*}}{dn} = \overline{e^*}\frac{d\overline{e^*}}{dn} + \frac{pf}{n}\Big[\frac{\overline{d}+1}{n} - \frac{d\overline{d}}{dn}\Big] \tag{1.24}$$

The term $\left[\frac{\overline{d}+1}{n} - \frac{d\overline{d}}{dn}\right]$ in equation 1.24 can be represented as $\varepsilon_{\overline{d},n} = \frac{n}{\overline{d}+1} * \frac{d(\overline{d}+1)}{dn}$, where $\varepsilon_{\overline{d},n}$ signifies the proportionate change in the number of neighbours of terrorists resulting from a proportionate change in the terrorist network size. If $\varepsilon_{\overline{d},n}$ falls within the range of 0 and 1, it signifies that due to the reduction in the cost of capture through infiltration with an increase in network size, the equilibrium utility of an individual terrorist increases alongside the expansion of the network. Nevertheless, when $\varepsilon_{\overline{d},n}$ is more than 1, the sign of $\frac{d\overline{u^*}}{dn}$ becomes uncertain. Specifically, the sign of $\frac{d\overline{u^*}}{dn}$ turns negative only when the penalties post-apprehension are considerably substantial, causing the utility of

terrorists to decline as the network size grows.

Variation with respect to p: We now explore how effort and utility of inidividual terrorists vary with the probability of infiltration. Upon calculating the derivative of equation 1.8 with respect to p and then simplifying the obtained expression, the outcome is as follows:

$$\frac{d\overline{e^*}}{dp} = \Big[\frac{-n(\overline{d}+1) + \Big(\frac{d\overline{d}}{dp}\Big)\Big(-np + \beta[n - p(\overline{d}+1)]^2\Big)}{[n - \beta\overline{d}[n - p(\overline{d}+1)]]^2}\Big] \tag{1.25}$$

Examining the impact of varying the probability of successful infiltration, the sign of $\frac{d\overline{e^*}}{dp}$ can be determined by focusing on the numerator, given the denominator is always positive in equation 1.25. It is plausible to consider that the network leader might reduce the number of neighbours for certain for some terrorists, if not for all. The numerator of equation 1.25 can be restated as $-\frac{\overline{d}+1}{n} + (\frac{d\overline{d}}{dp})[-\frac{p}{n} + \beta[1 - p(\frac{\overline{d}+1}{n})]^2]$.

Particular attention is drawn to the sign of $-\frac{p}{n} + \beta[1 - p(\frac{\overline{d}+1}{n})]^2$. From equation 1.20 we know the sign of $\frac{d\overline{e^*}}{d\overline{d}}$ can be positive, negative or equal to 0, depending on the interplay of the cost of getting captured and the benefits of not getting captured. Nonetheless, as the leader decreases $\overline{d}$ with the increase in p, the sign of $\frac{d\overline{e^*}}{dp}$ is unambiguously negative if $-\frac{p}{n} + \beta[1 - p(\frac{\overline{d}+1}{n})]^2 > 0$. However, when the term $-\frac{p}{n} + \beta[1 - p(\frac{\overline{d}+1}{n})]^2$ is negative, the sign of $\frac{d\overline{e^*}}{dp}$ becomes ambiguous. In such a scenario, the sign of $\frac{d\overline{e^*}}{dp}$ can only be positive when the leader can effectively increase the benefits by reducing the number of neighbours for each terrorist.

Similarly as above, taking derivative of equation 1.21, with respect to p, we get,

$$\frac{d\overline{u^*}}{dp} = \overline{e^*}\frac{d\overline{e^*}}{dp} - \frac{f}{n}\Big[(\overline{d}+1) + p\frac{d\overline{d}}{dp}\Big] \tag{1.26}$$

In cases where the sign of $\frac{d\overline{e^*}}{dp}$ is negative and the term within the parenthesis is positive, the sign of $\frac{d\overline{u^*}}{dp}$ becomes conclusively negative. Additionally, sizeable fines following apprehension can also lead to a decrease in the utility of terrorists. However, it is impor-

tant to note that the sign of $\frac{d\overline{u^*}}{dp}$ can also be positive based on the marginal benefit from increasing efforts and the marginal cost of capture.

Variation with respect to f: We now focus how the equilibrium efforts and utilities of terrorists responds to changes in f. Taking derivative of equation 1.8 with respect to f and subsequently simplifying the expression, the outcome is as follows:

$$\frac{d\overline{e^*}}{df} = \Big[\frac{\Big(\frac{d\bar{d}}{df}\Big)\Big(-np + \beta[n - p(\bar{d}+1)]^2\Big)}{[n - \beta\bar{d}[n - p(\bar{d}+1)]]^2}\Big] \tag{1.27}$$

Given that the denominator of equation 1.27 is positive and understanding that the degree of each terrorist is inversely related to fines, the equation presents some insights. Even if the term $-\frac{p}{n} + \beta[1 - p(\frac{\bar{d}+1}{n})]^2$ is positive, the influence of $(\frac{d\bar{d}}{df})$ contributes to the decline of equilibrium efforts. Conversely, when $[-\frac{p}{n} + \beta\left(1 - p\frac{\bar{d}+1}{n}\right)^2] < 0$, the equilibrium effort increases with fines. This can be explained by the fact that as fines increase, the leader reduces the number of connections each individual terrorist has to minimise the risk of infiltration. This results in an increase in the number of components within the network. However, within these components, the individual efforts will increase. Thus the sign of $\frac{d\overline{e^*}}{df}$ is dependent on the sign of $\frac{d\overline{e^*}}{d\bar{d}}$.

Similar to the previous discussions, calculating the derivative of equation 1.21 with respect to f yields:

$$\frac{d\overline{u^*}}{df} = \overline{e^*}\frac{d\overline{e^*}}{df} - \frac{p}{n}\Big[(\bar{d}+1) + f\frac{d\bar{d}}{df}\Big] \tag{1.28}$$

Much like the explanation for the equilibrium utility variation concerning p, the implications of changes in f can be understood. When $\frac{d\overline{e^*}}{df}$ takes a negative value and the term within the parenthesis remains positive, the sign of $\frac{d\overline{e^*}}{df}$ is unequivocally negative. However, when $\frac{d\overline{e^*}}{df} > 0$, the actual sign of $\frac{d\overline{u^*}}{df}$ is depends on the interplay of the marginal benefit from increasing efforts and the marginal cost of capture.

Variation with respect to β: Lastly, we explore how the equilibrium efforts and

utilities of individual terrorists changes with changes in β (represents the degree of complementarity between terrorists efforts). Calculating the derivative with respect to β and then simplifying, we obtain:

$$\frac{d\overline{e^*}}{d\beta} = \Big[\frac{\Big(\frac{d\bar{d}}{d\beta}\Big)\Big(-np + \beta[n - p(\bar{d}+1)]^2\Big) + \bar{d}(n-(\bar{d}+1))^2}{[n - \beta\bar{d}[n - p(\bar{d}+1)]]^2}\Big] \tag{1.29}$$

From the above equation we can see the denominator is strictly positive. Therefore, the sign of $\frac{d\overline{e^*}}{d\beta}$ depends on the sign of the numerator. Intuitively, we understand that an increase in the degree of complementarity between the efforts of terrorists β leads to an increase in the number of neighbours, as it increases payoffs for individual terrorists. However, an increase in neighbours does not necessarily lead to an increase in effort (see the comparative statics of changes in effort with the changes in number of neighbours for a terrorist). If the equilibrium effort is non-decreasing with the number of neighbours, then the above equation becomes unambiguously positive. Otherwise, it depends on the relative strength of the marginal benefit and the marginal cost in the expression above.

Now we look at the terrorist utility. Taking derivative of equation 1.21, with respect to β, we get,

$$\frac{d\overline{u^*}}{d\beta} = \overline{e^*}\frac{d\overline{e^*}}{d\beta} - \frac{pf}{n}\Big[\frac{d\bar{d}}{d\beta}\Big] \tag{1.30}$$

If $\frac{d\overline{e^*}}{d\beta}$ is non-positive, the sign of $\frac{d\overline{u^*}}{d\beta}$ is unambiguously negative. Otherwise, it is ambiguous and depends on whether the marginal benefits from the increase in complementarity between the efforts of terrorists are higher than the marginal costs of increased connections designed due to the increase in complementarity.

The comparative statics governing the welfare of the network mirror the properties observed in the utility of individual terrorists, as the welfare of the network is a scalar addition of the utilities of individual terrorists. Given this relationship this section is skipped.

1.3.6 Case 2: No Probability of capture through connections

In this section, we revisit the general formulation of the utility function of individual terrorist (equation 1.1) and discuss the efficient network structures of the model where the probability of capture through connections are 0. Previously, we explored the scenario where a terrorist is captured with probability 1 (i.e., $\delta = 1$), both through direct and indirect connections. Now, we shall consider the cases: when a terrorist cannot be captured through direct or indirect connections ($\delta = 0$). By simplifying and rewriting equation 1.1, we obtain:

$$u_i = \Big(1 - p\frac{\sum_{i\neq j, d(i,j)\neq\infty} \delta^{d(i,j)} + 1}{n}\Big)e_i(g_{ii} + \beta\sum_{j\in N} g_{ij}e_j) - p\frac{\sum_{i\neq j, d(i,j)\neq\infty} \delta^{d(i,j)} + 1}{n}f - \frac{1}{2}e_i^2 \tag{1.31}$$

Lemma 8: For $\delta = 0$, terrorist network is designed of components.

Proof of Lemma 8: By plugging $\delta = 0$ into equation 1.31, we observe that u_i increases with the number of neighbours of terrorist i and is independent of the level of infiltration. Therefore, the efficient network is a complete component. Intuitively, this implies that when a terrorist can only be captured directly and not through any connections, the leader then designs maximally connected or complete components that maximize the utility for any individual terrorist. In this case, the equilibrium effort and the associated utility can be computed straightforwardly.

Corollary 3: Terrorists maximally connected in a component when $\delta = 0$, have the

following equilibrium efforts and utilities,

$$\overline{e^*} = \begin{cases} \frac{1}{1-\beta[n-1]} & \text{if } \overline{e^*} < B \\ B & \text{otherwise} \end{cases}$$
$$\overline{u^*} = \begin{cases} \frac{1}{2}\left(\frac{1}{1-\beta[n-1]}\right)^2 & \text{if } \overline{e^*} < B \\ B(1+\beta(n-1)B) - \frac{1}{2}B^2 & \text{otherwise} \end{cases} \tag{1.32}$$

The equilibrium efforts and utilities of individual terrorists are independent of the level of infiltration. In this scenario, the total welfare of the network is $n \times \overline{u^*}$.

1.3.7 Case 3: Unequal Probability of Capture through Connections

In this section, we consider the final case where a terrorist has an unequal probability of capture through connections i.e., $\delta \in (0, 1)$. This implies that a terrorist is captured with a higher probability through direct connections compared to indirect connections. In this scenario, an efficient network may consist of non-maximally connected sub-structures, depending on the level of infiltration. We illustrate this with an example. Consider the parameter values $n = 6$, $\beta = 0.11$, $\delta = 0.75$, and $f = 0.5$, while varying the level of infiltration. We have focused on $p \in [0.4, 0.6]$, as outside this range, the efficient network is composed of maximally connected sub-structures.

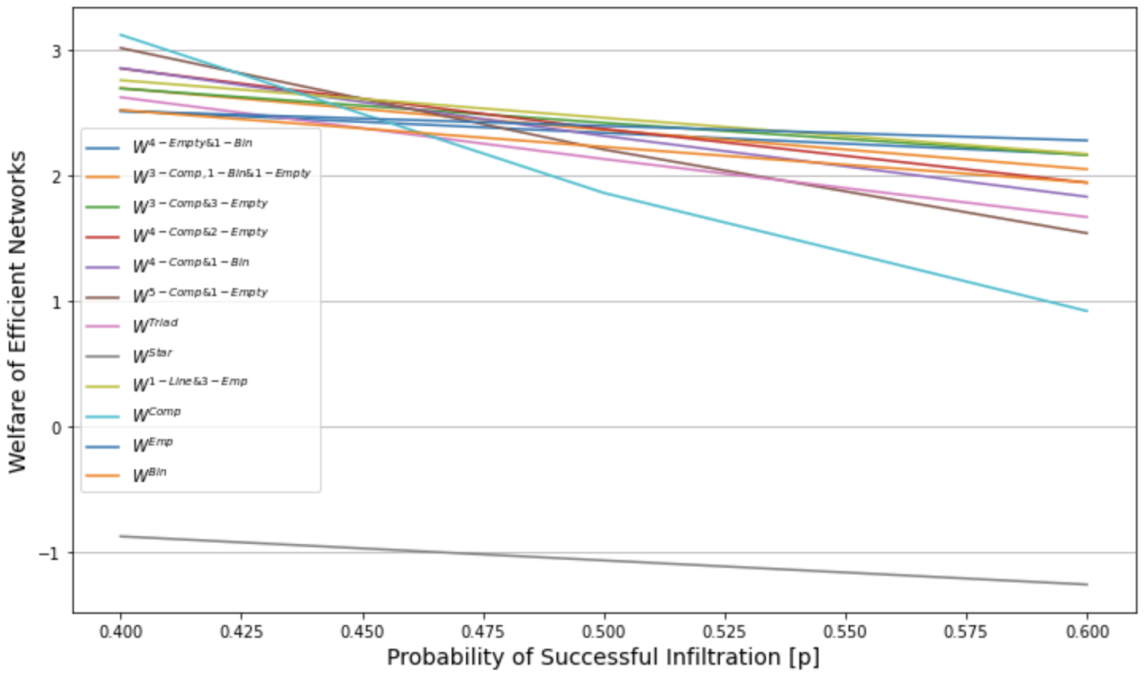

Figure 1.13 Transition of efficient Network with variation of p at $n = 6$, $\beta = 0.11$, $\delta = 0.75$ and $f = 0.5$

In the Figure 1.13 above, we considered all the efficient networks with maximally connected sub-structures for $n = 6$ and compared them with two efficient networks with non-maximally connected sub-structures: one where three nodes are designed as a line sub-structure and three are empty sub-structure, and another where the nodes are designed to have a star structure. We found that for some $p \in (0.45, 5.25]$, the efficient network is composed of non-maximally connected sub-structure. While we are not asserting that the specific configuration of three nodes designed as a line sub-structure and three empty sub-structure is the most efficient, we can conclude with certainty that for $\delta \in (0, 1)$, $p \in (0.45, 5.25]$, $n = 6$, $\beta = 0.11$, $\delta = 0.75$, and $f = 0.5$, an efficient network cannot be designed of maximally connected sub-structures i.e., components.

Therefore, we can say for a given p, f and β, for $\delta = 0$ and $\delta = 1$ the efficient terrorist network is designed of maximally connected components and $\delta \in (0, 1)$ the efficient terrorist network maybe be designed of non-maximally connected components.

1.4 Conclusion and Future Extensions

We developed a game-theoretic model of terrorism to gain insights into the sub-structures of efficient terrorist networks in the presence of infiltration. Our analysis reveals that, with infiltration, there are conditions under which there is a degree of separation between the various sub-structures in the network. We considered various cases regarding how a terrorist can be captured. If a terrorist is captured with probability one through both direct and indirect connections, the efficient network is composed of components. The shape and number of components within the efficient network vary with the probability of infiltration, the degree of complementarity between terrorists efforts, the network size and the fines. We observe that these components can be either symmetric or asymmetric depending on the probability of infiltration. We also observe that, at low infiltration levels, the efficient network is a single complete component. However, when infiltration is high, the efficient network is composed of smaller, multiple components. Even when the probability of successful infiltration is 1, the efficient network is not necessarily composed of empty components. We identify two threshold values of the probability of infiltration below and above which the efficient network is composed of symmetric components. Using simulation, we showed that when fine is above a certain value, the efficient network is composed only of symmetric components. If a terrorist is captured only directly and not through any connections, the efficient network is composed of a single complete component. This complete component is independent of the probability of infiltration. However, if a terrorist is captured with a higher probability through direct connections than through indirect connections, an efficient network may be complete, empty or have non-maximally connected sub-structures.

For future research, there are several promising directions for extending our model. In our current model, we focused on how terrorists can benefit from their connections in carrying out terrorist activities. One intriguing direction for exploration is to consider how these connections may also aid terrorists in evading capture during infiltration ef-

forts. Another direction of research could involve relaxing the assumption of an exogenous network structure to exploring the evolution of networks influenced by the probability of infiltration. Such a dynamic perspective could provide valuable insights into how terrorist networks adapt and grow over time. In our existing model, we assumed that the terrorist leader operates from a concealed location. A fascinating extension of this work would be to investigate scenarios where the leader is situated within the network and analyse the optimal position for the leader within the network structure. Furthermore, empirical research can play a crucial role in enhancing our understanding of terrorist networks in the presence of infiltration. Gathering data from sources such as the Global Terrorism Database can provide valuable insights and opportunities for real-world validation. These are the avenues of research that we intend to explore in our future work, and they hold the potential to further enrich our understanding of the dynamics of terrorist networks in the face of infiltration.

Chapter Two

Impact of Voluntary Disclsoures on Competition*†

2.1 Introduction

Individual entities like countries, companies, and individuals constantly compete with one another, whether it's the space race between the Soviet Union and the U.S., the tech rivalry between Apple and Samsung, or the tennis battles between Novak Djokovic and Roger Federer. One prime example taken from 'Royal Museums Website' is the space race between the Soviet Union and the U.S. taken[1] On October 4, 1957, the Soviet Union launched Sputnik 1, the world's first artificial satellite, marking an important moment in this competition. This small satellite, orbiting the Earth every 96 minutes, was a powerful demonstration of Soviet technological prowess, signaling their capability to launch intercontinental ballistic missiles (ICBMs) and raising alarm across the United States. Sputnik 1's successful launch sent shockwaves through the U.S., sparking fears of falling behind in both space and military technology. The Soviet Union's early lead in space exploration was seen as a significant threat, heightening Cold War tensions and fueling concerns about potential space-based missile attacks. In response, the U.S. rapidly

*We would like to thank participants at the Research Away Day 2023, University of Birmingham.
†This chapter is based on work with Siddhartha Bandyopadhyay and Zeyu Qiu.
[1]https://www.rmg.co.uk/stories/topics/space-race-timeline.

accelerated its space efforts, establishing NASA in 1958 and significantly increasing investment in space and missile programs. This fierce competition ultimately led to the U.S. landing the first humans on the Moon in 1969. Much like the Russian military buildup near Ukraine on February 24, 2014, Sputnik 1 was a strategic show of force that compelled a swift and substantial response from a global rival.[2] This chapter aims to investigate experimentally, how voluntary disclosure of information affects competition. In this chapter, by voluntary disclosure of 'information', we mean voluntary disclosure of 'verifiable information'. Unverifiable information is not focused in this paper. We will explain this in detail now.

In such competitive environments mentioned above, revelation of information plays a crucial role. Accurate and timely information about a rival's capabilities, strategies, or intentions can significantly influence the outcome of the competition. For instance, in the context of the space race, the U.S. response was heavily influenced by the public display of information of space and military technology by Soviet Union. Understanding the extent of a rival's strength allows an entity to calibrate its strategies, allocate resources more effectively, and make informed decisions that could ultimately determine success or failure. Therefore, the revelation of information are elements in affecting competition, often dictating the pace and direction of the competitive struggle. Here in our chapter, we refer disclosures as 'all-or-nothing' of verifiable information.

In the example above and other notable events in history, in addition to how voluntary disclosure of verifiable information affects competition, we observe that individual entities often engage in these competitions with competitors of different (asymmetric) strength for a prize. In our chapter, these differences in absolute strength are attributed to two key parameters: abilities and marginal costs of effort. Abilities can be likened to the reputation and experience of scientists in a research and development division, while marginal costs represent the cost of hiring these scientists to conduct research. In our

[2]The Russia vs Ukraine example is taken from Ewerhart and Lareida (2024).

analysis, we consider abilities to be publicly observable, whereas marginal costs remain private information. We will henceforth refer to these entities as players or participants. The chance of winning (or probability of success) for a player depends on their own marginal costs, abilities, and effort, as well as those of their opponent. In our chapter, we consider that players have ex-ante asymmetric abilities. Abilities reflect how the contest is inherently biased i.e., in simple terms, if both players exert the same level of effort, the player with higher ability has a greater than 50% chance of winning, while the other has less than 50%. Additionally, players differ in their marginal costs, which can be either symmetric or asymmetric. Our chapter explores the impact of revealing these marginal costs in an ex-ante asymmetric ability setting. Revealing information about marginal costs could influence the effort exerted by competitors. For instance, if a player reveals their private information, it might discourage their opponent from exerting more effort, leading to reduced competition. Conversely, the opponent's potential exposure of weaknesses could allow the player to reduce their own effort while still increasing their chances of winning. Furthermore, participants sometimes compete against each other only once in a contest. For instance, in knockout competitions such as boxing or tennis or patent competitions, participants face each other only once, with the winner advancing to the next round. There is no opportunity for repeated interactions with the same opponent, making each contest a decisive and singular event. To explore the incentives behind voluntary disclosure of private information in such competitive settings, we conducted a one-shot experimental study involving two ex-ante asymmetric players.

Formally, this chapter experimentally studies bidding (i.e., investment level) behaviour, the effects on the probability of winning, and expected payoffs in simultaneous-move contests of incomplete information with voluntary disclosure of information. To the best of our knowledge, such asymmetric contests have not yet been explored experimentally, even without voluntary disclosure of information. While Brookins and Ryvkin (2014) examined symmetric contests, asymmetric contests have not been experimentally studied until now. As previously mentioned, we introduce asymmetries in the contest in terms of

publicly observable abilities (ex-ante) and private marginal costs (ex-post). We explore a simultaneous-move asymmetric game under incomplete information, both without and with voluntary disclosure. Our focus is on two types of disclosure setting: one where both players can voluntarily disclose information, and another where only one player can disclose information while the other's information remains common knowledge. Our research questions explore how the option to reveal cost information impacts player investment behaviour, probability of winning and expected payoffs. Specifically, we examine whether players choose to reveal their cost information when given the option and whether they exert different levels of effort in disclosure versus non-disclosure settings. Additionally we also examine whether high-ability players behave differently than low-ability players. We develop an experimental design to investigate these above mentioned research questions.

We conducted an online experiment using Prolific, focusing on one-shot two-player contest setting where players differ ex-ante in their observable abilities and have private information about their costs. One-shot contests are common in real life. For example, companies invest in research and development to create new technology, with the first company to succeed winning a patent and a monopoly on the product, while others gain nothing. Another example is a single-elimination sports tournament, where teams or individuals compete in a single match to advance. The loser is immediately eliminated from the competition. In our chapter the contest game consists of two stages: the revelation stage and the investment stage, which are played sequentially. At the beginning of the experiment, both players are assigned different abilities, which are public information within each pair. Importantly, these abilities are consistent across all pairs in the experiment. After assigning abilities, each player is allocated a marginal cost drawn from a discrete interval. The experiment proceeds differently depending on the setting. In the baseline setting, both players participate only in the investment stage, with cost information kept private, and neither player has the opportunity to reveal their costs. However, there are two stages in both treatment 1 and treatment 2. In Treatment 1, following the cost allocation and before the investment stage, both players are given the

option to reveal their costs, while observing their own costs. Depending on the players decisions, one player's cost will be revealed to the other. This stage is known as the revelation stage. In Treatment 2, after the cost allocation, one player is randomly selected, and their cost is made common knowledge. Similar to treatment 1, in the revelation stage in treatment 2, the other player, having observed this common knowledge and knowing their own cost, then decides in the revelation stage whether to reveal their cost. After the revelation stage in both treatments, the contest proceeds like the baseline, with players making investment decisions based on the available information. Note the two stages are played sequentially, however in each stage the decisions are taken simultaneously. We will detail the baseline and treatments further in the experimental design section.

In our chapter, we utilise a between-subjects design to compare bidding behaviour, probability of winning, and expected payoffs across three different settings: incomplete information with no disclosure (Baseline), two-sided disclosure (Treatment 1), and one-sided disclosure with public information on the other side (Treatment 2).[3] Additionally, we assess participants risk preferences using the method developed by Binswanger (1980) to better understand how individual risk attitudes influence behaviour in the experiment.

Our results indicate that the majority of participants in the experiment exhibit risk-averse behaviour. In each sample, across the baseline and both treatments, there is a statistically significant proportion of participants who display risk aversion compared to risk-loving tendencies. This finding aligns with the experimental results of Mago et al. (2013). In both two-sided revelation (Treatment 1) and one-sided revelation (Treatment 2), the decision to reveal private information is significantly less than one, indicating that participants do not always disclose their marginal costs when given the opportunity. However, the frequency of revelation is higher than non-revelation. In Treatment 1, we find that participant's unit costs and risk aversion negatively affect the probability of revelation, with these effects being statistically significant at the 5% and 1% levels,

[3]This chapter builds on the work of Bose (2024), submitted as part of the Annual Progress Review.

respectively. In contrast, in Treatment 2 (one-sided revelation), no statistically significant relationship is observed. Qualitatively, we observe that overall investment levels are negatively related to unit costs across treatments in nearly all regressions. Although risk aversion in the baseline and Treatment 1 is negatively correlated with investment, these effects are not statistically significant. This finding qualitatively supports the work of Millner and Pratt (1991) and Mago et al. (2013). However, in Treatment 2, risk aversion is positively correlated with investment. This may be due to the common knowledge of one participant's unit cost in the pair, enabling the other participant to recognise their relative strength or weakness before the revelation. Consequently, risk-averse participants, fearing potential losses, may exert greater effort to avoid them, consistent with the theoretical findings of Skaperdas and Grofman (1995). We also observe that the average investment is highest in the baseline, followed by Treatment 1, and lowest in Treatment 2. This pattern may be attributed to the availability of information (due to the decision to reveal and common knowledge). The overall probability of winning is consistent across treatments, as probabilities in a pair sum to 1. In Treatment 2, less effort is exerted compared to Treatment 1 and the baseline, leading to the highest overall expected payoffs in Treatment 2, as the cost of investment is lower. Although there is no significant difference in investment levels between high- and low-ability participants, the trend suggests that high-ability participants, on average, invest more than low-ability participants. Additionally, we observe that in Treatment 1, the average investment with revelation is higher than in Treatment 2, whereas the average investment without revelation in Treatment 2 is higher than in Treatment 1. These results will be discussed in further detail in the results section.

The remainder of the chapter is organized as follows: Section 2.2 provides a summary of the related literature. Section 2.3 outlines the model. Section 2.4 focuses on the experimental design, and procedures. Section 2.5 presents the results, and Section 2.6 offers concluding remarks and future extensions.

2.2 Related Literature

Contests have been studied across various economic contexts, including rent-seeking models (see e.g., Tullock (1980); Nitzan (1991); Baye et al. (1993)), warfare conflicts (see e.g., Amegashie and Kutsoati (2007); Chang et al. (2007)), tournaments (see e.g., Rosen (1985); Lazear (2014)), R&D competition (see e.g., Dasgupta and Stiglitz (1980); Taylor (1995)), political campaigning (see e.g., Skaperdas (1996)), and conflict networks (see e.g., Franke and Öztürk (2015); Cortes-Corrales and Gorny (2024)).

Empirical investigation of contest phenomena using field data is challenging (e.g., Knoeber and Thurman (1994) and Bognanno (2001)), primarily because only the outcomes are observable, while key details of the incentive structure, such as player's abilities and prize valuations, remain hidden.[4] Laboratory experiments, on the other hand, allow researchers to exert tighter control over incentives, making them a natural alternative for testing theoretical models. Along with understanding revelation decision of participants, this chapter, is the first study to conduct an online contest experiment to examine whether participants behaviour aligns with findings from the offline contest experimental literature in terms of risk aversion.

The existing experimental literature on contests primarily focuses on scenarios where there is complete information about marginal costs of effort and prize valuations (see Dechenaux et al. (2015)). However, in many real-world applications, the assumption of complete information about rival's marginal cost or prize valuations is unrealistic. For instance, in R&D competition, it is unlikely that firms have perfect knowledge of their rival's cost structures. Similarly, lobbyists may have unobserved differences in their lobbying capabilities.

[4]In R&D competition, the value of the prize (patent) encompasses the stream of the firm's future profits, which is typically unavailable to researchers (Fonseca (2009)).

While the theoretical literature on contests with complete information is well-established (for comprehensive results on one-shot simultaneous-move contests, see, e.g., Malueg and Yates (2005); Cornes and Hartley (2012)), there has been growing interest in the theory of contests with incomplete information (see e.g., Malueg and Yates (2004); Wärneryd (2003)). For example, Fey (2008) and Ryvkin (2010) theoretically analysed bidding in symmetric contests with incomplete information using a framework similar to independent private value auctions Klemperer (2004). Specifically, Fey (2008) established the existence of a smooth symmetric equilibrium bidding function in a Tullock contest model with two players who have privately known, uniformly distributed marginal costs of effort. Ryvkin (2010) extended this result, showing that the existence of such an equilibrium also holds for an arbitrary number of players, arbitrary cost distributions, and more general contest success functions. Wärneryd (2003) studies two-player SO-Tullock contests in which players have a common value drawn from a continuous distribution and a common constant marginal cost of effort, and in which each player either observes the value or only knows the distribution from which the value is drawn.[5] Wärneryd (2012) extends this study to a multi-player setting. Wasser (2013a) considers modified, continuous versions of Tullock lotteries (see also Wasser (2013b)), who establishes existence of equilibrium in private-value imperfectly discriminating contests with everywhere continuous success function).

Although the literature above focussed on symmetric contests with incomplete information, however it is not uncommon for people to compete in asymmetric contests. For example, consider the chess match between grandmaster Magnus Carlsen and 18-year-old prodigy R Praggnanandhaa from India in the 3rd round of the Norway Chess 2024 tournament. Despite their different levels of experience due to the number of games played in the past (which is the indicator of ability), Praggnanandhaa managed to defeat the world's top-ranked player, marking a monumental moment in his career and securing his first classical victory over the reigning champion. This outcome, despite the disparity in

[5]SO stands for Szidarovszky and Okuguchi (1997)

experience, suggests the influence of unobserved factors. In our chapter, we explore experimentally incomplete information contests with publicly observable asymmetric abilities and private marginal costs. Asymmetric contests with complete information have been studied extensively in the theoretical literature (see e.g., Dixit (1987); Baik (1994); Stein (2002); Nti (1999)). Additionally, one-sided and two-sided incomplete information contests have been studied in the literature (see e.g., Hurley and Shogren (1998); Einy et al. (2015)). More generally, the existence and uniqueness of equilibrium in contests with ex-ante asymmetries and private information were analysed by Ewerhart and Quartieri (2020), and our chapter is a special case of their framework as stated in Ewerhart and Lareida (2024). However, the experimental investigation of ex-ante asymmetries and private information remains unexplored, which is the focus of our study.

Pre-play communication involving the disclosure of verifiable information has been widely studied (see e.g., Okuno-Fujiwara et al. (1990); Van Zandt and Vives (2007); Hagenbach et al. (2014)). Ewerhart and Lareida (2024) extends the standard probabilistic contest model by incorporating pre-play communication of verifiable information. In these settings, participants typically hold private information about factors such as marginal costs, valuations, or abilities that indicate their competitive strength. At the interim stage—after observing their own type but before the contest—players can choose to disclose this information to their opponent. Theoretically, Ewerhart and Lareida (2024) examines the incentives for voluntary disclosure, focusing on contests that are uniformly asymmetric, where one contestant is more likely to win, provided they stay active. Although restrictive, the sufficient condition of uniform asymmetry in their paper aligns with models that account for heterogeneity in both valuations (see e.g., Amann and Leininger (1996); Eric and John (2000)) and abilities (see e.g., O'keeffe et al. (1984); Meyer (1992); Franke et al. (2014)).

While the voluntary disclosure of private information in asymmetric contests has been studied theoretically, to the best of our knowledge, it has not yet been explored ex-

perimentally. The present chapter provides the first experimental test of the effects of voluntary disclosure of information in asymmetric contests. We considered a one-shot contest game with two-players. We focused on understanding how voluntary disclosure of information affects the average level of investment, probability of winning and expected payoffs of participants. Previous experimental studies on information disclosure include Boosey et al. (2020) and Sheremeta (2010). However, interim voluntary disclosure in contests has not been experimentally explored. By interim voluntary disclosure we mean participants choose to disclose their information after observing their own type. In our chapter participants have the choice to reveal their private information when allowed. By disclosure we assume 'all-or-nothing' not partial disclosure (e.g., see Hagenbach et al. (2014)). We conducted the experiment on the Prolific platform, where participants played a one-round contest game[6]. Additionally we elicit risk in our experiment following Binswanger (1980) technique.

Our findings contribute to the contest literature by experimentally examining whether voluntary disclosure of information affects competition. Consistent with previous findings in the literature (see e.g., Millner and Pratt (1991); Mago et al. (2013)), a significant portion of participants in our experiment exhibited risk aversion compared to risk-loving. Our results show that participants do not always reveal their information when given the option. The probability of revelation is correlated with their unit costs and risk-aversion. In our chapter in treatment 1, where both participants are allowed to disclose their private information, we observe that the average investment with revelation is significantly greater than that with non-revelation. However, in treatment 2, where one participant's marginal cost is common knowledge, there is no significant difference between the average level of investment with revelation and without revelation. The implications of risk-averse behaviour on investment qualitatively support the findings of Millner and Pratt (1991) and Mago et al. (2013) in Baseline and Treatment 1. In Treatment 2, our results qualitatively align with the theoretical findings of Skaperdas and Grofman (1995). Now we

[6]One round contest experiment has been previously studied by Schmidt et al. (2006),Deck and Jahedi (2015) and Anderson and Stafford (2003).

will discuss the theoretical model below.

2.3 Theoretical Model

There are two risk-neutral players indexed by $i \in \{1, 2\}$. Each player differs ex-ante in their ability parameter, with $\gamma_i > \gamma_j > 0$. The ability parameters are publicly observable to both players competing in the contest. Additionally, each player i is characterised by a private constant marginal cost of effort $c_i > 0$. The values of c_i for the two players are drawn independently from a commonly known distribution $F(c)$ with support in the interval $[\underline{c}, \overline{c}]$, with finite $\overline{c} > \underline{c} > 0$. The players participate in a contest by simultaneously submitting effort levels $e_i \geq 0$. Following Rosen (1985), we assume that player i's probability of winning against $j \neq i$ is given by:

$$p_i(e_1, e_2, \gamma_1, \gamma_2) = \begin{cases} \frac{\gamma_i e_i}{\gamma_1 e_1 + \gamma_2 e_2} & \text{if } (e_1 + e_2) \neq 0 \\ \frac{\gamma_i}{\gamma_1 + \gamma_2} & \text{if } (e_1 + e_2) = 0 \end{cases} \tag{2.1}$$

Thus, player i's expected payoff may be written as,

$$\Pi_i(e_1, e_2) = V\ p_i(e_1, e_2) - c_i\ e_i \tag{2.2}$$

In the equation above, if player i wins the contest, they receive $V > 0$, the value of the prize; otherwise, they receive nothing. Note that the prize valuation, V, is the same for both players. Since the ability of the players is publicly observable, the type of players is solely dependent on the marginal cost c_i.

We know a Bayesian Nash Equilibrium exists as it is a special case of Ewerhart and Quartieri (2020) model. We consider following three settings of this game, each differing in the allowance of private information revelation:

1. Baseline: Incomplete Information, No Disclosure

2. Treatment 1: Incomplete Information, Two-sided Disclosure

3. Treatment 2: Incomplete Information, One-Sided Disclosure

We will now discuss each of these settings in detail in the next section.

2.4 Experimental Design and Procedures

2.4.1 Design

Treatment	Information	Reveal	Common Knowledge	Sessions	Subjects	Observations
Baseline	Incomplete	None	None	5	282*	162
Treatment 1	Incomplete	Both sides	None	5	312*	168
Treatment 2	Incomplete	One side	One-side	6	368*	150#
* There were dropouts						
# Data collected for 35 pairs where low ability participants were allowed to disclose and 40 pairs where high ability participants were allowed to disclose						

Table 2.1 Summary of experimental sessions and treatments

We have developed an experimental setup centred around a contest success function (CSF). The experiment employs a between-subject design, wherein allowing the revelation of private information by participants is varied resulting in three settings (one baseline and two treatments). A total of 962 participants were recruited for the experiment through the online platform Prolific. Initially, we started with three sessions for each setting, employing 48, 68, and 68 participants in each session. However, due to high dropout rates on Prolific, additional sessions with different sizes of participants were later undertaken. In total, we ran five sessions of the baseline with 282 participants, five sessions for Treatment 1 with 312 participants, and six sessions for Treatment 2 with 368 participants. The summary of experimental sessions and treatments are summarised in

table 1. Each session has two parts first is the investment task followed by the lottery task. We will now explain the details of each session for the different settings.

In the first part, participants are randomly paired and proceed through one decision round of the corresponding contest game. This contest game comprises two stages, played sequentially, with the revelation stage preceding the investment stage. Participants make simultaneous decisions in each stage. We will explain the stages in reverse order, beginning with the investment stage followed by the revelation stage. Following the participant pairing, participants in a pair are assigned different abilities, which are 4 and 3. In this one-shot experiment, each participant receives an endowment $E = 120$ experimental points, valued at £0.01 per point. Participants have a project where they can invest any integer number of points, denoted as e_i, from the set $\{0, 1, 2, \ldots, 120\}$ into the project or keep the points. Investment decisions are made simultaneously. Subsequently, one project from each pair is selected as successful. The abilities of 4 and 3 assigned to participants translate their investments into their project's success. Therefore, the probability (chance) of success for participant 1's project is determined by the equation $p_1 = \frac{4e_1}{4e_1+3e_2}$, and the probability of success for participant 2's project is determined as $p_2 = 1 - p_1 = \frac{3e_2}{4e_1+3e_2}$, where e_1 and e_2 represent the investments of player 1 and player 2, respectively. If both participants opt for zero investment, the probability of success for participant 1's project is set to $p_1 = \frac{4}{7}$ and for participant 2's project is set to $p_2 = \frac{3}{7}$. Note that, additionally, for the same investment level and zero total investment, participant 1's project has a higher chance of success than participant 2's project.

However, engaging in a contest entails costs. Following random pairing and ability assignment, participants marginal costs (referred to as unit costs in this experiment due to the linear nature of investment costs) are selected from the set $S \in \{0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5\}$, with all ten values equally likely. Once the marginal cost is determined, participants are informed of their respective costs. These costs may be the same or different for participants within a pair in the experiment. Formally, the cost of investment for

participant i is represented as $c_i \times e_i$, where c_i denotes the marginal cost of investment for participant i and e_i represents participant i's investment.

After both participants have invested in their projects, based on participants ability, the probability of success for each project is computed based on the formula mentioned above. Based on these probabilities for participants in a pair, one project is selected as successful. If participant i's project succeeds, participant i wins the contest and receives a prize of $V = 120$ points.[7] However, if participant i's project fails, there are no additional earnings for participant i. It is important to note that every participant bears the cost of their investment when investing in their project. The payoff for participant i, denoted as π_i, in this setup is determined as follows:

$$\pi_i = \begin{cases} 240 - (\text{unit cost}) \times (\text{investment}), & \text{if project is successful} \\ 120 - (\text{unit cost}) \times (\text{investment}), & \text{otherwise} \end{cases}$$

We will explain the stage preceding the investment stage in the treatment section. Participants engage in the experiment under one of the three settings.

In addition to the first part, in the second part, common to all settings, we elicit the risk preferences of participants using the Binswanger (1980) method. There are 7 questions, each presenting participants with a choice between two options: Option A and Option B. Option A guarantees a sure monetary gain of 50 points, while Option B offers a lottery with an uncertain outcome. In Option B, there is a 50 percent chance of receiving a reward and a 50 percent chance of receiving nothing. The reward amount in Option B increases progressively, with the potential to win up to £2 in the final lottery.

At the end of the experiment, after results were shown on the screen, participants completed a short post-experimental questionnaire eliciting basic demographic and behavioural information. This included age, gender, whether English is their first language,

[7]Note that the prize value is £1.20, as each point is valued at £0.01.

the importance they place on maximizing income, the difficulty of the instructions, the number of previous experiments they have participated in, and any additional feedback or comments. The experimental instructions are provided in Appendix B.6, and screenshots of the pages shown to participants are included in Appendix B.7.

2.4.2 Treatments

In our experimental design, which adopts a between-subjects approach, we introduce the baseline model and two distinct treatments. Our research question centres on the impact of voluntary information disclosure on asymmetric contests. To address this question, we explain the rationale behind choosing a between-subjects approach, where each participant experiences only one setting. In this approach, participants are less prone to order effects. The between-subjects design facilitates a clearer attribution of causality. By focusing on differences between different groups, we can more clearly show the cause-and-effect relationships. This design choice enhances our ability to discern the specific effects of information disclosure on competition (effort or investment levels), contributing to the robustness and clarity of our study outcomes.

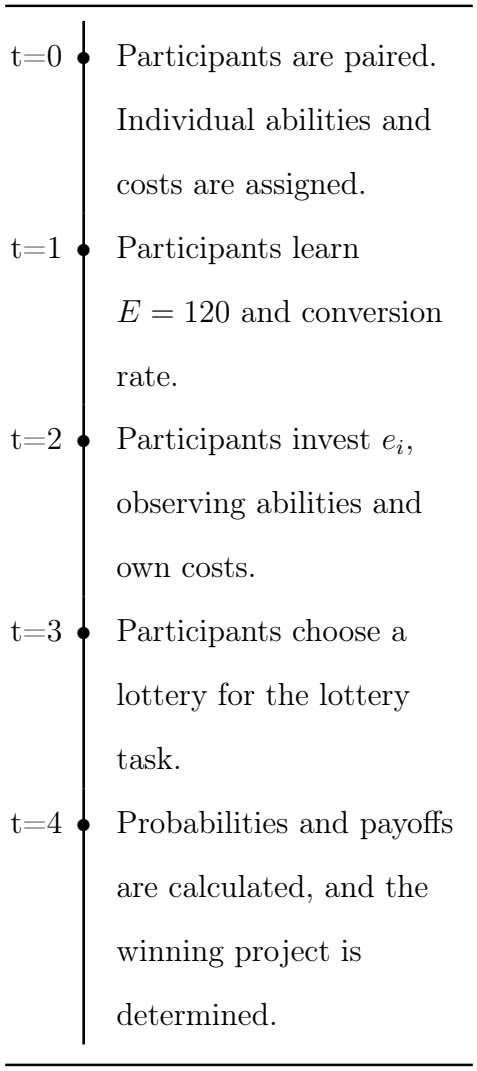

Figure 2.1 Sequence of Events in Baseline Setting

We first explain the baseline model before delving into the treatments. The baseline model represents an incomplete information contest game with two players with asymmetric attributes featuring solely the investment stage without a revelation stage. The sequence of events in baseline settings is presented in Figure 2.1. Participants are assigned different abilities, which are publicly observable. Following this, costs are randomly assigned from the specified set S mentioned earlier, and these costs remain private information. The baseline condition comprises only the investment stage, while the two treatment conditions include an additional stage known as the revelation stage. In the baseline setting, participants are not allowed to reveal this private information to their paired counterparts. In contrast, in the treatments, the investment stage is preceded by the revelation stage where one or both participants have the option to reveal their private

marginal cost information to their paired participant after observing them. After observing the decisions of the revelation stage, participants then play the investment stage which is the same in all the settings. In treatment 1, both participants have the option to reveal their cost information simultaneously. Based on the decisions made during the revelation stage, both participants may or may not observe the private information of the other participant in the pair. It is important to note that a participant can ascertain their relative strength in terms of marginal costs only when their paired counterpart's private cost information is revealed. We considered an additional scenario (i.e., treatment 2) where one participant's cost is publicly known, while the other has the option to reveal its own cost. In this scenario, after participants draw their costs from set S, one participant is randomly selected, and their cost becomes public information. With this knowledge, the other participant has the opportunity to reveal their private decision. Following the decision-making phase, the game progresses to the investment stage, as seen in the baseline setting. At the end of the experiment, participants are informed about the probability of their project's success, whether their project was successful, as well as their payoff and final earnings from the experiment, presented in pounds. The sequence of events for treatment 1 and treatment 2 are shown in Figures below (Figure 2.2 and Figure 2.3).

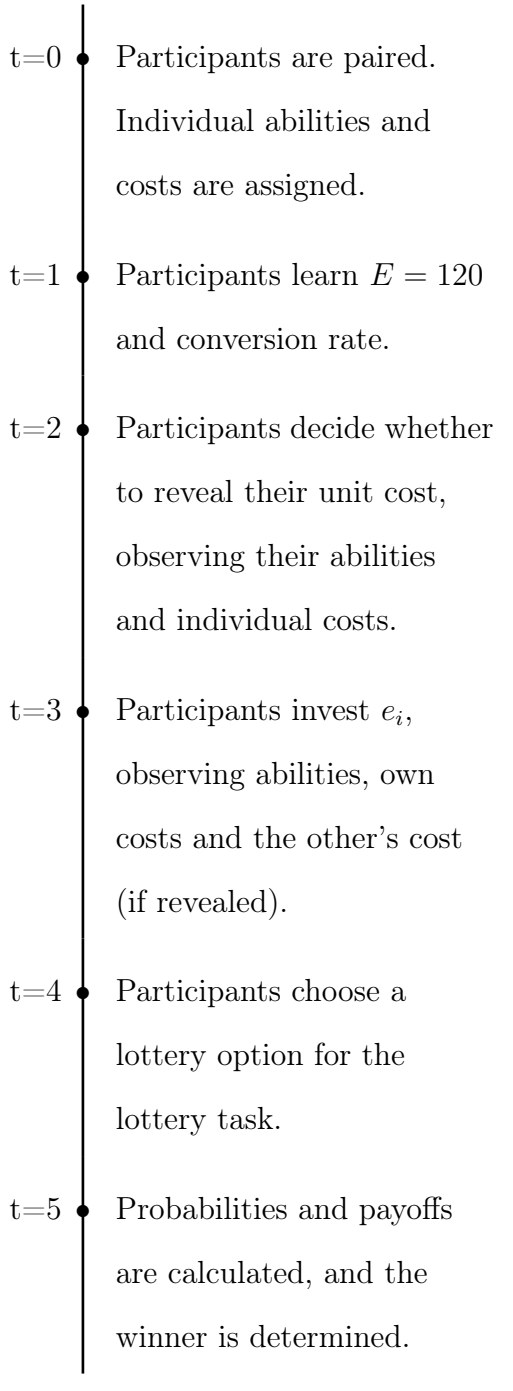

Figure 2.2 Sequence of Events in Treatment 1

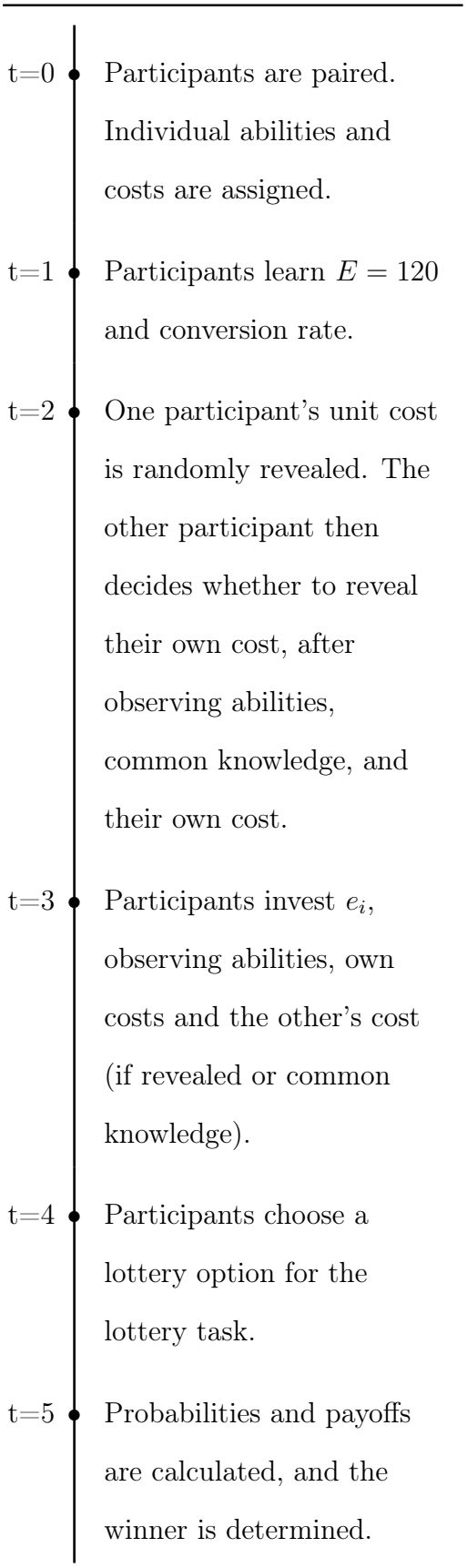

Figure 2.3 Sequence of Events in Treatment 2

The treatments in our experiment are inspired by the research of Ewerhart and Lareida (2024), which provides a theoretical framework showing that in any uniformly asymmetric contest with pre-play communication of verifiable information, full revelation emerges as the unique perfect Bayesian equilibrium. However, if the sufficient condition of uniform asymmetry is not met, full revelation may not occur in a two-sided revelation setting. Importantly, uniform asymmetry is not required to achieve full revelation as the unique equilibrium outcome in one-sided revelation scenarios. The rationale behind the revelation in Bayesian Nash equilibrium is as follows: In a uniformly asymmetric contest with two-sided revelation, where the low-ability participant has at least two possible marginal cost realisations, a unilateral disclosure by the low-ability participant with the highest cost leads to increase in effort, probability of winning, and expected payoff compared to non-disclosure. In this situation, after the low-ability participant, reveals their private information (i.e., their relative weakness), they behave with greater confidence, exerting more effort and thus increasing their chances of winning. Thus, self-disclosure benefits the weaker participant with the highest cost. In contrast, in one-sided revelation where the low-ability participant's marginal cost is common knowledge and the high-ability participant has at least two possible marginal cost realizations, a unilateral disclosure by the high-ability participant with the lowest-cost, leads both participants to reduce their efforts. However, the high-ability participant's probability of winning and expected payoff increase compared to non-disclosure. This is because, when the low-ability participant's marginal cost is public, the high-ability participant's self-revelation discourages the low-ability participant, allowing the high-ability participant to exert less effort while still winning with a higher probability. These insights are drawn from Ewerhart and Lareida (2024).

Through these treatments, our experiment aims to understand the strategic decisions surrounding allowing marginal cost information disclosure under verifiable information. We will now proceed towards explaining the recruitment and procedures of the experiment.

2.4.3 Recruitment and Procedures

Initially, we conducted three sessions for each setting, employing 24, 34, and 34 pairs of participants in each session. However, due to high dropout rates on Prolific, additional sessions with varying participant numbers were undertaken. In total, we ran five sessions of the baseline with 282 participants, five sessions for Treatment 1 with 312 participants, and six sessions for Treatment 2 with 368 participants. Ultimately, we used 162, 168, and 150 observations for the baseline, Treatment 1, and Treatment 2 settings, respectively in our analysis.[8]

Participants for the study were recruited online from around the world via the Prolific platform. The experiment was computerized and programmed using oTree software Chen et al. (2016). During recruitment, we ensured equal participation of males and females.[9]Sessions were conducted between 10 am to 3pm UK, with the session times for each setting randomised within this period. Along with earnings from the experiment (both investment and lottery tasks), participants received a guaranteed amount of £1 as a show-up fee upon successful completion of the experiment. Participant earnings from the investment part of the experiment depended not only on their own decisions but also on the decisions of their paired participants. These earnings were calculated using an exchange rate of £0.01 per point. In the lottery task, one of the seven lottery task questions was randomly selected, and participants were paid based on their choice. Participants received the show-up fee immediately after the experiment, and earnings were disbursed within a week.

Participants whose paired participants took more than 20 minutes to make decisions were considered dropouts. In such cases, the experiment was manually terminated, and the remaining participant received both the show-up fee and their earnings, calculated

[8]Due to dropouts, the number of observations is less than the number of participants.

[9]However, due to participant dropouts, the final sample analysed did not have an equal percentage of males and females.

as the average earnings of participants who completed the experiment in that session. Participants who voluntarily dropped out received no payments. Participants earned an average of £3.50, which included earnings from the investment task, the lottery task, and a £1 show-up fee. On average, participants took 17 minutes to complete the experiment.

2.5 Results:

We will now the various results of our experiments.

2.5.1 Hypothesis 1: Participants are risk-neutral.

Millner and Pratt (1991) and Mago et al. (2013) have shown that participants in a contest experiment tend to be risk-averse. Our online experiment confirms this risk-averse behaviour, consistent with the previous findings. The implications of risk-averse behaviour on the probability of revelation and investment decision of participants are discussed in hypothesis 2 and bidding of participants (baseline, treatment 1 and treatment 2) section.

To elicit participants risk preferences, we used the Binswanger (1980) risk elicitation technique. This involved a lottery task consisting of seven questions, each presenting two choices: Lottery A and Lottery B. Lottery A is the safe option, offering a guaranteed 50p reward. In contrast, Lottery B is an uncertain option where participants have a 50% chance of earning nothing and a 50% chance of earning a positive reward, which increases from 80p in the first question to £2 in the seventh question.

For example, in question 2, Lottery A guarantees a 50p reward, while Lottery B offers a 50% chance of earning nothing and a 50% chance of earning £1. Although the expected payoff for both options is the same, choosing Lottery B indicates risk-loving behaviour while if someone is risk-neutral, he/she should be indifferent between Lottery

A or B in question 2. In question 3, the potential reward for Lottery B increases to £1.20, and if participants continue to choose Lottery A, it suggests risk-averse behaviour.

	Baseline	Treatment 1	Treatment 2	Total
1 (other)	25	25	20	70
2 (risk-averse)	96	98	77	270
2.5 (risk-averse and risk-neutral)	28	26	34	88
3 (risk-loving)	13	19	19	51
Total	162	168	150	480

Table 2.2 Risk preference of participants across treatments

Represented in Table 2.2, based on participant's choices in the lottery task, we categorise them into four types. If a participant chose Lottery A (the safe option) in more than the first two questions, they are classified as risk-averse. Those who selected Lottery A in exactly the first two questions are considered either risk-averse or risk-neutral. Participants who only chose Lottery A in the first question or consistently selected Lottery B are classified as risk-loving. Lastly, if a participant switched from Lottery B to A, they exhibited inconsistent behaviour and were classified as 'others'. Our experiment revealed that the majority of participants exhibit risk-averse behaviour. We conducted a two-sample test of proportions (Z-test) to compare the proportion of risk-averse individuals to risk-loving individuals within each treatment. The results were significant at the 1% level. Additionally, we found that more than half of the participants in both the baseline and treatment 1 exhibited risk-averse behaviour, statistically significant at the 5% level. However, in treatment 2, although the proportion of risk-averse individuals was higher, it was not statistically different from 50% of the sample size in treatment 2. These results are shown in Table 2.3.

	Baseline	Treatment 1	Treatment 2
Proportion of risk-averse	0.59	0.58	0.51
	(0.04)	(0.04)	(0.04)
Proportion of risk-loving	0.08	0.11	0.13
	(0.02)	(0.02)	(0.03)
Proportion of risk-averse vs Proportion of risk-loving (p-values)	0.00	0.00	0.00
Proportion of risk-averse = 0.5 (p-values)	0.02	0.03	0.7
N (Sample size)	162	168	150

Notes: Standard errors in parentheses

Table 2.3 Risk-Averse behaviour of participants across treatments

2.5.2 Hypothesis 2: In non-uniformly asymmetric contests, the perfect Bayesian equilibrium is full revelation with one-sided information but not with two-sided information.

According to the paper by Ewerhart and Lareida (2024), in any non-uniformly asymmetric contest (for formal definition see, Ewerhart and Lareida (2024); Dixit (1987)) with pre-play communication of verifiable information, the perfect Bayesian equilibrium outcome need not be fully revealing for two-sided information.[10] However, even if the contest is not uniformly asymmetric, revelation is the perfect bayesian nash equilibrium for one-sided information. We considered a similar setting where the contest is not uniformly asymmetric and wanted to observe the revelation decision among participants. Our experimental results partly align with this theorem. In both treatments, participants chose to reveal their information more often than not, and, the decision to reveal is significantly

[10]See section 6: Limits of the scope of the disclosure principle of Ewerhart and Lareida (2024).

less than 1 (see Table 2.4).

	Treatment 1	Treatment 2
Proportion of Reveal Decision = 1	0.57	0.53
	(0.49)	(0.50)
p-values	0.000	0.000
N (Sample size)	168	75

Notes: Standard deviations in parentheses

Table 2.4 Revelation Decision of participants across treatments

To understand behaviour in Treatment 1, we ran a probit model with Revelation (i.e., Reveal Decision) as the dependent variable.[11] Across all regression models, we include an independent variable called 'Unit Cost' which refers to the unit cost assigned to participant. Model (2) is augmented by adding another independent variable called 'ability' which measures the assigned ability, i.e., high (4) or low (3). In Model (3), we additionally add 'Risk aversion' as an independent variable, which measures the number of safe options in our lottery task. Model (4) includes both 'Ability' and 'Risk aversion' and the last model controls for the participant's gender, the importance placed on maximizing income, and their understanding of the instructions, in addition to the independent variables from Model (4).

Table 2.5 indicates that across all models, the coefficient of 'Unit Cost' is negative and statistically significant at 5% level, meaning that one unit increase in the Unit cost will decrease the probability to reveal by around 30%. We also find that the coefficients of 'Risk-averse' are negative and statistically significant at either 1% or 5% level, showing that more risk-averse subjects will reveal less. One more safe option in the lottery task will lower the probability of revealing by 5%.

[11]Note: Reveal Decision is a dummy variable with Reveal Decision = 1 if participants reveal and 0 if not.

Dependent Variable	Reveal Decision made by participant				
	(1)	(2)	(3)	(4)	(5)
Unit Cost	-0.32**	-0.30**	-0.32**	-0.29**	-0.28**
	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Ability		-0.10		-0.10	-0.09
		(0.07)		(0.07)	(0.07)
Risk-averse			-0.05***	-0.05***	-0.05**
			(0.02)	(0.02)	(0.02)
Controls	No	No	No	No	Yes
N	168	168	168	168	168

*Note: Probit regression estimates. Controls include participant's gender, importance to maximize income, and understanding of instructions. Delta-method standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table 2.5 Reveal decision behaviour in Treatment 1

Our experiments reveal that the probability of revelation is higher when unit costs are lower (indicating absolute strength) compared to when unit costs are higher (indicating absolute weakness). One possible explanation is that at low marginal costs, participants gain confidence and seek to discourage their paired participants, leading to a higher probability of revelation. Conversely, when marginal costs are high, participants perceive this as a weakness, resulting in a lower probability of revelation. This explains the observed negative correlation. One possible explanation is that by disclosing private information, risk-averse participants may feel exposed to competitive disadvantages or strategic retaliation, leading to an increase in perceived risks. As a result, they are less likely to reveal information, which decreases the probability of revelation.

Additionally, we rationalise these decisions from behavioural point of view: Firstly, based

on 'Rational Choice Theory', individuals make decisions by comparing the costs and benefits of their actions. When marginal costs are low, the benefits of revealing this strength (discouraging competition) outweigh the risks, hence the probability increases. Conversely, high costs are seen as a weakness, and the benefits of hiding them (preventing opponents from gaining an advantage) outweigh the potential risks of revelation, hence the probability falls. Secondly, based on the work of Kahneman and Tversky (1979), people are risk-averse, especially when facing potential losses. Participants with higher costs may avoid revealing this information to prevent exacerbating their disadvantage. Our experiments indicated that participants with higher perceived risks or disadvantages are more likely to withhold information to protect their interests and therefore probability of revelation falls. And lastly, psychological theories, such as 'self-efficacy' theory by Bandura (1977), suggest that individuals with higher confidence in their abilities are more likely to share information about their strengths. Those with lower confidence are more likely to hide their weaknesses.

In conclusion, our findings in treatment 1, indicate that qualitatively, ability is inversely related with the probability to reveal. Participants probability of revelation is inversely related with their risk-aversion. Along with the 6.1 section of Ewerhart and Lareida (2024) the inverse relation between probability to reveal and unit cost, aligns with the rational choice and prospect theory, as well as psychological factors related to self-efficacy and confidence.

Similar to treatment 1, in Treatment 2 as well, full revelation is not always observed. Participant's probability to reveal their information in this setting are positively related to the other participant's unit cost when it is common knowledge. However, when controlling for participant's gender, the importance they place on maximizing income, and their understanding of the instructions, the relationship between probability of revelation and the other participant's unit cost becomes negative. The common knowledge of one participant's marginal cost allows the other participant to gauge their relative strength

during the revelation stage, influencing their own decision to reveal. This is explained in qualitative terms as it is not statistically significant.

In this context, we also observed that participants probability to reveal when their own marginal cost is higher, though it is not statistically significant. Qualitatively the relationships can be explained that when participants knew their costs were high, they might have chosen to reveal this information to pacify the other player. By revealing their higher costs, participants could signal a concession or a willingness to cooperate, thereby reducing the competitive tension and possibly deterring aggressive behaviour from their opponent. This strategic pacification helps reduce competitive pressure and might make the contest environment less hostile. Another explanation could be psychological and behavioural factors. Revealing a weakness in terms of marginal costs could be a tactic to invoke empathy or reduce the competitiveness of the opponent. Participants might hope that by showing their vulnerability, the other player will behave more sympathetically. Lastly, probability of revelation at higher marginal costs could be attributed to risk management. By revealing high marginal costs, participants might aim to manage their risk by avoiding a bidding war that they are likely to lose due to their higher costs. This behaviour aligns with risk aversion, where participants prefer to avoid the potential high costs of aggressive competition.

Qualitatively, there is a positive correlation between the probability of revelation and risk-averse behaviour in one-sided revelation which can be explained by the desire of risk-averse participants to reduce uncertainty. Knowing the opponent's private information might increase the perceived risks associated with keeping their own information hidden, as doing so could lead to greater unpredictability in the opponent's actions. By revealing their private information, risk-averse participants may aim to equalise the informational asymmetry, reducing potential disadvantages and bringing more transparency. This transparency can help them avoid outcomes that feel uncertain or too risky, explaining the higher probability of revelation among risk-averse individuals in this scenario.

To understand behaviour in Treatment 2, we ran a probit model with Revelation (Reveal Decision) as the dependent variable.[12] Across all regression models, we include a variable called 'Unit Cost' which refers to the unit cost assigned to participant. From Models (2) to (4), we additionally include a variable called 'Other Cost Common Knowledge' which takes the value of other's cost if other's cost is common knowledge and equals zero if other's cost is not publicly known. Model (2) is augmented by adding independent variables called 'Other Cost Common Knowledge' and 'ability' which measures the assigned ability, i.e., high (4) or low (3). In Model (3), we additionally add 'Risk aversion' as an independent variable, which measures the number of safe options in our lottery task. Model (4) includes both 'Ability' and 'Risk aversion' and the last model controls for the participant's gender, the importance placed on maximizing income, and their understanding of the instructions, in addition to the independent variables from Model (4). The analysis showed a positive relationship between revelation and unit cost, indicating that as participant's unit costs increase by one unit, participants are around 30% more likely to reveal their costs. Additionally, while common knowledge of other participant's unit costs initially shows a positive relationship with the probability of revelation in the first three regressions of Table 2.6, this relationship turns negative when controlling for participant's gender, the importance they place on maximizing income, and their understanding of the instructions. However, the results were not statistically significant. Qualitatively the trend indicates that higher own marginal costs, higher costs of the paired participant (without controls), and lower costs of the paired participant (with controls) lead to increased probability of revelation. Additionally, qualitatively, a one-unit increase in ability and risk aversion leads to an 8-9% and 3-4% increase in the probability of revelation, respectively.

[12]Reveal Decision is a dummy variable with Reveal Decision = 1 if participants reveal and 0 if not.

Dependent Variable	Revelation made by participant				
	(1)	(2)	(3)	(4)	(5)
Unit Cost	0.28	0.29	0.30	0.31	0.24
	(0.20)	(0.20)	(0.20)	(0.19)	(0.20)
Other Cost Common Knowledge		0.01	0.01	0.02	-0.02
		(0.20)	(0.20)	(0.20)	(0.19)
Ability		0.09		0.08	0.09
		(0.11)		(0.11)	(0.11)
Risk Averse			0.04	0.04	0.03
			(0.03)	(0.03)	(0.03)
Controls	No	No	No	No	Yes
N	75	75	75	75	75

*Note: Probit regression estimates. Controls include participant's gender, importance to maximize income, and understanding of instructions. Delta-method standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table 2.6 Reveal decision behaviour in Treatment 2

To summarise the behaviour in Treatment 2, where participants with high costs revealed their costs more frequently, can be understood as a strategic move to pacify the opponent and reduce competitive tension. This aligns with both psychological tactics and risk management strategies. Additionally, the positive relationship between risk aversion and the probability of revelation can be explained by risk-averse participant's desire to reduce uncertainty and thus avoiding risky outcomes. The probit model supports this trend, though the results are not statistically significant.

2.5.3 Bidding of Participants In Baseline Settings

Our experiments aimed to understand how participants bids (or investment level) responded to changes in unit costs.[13] In the baseline treatment, no revelation of private information was allowed. However, in Treatment 1, we looked at bids where two-sided revelation of private information was allowed, and in Treatment 2, we focused on bids with one-sided revelation. Given the ex-ante differences in abilities in a pair, we specifically explored how these initial ability disparities influenced the investment levels in the contest. Note that the actual overall and individual investment levels for each cost values are shown in the Appendix B.1 and B.2. Comparison of average investment levels overall and by ability both between and within settings are explained in the next section.

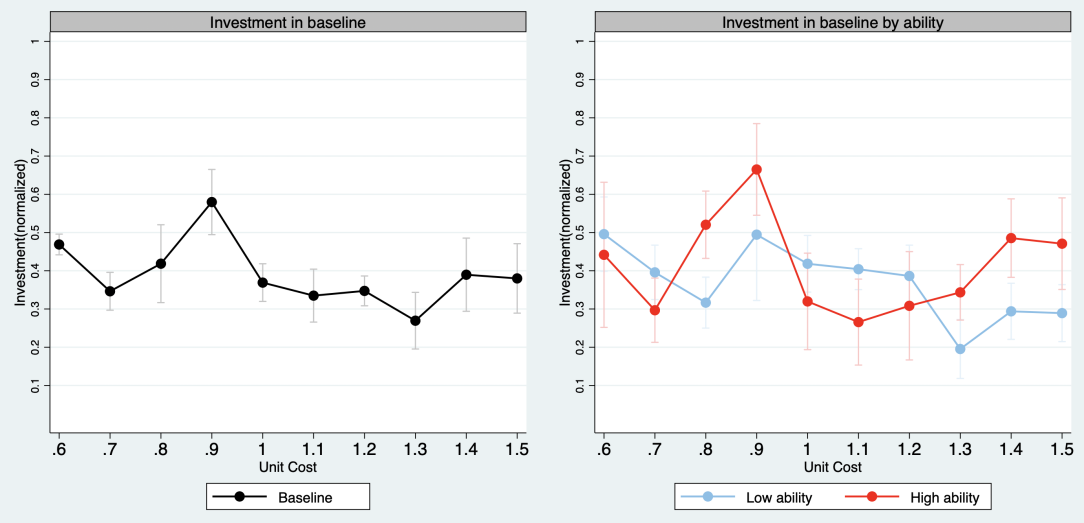

Figure 2.4 Investment Bids Responses with Cost in No-Disclsoure Setting

[14]

We first explain the above Figure 2.4 qualitatively, then we will delve deep into the regressions. On the left side, we explored how overall investment levels varies in the baseline as unit cost changes, while on the right side, we analysed how investment levels of different ability participants varies with varying costs. Qualitatively, the right-hand diagram shows that at lower costs, low-ability participants tend to invest more than high-ability

[13]Note the investment level is normalized by the value of the prize.
[14]Mean investment for each cost is shown in the Appendix B.1 and B.2.

participants, possibly anticipating that ex-post cost differences might mitigate the initial ability gap. However, as costs increase, low-ability participants become more aware of the compounded disadvantages of lower ability and higher costs, leading to a reduction in their investment compared to high-ability participants. In contrast, high-ability participants start with lower bids at low costs but increase their investment as costs rise, resulting in the intersection of the average investments of different ability participants as depicted in the left diagram of Figure 2.4.

In Table 2.7 below, we present the results of a linear regression analysis with overall average normalized investment as the dependent variable.[15] From now on, refer normalized investment as investment. Across all regression models, we include a variable called 'Unit Cost' which refers to the unit cost assigned to participant. Model (2) is augmented by adding an independent variables called 'ability' which measures the assigned ability, i.e., high (4) or low (3). In Model (3), we additionally add 'Risk aversion' as an independent variable, which measures the number of safe options in our lottery task. Model (4) includes both 'Ability' and 'Risk aversion' and the last model (5) adds controls along with the independent variables as defined earlier from Model (4). Although no significant results were observed, the coefficients qualitatively indicate that Unit Cost and Risk Aversion are negatively related to investment levels, while Ability is positively related to investment. One unit increase in the unit cost will decrease the investment by around 0.01 points and high-ability participants will invest 0.03 points more than the low-ability ones. Finally, one more choice of safe option in the lottery task will decrease investment by 0.01 points. [16] Additionally, we conducted further regressions by each ability. The results showed that the average investment level of low-ability participants decreases as costs rise, with this relationship being statistically significant. In contrast, while the in-

[15]In this chapter, the investment level is rescaled by dividing it by the prize value $V = 120$ (which is also the endowment size) to obtain the normalized investment, following the approach used in Brookins and Ryvkin (2014).

[16]Without normalization, a one-unit increase in the unit cost decreases investment by approximately 12 points (0.10×120). High-ability participants invest about 3.6 points more (0.03×120) than low-ability participants. Additionally, each additional selection of the safe option in the lottery task reduces investment by 1.2 points (0.01×120).

vestment levels of high-ability participants did not show statistically significant results, there is a qualitative indication of a positive relationship with increasing costs. The detailed regression results by ability are presented in the Appendix B.3.

Dependent Variable	Investment Level of Participants				
	(1)	(2)	(3)	(4)	(5)
Unit Cost	-0.10	-0.09	-0.10	-0.09	-0.09
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
Ability		0.03		0.03	0.03
		(0.04)		(0.04)	(0.04)
Risk Averse			-0.01	-0.01	-0.01
			(0.01)	(0.01)	(0.01)
Constant	0.48**	0.36**	0.53***	0.41**	0.20
	(0.09)	(0.18)	(0.09)	(0.18)	(0.19)
Controls	No	No	No	No	Yes
N	162	162	162	162	162

*Note: OLS estimates. Controls include participant's gender, importance to maximize income, and understanding of instructions. Robust standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table 2.7 Regression Analysis of Investment Bids in Baseline

2.5.4 Bidding of Participants In Treatment 1 Settings

In this section, we study how the average overall investment level and average investment level of different ability participants changes with variations in participants unit costs in treatment 1. As mentioned before, the investment are normalized investment.[17] Unlike the baseline, in Treatment 1, both participants have the opportunity to reveal their private information. Our goal is to understand how the revelation of information influences the

[17]Normalized Investment is Actual Investment divided by V.

average investment level when participants face different unit costs in a one-shot contest game.

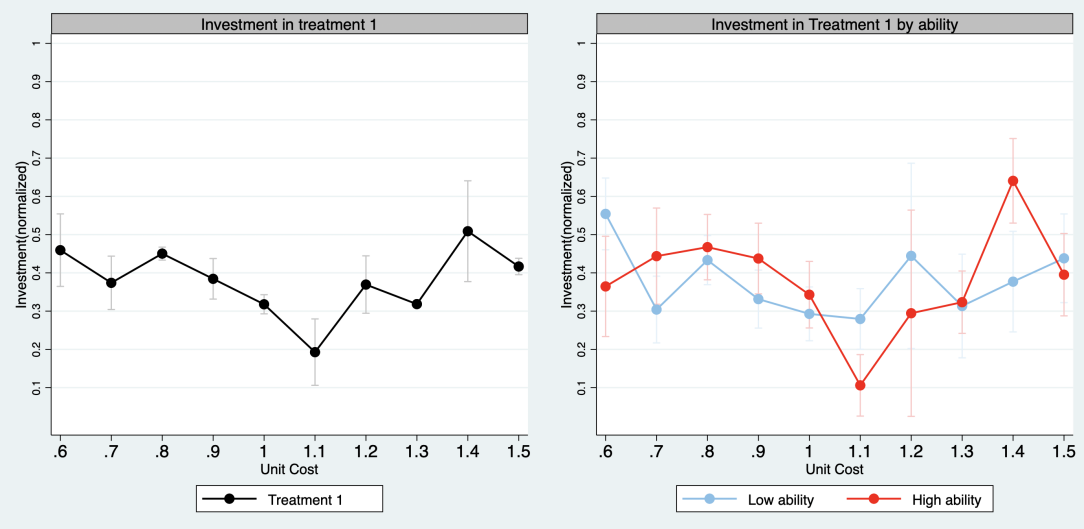

Figure 2.5 Investment Bids Responses with Cost in Two-sided Disclosure Setting.

18

We begin by qualitatively explaining Figure 2.5 before discussing the regression analysis in detail. On the left side, we showed how overall investment levels in the treatment 1 vary as unit costs change, while on the right side, we analysed how investment levels differ by participant ability across varying costs. In the left-hand diagram, the average investment curves of high-ability and low-ability participants intersect. Additionally, the overall investment levels on the right-hand side show a slight decreasing trend in response to changes in unit cost (see Table 2.8 below).

In Table 2.8 below, we present the results of a linear regression analysis where the dependent variable is average investment. Across all regression models, we include a variable called 'Unit Cost' which refers to the unit cost assigned to participant. From Models (2) to (5), we additionally include two independent variables called 'Reveal Decision' which takes value of 1 if decided to reveal and equals to zero if not and an interaction term between 'Other Unit Cost' and 'Other reveal decision' which measures the other's unit cost when the other paired participant decided to reveal. If the other paired participant

[18]Mean investment for each cost is shown in the Appendix B.1 and B.2.

decides to reveal it will take 1 otherwise 0. Model (2) is augmented by adding an independent variable called 'ability' which measures the assigned ability, i.e., high (4) or low (3). In Model (3), we additionally add 'Risk aversion' as an independent variable, which measures the number of safe options in our lottery task. Model (4) includes both 'Ability' and 'Risk aversion' and the last model (5) controls for the participant's gender, the importance placed on maximizing income, and their understanding of the instructions, in addition to the independent variables from Model (4).

Although the results are not statistically significant, we interpret them qualitatively for overall investment levels. As shown in Models (2) and (5), the coefficients of 'Reveal Decision' is positive and statistically significant at 10% level. This shows that those who revealed their costs will invest 0.08 points more of their endowments, i.e., experimentally, approx 10 (120×0.08) points than those who hid their costs. Participants were more likely to choose revelation over non-revelation, suggesting an awareness of their relative strength in the contest. Higher unit costs increase the cost of investment, which negatively impacts participants investment decisions. However, when the paired participant's unit cost is revealed, participants tend to bid more aggressively, particularly if they perceive the opponent's cost to be high. The data aligns with our expectations, indicating that while unit costs and risk aversion negatively influence investment levels, the decision to reveal information, the revealed unit cost of the paired participant, and ability positively affect investment. The regressions of average investment levels by ability are shown in the Appendix B.4. Qualitatively, the investment levels of low-ability participants show a negative relationship with unit cost. For high-ability participants, their investment levels also display a negative relationship with unit cost when it is the only independent variable. However, when other independent variables—such as the reveal decision, the other participant's unit cost when revealed, and risk aversion—are included, the relationship becomes positive, though these results are not statistically significant.

Dependent Variable	Investment Decision made by participant				
	(1)	(2)	(3)	(4)	(5)
Unit Cost	-0.05	-0.03	-0.02	-0.03	-0.02
	(0.08)	(0.09)	(0.09)	(0.09)	(0.09)
Reveal Decision		0.08*	0.07	0.07	0.08*
		(0.05)	(0.05)	(0.05)	(0.04)
Other Unit Cost * Other reveal Decision		0.02	0.02	0.02	0.03
		(0.04)	(0.04)	(0.04)	(0.04)
Ability		0.02		0.02	0.01
		(0.05)		(0.05)	(0.05)
Risk Averse			-0.01	-0.01	-0.02
			(0.01)	(0.01)	(0.01)
Constant	0.43***	0.26	0.40***	0.32*	0.46**
	(0.09)	(0.18)	(0.11)	(0.18)	(0.23)
Controls	No	No	No	No	Yes
N	168	168	168	168	168

*Note: OLS estimates. Controls include participant's gender, importance to maximize income, and understanding of instructions. Robust standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table 2.8 Regression Analysis of Investment Bids in Treatment 1

2.5.5 Bidding of Participants In Treatment 2 Settings

In this scenario, one participant is randomly selected, and their cost is made common knowledge, while the other participant is given the opportunity to reveal their cost. We aim to understand how one-sided revelation and common knowledge on the other side impact investment levels when participants face different unit costs.

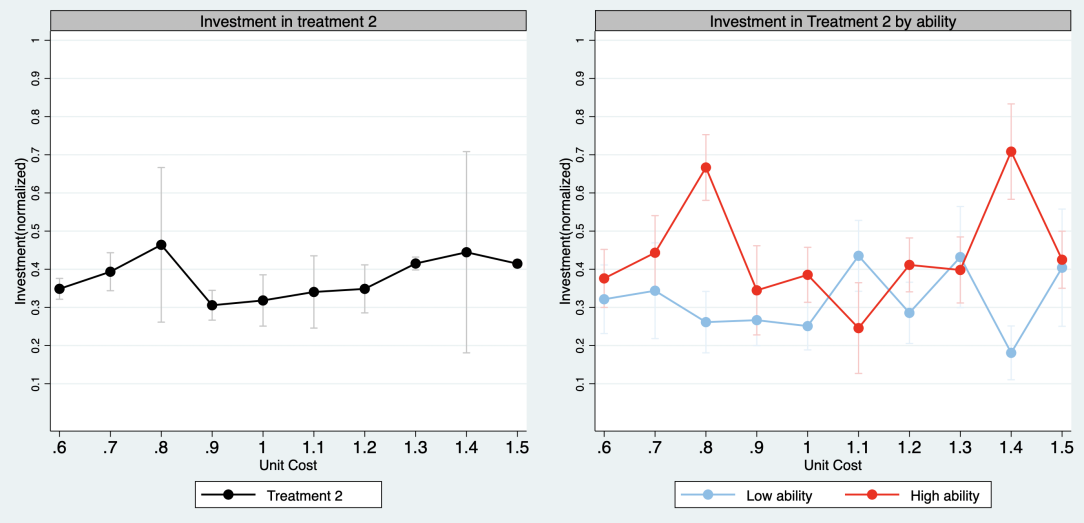

Figure 2.6 Investment Bids Responses with Cost in One-sided Disclosure Setting.

[19]

In this setting, qualitatively we observe that both the average investment level and the individual investment levels by ability are positively related to unit costs. In this setting we observe that for almost all unit costs, the investment level for high ability participants are above the investment level for low ability participants. However taking additional independent variables like Reveal Decision, Unit Cost of other participant when it is revealed or common knowledge shows a negative relationship between overall investment level and unit costs, as shown in Table 2.9.

In Table 2.9, we present the results of a linear regression analysis with average investment as the dependent variable. By investment we mean normalized investment. Across all regression models, we include a variable called 'Unit Cost' which refers to the unit cost assigned to participant. From Models (2) to (5), we additionally include two independent variables called 'Reveal Decision' which takes value of 1 if decided to reveal and equals to zero if not and an interaction term between 'Other Unit Cost' and 'Other reveal decision' which measures the other's unit cost when the other paired participant decided to reveal. If the other paired participant decides to reveal it will take 1 otherwise 0. In this treatment, the 'Other reveal decision' also encompasses the common knowledge of a

[19]Mean investment for each cost is shown in the Appendix B.1 and B.2.

participant's unit cost in the pair and is set to 1. Model (2) is augmented by adding an independent variables called 'ability' which measures the assigned ability, i.e., high (4) or low (3). In Model (3), we additionally add 'Risk aversion' as an independent variable, which measures the number of safe options in our lottery task. Model (4) includes both 'Ability' and 'Risk aversion' and the last model (5) adds additional controls along with the independent variables as defined earlier from Model (4). The regressions on the average investment levels by individual abilities are shown in the Appendix B.5. We observe that for low-ability participants, the average investment level is positively related to unit cost when it is the only independent variable considered. However, after accounting for additional independent variables and controls, this relationship turns negative. In contrast, for high-ability participants, the relationship between investment and unit cost is initially negative without controls, but becomes positive once controls are included in the regression.

Although the results are not statistically significant, we interpret them qualitatively for overall investment levels. First, we find that the coefficients of 'Reveal Decision' are negative though not statistically significant. This reverses our finding in Treatment 1 where 'Reveal decision' is positively correlated with investment level. In Treatment 2, participants who revealed their costs invest 0.01 to 0.03 points (i.e., experimentally 1.2 to 3.6 points) less than those who hided their costs. Participants were more likely to choose revelation over non-revelation, suggesting an awareness of their relative strength in the contest. Higher unit costs increase the cost of investment, which negatively impacts participant's investment decisions. However, when the paired participant's unit cost is revealed, participants tend to bid more aggressively, particularly if they perceive the opponent's cost to be high. The data aligns with our expectations, indicating that while unit costs, other participant's unit cost when known and risk aversion negatively influence investment levels, the decision to reveal information and ability positively affect investment. The reveal decision in this treatment reflects both the common knowledge of participant's costs and their choice to reveal information. One possible explanation

for the negative relationship with investment is that participants who have their costs publicly known may reduce their investment, perceiving themselves to be at a strategic disadvantage. However, this relationship is not statistically significant.

Dependent Variable	Investment Decision made by participant				
	(1)	(2)	(3)	(4)	(5)
Unit Cost	0.14	-0.06	-0.05	-0.05	-0.03
	(0.08)	(0.10)	(0.10)	(0.10)	(0.10)
Reveal Decision		-0.01	-0.02	-0.03	-0.02
		(0.06)	(0.06)	(0.06)	(0.06)
Other Unit Cost * Other reveal Decision		0.03	0.03	0.04	0.03
		(0.10)	(0.10)	(0.10)	(0.10)
Ability		0.08		0.08	0.07
		(0.06)		(0.06)	(0.06)
Risk Averse			0.03	0.02	0.03
			(0.02)	(0.02)	(0.02)
Constant	0.35***	0.13	0.33*	0.04	0.07
	(0.08)	(0.22)	(0.14)	(0.24)	(0.26)
Controls	No	No	No	No	Yes
N	75	75	75	75	75

*Note: OLS estimates. Controls participant's gender, importance to maximize income, and understanding of instructions. Robust standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table 2.9 Regression Analysis of Investment Bids in Treatment 2

In the next section, we will compare average investment levels overall and by ability, both across and within different settings. Note that, as in Subsections 2.5.6–2.5.13, 'investment' refers to normalized investment, calculated by dividing the actual investment by the prize value. Similarly, expected payoffs are also normalized due to the normalization of investment. For instance, if normalized investment is 0.01, the actual investment

is $0.01 \times 120 = 12$ units. Likewise, if the expected payoff is 1.21, the actual payoff is $1.21 \times 120 = 145.2$ points.

2.5.6 Comparison of Investment, Probability of Winning, and Expected Payoff Across Treatments.

In our chapter, we defined the baseline scenario as a situation with incomplete information, where participants does not had the opportunity to reveal their private information about marginal costs. In Treatment 1, both participants were given the opportunity to reveal their private information. In Treatment 2, one participant was randomly selected, and their cost was made public, while the other participant was given the opportunity to reveal their private information.

Our experiment compared investment levels, the probability of winning, and expected payoffs across treatments using a one-sided t-test. The results indicated no significant differences in these variables across the treatments. Although the statistical results were not significant, qualitatively the data in the Table below suggest a trend where investment levels decrease from the baseline to Treatment 1 and further decrease in Treatment 2.

One possible explanation for this behaviour is that the opportunity to reveal marginal costs in treatment 1 and 2 have led participants (see Hypothesis 2 above) to disclose their cost information more frequently. As a result, during the contest stage, participants in treatment 2 had the most information about their relative strength, followed by those in treatment 1, and then participants in the baseline. This may lead participants in any pair to exert the lowest effort levels in treatment 2, followed by treatment 1, and then the baseline. In any pair in treatment 1 and treatment 2, the participant with higher relative strength in terms of cost might discourage their counterpart and therefore exert less effort in the contest, while the participant with lower relative strength might be discouraged and also exert less effort.

Additionally, the probability of winning remains consistent across all treatments, which is expected since the probabilities within each pair sum to 1. The expected payoffs increases across the treatments, which could be attributed due to the cost of investment and the investment itself. It further shows that expected payoffs would increase with more information available.

	Treatment		
	Baseline	Treatment 1	Treatment 2
Investment	0.39	0.38	0.36
	(0.28)	(0.30)	(0.26)
Probability of Winning	0.5	0.5	0.5
	(0.32)	(0.33)	(0.32)
Expected Payoff	1.10	1.11	1.12
	(0.30)	(0.33)	(0.29)
N	162	168	150

Notes: Standard deviations in parentheses

Table 2.10 Overall Descriptive Statistics of Investment, Probability of Winning, and Expected Payoff

2.5.7 Comparison of Investment, Probability of Winning, and Expected Payoff Across Treatments by Ability.

Similar to comparing the investment levels, probability of winning and expected payoffs for participants across treatments, we now do same comparison by abilities across treatments. Specifically, we examined how low-ability participants (ability level 3) and high-ability participants (ability level 4) behaved differently across the baseline and treatments. To explore this, we conducted one-tailed t-tests.

Our analysis revealed that for ability level 3, investment is higher in Treatment 1 compared to Treatment 2, with this difference being weakly significant. However, other comparisons of investments across treatments by ability yielded insignificant results. Despite the lack of strong statistical significance, we can still explain the results qualitatively.

Looking at Table 2.11, we observe for ability level 3 participants, investment is highest in Treatment 1, followed by the baseline, and then Treatment 2. In the two-sided opportunity to reveal (Treatment 1), participants with ability level 3 appear to gain confidence and invest more. In Treatment 2, when one participant's cost is common knowledge and the other participant has the opportunity reveal, investment of ability 3 participant decreases over all. In treatment 2, the average investment level of ability 3 participants includes both their investment when they have the opportunity to reveal their marginal cost information and when this information is common knowledge. One possible reason for the overall decrease in the investment level of ability 3 participants in treatment 2 could be linked to their investment decisions when their marginal cost is common knowledge. The decision to invest during the contest stage may be influenced by several factors: the common knowledge of a participant's own marginal cost, the revelation decision of their paired opponent, and, if disclosed, the opponent's unit cost. For example, if a low-ability participant's marginal cost is common knowledge, they might reduce their investment, perceiving themselves to be at a disadvantage due to the potential revelation decision of their paired opponent.

In contrast, for ability level 4 participants, the average investment is highest in treatment 2, then treatment 1 followed by baseline. Common knowledge of marginal costs of ability 4 participant in Treatment 2 appears to increase their average investment levels. This suggests a different strategic response between low-ability and high-ability participants when their costs become public knowledge.

We now focus on the probability of winning and the expected payoffs of participants based

on their abilities. Given that we already know the participant's average investment levels, this allows us to explain their effects on the probability of winning and expected payoffs. We compared the probability of winning across treatments by ability and observed that, for participants with ability level 4, the probability of winning in the treatment 2 was higher compared to baseline. The p-value = 0.033 indicates statistical significance at the 5% level. Other comparisons did not yield statistically significant results. However, we try to explain the trends of probability of winning by abilities across treatments below

For participants with ability level 3, the probability of winning is highest in the baseline, followed by treatment 1, and then treatment 2. Conversely, for participants with ability level 4, the probability is highest in treatment 2, followed by the baseline, and then treatment 1. Comparing the baseline and treatment 1, mentioned above we observed that the average investment level for participants with ability level 3 increases, while it decreases for those with ability level 4. However, the investment level for ability level 4 participants remains higher than that of ability level 3 participants, leading to a reduction in the probability of winning for ability level 3 and an increase for ability level 4.

We now compare the average investment levels between treatment 2 and the baseline, as well as between treatment 1 and treatment 2. Among all groups, treatment 2 has the highest investment for ability 4 and lowest for ability 3, leading to a highest probability of winning for high-ability subject and lowest for low-ability ones.

Now focusing on the expected payoffs: The probability of winning has a positive effect on the expected payoffs of participants while the cost of investment decreases it. We observed that the expected payoffs for high-ability participants are higher in treatment 2 compared to the baseline. This difference is statistically significant at the 5% level, with a p-value = 0.02. For participants with ability level 3, the expected payoffs are highest in treatment 2, followed by the baseline, and then treatment 1. For participants with ability level 4, the highest expected payoffs occur in treatment 2, followed by treatment

1, and then the baseline.

	Treatment					
	Baseline		Treatment 1		Treatment 2	
	Ability 3	Ability 4	Ability 3	Ability 4	Ability 3	Ability 4
Investment	0.36	0.40	0.37	0.39	0.31	0.42
	(0.25)	(0.32)	(0.29)	(0.31)	(0.25)	(0.26)
Probability of winning	0.47	0.53	0.45	0.55	0.39	0.61
	(0.32)	(0.32)	(0.33)	(0.33)	(0.30)	(0.30)
Expected Payoff	1.09	1.10	1.08	1.14	1.05	1.18
	(0.32)	(0.29)	(0.32)	(0.33)	(0.29)	(0.28)
N	81	81	84	81	75	75

Notes: Standard deviations in parentheses

Table 2.11 Descriptive Statistics of Investment, Probability of Winning, and Expected Payoff by Ability.

2.5.8 Comparison of Investment, Probability of Winning, and Expected Payoff Within Treatments by Ability.

In this section, we compare the investment levels, probability of winning, and expected payoffs of participants by ability within the baseline and treatments. Referring to Table 2.11 above, we observe that the average investment levels for participants with ability 4 are higher compared to those with ability 3. While we did not find significant differences in the baseline and treatment 1, but treatment 2 yielded a p-value = 0.006, which is significant at the 1% level.

One possible explanation is that high-ability participants may invest more to capitalise on their competitive advantage over low-ability participants. Additionally, high-ability participants might perceive the contest as less risky due to their higher probability of

success, making them more willing to invest heavily. They likely view the contest as a safer bet compared to low-ability participants, who face greater risks of losing.

We next compare the probability of winning for participants of different abilities in the baseline and the treatments. We generally observe that the probability of winning is higher for high-ability participants compared to low-ability participants. While the result is not statistically significant for the baseline, it is significant for treatment 1 and treatment 2, with p-values = 0.02 and 0.0002, respectively, indicating significance at the 5% and 1% levels. These results directly reflect the investment levels of ability 4 and ability 3 participants, as previously noted, where the average investment level is higher for ability 4 participants compared to ability 3 participants.

Lastly, we focus on the expected payoffs for ability 3 and ability 4 participants within the baseline and the two treatments. We observe that, in the baseline, the expected payoff for ability 4 participants is lower than that for ability 3 participants. However, in treatment 1 and treatment 2, the expected payoff for ability 4 participants exceeds that of ability 3 participants. Although the results for the baseline and treatment 1 are not statistically significant, the result for treatment 2 is statistically significant at the 10% level.

One explanation for the lower average expected payoff for ability 4 participants compared to ability 3 participants in the baseline could be the cost of investment, i.e., the unit cost times the investment. Since unit costs are randomly allocated to participants in a pair, it is possible that the unit cost incurred by ability 4 participants was higher than that of ability 3 participants. Additionally, the difference in the average probability of winning between ability 3 and ability 4 participants may not be significantly different from zero, leading to a reduction in the expected payoff for ability 4 participants. In treatment 1, although the probability of winning does not significantly differ by ability, the average expected payoff still maintains the ordinal ranking. Lastly, the stark difference in the probability of winning between ability 3 and ability 4 participants in treatment 2

is reflected in the expected payoff difference, which is weakly significant.

2.5.9 Comparison of Investment, Probability of Winning, and Expected Payoff Across Treatments by Revelation.

In this section, we focused on understanding the revelation decisions across treatments, particularly examining whether there are differences between treatment 1 and treatment 2 in terms of investment levels, probability of winning, and expected payoffs based on revelation and non-revelation.

With revelation, we observe in Table 2.12 that the average investment level and probability of winning are higher in treatment 1 than in treatment 2. However, the average expected payoff is greater in treatment 2 than in treatment 1. Despite these observations, none of the differences are statistically significant. One possible explanation for these insignificant results could be that, with revelation, participants in both treatment 1 and treatment 2 have complete information at the contest stage, leading to similar behaviour.

With non-revelation in Table 2.12, the average investment level, probability of winning, and expected payoff are higher in treatment 2 than in treatment 1. While the difference in investment levels is not statistically significant, the differences in the probability of winning and expected payoffs are significant at the 5% and 10% levels, with p-values = 0.04 and 0.06, respectively. Even though the difference in average investment is not significant, the trend suggests that in treatment 2, even without revelation, the common knowledge of marginal costs provides participants with more information at the contest stage compared to treatment 1. This additional information allows them to bid more, increasing their probability of winning and leading to higher expected payoffs.

	Treatment			
	Treatment 1		Treatment 2	
	Revelation	Non-Revelation	Revelation	Non-Revelation
Investment	0.41	0.33	0.38	0.40
	(0.31)	(0.28)	(0.25)	(0.26)
Probability of winning	0.51	0.48	0.55	0.58
	(0.32)	(0.35)	(0.30)	(0.34)
Expected Payoff	1.10	1.13	1.14	1.21
	(0.33)	(0.32)	(0.31)	(0.30)
N	96	72	40	35

Notes: Standard deviations in parentheses

Table 2.12 Descriptive Statistics of Investment Levels, Probability of Winning, and Expected Payoffs by Revelation Across Treatments

2.5.10 Comparison of Investment, Probability of Winning, and Expected Payoff within Treatments by Revelation.

Now, we explore the effects of revelation and non-revelation on investment, probability of winning, and expected payoff within treatment 1 and treatment 2. In treatment 1, we observe in Table 2.12 that the average investment with revelation is greater than that with non-revelation, with a p-value = 0.04, indicating significance at the 5% level. However, in treatment 2, where one participant's marginal cost is common knowledge, there is no significant difference between the average investment level with and without revelation. Interestingly, the ordinal ranking shows that the average investment is higher without revelation than with revelation. This could be due to the fact that in treatment 2, we considered average investment with one-sided revelation, while the other participant's cost is common knowledge. Participants may choose not to reveal their own marginal cost and instead exert higher investment to win the contest when armed with common

knowledge.

For the probability of winning, the ordinal ranking in treatment 1 shows that participants have a higher probability of winning with revelation than without, although this result is not statistically significant. This trend may be explained by participants exerting higher investments with revelation. In treatment 2, the probability of winning is higher without revelation than with revelation, which is consistent with the ordinal ranking of investment levels. This result is statistically significant at the 10% level, with a p-value = 0.09.

Regarding expected payoffs, treatment 1 does not show statistically significant results. However, the higher probability of winning with revelation translates into a higher expected payoff compared to non-revelation. In treatment 2, the probability of winning is higher without revelation than with revelation, leading to a higher expected payoff in the non-revelation condition. This difference is statistically significant at the 5% level, with a p-value = 0.037.

2.5.11 Impact of Revelation by Low-Ability Participants on Investment, Winning Probability, and Payoffs in Treatment 1

Proposition 1 of Ewerhart and Lareida (2024) states that in a uniformly asymmetric contest if the low-ability player has at least two possible type realisations, a unilateral disclosure by the low-ability player facing the highest marginal cost, induces a strict increase in efforts compared to non-disclosure. Consequently, after revealing their relative weakness in terms of costs, the low-ability player with the highest cost behaves as if they have gained confidence. They bid more aggressively and win with a strictly higher probability. Moreover, this self-disclosure is always strictly beneficial for them. In our

experiment we aim to understand impact of revelation decision of low-ability participants on investment, probability of winning, and expected payoffs compared to non-revelation, when the contest is not uniformly asymmetric.

In Treatment 1 of our experiment, participants had the option to reveal their types. We first focused on understanding the behaviour of the low-ability participant facing the highest cost. We conducted a t-test (see results on Table 2.13) to compare the normalized investment (i.e., investment divided by the size of the prize), probability of winning, and expected payoff with and without the revelation of the high cost by the low-ability participant.[20] As predicted by the theory, the effort or investment level of the low-ability player incurring the highest cost increases with revelation, and this increase is statistically significant at the 5% level. Similarly, the probability of winning with revelation is weakly significant at the 10% level. Given the small sample size, we observed a notable difference in effect size. Specifically, when the low-ability participants incurring the highest cost reveals their decision, their probability of winning rises to 80%, compared to just 36% when they choose not to reveal it. This highlights the considerable impact of decision revelation, even with a limited sample. However, the expected payoff decreases with revelation, though this decrease is not statistically significant. Since most participants in the experiment overbid, we can infer that for low-ability players incurring the highest cost, this behaviour becomes costly, leading to an increase in the cost of investment and a reduction in overall payoffs. In the next paragraph, we will explore whether this hypothesis holds for other marginal costs of low-ability players.

[20]Note that in our model, there are 10 possible cost realisations, with the highest cost in the interval being 1.5.

	Investment	probability of winning	expected payoff
Revealation	0.68	0.8	0.74
	(0.42)	(0.37)	(0.46)
Non-Revelation	0.25	0.36	0.98
	(0.24)	(0.52)	(0.24)
Revelation vs Non-revelation (p-values)	0.04	0.08	0.76
N (combined)	7	7	7

Notes: Standard deviations in parentheses. In all columns we compared revelation - non-revelation > 0

Table 2.13 Decisions of low ability participants incurring the highest cost in Treatment 1 at Contest stage

To understand the investment decision and its effect on probability of winning and expected payoffs of all possible cost realised low-ability players in treatment 1, we conducted a one-sided t-test with equal variances to compare mean investments between the non-revelation and revelation conditions. We found that the mean investment was lower under the non-revelation condition compared to the revelation condition. This difference was weakly significant at the 10% level with p-value = 0.066. Although the probability of winning increased with revelation for players of ability 3, this change was not statistically significant. Additionally, the expected payoffs for ability 3 players decreased with revelation qualitatively not statistically.

	Investment	probability of winning	expected payoff
Revealation	0.41	0.46	1.07
	(0.37)	(0.37)	(0.32)
Non-Revelation	0.31	0.43	1.11
	(0.37)	(0.55)	(0.33)
Revelation vs Non-revelation (p-values)	0.06	0.30	0.71
N (combined)	84	84	84

Notes: Robust standard deviations in parentheses. In all columns we compared revelation - non-revelation > 0

Table 2.14 Decisions of low ability participants in Treatment 1 at Contest stage

Our results (from Table 2.4) indicate that in general participants revealed their types more frequently than not in Treatment 1, and this difference is statistically significant. We explain our findings step by step. One possible explanation increase in investment levels and probability of winning is that revelation increases transparency about each participant's marginal costs, leading to heightened competitive pressure. Both high-ability and low-ability participants may feel compelled to invest more to secure their advantage. This is supported by our post-experiment questionnaire, where a large proportion of participants expressed a desire to maximize their income. This competitive escalation drives up investment levels, even though it might not proportionately increase the probability of winning due to similar aggressive responses from both participants in the pair. Therefore, for treatment 1, the overall trend in observations shows an increase in probabilities for both players due to increased investment. However, this increase is not statistically significant. The decrease in expected payoffs for both players can be explained by the possibility that, with revelation, participants perceive higher risks and uncertainties regarding their opponent's strategies. This uncertainty can drive them to invest more as a precaution, aiming to hedge against potential losses. However, this risk-averse behaviour increases costs without guaranteeing a win, thereby reducing expected payoffs. Finally,

participants might misalign their strategies, overestimating the importance of investment over other factors like abilities that influence winning probabilities. Since it is a one-round contest game, there is no opportunity for learning behaviour. This misalignment leads to excessive investment without a corresponding increase in the probability of winning, ultimately reducing net payoffs.

2.5.12 Impact on Investment for Low-Ability Participants When Their Cost is Common Knowledge and High-Ability Has the Option to Reveal

In Treatment 2, both participants are assigned their respective abilities of 4 and 3 at the start of the experiment. Subsequently, marginal costs are randomly allocated to the participants. One participant is chosen at random, and their cost is made common knowledge, while the other participant can choose whether to reveal their cost. In this case, we will discuss the scenario where the marginal cost of the ability 3 participant is common knowledge, and the ability 4 participant has the opportunity to reveal their cost. According to Proposition 2 in Ewerhart and Lareida (2024) paper, in a uniformly asymmetric contest, when the marginal cost of the low-ability player is public information and the high-ability player has at least two possible marginal cost realisations, a unilateral disclosure by the strongest type (i.e., lowest marginal cost) of the high-ability player leads to a reduction in the effort of the low-ability player compared to when the high-ability players marginal cost is not revealed. In simple terms, the theory states that if the marginal cost of the low-ability player is public, then self-revelation by a high-ability player with the lowest cost discourages the low-ability player, leading to reduced effort exertion by the low-ability player. Additionally, Ewerhart and Lareida (2024) state that if only one participant is privately informed, the assumption of uniform asymmetry is typically not necessary to achieve full revelation as the unique equilibrium outcome.[21] Therefore, we wanted to see whether Proposition 2 of Ewerhart and Lareida (2024) still holds even when

[21]See Theorem 2 of Ewerhart and Lareida (2024).

the contest is not uniformly asymmetric. Therefore, we sought to explore this hypothesis experimentally.

In our experimental results (see Table 2.15), we observed that when ability 3 participants cost is public information then they increase their investments when ability 4 for all realised marginal costs reveals their marginal cost as compared to non-revelation. This is also true when ability 4 participants are incurring the lowest cost. However, this increase in investments for participants with ability 3 is not statistically significant. However, it could be argued that our results lack sufficient convincing power, as the sample size in this case is only 4. However, there are a few possible reasons for this behaviour. One could be that the revelation of the ability 4 participant's cost provides the ability 3 participants with more information, enabling them to better estimate the effort required to compete. This additional information might lead them to increase their investments to match or exceed the perceived effort of the ability 4 participant. Second, with the marginal cost of the ability 4 participant revealed, the ability 3 participants may feel there is less uncertainty and risk involved in their investment decisions. This perceived reduction in risk could lead to a slight increase in their investments. Lastly, psychological factors such as competitiveness or a desire not to be perceived as weak might motivate ability 3 participants to increase their investments when they have more information about their opponent's costs. These are some potential reasons why ability 3 participants might increase their investments when the ability 4 participants reveal their marginal cost, despite the increase not being statistically significant.

	Investment, when other cost =0.6	Investment (overall)
Revealation	0.08	0.32
	(0.12)	(0.06)
Non-Revelation	0.04	0.23
	(0.05)	(0.05)
Revelation vs Non-revelation (p-values)	0.66	0.85
N (combined)	4	40

Note: Standard deviations in parentheses. In all columns, we compared revelation - non-revelation < 0

Table 2.15 Decisions of low ability participants in Treatment 2 at Contest stage

2.5.13 Impact of High-Ability Participants Revelation Decision on Investment, Probability of Winning, and Expected Payoffs in Treatment 2

In the previous proposition, we examined Treatment 2, where we discussed the impact of revelation decision of high-ability participants on the investment level of low-ability participants. We now highlight the finding of proposition 2 of Ewerhart and Lareida (2024) paper. Consider a uniformly asymmetric contest where the low-ability players marginal cost is common knowledge. When the strongest type of high-ability player (i.e., the one with low marginal cost) reveals their type, it discourages the low-ability player, leading them to reduce their effort. Now in this section we focus on the effects of revelation on the investment, probability of winning and expected payoffs of high-ability participant. The high-ability player with the lowest marginal cost exerts less effort. Despite lower effort, the high-ability player wins with a higher probability. The expected payoff for the high-ability player strictly increases compared to non-revelation. We want to check whether this result still holds on the side of high-ability participants even when the con-

test is not uniformly asymmetric.

First, we will discuss the behaviour of the high-ability participant incurring the lowest cost following the decision to reveal, followed by the behaviour of high-ability participants incurring different costs. We conducted a t-test to compare the investment decision and its impact on the probability of winning and expected payoffs for the high-ability participant with the lowest cost, both with and without revelation.[22] As predicted by the theory, investment levels decrease and expected payoffs increase with revelation. However, unlike the theory the probability of winning decreases. None of these results are statistically significant. It is important to highlight that, given the small sample size of 4, the effect size of the investment appears to differ significantly. Specifically, when the high-ability participant with the lowest cost reveals their decision, their normalized investment is 0.31, compared to 0.50 when they choose not to reveal it. The decrease in the probability of winning can be attributed to the lower effort exerted by the high-ability participant and the higher effort exerted by the low-ability participant. Since the high-ability participant incurs the lowest cost, the expected payoffs increase marginally by 0.002 points with revelation, however the difference is not statistically different than 0.

[22]In our experiment the lowest cost incurred by any participant is 0.6

	Investment	probability of winning	expected payoff
Revelation	0.31	0.85	1.66
	(0.03)	(0.21)	(0.19)
Non-Revelation	0.5	0.96	1.66
	(0.23)	(0.06)	(0.20)
Revelation vs Non-revelation (p-values)	0.23	0.7	0.5
N (combined)	4	4	4

Note: Standard deviations in parentheses. In column 1, we compared revelation - non-revelation < 0, however in column 2 and 3 we compared revelation - non-revelation > 0

Table 2.16 Decisions of high ability participants incurring the lowest cost in Treatment 2 at Contest stage

Here we explain our experimental results when the high-ability participants (overall) reveals their marginal cost. We observed that this revelation leads to a reduction in their effort or investment, supporting our hypothesis that high-ability participants with the lowest cost exert less effort when the low-ability participants marginal cost is common knowledge. Although this trend aligns with the predictions of Ewerhart and Lareida (2024) paper of uniformly asymmetric contest, it lacks statistical significance. Interestingly, the probability of winning for high-ability participants decreases with revelation, albeit not significantly. This could be attributed to the narrowing competitive gap caused by reduced effort from high-ability participants due to their inherent high ability and increased effort from low-ability participants, who may be more motivated when costs are known. The most significant finding is the statistically significant reduction in expected payoffs for high-ability participants upon revelation. This unexpected outcome may result from strategic responses by low-ability participants who, contrary to theoretical predictions of discouragement, become more motivated to overcome their revealed disadvantage. Additionally, risk-averse behaviour among high-ability participants might lead them to adopt more conservative strategies when their type is known, prioritising

guaranteed payoffs over maximizing expected returns. These findings suggest that the interplay of cost revelation, effort adjustment, and strategic responses in contests is more complex than initially theorized, highlighting the need for further investigation into the psychological and strategic aspects of competitive behaviour under varying information conditions.

	Investment	probability of winning	expected payoff
Revelation	0.42	0.63	1.17
	(0.27)	(0.28)	(0.33)
Non-Revelation	0.44	0.71	1.32
	(0.26)	(0.31)	(0.28)
Revelation vs Non-revelation (p-values)	0.56	0.19	0.92
N (combined)	40	40	40

Note: Standard deviations in parentheses. In column 1, we compared revelation - non-revelation < 0, however in column 2 and 3 we compared revelation - non-revelation > 0

Table 2.17 Decisions of high ability participants in Treatment 2 at Contest stage

2.6 Conclusion and Future Extensions

We compared bidding behaviour in asymmetric contests across three disclosure settings: Incomplete Information with No Disclosure (baseline), Incomplete Information with Two-sided Disclosure (treatment 1), and Incomplete Information with One-sided Disclosure (treatment 2) of participant's private costs in a one-shot contest game. Our findings indicate no significant differences in average bidding functions across the three settings. In this asymmetric contest, there is no significant difference in the bidding behaviour of high-ability and low-ability participants across settings. However, within settings, we find qualitatively low-ability participants tend to invest less than high-ability participants in the baseline and Treatment 1. However, in Treatment 2, high-ability participants bid sig-

nificantly higher than low-ability participants. The probability of winning for low-ability participants is significantly lower than for high-ability participants in both Treatment 1 and Treatment 2. The expected payoff for high-ability participants is higher than for low-ability participants, with this difference being only weakly significant in Treatment 2.

When information is revealed, the average investment level and probability of winning are qualitatively higher in Treatment 1 compared to Treatment 2. However, qualitatively the average expected payoff is greater in Treatment 2 than in Treatment 1. In contrast, with non-revelation, the average investment level, probability of winning, and expected payoff are higher in Treatment 2 than in Treatment 1, with the differences in probability of winning and expected payoffs being significant.

Two major conclusions can be drawn from this chapter: First, in asymmetric contests where revelation is allowed, participants do not always disclose their unit costs in both two-sided and one-sided disclosure treatments. Second, in the two-sided disclosure treatment, the probability to reveal is negatively related to participant's own marginal costs and risk-aversion behaviour, with this relationship being statistically significant at 1% to 5% level. However, in one-sided disclosure, the probability to reveal is positively related to participants unit costs and risk-aversion (though not statistically significant), which may be attributed due to the presence of common knowledge in this treatment.

In this chapter, we elicit the risk preferences of participants using the Binswanger (1980) risk elicitation technique, which is a departure from methods used in previous contest studies. We found that the proportion of risk-averse individuals is significantly higher than that of risk-loving individuals across all treatments. Our findings indicate that the majority of participants exhibit risk-averse behaviour. The implications of risk-averse behaviour on investment, though not statistically significant in our study, qualitatively support the experimental findings of Millner and Pratt (1991) and Mago et al. (2013) in baseline and treatment 1. In Treatment 2, our findings qualitatively align with the

theoretical results of Skaperdas and Gan (1995), where investment is positively associated with risk-averse behaviour.

Chapter Three

War or Peace: A Model of Leadership during Conflict[†]

3.1 Introduction

The concept of a 'peace dividend' is well known i.e. reduced military spending (see d'Agostino et al. (2017)) would lead to economic benefits, but conflicts abound across the world. Gupta et al. (2007) note how elusive it has been and note 'Between 1989 and 2000, more than 4 million people are estimated to have died in violent conflicts, while international terrorist attacks increased from about 342 a year between 1995 and 1999 to 387 between 2000 and 2001'. Things have not got better in the last two decades and we are seeing conflict not just in Ukraine but also in several other places. A recent example of intra-country conflict is Sudan. In December 2018, citizens in the northern Sudanese town of Atbara set fire to the local headquarters of the ruling National Congress Party (NCP). Hassan and Kodouda (2019) states the protests were initially triggered by rising prices and the removal of subsidies on basic goods. However, the demonstrators quickly linked these economic hardships to the autocratic rule of President Omar al-Bashir and his Inqaz (Salvation) regime. In the days that followed, the protests spread across Su-

[†]This chapter is based on work with Siddhartha Bandyopadhyay, Amit Chattopadhyay (University of Aston) and Mandar Oak (Shiv Nadar University & University of Adelaide).

dan, with demands for an end to Bashir's military-backed presidency and a transition to civilian rule. By April 2019, after months of sustained popular protests fuelled by economic mismanagement and calls for democracy, Bashir was ousted in a military coup (Stigant and Murray (2019)) . The unrest has since contributed to a deepening humanitarian crisis in Sudan, marked by widespread displacement, loss of life, and human rights violations. In the context of inter-country conflicts, a report by Lalwani et al. (2022) argues that following the 2020 confrontation, India and China have engaged in 17 rounds of military talks but have failed to agree on disengagement terms for key contested areas along the border. Despite diplomatic efforts, tensions remain high, reflecting the broader strategic rivalry between the two nuclear-armed neighbours over territorial claims in the Himalayas. These conflicts underscore the increasing complexity of both inter- and intra-country tensions, driven by political instability, geopolitical rivalries, and resource-based disputes, which continue to fuel conflicts worldwide.

There are several causes of conflict, ranging from economic inequalities to ethnic tensions. For example, economic factors such as unemployment, extreme poverty, inflation, and inequality were significant drivers for the uprisings of the Arab Springs (Kuhn (2012)). Ethnic and religious divisions have fuelled long-standing violence between the Hutu and Tutsi, as seen in the Rwandan Genocide (Mamdani (2001)). Additionally, geopolitical and territorial disputes contribute to tensions, as in the South China Sea, where competing territorial claims have led to military standoffs (Hayton (2014)). Finally, political instability often exacerbates conflict, as demonstrated by the civil war in Syria. A combination of authoritarian rule, economic hardship, and demands for democratic reforms led to widespread protests and ultimately a devastating armed conflict (Phillips (2016)). In this chapter we look at the role of the political process itself as a determinant of conflict, understanding the role played by the ability and ideology of the politicians in office.

In terms of conflict linked to electoral success, evidence suggests that during times of conflict, hawks and hawkish policies often dominate (see Kahneman and Renshon (2007)).

For example, following the 9/11 attack, hawks had a fair amount of success in determining U.S. foreign policy as well as enjoyed electoral success recently across the globe. This suggests that hawks and hawkish policies dominate in times of conflict. In particular, a recent paper (Bandyopadhyay et al. (2022)) has examined whether such hawkishness could arise from the incentives of the political process itself and exacerbate conflict. They give a number of examples from recent conflicts contrasting for instance the stance taken by leaders (particularly those whose credentials are untested in foreign policy) versus others who do not face election pressures, including military leaders who are not expected to be natural doves.

More recently, Benjamin Netanyahu's hawkish policy (whether strategic or because he is an inherent hawk), has bought him electoral victory. To paraphrase the writing of Tovah Lazaroff from 'The Jerusalem Post', in the current conflict, Netanyahu's approach to hostage negotiations seems to be influenced by political considerations.[1] Some suggest that his refusal to negotiate under certain conditions may be driven partly by political incentives. For example, in recent talks about hostage deals with Hamas, Netanyahu has received criticism from various groups. They accuse him of prioritising his political survival over humanitarian concerns and even long term military objectives. These criticisms point out the political pressures Netanyahu faces from his right-wing supporters, who back his tough stance, as well as from the families of hostages, who demand action for the release of their loved ones.

However, political leaders in the past have ended up signing significant peace treaties (see e.g., Good Friday Agreement, Northern Ireland 1998 [2] and Comprehensive Peace Accord, Nepal, 2006[3]) and depending on the ideology and effectiveness of the leader we want to understand if the voting process can under certain circumstances also lead to peace. We do so in a model where two groups negotiate over a fixed resource. For simplicity, we

[1] https://www.jpost.com/israel-hamas-war/article-807490
[2] https://www.bbc.com/news/uk-northern-ireland-61968177
[3] https://www.satp.org/satporgtp/countries/nepal/document/papers/peaceagreement.htm

assume that one group has initial control over the resource. Our chapter seeks to understand how instances of hawkish behaviour documented above arise in a political process. In order to formalize this idea, we embed a model of conflict (similar to Grossman (1994)) in a principal-agent model of political competition in which the voters (the principal) use re-election as an incentive to induce the incumbent political leader (the agent) to choose a settlement over resources with an insurgent group. We look for an optimal solution that strikes a balance between retaining economically valuable resources that also has ideological value vs increasing conflict. The conflict is modelled as dividing a fixed resource, for concreteness sake, we can think of dividing a piece of land, between the citizenry and insurgents. However, unlike Grossman (1994) (and Bandyopadhyay et al. (2022)) there are two dimensions to the utility derived from land-one arising because of its economic value and other from an intrinsic or ideological dimension. The incumbent politician, as the representative of the citizenry chooses a policy, i.e., a division of land between the groups. Following the land division there may be insurgent activities (which we think of as conflict) that impose costs on the citizenry. Incumbents vary along three dimensions, their ability in managing the costs of conflict as well as their ability to manage resources net of the costs of conflict (we assume these two dimensions are positively correlated in this chapter) and finally their ideology given by how much they intrinsically value land. Incumbent's ability denotes his success in minimizing the cost to the citizenry from the insurgent activities as well his ability to make the most of his resources after subtracting the cost of conflict, while ideology denotes the intrinsic utility from holding on to land.

Voters hold complete information about the incumbent's type (ability across the two dimensions and ideology) and have to decide whether to re-elect the incumbent. We wish to understand whether the incumbent has an incentive to choose hawkish or extremist policies given their abilities across the two dimensions as well as ideology. To make clear what we mean by this extremism or hawkishness, a hawk (dove) is a person who has a higher (lower) ideological land valuation (relative to the median voter) from retaining more land, while a hawkish (dovish) policy from a particular leader is a policy more (less)

extreme than the one the (median) voter would ideally like to choose. We characterize the optimal contract from the voter's perspective that maximizes her utility subject to the participation constraint of the politician.

This chapter presents an extension of Bandyopadhyay et al. (2022) with two variations namely an ideological dimension and an ability on how to manage resources net of conflict. We restrict attention to the complete information case but the results differ substantially from their complete information model. They find (in a model where there is no ideological conflict), electoral incentives lead politicians to choose policies that are increasing in their ability to manage conflict but may be more or less hawkish than those desired by the voter depending on whether they value the economic resource more or less than the voter. This is not true when there is an ideological component to their utility for the resource. In this chapter, we also find the threshold level of ability that leads voters to re-elect leaders when both ability and ideological preferences are known. We find that policy of re-elected politician is non-monotonic with their ability. Furthermore, we conduct comparative statics with respect to the leader's ideological preferences, illustrating how the policy choice between replacement and re-election varies accordingly. We found that politicians who are hawks tend to choose lower policies when they are re-elected, compared to when they are replaced. Conversely, politicians who are doves tend to choose higher policies when they are re-elected, compared to when they are replaced. This difference is influenced by the varying ideological preferences of both voters and politicians.

In sum, our model provides a new explanation of conflict, showing that it arises from re- election motives and how in a scenario where a resource has both economic and ideological value can either increase and dampen conflict depending on the ideology an ability of the politician in office.

The rest of the chapter is organised as follows. In section 3.2, we review the relevant literature. Section 3.3 presents the model, discussing the first-best contract and its char-

acterisation. Section 3.4 presents the results. Finally, in section 3.5, we conclude the chapter.

3.2 Related Literature

In the context of political economy , one view suggests that elections serve to aggregate either preferences or information (e.g., Piketty (2000); Razin (2003); Meirowitz and Shotts (2009); Austen-Smith and Banks (1996); Dewan and Myatt (2007)), while another body of work views elections as a means of holding politicians accountable (see e.g.,Canes-Wrone et al. (2001); Kartik and McAfee (2007); Fox (2007)). In principle, competitive elections should lead to better policy outcomes by aligning political decisions with citizen's preferences. Our questions look at the latter function of voting. Our work is related to models of contracting under a principal-agent setting. The impact of elections on performance can emerge through two distinct channels: they allow citizens to select politicians of different types, and they provide incentives for politicians to implement policies favoured by voters, as voters can sanction incumbents based on their performance.

Our work is related to agency problems, starting from the work of Spence (1973) on job market signalling. More specifically, our chapter aligns with incumbent-challenger models, which are agency models of political competition. The literature on incumbent-challenger models is extensive (see Besley (2007) for a comprehensive review), with the simplest models focusing on pure selection strategies to eliminate ineffective politicians. Several well-known models examine electoral accountability, where the voter's re-election rule is based on the incumbent's performance meeting a predetermined standard (for a comprehensive survey, see Ashworth (2012)). Electoral accountability requires two key components: an electorate that decides whether or not to retain an incumbent, potentially based on their performance, and an incumbent who can respond to her expectations of the electorate's decision. Most of the applied theory literature uses a two-period framework

to capture these components. In the first period, the incumbent makes a policy decision that impacts a performance measure observed by a representative voter. The voter then chooses to either re-elect the incumbent or replace them with a challenger. The winner of the election then governs in the second policy-making period, where they choose another action. While both policy-making periods offer the same set of choices to the politician, there is no election after the second period, and the game ends with the final action. Our chapter differs in that the policy—specifically the division of land between voters and an insurgent group—is set in the first period and cannot be changed in the second period which is where the politician has to deal with the impact of the policy. This means that in the second period, an incumbent (if re-elected) or new politician (if replaced) comes to office and manages the economy's resources and conflict resolution, depending on the policy chosen in the first period, with his ability affecting the cost of conflict management and the value of the resource net of the conflict. In much of the contemporary literature (see e.g., Laffont (1993); Fearon (1999)), the re-election standard is determined in equilibrium by the voter's incentive to select better-performing politicians for future terms. Such models were initially developed to study labour-market relationships, where an agent aims to maximize a principal's perception of their competence (see e.g., Dewatripont et al. (1999); Holmström (1999)). This approach has been adapted to politics by Persson and Tabellini (2002), Alesina and Tabellini (2007), Alesina and Tabellini (2008), among others. In politics, the tools to provide incentives are far more limited compared to firms, usually restricted to a basic retain-or-fire choice. Incumbents aim to boost their re-election odds, which can yield different results from maximizing expected competence. Bonfiglioli and Gancia (2013) examine how electoral incentives influence actions with varying time profiles of costs and benefits and explore the impact of different forms of uncertainty on these incentives, and discuss the normative implications for the design of political institutions. This approach contrasts with the earlier works of Barro (1973), Ferejohn (1986), and Austen-Smith and Banks (1989). In these earlier models, politicians are assumed to be identical, eliminating any role for voter selection. Voters are indifferent between candidates at the election stage. Consequently, any re-election rule can be

sequentially rational, and the combination of such a rule with the incumbent's optimal action forms an equilibrium. Unlike the previous papers, in our chapter, we consider an agency problem, where voters preference is homogenous, but politicians have heterogeneous abilities in managing conflict and the economy. Elections are designed to select the most competent politician, hold them to a favoured policy or both. In this context, incumbent policymakers are motivated by re-election concerns, held to 'contracts' that choose policies that maximize voter's expected payoff subject to the politician's participation constraint. In the second period, either the replaced or re-elected politician is tasked with managing conflicts and the economy based on the policy chosen in the first period but there is no decision to make as the division of resources together with the model parameters on ability and ideology determine the payoffs in the second period.

Electoral accountability in cases where politician's actions are unobservable has been widely studied (see e.g., Barro (1973); Rogoff and Sibert (1988); Ferejohn (1986); Rogoff (1990); De Mesquita (2007); Fearon (2011)). Rogoff and Sibert (1988) and Rogoff (1990) apply this framework to analyse political budget cycles, while the other papers primarily address moral hazard problems. Additionally, there are models that incorporate both moral hazard and adverse selection, where politicians differ in both ability (leading to adverse selection) and in the observability of their actions (leading to moral hazard) e.g., Banks and Sundaram (1991) and Bonfiglioli and Gancia (2013). These models of electoral accountability are supported by substantial empirical evidence as well, see for example Besley and Case (1995).

Electoral incentives can potentially lead to conflict as well. The empirical literature on war during election periods highlights the political costs of active conflicts for incumbent leaders, as war-related casualties tend to reduce their popularity (see e.g., Gartner and Segura (1998), Gartner and Segura (2000); Karol and Miguel (2007)). Consequently, democratically elected leaders may be reluctant to engage in wars. Arguments suggest that term limits increase the chances of interstate conflict by removing electoral account-

ability (Conconi et al. (2014)). However, Zeigler et al. (2014) show that taking away a leader's chance for re-election can affect conflict initiation in different ways. Carter and Nordstrom (2017) find that term-limited dovish leaders are less likely to initiate conflicts compared to those who are electorally accountable, while no such relationship exists for hawkish leaders. Our findings show that it is possible for some re-elected irrespective of ideology leaders to cede more land to insurgents and manage the resources of the economy effectively post-conflict to increase voter utility. However, exposure to violent events can also produce a 'rally around the flag' effect, potentially benefiting incumbents by boosting their popularity (e.g., see Morales (2021)). This dynamic enhances the incentives for some leaders to initiate conflict. Adam et al. (2024) shows that elections can motivate incumbents to gamble on costly wars to boost their re-election chances, underscoring the role of re-election incentives in driving war decisions.

While many of these incumbent challenger models have asymmetric information, that is not necessary for policies to be distortionary. Aidt and Dutta (2007) investigate political failures stemming from the interaction between observation lags, economic growth, and a binding revenue constraint. The failure in their model is not driven by asymmetric information (since their politicians are homogeneous), instead they focus on the mix of short-term versus long-term public goods provided due to the interactions described. In contrast, Bonfiglioli and Gancia (2013) show that when a politician's ability is ex ante unknown and policy choices are unobservable, elections can enhance political accountability and selection. However, incumbents may underinvest in costly policies with future returns to signal high ability and increase their chances of re-election. Interestingly, uncertainty can reduce political myopia and potentially increase social welfare. Our model unlike many of these models do not have asymmetric information but focuses on optimal voter 'contracts' when faced with ideological and efficiency differences with the incumbent politician. As Aidt and Dutta (2007) show, even without asymmetric information, interesting issues come up arising from some kind of friction in the process. In our model, this comes from preference divergence between politician and voter in ideology over both

the economic and ideological dimensions of conflict as well as rents from re-election.

Our work has broad links with rational choice explanations of terrorism where terrorism is viewed as a strategic choice and its consequent violence (see, e.g., Pape (2003); Berman (2003)). The role of a political in the context of conflict is analysed within a complete information framework by Hess and Orphanides (1995), and this analysis connects to the literature examining whether multilateralism can achieve an efficient level of security and the form it should take (see e.g., Gupta (2010); Gupta (2012); Gupta (2014)). Schultz (2003) analyses the behaviour of hawks and doves throughout the US-USSR conflict, employing a different definition of hawks and doves to our chapter. He posits that doves are individuals who inherently hold optimistic prior beliefs about their opponent's motives, while hawks hold the opposite view. This chapter also contributes to a well-established literature on conflict and the distribution of resources across groups (see e.g., Grossman (1994); Conley and Temimi (2001); Hirshleifer (1995); Garfinkel and Skaperdas (2007); Sánchez-Pagés (2009)). We contribute to the literature by considering the impact of the political process intermingled with ideology and efficiency in analysing the outcomes that arise.

3.3 Model

We analyse a two-period model of conflict. The framework employed is based on the work of Grossman, 1994, with specific modeling details drawn from Bandyopadhyay et al., 2022. The conflict involves two groups, the citizens (denoted as C) and the insurgents (I), competing over a fixed amount of land $Y \in \mathbb{R}_+$.[4] The distribution of land Y is determined by an incumbent politician, who allocates $y \in Y$ to the citizens, leaving the remaining $Y - y$ to the insurgents. Thus, the proposed division by the incumbent politician is $(y, Y - y)$. Importantly, the incumbent politician selects the share of land

[4]This model can represent conflicts between any two groups, individuals, or countries over a limited resource.

on behalf of the citizens. For the purposes of this model, we refer to the representative member of the citizens as the voter, and the politician in office who determines the land division as the incumbent. The representative voter can be interpreted as a median voter.

The utility function $u : [0, y]$, where $u' > 0$ and $u'' \leq 0$, represents the voter's preferences regarding a land division. Unlike the previous model by Bandyopadhyay et al., 2022, we introduce an ideological valuation of the land by the voters, denoted as γy, where $\gamma \in [0, 1]$ represents the ideological parameter of the voter. The incumbent's ideological preferences over land division may differ from those of the voter. We represent the incumbent's ideological preference for the land as $\alpha\gamma y$, where $\alpha \in (0, 2)$ is the incumbent's ideological parameter in land valuation. $\alpha < 1$ indicates that the incumbent is dovish relative to the voter, while an $\alpha > 1$ suggests that the incumbent is hawkish. After observing the choice of y made by the incumbent, the voter decides whether to re-elect him.

Following the land division proposed by the incumbent on behalf of the citizens, the insurgents (I) may engage in terrorist activities or violent insurgency. The cost of this insurgency imposed on the voter is represented by $c(y) \geq 0$, where $c' \geq 0$ and $c'' \geq 0$. This cost is realised in the next period. The politician in office during the next period is responsible for managing the conflict and economy's resources, and their effectiveness depends on their ability, denoted by θ. The effectiveness in mitigating the conflict is represented by $\beta(\theta) > 0$, where $\beta' \leq 0$. In addition to conflict management, our model introduces an additional dimension where the politician, depending on their ability, also manages the resources in the economy. The effectiveness of the incumbent of ability θ in managing the economy's resources is represented by $\mu(\theta) > 0$, where $\mu' \geq 0$. Therefore, incumbents vary along three dimensions, their ability in managing the costs of conflict as well as their ability to manage resources net of the costs of conflict and finally their ideology given by how much they intrinsically value land.

Sequence of Actions: The game played is as follows:

1. At $t = 0$, The type of the incumbent (α, θ) and the type of the voter γ is determined. The voters (from C), set a re-election threshold $\hat{y}$, such that the incumbent is re-elected only if $y \geq \hat{y}$.

2. At $t = 1$, The incumbent chooses a policy $y \in [0, Y]$. If $y > \hat{y}$, the incumbent is re-elected, otherwise, they are replaced. In case the incumbent is replaced, a new politician is chosen from the distribution $F(\theta)$, with the probability density given by $f(\theta)$.

3. At $t = 2$, Payoffs are realised.

We denote the net resources available after the insurgency is defined as $[u(y) - \beta(\theta)c(y)] \geq 0$.[5] Therefore, the expected payoff of the voter can be written as $\mu(\theta)[u(y) - \beta(\theta)c(y)] + \gamma y$ if the incumbent is re-elected, and $\mu(\theta')[u(y) - \beta(\theta')c(y)] + \gamma y$ if the incumbent is replaced by a politician with ability θ'. The incumbent's expected payoff differs from the voter's in two key ways: First, the incumbent's ideological valuation of the land is scaled by a factor of α. Second, if the incumbent is re-elected, there is an additional payoff $r > 0$, which can be interpreted as the rent or benefit from holding office in the next period. Therefore, the incumbent's payoff, if re-elected, is given by $\mu(\theta)[u(y) - \beta(\theta)c(y)] + \alpha\gamma y + r$, and if replaced by a politician with ability θ', it is $\mu(\theta')[u(y) - \beta(\theta')c(y)] + \alpha\gamma y$. This formulation reflects that the politician in office during period 2 inherits the policy set by the previous incumbent and is responsible for managing both the cost of conflict and the economy. In our model, we assume that the land division policy cannot be instantly reversed. There is no discounting in our model, and the total payoffs for both the voters and the incumbent are the sum of the payoffs across both periods. Now we will discuss the general formulation of the first best contract.

[5] Net resources cannot be negative.

3.3.1 First Best: (α, θ, γ) - Contingent Contract

In the first-best (FB) scenario, the incumbent's ideology α and ability θ are known to the voter and the voter's ideological valuation parameter γ can also be observed by the politician. Since the politician's ideological valuation is a multiple α of the voter's ideological valuation γ, we denote the incumbent's type as (α, γ, θ). The FB scenario represents the highest utility that a voter with ideology γ can attain if they could offer a type-contingent contract to the incumbent, subject to both the incumbent's and the voter's participation constraints. The expected utility from replacing an incumbent, whose chosen policy is $y_0(\alpha, \gamma)$, is denoted as $v_0(\alpha, \gamma)$ for the incumbent and $V_0(\alpha, \gamma)$ for the voter.

Definition: The first-best contract for a type (α, γ, θ) is a pair (d^*, y^*), where the agent implements the policy $y^* \in Y$ and the voter's re-election decision is $d^* \in \{re-elect, replace\}$, such that:

- d^*=re-elect, and

$$y^* = \arg\max_{y \in [0,Y]} \mu(\theta)\Big[u(y) - c(y)\beta(\theta)\Big] + \gamma y$$
$$\text{s.t.} \quad \mu(\theta)\Big[u(y) - c(y)\beta(\theta)\Big] + \alpha\gamma y + r \geq v_0(\alpha) \quad (3.1)$$

if,

1. a solution to the above problem exists, and
2. $\mu(\theta)\left[u(y^*) - c(y^*)\beta(\theta)\right] + \gamma y \geq V_0(\alpha, \gamma)$

- otherwise d^*=replace, and $y^* = y_0(\alpha)$.

3.3.2 Characterisation of the First Best

We characterise the first best with specific functional forms. However, even with these forms, fully characterising the first-best outcome remains complex, as it depends on various configurations of the parameters α, θ, γ, and r. In results section, we will examine the first-best outcome in detail for particular parameter values.

Specifically, we assume that:

$$\mu(\theta) = 1 + 3\theta, \quad u(y) = y, \quad \beta(\theta) = 2 - \frac{\theta}{2}, \quad c(y) = \frac{1}{2}y^2. \tag{3.2}$$

We further assume that the politician's ability, θ, is drawn from a uniform distribution on $[0, 1]$ and is independent of the ideology parameter α.

Using the above functional forms, the voter payoff function $V(\alpha, \gamma, \theta)$ and the politician payoff function $v(\alpha, \gamma, \theta)$, when the politician is facing re-election is as follows: [6]

$$V(\alpha, \gamma, \theta) = [1 + 3\theta]\Big[y - \frac{y^2}{2}\Big(2 - \frac{\theta}{2}\Big)\Big] + \gamma y$$

$$v(\alpha, \gamma, \theta) = [1 + 3\theta]\Big[y - \frac{y^2}{2}\Big(2 - \frac{\theta}{2}\Big)\Big] + \alpha\gamma y + r$$

If an incumbent knows or anticipates that they will not be re-elected, their optimal strategy would be to choose y to maximize their expected utility, which is given by:

$$yE_{\theta'}(\mu(\theta)) - \frac{y^2}{2}E_{\theta'}\Big(\mu(\theta)\beta(\theta)\Big) + \alpha\gamma y \tag{3.3}$$

Substituting the functional forms of $\mu(\theta)$ and $\beta(\theta)$ from equation 3.2, we get,

$$= y\int_0^1 (1 + 3\theta)\, d\theta - \frac{y^2}{2}\int_0^1 (1 + 3\theta)\Big(2 - \frac{\theta}{2}\Big)\, d\theta + \alpha\gamma y$$

[6] Note the politician incurs the rent r in the second period only if they are re-elected.

$$= y\int_0^1 (1+3\theta)\,d\theta - \frac{y^2}{2}\int_0^1 \Big(2+\frac{11}{2}\theta-\frac{3}{2}\theta^2\Big)\,d\theta + \alpha\gamma y$$

$$= y\Big[\theta+\frac{3}{2}\theta^2\Big]_0^1 - \frac{y^2}{2}\Big[2\theta+\frac{11}{4}\theta^2-\frac{1}{2}\theta^3\Big]_0^1 + \alpha\gamma y$$

$$= y\Big(1+\frac{3}{2}\Big) - \frac{y^2}{2}\Big[2+\frac{11}{4}-\frac{1}{2}\Big] + \alpha\gamma y$$

$$= \frac{5}{2}y - \frac{y^2}{2}\Big[\frac{17}{4}\Big] + \alpha\gamma y \tag{3.4}$$

where the expectations are taken over the replacement's ability θ', which yields y that depends on both α and γ, and which we denote by,

$$y_0(\alpha,\gamma) = \frac{2(5+2\alpha\gamma)}{17} \tag{3.5}$$

As stated earlier, when the incumbent facing replacement adopts the policy $y_0(\alpha,\gamma)$, the expected utility is $v_0(\alpha,\gamma)$ for the incumbent and $V_0(\alpha,\gamma)$ for the voter. These values are found by substituting the incumbent's policy into the expected payoffs for both the voter and the incumbent when facing replacement. It can be shown that:

$$v_0(\alpha,\gamma) = \frac{(5+2\alpha\gamma)^2}{34} \quad \text{and} \quad V_0(\alpha,\gamma) = \frac{(5+2\alpha\gamma)(2\gamma(2-\alpha)+5)}{34} \tag{3.6}$$

If problem 3.1, with the specified functional forms in equation 3.2, has an interior solution, then the policy of the politician facing re-election, $y(\alpha,\gamma,\theta) = \frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)}$, yields the voter's indirect utility $V(\alpha,\gamma,\theta) = \frac{(1+3\theta+\gamma)^2}{(1+3\theta)(4-\theta)}$. [7] The voter will re-elect (or replace) the incumbent if $\frac{(1+3\theta+\gamma)^2}{(1+3\theta)(4-\theta)} \gtreqless V_0(\alpha)$, i.e

$$\theta \gtreqless \overline{\theta} \tag{3.7}$$

[7] Refer to the Appendix C.1 and C.2 for calculations.

where,

$$\begin{aligned}\overline{\theta} =& \frac{-(-71-16\gamma-88\gamma^2\alpha+44\gamma^2\alpha^2)}{2(381+60\gamma+24\gamma^2\alpha-12\gamma^2\alpha^2)} \\ &+ \frac{\sqrt{(-71-16\gamma-88\gamma^2\alpha+44\gamma^2\alpha^2)^2}}{2(381+60\gamma+24\gamma^2\alpha-12\gamma^2\alpha^2)} \\ &+ \frac{\sqrt{-4(381+60\gamma+24\gamma^2\alpha-12\gamma^2\alpha^2)(-12\gamma+34\gamma^2-66-32\gamma^2\alpha+16\gamma^2\alpha^2)}}{2(381+60\gamma+24\gamma^2\alpha-12\gamma^2\alpha^2)}\end{aligned}$$

Note that solving for θ from the $\frac{(1+3\theta+\gamma)^2}{(1+3\theta)(4-\theta)} \gtreqless V_0(\alpha)$ gives rise to a quadratic equation. The lower root (i.e., $\underline{\theta}$) is disregarded as it results in a negative value (given our specified parameter values), which lies outside the permissible range of θ .

We now aim to determine whether the voter's indirect utility always increases with the incumbent's ability. To explore this, we take the derivative of the voter's indirect utility $V(\alpha, \gamma, \theta)$ with respect to the incumbent's ability, yielding:

$$\frac{\partial V^*}{\partial \theta} = \frac{(1+\gamma+3\theta)((6\gamma+39)\theta-11\gamma+13)}{2(1+3\theta)^2(4-\theta)^2} \tag{3.8}$$

We aim to determine the range of values for θ for which $\frac{\partial V}{\partial \theta} > 0$ holds i.e., $(1+\gamma+3\theta)((6\gamma+39)\theta-11\gamma+13) > 0$. Since $(1+\gamma+3\theta)$ and the denominator are positive, therefore for $\frac{\partial V}{\partial \theta} > 0$, we need, $((6\gamma+39)\theta-11\gamma+13)$ be positive.

Upon examination, it becomes evident that $\frac{\partial V}{\partial \theta} > 0$ is met, as the condition $\theta > \frac{11\gamma-13}{6\gamma+39} = \hat{\theta}$ is always true, given that $\gamma \in [0,1]$ within our model. Hence, the $\frac{\partial V}{\partial \theta} > 0$ holds true $\forall \theta \in [0,1]$. We now examine the range of γ such that the net resource disposal function $\Big[u(y) - c(y)\beta(\theta)\Big]$ is non-negative. Therefore restrictions on γ need to be imposed.

We know that if $\theta \geq \overline{\theta}$, the incumbent secures re-election, otherwise they face replacement. The policy selected by the incumbent when anticipating re-election is given by $y^* = \frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)}$, whereas the policy chosen when anticipating replacement is $y^* = \frac{2(5+2\alpha\gamma)}{17}$. To ensure that net resources in the economy remain non-negative, we substitute the re-

spective policies chosen by the politician, whether facing re-election or replacement, into the net resource disposal function. We show the calculations below,

Applying functional forms from equation 3.2 to the net resource disposal function $\Big[u(y) - c(y)\beta(\theta)\Big]$, we get,

$$D = \Big[y - \frac{y^2}{2}\Big(2 - \frac{\theta}{2}\Big)\Big]$$

$$D = \Big[y - \frac{y^2}{2}\frac{4-\theta}{2}\Big]$$

Substituting, the policy chosen by the politician anticipating re-election, we get,

$$D = \frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)}\Big[1 - \frac{2(1+3\theta+\gamma)}{2(1+3\theta)(4-\theta)}\frac{4-\theta}{2}\Big]$$

Simplifying, we get,

$$D = \frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)}\Big[1 - \frac{1+3\theta+\gamma}{2(1+3\theta)}\Big]$$

$$D = \frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)}\Big[\frac{2(1+3\theta) - 1 - 3\theta - \gamma}{2(1+3\theta)}\Big]$$

$$D = \frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)}\Big[\frac{1+3\theta-\gamma}{2(1+3\theta)}\Big] \tag{3.9}$$

For D to be non-negative, $1 + 3\theta \geq \gamma$ need to hold for $\forall\theta \in [0, 1]$.

Similarly, substituting, the policy chosen by the politician anticipating replacement in H below, we get,

$$H = \frac{2(5+2\alpha\gamma)}{17}\Big[1 - \frac{2(5+2\alpha\gamma)}{34}\int_0^1 \Big(2 - \frac{\theta}{2}\Big)d\theta\Big]$$

$$H = \frac{2(5+2\alpha\gamma)}{17}\Big[1 - \frac{(5+2\alpha\gamma)}{17}\int_0^1 \frac{(4-\theta)}{2}d\theta\Big] \tag{3.10}$$

In the net resource disposal function the term in the parenthesis need to non-negative, therefore we can write,

$$\Big[1 - \frac{(5+2\alpha\gamma)}{17}\int_0^1 \frac{(4-\theta)}{2}d\theta\Big] \geq 0$$

$$1 \geq \frac{(5+2\alpha\gamma)}{34}\int_0^1 (4-\theta)d\theta$$

$$1 \geq \frac{5(5+2\alpha\gamma)}{68}$$

$$\frac{68}{5} - 5 \geq 2\alpha\gamma$$

$$\frac{43}{10\alpha} \geq \gamma$$

Hence for H to be non-negative, $\frac{43}{10\alpha} \geq \gamma$ need to hold.

Note that the net disposal functional form of a politician facing re-election differs from that of one facing replacement, as the net resources available in the economy depend on the politician's ability in period 2. If a politician is replaced, they are succeeded by another politician of type θ', drawn from a uniform distribution $[0, 1]$. We now verify whether the range for $\gamma \in [0, 1]$, given $\alpha \in (0, 2)$ and $\theta \in [0, 1]$, ensures that the net resource disposal function remains non-negative. Specifically, we check whether the terms in parentheses in equations 3.9 and 3.10 are non-negative. This requires that

$$1 - \left[\frac{1+3\theta-\gamma}{2(1+3\theta)}\right]$$

and

$$\left[1 - \frac{(5+2\alpha\gamma)}{17}\int_0^1 \frac{4-\theta}{2}d\theta\right]$$

remain non-negative. By combining and simplifying these conditions, we can express the requirement as:

$$\min\left\{\frac{43}{10\alpha}, 1+3\theta\right\} \geq \gamma,$$

which holds for $\gamma \in [0,1]$. Therefore we can confirm with our parameter restrictions, the net resource disposal in the society cannot be negative. We now rewrite the first best conditions using our specific functional forms from equation 3.2 with the help of a following Lemma.

Lemma: If α, γ, θ and r are such that the problem 3.1 has an interior solution, then the first best policy is given by,

$$y^*(\alpha,\gamma,\theta) = \frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)}, \quad d^*(\alpha,\gamma,\theta) = re-elect \;\; if \;\; \theta \geq \overline{\theta} \tag{3.11}$$

$$y^*(\alpha,\gamma,\theta) = \frac{2(5+2\alpha\gamma)}{17}, \quad d^*(\alpha,\gamma,\theta) = replace \;\; if \;\; \theta < \overline{\theta} \tag{3.12}$$

Problem 3.1 is more likely to have an interior solution if i) r and θ are large and ii) if α is not too large or small relative to 1.

Policy chosen by Re-elected Politicians

Up to this point, through equations 3.11 and 3.12, we have established that a politician gets re-elected by voters if their ability exceeds a certain threshold. We the voter's expected utility is given by $\mu(\theta)[u(y) - c(y)\beta(\theta)] + \gamma y$. As θ increases, both $-\beta(\theta)$ and $\mu(\theta)$ increase for a given y, causing the first term of the voter's expected utility to increase unambiguously, while the second term remains constant. This indicates that with the increase in politicians ability their effectiveness in managing economy's resources and conflict increases. Now, suppose the re-elected politician reduces y (or cedes less land to the voters); in this case, γy (i.e. ideological benefit of voters) decreases, while whether the net resources $u(y) - c(y)\beta(\theta)$ of the economy increases or decreases is uncertain. Therefore, we are interested in knowing whether the amount of resources ceded to the insurgent group can be non-monotonic in ability of the re-elected politician. To explore this, we maximize the policy function $y(\alpha,\gamma,\theta) = \frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)}$, which is chosen by the

incumbent facing re-election, with respect to ability,

$$\frac{\partial y}{\partial \theta} = \frac{3(9\theta^2 + (6\gamma + 6)\theta - 11\gamma + 1)}{(1 + 3\theta)^2(2 - \theta)^2} \tag{3.13}$$

By setting equation 3.13 less than 0, we obtain a threshold value of θ, below which politicians can increase the voters utility while ceding more land to the insurgents. We now obtain the condition below,

$$9\theta^2 + (6\gamma + 6)\theta - 11\gamma + 1 < 0$$

Where $\theta < \frac{-\gamma - 1 + \sqrt{\gamma(\gamma+13)}}{3} = \tilde{\theta}$,[8].

From equations 3.11 and 3.12, we obtained that the re-election threshold for the politician is $\overline{\theta}$. Note, the voter utility is montonically increasing with politician ability i.e., $\frac{\partial V}{\partial \theta} > 0$, given the ideological parameter γ of the voter. If the re-election threshold $\overline{\theta} \leq \tilde{\theta}$, then $\forall\ \theta \in [\overline{\theta}, \tilde{\theta})$, we can find re-elected politicians who due to their resource management can allocate more land to the insurgents while still increasing voter payoffs.[9] Note $\tilde{\theta}$ is defined as a threshold value where re-elected politicians is indifferent between ceding more or less land to the insurgents (or voters). For $\theta \in [\tilde{\theta}, 1]$, re-elected politicians concede less land to insurgents to increase voter utility.

3.4 Results

We will now discuss the results below using different parameter values.

Example 1: With parameter values of $\gamma = 1$ and $\alpha = 1$, the re-election standard set by voters is $\overline{\theta} = 0.54$. We obtained $\tilde{\theta} = 0.58$. With rent $r = 0.5$, the participation constraint of the politician is satisfied. Therefore using simulations we show that re-

[8]We have ignored the negative root as $\theta \in [0, 1]$.

[9]Note, $\overline{\theta} > \tilde{\theta}$, re-elected politicians policy is monotonic with their ability.

elected politicians do in fact concede less land to the voters and increase voter utility due to their resource management, as $\tilde{\theta} \approx 0.58 > \overline{\theta} \approx 0.54$. Therefore, for $\theta \in [0.54, 0.58]$, re-elected politicians concede less land to voters yet increase voter utility, whereas for $\theta \in (0.58, 1]$, re-elected leaders increase voter utility by ceding more land to voters. The policy of the re-elected politician is given by Figure 3.1 below,

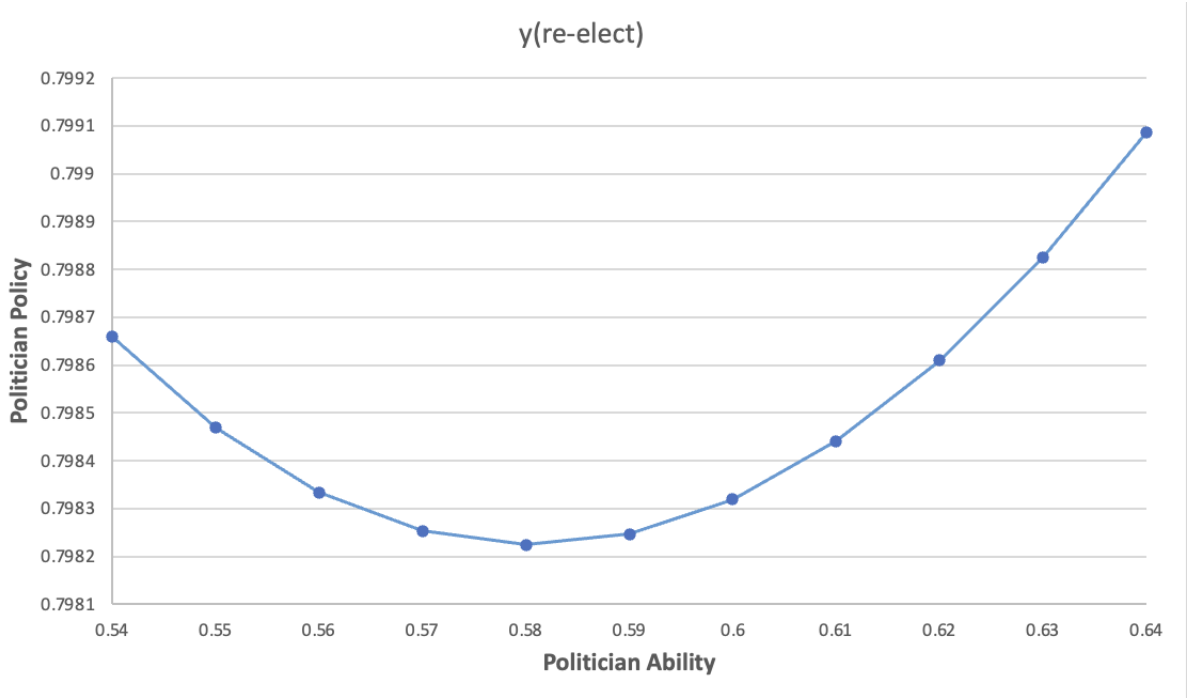

Figure 3.1 Optimal Policy for re-elected politicians

Note in the diagram above we showed for $\theta \in [0.54, 0.64]$, y is non-monotonic with θ. For $\theta \in (0.64, 1]$ the re-election policy is monotonically increasing in θ therefore not in the diagram.

We now discuss the policy chosen by all politicians whether re-elected or replaced. In this scenario, the voter's ideological preference aligns with that of the incumbent. For $\theta \in [0.54, 0.94)$, a re-elected politician cedes less land to the voters and more to the insurgents compared to a replaced politician of the same ability. However, for $\theta \in [0.94, 1]$, the re-elected politician cedes more land to the voters than a replaced politician with the same ability. In the range $\theta \in [0.54, 0.58]$, the policy difference between the re-elected and replaced politicians widens, indicating that as θ increases, the re-elected politician

cedes even less land, while voter utility rises due to improved post-conflict resource management. For $\theta > 0.58$, the gap narrows. Although re-elected politicians continue to cede less land to insurgents than replaced politicians, the amount ceded decreases further as their ability increases till $\theta < 0.94$, after which re-elected politicians cedes more land to the voters compared to replaced politician of same ability. [10] The optimal policy of the politicians at $\gamma = 1, \alpha = 1$ and $r = 0.5$ are demonstrated in Figure 3.2.

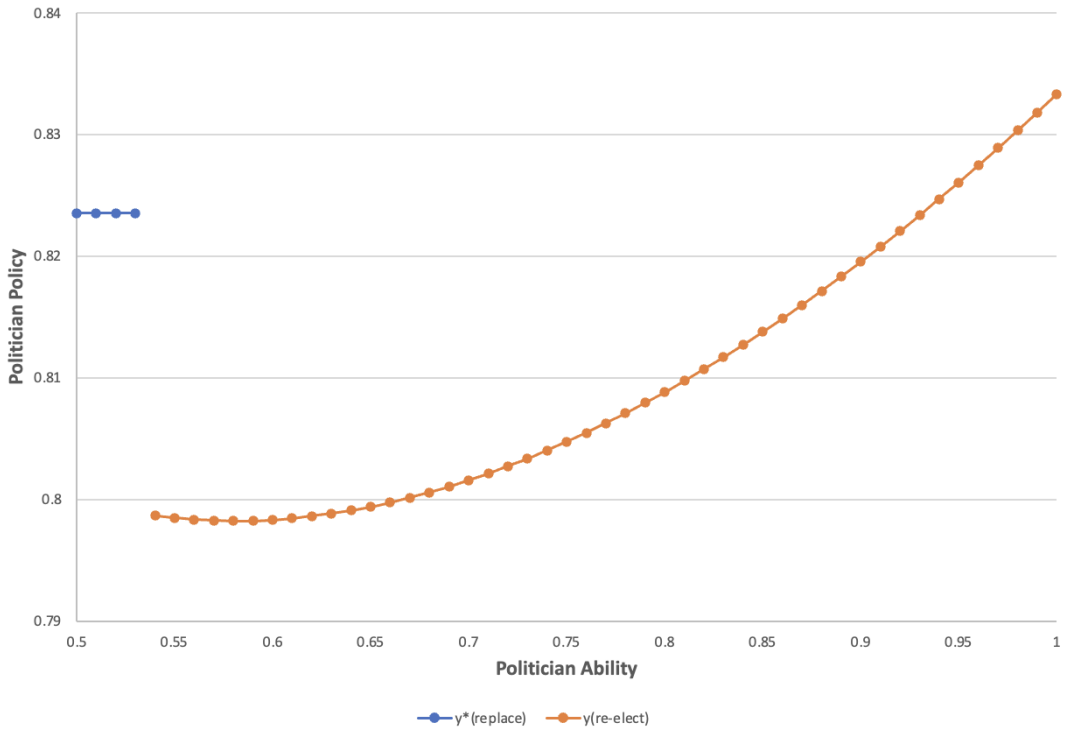

Figure 3.2 Optimal Policy under $\gamma = 1$, $\alpha = 1$ and $r = 0.5$

Example 3: By setting parameter values to $\gamma = 1$ and $\alpha = 1.2$, we vary θ over the interval $[0, 1]$. We know from equation 3.8 that $\frac{dV}{d\theta} > 0$ for all θ. With the mentioned parameters we obtain $\tilde{\theta} \approx 0.58$ and $\overline{\theta} \approx 0.53$. With participation constraint met at rent $r = 0.5$, for re-elected politicians $\theta \in [0.53, 0.58]$, y decreases as θ increases, while for $\theta \in (0.58, 1]$, y increases as θ rises. This indicates the non-monotonic relation of re-elected politician's policy and their ability. Refer to diagram 3.1 to see the policy of the re-elected politicians.[11] It is noteworthy, for $\theta \in [0.53, 1]$, a re-elected politician cedes less land to the

[10] Note in Figure 3.1, we have focused on the $\theta \geq 0.5$, as for $\theta < 0.5$ the policy of the politician (replaced) is a constant.

[11] Note there is no change in the optimal policy of re-elected politician except now the re-election threshold is $\overline{\theta} = 0.53$ instead of 0.54.

voters and more to the insurgents compared to a replaced politician of the same ability. In the range $\theta \in [0.53, 0.58]$, the policy difference between the re-elected and replaced politicians widens, indicating that as θ increases, the re-elected politician cedes even less land, while voter utility rises due to improved post-conflict resource management. For $\theta > 0.58$, the gap narrows. Although re-elected politicians continue to cede less land to insurgents than replaced politicians, the amount ceded decreases further as their ability increases. This is due to the fact that, politicians in this scenario, are inherent 'hawks' compared to the voters in terms of ideological valuation of the land. When faced with the possibility of replacement, they tend to stick to their inherent policies. However, when seeking re-election, they align their policies with voters ideological valuation. Therefore, the policy chosen by the replaced politician is more compared to the policy adopted by the re-elected politician. The optimal policy of the politicians at $\gamma = 1, \alpha = 1.20$ and $r = 0.5$ are demonstrated in Figure 3.3.

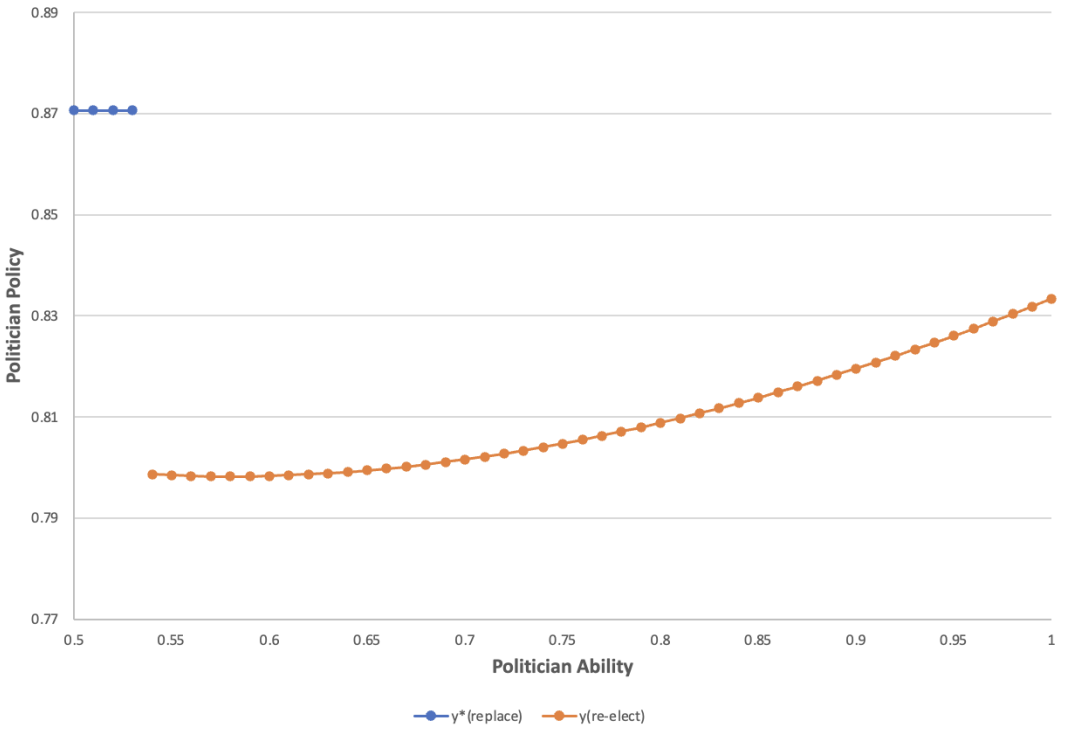

Figure 3.3 Optimal Policy under $\gamma = 1$, $\alpha = 1.2$ and $r = 0.5$

Example 4: By setting parameter values to $\gamma = 1$ and $\alpha = 0.8$, we vary θ over the interval $[0, 1]$. We know from equation 3.8 that $\frac{dV}{d\theta} > 0$ for all θ. With the mentioned

parameters we obtain $\tilde{\theta} \approx 0.58$ and $\overline{\theta} \approx 0.53$. With participation constraint met at rent $r = 0.5$, for re-elected politicians $\theta \in [0.53, 0.58]$, y decreases as θ increases, while for $\theta \in (0.58, 1]$, y increases as θ rises. This indicates the non-monotonic relation of re-elected politician's policy and their ability. Refer to Figure 3.1 to see the policy of the re-elected politicians.[12] It is noteworthy for $\theta \in [0.53, 1]$, a re-elected politician cedes more land to the voters and less to the insurgents compared to a replaced politician of the same ability. In the range $\theta \in [0.53, 0.58]$, the policy difference between the re-elected and replaced politicians decreases, indicating that as θ increases, the re-elected politician cedes less land, while voter utility rises due to improved post-conflict resource management. For $\theta > 0.58$, the gap widens. Although re-elected politicians continue to cede more land to insurgents than replaced politicians, the amount ceded increases further as their ability increases. This is due to the fact that, politicians in this scenario, are inherent 'doves' compared to the voters in terms of ideological valuation of the land. When faced with the possibility of replacement, they tend to stick to their inherent policies. However, when seeking re-election, they align their policies with voters ideological valuation. Therefore, the policy chosen by the replaced politician is less compared to the policy adopted by the re-elected politician. The optimal policy of the politicians at $\gamma = 1, \alpha = 0.8$ and $r = 0.5$ are demonstrated in Figure 3.4

[12]Note there is no change in the optimal policy of re-elected politician except now the re-election threshold is $\overline{\theta} = 0.53$ instead of 0.54.

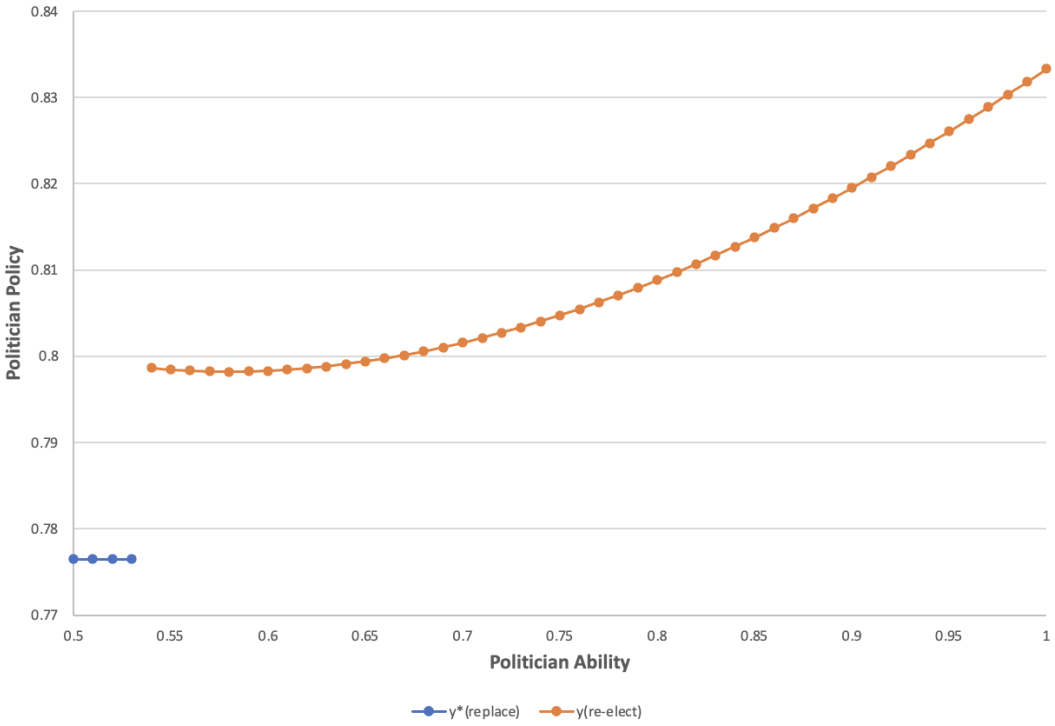

Figure 3.4 Optimal Policy under $\gamma = 1$, $\alpha = 0.8$ and $r = 0.5$

Note, for $\gamma < 0.87$, re-elected politicians policy is monotonic with their ability.

3.5 Conclusion:

In our chapter, we analyse a two-period principal-agent model. We demonstrate how voters use re-election as an incentive for the incumbent to opt for a settlement over territory that optimally balances retaining economically valuable resources which also has ideological utility against escalating conflict. Incumbent abilities vary in managing conflict costs, resource management of resources net of conflict costs, and intrinsic land ideology. The incumbent's ability is linked to success in minimizing costs from insurgent activities as well as managing resources post-conflict, while ideology signifies intrinsic land utility from the resource. We consider a complete information setting where the voters know the politician's abilities as well as his intrinsic valuation of land. We find the re-election standard set by the voters in re-electing politicians. The presence of ideological valuation for land valuation as well as resource management abilities may make

politician's policies non-monotonic with ability. Our comparative statics with politician's ideological valuation of land, show that policies chosen by 'hawk' politicians are lower when they face re-election than when they face replacement, while 'dove' policies are the opposite. When voters and politicians have the same ideological valuation for land, policies chosen by politicians facing re-election are lower near the threshold ability level but increase as ability diverges from the threshold compared to facing replacement. While this provides useful insights into when war or peace is more likely, understanding what happens in this set up under incomplete information will enrich the analysis, something that we leave for future research.

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Appendix One

Chapter 1 Appendix

A.1 Proofs

A.1.1 Proof of Lemma 1:

We begin by observing that the action space for each terrorist can be restricted to the interval $[0, B]$, where B is a finite upper bound. This restriction ensures that the action spaces of all terrorists are convex (by definition) and compact subsets of the Euclidean space. Next, let us examine equation 1.4, which reveals that the utility function of a terrorist is continuous in the product of their actions $(e_1, e_2, \ldots, e_n)$. Now, consider the payoff function of terrorist $i \in N$, denoted as $(1 - p\frac{m_i+1}{n})e_i(1 + \beta \sum_{i \in N} g_{ij}e_j)$. This function is linear in e_i, making it quasi-concave in e_i. The second term $p\frac{m_i+1}{n}f$ is constant with respect to changes in e_i. Additionally, the quadratic cost function is convex in e_i. Hence, by analysing the utility function of terrorist i, we can conclude that it is a concave function in e_i and, therefore, quasi-concave. Since all the assumptions of the Debreu-Fan-Glicksberg Theorem [1] are satisfied – including the quasi-concavity of the utility functions, the convexity of the strategy spaces, and the compactness of the strategy sets – the game admits a Nash equilibrium.

[1] See Debreu (1952),Fan (1952) and Glicksberg (1952).

A.1.2 Proof of Lemma 2:

By the definition of the path stated earlier, we can express it as:

$$|M_i \cup \{i\}| = |M_q \cup \{q\}|$$

Using the set union formula, we can rewrite the above equation as:

$$|M_i| + 1 - |M_i \cap \{i\}| = |M_q| + 1 - |M_q \cap \{q\}|$$

Since both sets $\{i\}$ and $\{q\}$ contain only one element, their cardinality is 1. Additionally, by the definition of path-connected members, M_i and $\{i\}$ are mutually exclusive sets. Therefore, $|M_i \cap \{i\}| = 0$. Similarly, M_q and $\{q\}$ are also mutually exclusive sets, so $|M_q \cap \{q\}| = 0$. Therefore, the equation can be simplified to:

$$|M_i| + 1 = |M_q| + 1$$

By the network definition, the cardinality of path-connected members is written as $|M_i| = m_i$ for all $i \in N$. Hence, the above equation can be rewritten as: $m_i + 1 = m_q + 1$. Therefore, we have successfully proven Lemma 2.

A.1.3 Proof of Proposition 1:

We maximise equation 1.4 with respect to the effort of individual terrorist e_i and set it equal to 0. Simplifying, we can write the equilibrium effort of individual terrorist in terms of equilibrium efforts of their neighbours,

$$e_i^* = \Big(1 - p\frac{m+1}{n}\Big)\Big(1 + \beta \sum_{j \in N} g_{ij} e_j\Big) \tag{A.1}$$

Substituting this implicit equilibrium efforts in equation 1.4 (the general utility function associated with $\delta = 1$) we can write the utility of individual terrorist implicitly as,

$$u_i = \frac{1}{2}\Big(1 - p\frac{m_i + 1}{n}\Big)\Big(1 + \beta \sum_{j \in N} g_{ij} e_j\Big)^2 - p\frac{m_i + 1}{n} f \tag{A.2}$$

To prove Proposition 1, we know from equation 1.4 that terrorist $i \in N$ will never choose zero efforts, as that would lead to $u_i < 0$. We then examine the first partial derivative of equation A.1 and A.2, where $\frac{\partial e_i}{\partial e_j}$ and $\frac{\partial u_i}{\partial e_j}$ will always be strictly greater than zero if $g_{ij} = 1 \; \forall \; \{i \neq j \in N\}$, given that $\boldsymbol{e} >> 0$ and $\beta \in (0, \frac{1}{n-1})$. In the network definition subsection, we defined m_i as the number of path-connected terrorists to i. Let u_i be the corresponding utility for terrorist i with degree $d_i = m_i$, where $d_i = \sum_{j \in N_i} g_{ij}$. We disregard scenarios where terrorist i has a degree $d_i > m_i$ since $d_i \subseteq m_i$. Revisiting equation 1.4, if terrorist i has a degree $d_i^{'} < d_i = m_i$, then $u_i^{'} < \hat{u}_i$ since $d_i^{'} < d_i$ and $e_j^{'} < e_j$ [2]. However, the cost of infiltration, given by $\Big(p\frac{m_i+1}{n}\Big)$, remains the same in both scenarios. Therefore, we can deduce that the leader designs a network where terrorists are maximally connected within a substructure (i.e., components are designed), and thus, the proposition is proved.

A.1.4 Proof of Corollary 1

Proof of Interior Equilibrium Effort

Looking back at the equilibrium conditions (equation 1.6), we know,

$$e_i^* = \Big(1 - p\frac{\overline{d} + 1}{n}\Big)\Big(1 + \beta \overline{d} e_j^*\Big)$$

Given the model parameters, its a isomorphic decision problem, so we are focussing on the symmetric equilibrium, therefore $e_i^* = e_j^* = \overline{e^*}$, hence we can write the above equation

[2] as $\frac{\partial e_i}{\partial e_j} > 0$ and $\frac{\partial u_i}{\partial e_j} > 0$ if $g_{ij} = 1 \; \forall \; i \neq j \in N$, $\beta \in (0, \frac{1}{n-1})$ and $\boldsymbol{e} >> 0$

as,

$$\overline{e^*} = \Big(1 - p\frac{\overline{d}+1}{n}\Big)\Big(1 + \beta\overline{d}\overline{e^*}\Big) \tag{A.3}$$

Simplifying the equation A.3, we can write,

$$\overline{e^*} = \Big(1 - p\frac{\overline{d}+1}{n}\Big) + \Big(1 - p\frac{\overline{d}+1}{n}\Big)\beta\overline{d}\overline{e^*}$$

$$\overline{e^*}\Big[1 - \Big(1 - p\frac{\overline{d}+1}{n}\Big)\beta\overline{d}\overline{e^*}\Big] = \Big(1 - p\frac{\overline{d}+1}{n}\Big)$$

Hence the interior equilibrium effort can be written as,

$$\overline{e^*} = \frac{n - p(\overline{d}+1)}{n - \beta\overline{d}(n - p(\overline{d}+1))}$$

Proof of Equilibrium Utility

Plugging equilibrium effort equation (equation 1.7) in the individual utility function (equation 1.5), we can write the equilibrium utility as,

$$\overline{u^*} = \frac{1}{2}\Big(1 - p\frac{\overline{d}+1}{n}\Big)^2\Big(1 + \beta\overline{d}\overline{e^*})^2 + \frac{\overline{d}+1}{n}p(-f) \tag{A.4}$$

Now substituting equilibrium effort in equation A.4, we get,

$$\overline{u^*} = \frac{1}{2}\Big(1 - p\frac{\overline{d}+1}{n}\Big)^2\Big(1 + \beta\overline{d}\Big(\frac{n - p(\overline{d}+1)}{n - \beta\overline{d}[n - p(\overline{d}+1)]}\Big)\Big)^2 + \frac{\overline{d}+1}{n}p(-f)$$

We now simplify the equilibrium utility step by step,

$$\overline{u^*} = \frac{1}{2}\Big(1 - p\frac{\overline{d}+1}{n}\Big)^2\Big(1 + \beta\overline{d}\Big(\frac{n - p(\overline{d}+1)}{n - \beta\overline{d}[n - p(\overline{d}+1)]}\Big)\Big)^2 + \frac{\overline{d}+1}{n}p(-f)$$

$$\overline{u^*} = \frac{1}{2}\Big(1 - p\frac{\overline{d}+1}{n}\Big)^2\Big(1 + \Big(\frac{n\beta\overline{d} - p\beta\overline{d}(\overline{d}+1)}{n - \beta\overline{d}n + p\beta\overline{d}(\overline{d}+1)}\Big)\Big)^2 + \frac{\overline{d}+1}{n}p(-f)$$

$$\overline{u^*} = \frac{1}{2}\Big(1 - p\frac{\overline{d}+1}{n}\Big)^2\Big(\frac{n - \beta\overline{d}n + p\beta\overline{d}(\overline{d}+1) + n\beta\overline{d} - p\beta\overline{d}(\overline{d}+1)}{n - \beta\overline{d}n + p\beta\overline{d}(\overline{d}+1)}\Big)^2 + \frac{\overline{d}+1}{n}p(-f)$$

$$\overline{u^*} = \frac{1}{2}\Big(1 - p\frac{\overline{d}+1}{n}\Big)^2\Big(\frac{n}{n - \beta\overline{d}n + p\beta\overline{d}(\overline{d}+1)}\Big)^2 - \frac{\overline{d}+1}{n}pf$$

The simplified interior equilibrium utility can be written as,

$$\overline{u^*} = \frac{1}{2}\Big(\frac{n - p(\overline{d}+1)}{n - \beta\overline{d}n + p\beta\overline{d}(\overline{d}+1)}\Big)^2 - \frac{\overline{d}+1}{n}pf$$

When the equilibrium effort admits a corner solution i.e. $\overline{e^*} = B$, the corresponding equilibrium utility can be written as,

$$\overline{u^*} = \Big(1 - p\frac{\overline{d}+1}{n}\Big)B\Big(1 + \beta\overline{d}B\Big) - \frac{\overline{d}+1}{n}pf - \frac{1}{2}B^2 \tag{A.5}$$

A.1.5 Proof of Corollary 2

Substituting the equilibrium utilities in the welfare function (equation 1.2), we can obtain the equilibrium welfare of an efficient network. The welfare corresponding to the interior equilibrium effort can be written as,

$$\overline{W^*_{int}} = \sum_{k=1}^{K}\Big(\overline{d_k}+1\Big)\Big[\frac{1}{2}\Big(\frac{n - p(\overline{d_k}+1)}{n - \beta\overline{d_k}n + p\beta\overline{d_k}(\overline{d_k}+1)}\Big)^2 - \Big(\frac{\overline{d_k}+1}{n}\Big)pf\Big]$$

Similarly, the welfare corresponding to the corner equilibrium effort, can be written as,

$$\overline{W^*_{cor}} = \sum_{k=1}^{K}\Big(\overline{d_k}+1\Big)\Big[(1 - p\frac{\overline{d_k}+1}{n})B(1 + \beta\overline{d_k}B) - \Big(\frac{\overline{d_k}+1}{n}\Big)pf - \frac{1}{2}B^2\Big]$$

When the components in the efficient network are symmetric, the corresponding utilities are:

$$\overline{W^*_{int}} = n\Big[\frac{1}{2}\Big(\frac{n - p(\overline{d}+1)}{n - \beta\overline{d}n + p\beta\overline{d}(\overline{d}+1)}\Big)^2 - \frac{\overline{d}+1}{n}pf\Big]$$

and,

$$\overline{W^*_{cor}} = n\Big[(1 - p\frac{\overline{d_k}+1}{n})B(1+\beta\overline{d_k}B) - \Big(\frac{\overline{d_k}+1}{n}\Big)pf - \frac{1}{2}B^2\Big]$$

A.1.6 Proof of Proposition 3

We will prove Proposition 3 with the help of Lemma 7A and Lemma 7B:

Proof of Lemma 7A: Based on Lemma 6A, we have shown that at $p = 0$, the terrorist network comprises a single component. Comparing $\overline{W}(p = 0, \overline{d} = n-1) = \frac{n}{2}\left(\frac{n}{n-\beta(n-1)}\right)^2$ and $\overline{W}(p = 1, \overline{d} = n-1) = -nf$, it becomes evident that $\overline{W}(p = 0, \overline{d} = n-1) > \overline{W}(p = 1, \overline{d} = n-1)$. Our focus lies in determining the existence of p^*, such that $\forall p \in [0, p^*]$, the efficient network maintains a single maximally connected component. To show this, we need to demonstrate that for such p's the following condition holds,

$$\overline{W}(p, \overline{d} = n-1) > \widehat{W} = \max_{\mathcal{G}} \sum_{k=1}^{K} (\overline{d_k}(\mathcal{G}) + 1)u_k(p, \overline{d_k}(\mathcal{G})) \tag{A.6}$$

Beyond p^*, the efficient network no longer exhibits a single complete component.

Consider a function $g(p)$ defined as follows: $g(p) = \overline{W}(p, \overline{d} = n-1) - \widehat{W}(p)$. We understand that $g(p)$ is continuous since $\overline{W}(p, \overline{d} = n-1)$ and $\widehat{W}(p)$ are continuous functions. We want to analyse $g(p)$ at $p = 0$ and $p = 1$.

1. At $p = 0$, we find $g(p = 0) = \overline{W}(p = 0, \overline{d} = n-1) - \widehat{W}(p = 0) > 0$. This inequality is based on Lemma 6A, which tells us that when $p = 0$, the efficient network is comprised of a single component.

2. At $p = 1$, we have $g(p = 1) = \overline{W}(p = 1, \overline{d} = n-1) - \widehat{W}(p = 1) < 0$. Given that

$\frac{\partial \overline{u}}{\partial p} < 0$ and considering that $\overline{W}$ is a linear transformation of $\overline{u}$, we can infer that $\frac{\partial \overline{W}}{\partial p} < 0$. We also understand that there is a monotonic non-increasing relationship between p and $\overline{d}$. This suggests when p increases, the efficient network transitions from being a single component to other efficient network structures.

By applying Bolzano's Theorem [3], we can conclude that there exists a $p \in (0, 1)$ such that $g(p) = 0$. Consequently, $\overline{W}(p, \overline{d} = n - 1) = \widehat{W}(p)$, and we can identify a p^*, such that $\forall p \in [0, p^*]$, the efficient network remains a single maximally connected complete component. Beyond p^*, this single complete component is no longer the efficient network.

Proof of Lemma 7B: Similarly, from Lemma 6B we know that at $p = 1$, the terrorist network will have n empty components. We are interested in discussing the existence of p^{**}, such that $\forall p \in [p^{**}, 1]$, the efficient network will have n empty components. To establish this, we need to demonstrate that for such p's the following condition holds,

$$\overline{W}(p, \overline{d} = 0) > \widehat{W} = \max_{\mathcal{G}} \sum_{k=1}^{K} (\overline{d_k}(\mathcal{G}) + 1) u_k(p, \overline{d_k}(\mathcal{G})) \tag{A.7}$$

Below p^{**}, the efficient network comprises of components which larger component size compared to empty networks.

Consider a function $h(p)$ defined as follows: $h(p) = \overline{W}(p, \overline{d} = 0) - \widehat{W}(p)$. We understand $h(p)$ is continuous since $\overline{W}(p, \overline{d} = 0)$ and $\widehat{W}(p)$ are continuous functions. We want to analyze $h(p)$ at $p = 0$ and $p = 1$.

1. At $p = 0$, we find $h(p = 0) = \overline{W}(p = 0, \overline{d} = 0) - \widehat{W}(p = 0) < 0$. Given that $\frac{\partial \overline{u}}{\partial p} < 0$ and considering that $\overline{W}$ is a linear transformation of u, we can infer that $\frac{\partial \overline{W}}{\partial p} < 0$. We also understand that there is a monotonic non-increasing relationship between p and $\overline{d}$. This suggests that when p is low, the efficient network will comprise of larger connected components compared to empty components, and the welfare of

[3] See Apostol, 1991

these efficient networks with larger connected components is higher than efficient networks with empty components.

2. At $p = 1$, we have $h(p = 1) = \overline{W}(p = 1, \overline{d} = 0) - \widehat{W}(p = 1) > 0$. This inequality is based on Lemma 6B, which tells us that when $p = 1$, the efficient network is comprised of only empty components.

By applying Bolzano's Theorem, we can conclude that there exists an $p \in (0, 1)$ such that $h(p) = 0$. Consequently, $\overline{W}(p, d = 0) = \widehat{W}(p)$, and we can identify a p^{**}, such that $\forall p \in [p^{**}, 1]$, the efficient network comprises of only empty components. Below p^{**}, the efficient network comprises of components with larger connected components compared to empty networks.

A.2 Tables

A.2.1 Optimal degree with changes in p when $n = 100, f = 1$ and $\beta = 0.01$

For	p	=	0.00,	d	where	u	is	maximum:	99.0000
For	p	=	0.01,	d	where	u	is	maximum:	99.0000
For	p	=	0.02,	d	where	u	is	maximum:	99.0000
For	p	=	0.03,	d	where	u	is	maximum:	99.0000
For	p	=	0.04,	d	where	u	is	maximum:	99.0000
For	p	=	0.05,	d	where	u	is	maximum:	99.0000
For	p	=	0.06,	d	where	u	is	maximum:	99.0000
For	p	=	0.07,	d	where	u	is	maximum:	99.0000
For	p	=	0.08,	d	where	u	is	maximum:	99.0000
For	p	=	0.09,	d	where	u	is	maximum:	99.0000
For	p	=	0.10,	d	where	u	is	maximum:	99.0000
For	p	=	0.11,	d	where	u	is	maximum:	99.0000
For	p	=	0.12,	d	where	u	is	maximum:	99.0000
For	p	=	0.13,	d	where	u	is	maximum:	99.0000
For	p	=	0.14,	d	where	u	is	maximum:	99.0000
For	p	=	0.15,	d	where	u	is	maximum:	99.0000
For	p	=	0.16,	d	where	u	is	maximum:	99.0000
For	p	=	0.17,	d	where	u	is	maximum:	99.0000
For	p	=	0.18,	d	where	u	is	maximum:	99.0000
For	p	=	0.19,	d	where	u	is	maximum:	99.0000
For	p	=	0.20,	d	where	u	is	maximum:	99.0000

For	p	=	0.21,	d	where	u	is	maximum:	99.0000
For	p	=	0.22,	d	where	u	is	maximum:	99.0000
For	p	=	0.23,	d	where	u	is	maximum:	99.0000
For	p	=	0.24,	d	where	u	is	maximum:	99.0000
For	p	=	0.25,	d	where	u	is	maximum:	99.0000
For	p	=	0.26,	d	where	u	is	maximum:	99.0000
For	p	=	0.27,	d	where	u	is	maximum:	99.0000
For	p	=	0.28,	d	where	u	is	maximum:	99.0000
For	p	=	0.29,	d	where	u	is	maximum:	99.0000
For	p	=	0.30,	d	where	u	is	maximum:	99.0000
For	p	=	0.31,	d	where	u	is	maximum:	99.0000
For	p	=	0.32,	d	where	u	is	maximum:	99.0000
For	p	=	0.33,	d	where	u	is	maximum:	99.0000
For	p	=	0.34,	d	where	u	is	maximum:	99.0000
For	p	=	0.35,	d	where	u	is	maximum:	99.0000
For	p	=	0.36,	d	where	u	is	maximum:	99.0000
For	p	=	0.37,	d	where	u	is	maximum:	98.0000
For	p	=	0.38,	d	where	u	is	maximum:	92.0000
For	p	=	0.39,	d	where	u	is	maximum:	86.0000
For	p	=	0.40,	d	where	u	is	maximum:	80.0000
For	p	=	0.41,	d	where	u	is	maximum:	74.0000
For	p	=	0.42,	d	where	u	is	maximum:	69.0000
For	p	=	0.43,	d	where	u	is	maximum:	63.0000
For	p	=	0.44,	d	where	u	is	maximum:	57.0000
For	p	=	0.45,	d	where	u	is	maximum:	52.0000
For	p	=	0.46,	d	where	u	is	maximum:	46.0000
For	p	=	0.47,	d	where	u	is	maximum:	40.0000
For	p	=	0.48,	d	where	u	is	maximum:	34.0000
For	p	=	0.49,	d	where	u	is	maximum:	26.0000

For	p	=	0.50,	d	where	u	is	maximum:	0.0000
For	p	=	0.51,	d	where	u	is	maximum:	0.0000
For	p	=	0.52,	d	where	u	is	maximum:	0.0000
For	p	=	0.53,	d	where	u	is	maximum:	0.0000
For	p	=	0.54,	d	where	u	is	maximum:	0.0000
For	p	=	0.55,	d	where	u	is	maximum:	0.0000
For	p	=	0.56,	d	where	u	is	maximum:	0.0000
For	p	=	0.57,	d	where	u	is	maximum:	0.0000
For	p	=	0.58,	d	where	u	is	maximum:	0.0000
For	p	=	0.59,	d	where	u	is	maximum:	0.0000
For	p	=	0.60,	d	where	u	is	maximum:	0.0000
For	p	=	0.61,	d	where	u	is	maximum:	0.0000
For	p	=	0.62,	d	where	u	is	maximum:	0.0000
For	p	=	0.63,	d	where	u	is	maximum:	0.0000
For	p	=	0.64,	d	where	u	is	maximum:	0.0000
For	p	=	0.65,	d	where	u	is	maximum:	0.0000
For	p	=	0.66,	d	where	u	is	maximum:	0.0000
For	p	=	0.67,	d	where	u	is	maximum:	0.0000
For	p	=	0.68,	d	where	u	is	maximum:	0.0000
For	p	=	0.69,	d	where	u	is	maximum:	0.0000
For	p	=	0.70,	d	where	u	is	maximum:	0.0000
For	p	=	0.71,	d	where	u	is	maximum:	0.0000
For	p	=	0.72,	d	where	u	is	maximum:	0.0000
For	p	=	0.73,	d	where	u	is	maximum:	0.0000
For	p	=	0.74,	d	where	u	is	maximum:	0.0000
For	p	=	0.75,	d	where	u	is	maximum:	0.0000
For	p	=	0.76,	d	where	u	is	maximum:	0.0000
For	p	=	0.77,	d	where	u	is	maximum:	0.0000
For	p	=	0.78,	d	where	u	is	maximum:	0.0000

For	p	=	0.79,	d	where	u	is	maximum:	0.0000
For	p	=	0.80,	d	where	u	is	maximum:	0.0000
For	p	=	0.81,	d	where	u	is	maximum:	0.0000
For	p	=	0.82,	d	where	u	is	maximum:	0.0000
For	p	=	0.83,	d	where	u	is	maximum:	0.0000
For	p	=	0.84,	d	where	u	is	maximum:	0.0000
For	p	=	0.85,	d	where	u	is	maximum:	0.0000
For	p	=	0.86,	d	where	u	is	maximum:	0.0000
For	p	=	0.87,	d	where	u	is	maximum:	0.0000
For	p	=	0.88,	d	where	u	is	maximum:	0.0000
For	p	=	0.89,	d	where	u	is	maximum:	0.0000
For	p	=	0.90,	d	where	u	is	maximum:	0.0000
For	p	=	0.91,	d	where	u	is	maximum:	0.0000
For	p	=	0.92,	d	where	u	is	maximum:	0.0000
For	p	=	0.93,	d	where	u	is	maximum:	0.0000
For	p	=	0.94,	d	where	u	is	maximum:	0.0000
For	p	=	0.95,	d	where	u	is	maximum:	0.0000
For	p	=	0.96,	d	where	u	is	maximum:	0.0000
For	p	=	0.97,	d	where	u	is	maximum:	0.0000
For	p	=	0.98,	d	where	u	is	maximum:	0.0000
For	p	=	0.99,	d	where	u	is	maximum:	0.0000

A.2.2 Optimal degree with Variation in p when $n = 100$, $f = 4$, and $\beta = 0.01$

For	p	=	0.328,	d	where	u	is	maximum:	99.0000
For	p	=	0.329,	d	where	u	is	maximum:	99.0000
For	p	=	0.330,	d	where	u	is	maximum:	99.0000
For	p	=	0.331,	d	where	u	is	maximum:	99.0000
For	p	=	0.332,	d	where	u	is	maximum:	99.0000
For	p	=	0.333,	d	where	u	is	maximum:	99.0000
For	p	=	0.334,	d	where	u	is	maximum:	99.0000
For	p	=	0.335,	d	where	u	is	maximum:	99.0000
For	p	=	0.336,	d	where	u	is	maximum:	99.0000
For	p	=	0.337,	d	where	u	is	maximum:	99.0000
For	p	=	0.338,	d	where	u	is	maximum:	99.0000
For	p	=	0.339,	d	where	u	is	maximum:	0.0000
For	p	=	0.340,	d	where	u	is	maximum:	0.0000
For	p	=	0.341,	d	where	u	is	maximum:	0.0000
For	p	=	0.342,	d	where	u	is	maximum:	0.0000
For	p	=	0.343,	d	where	u	is	maximum:	0.0000
For	p	=	0.344,	d	where	u	is	maximum:	0.0000
For	p	=	0.345,	d	where	u	is	maximum:	0.0000
For	p	=	0.346,	d	where	u	is	maximum:	0.0000
For	p	=	0.347,	d	where	u	is	maximum:	0.0000

Appendix Two

Chapter 2 Appendix

B.1 Overall Average Investment Level Across Settings

	Average Normalized Investment		
Unit Cost	Baseline	Treatment 1	Treatment 2
0.6	0.47	0.5	0.35
0.7	0.33	0.37	0.41
0.8	0.45	0.45	0.43
0.9	0.57	0.36	0.30
1	0.36	0.32	0.32
1.1	0.34	0.21	0.36
1.2	0.36	0.37	0.35
1.3	0.27	0.32	0.41
1.4	0.37	0.55	0.30
1.5	0.38	0.42	0.42
Average	0.390	0.387	0.365

Table B.1 Average Investment Bids Across Settings with Changes in Cost

B.2 Average Investment Level by Ability Across Settings

	Average Normalized Investment by Ability					
	Baseline		Treatment 1		Treatment 2	
Unit Cost	Ability 3	Ability 4	Ability 3	Ability 4	Ability 3	Ability 4
0.6	0.49	0.44	0.55	0.36	0.32	0.38
0.7	0.39	0.30	0.3	0.44	0.34	0.44
0.8	0.32	0.52	0.43	0.47	0.26	0.67
0.9	0.49	0.66	0.33	0.44	0.27	0.34
1	0.42	0.32	0.29	0.34	0.25	0.38
1.1	0.40	0.26	0.28	0.10	0.43	0.24
1.2	0.39	0.31	0.44	0.29	0.28	0.41
1.3	0.19	0.34	0.31	0.32	0.43	0.40
1.4	0.29	0.48	0.38	0.64	0.18	0.71
1.5	0.29	0.47	0.44	0.39	0.4	0.42
Average	0.367	0.410	0.375	0.379	0.316	0.439

Table B.2 Average Investment Bids Across Settings with Changes in Cost

B.3 Regression on Investment Level based on Individual Ability in Baseline

In this regression the dependent variable is Investment.[1] Across all regression models, we include a variable called 'Unit Cost' which refers to the unit cost assigned to the participant. In this regression, we take ability as given. In Section 7.3.1, we ran the regression with ability set to 3, and in Section 7.3.2, we ran the regression with ability

[1]This is the normalized investment level i.e., actual investment by participants divided by V.

set to 4. In Model (2), we additionally add 'Risk aversion' as an independent variable, which measures the number of safe options in our lottery task. The last model (3) adds controls in addition to the independent variables in Model (2).

B.3.1 Regression on Low Ability participants Investment Level in Baseline Setting

Dependent Variable	Investment Level of Participants		
	(1)	(2)	(3)
Unit Cost	-0.22**	-0.22**	-0.19*
	(0.09)	(0.09)	(0.10)
Risk Averse		0.00	0.00
		(0.01)	(0.01)
Constant	0.61***	0.60***	0.38**
	(0.11)	(0.12)	(0.18)
Controls	No	No	Yes
N	81	81	81

*Note: OLS estimates. Controls include participant's gender, importance to maximize income, and understanding of instructions. Robust standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table B.3 Regression Analysis of Investment Bids of Low Ability Participants in Baseline

B.3.2 Regression on High Ability participants Investment Level in Baseline Setting

Dependent Variable	Investment Level of Participants		
	(1)	(2)	(3)
Unit Cost	0.03	0.05	0.06
	(0.12)	(0.12)	(0.12)
Risk Averse		-0.03	-0.03
		(0.02)	(0.02)
Constant	0.36**	0.44**	0.44**
	(0.14)	(0.14)	(0.20)
Controls	No	No	Yes
N	81	81	81

*Note: OLS estimates. Controls include participant's gender, importance to maximize income, and understanding of instructions. Robust standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table B.4 Regression Analysis of Investment Bids of High Ability Participants in Baseline

B.4 Regression on Investment Level based on Individual Ability in Treatment 1

The dependent variable in this regression is the investment level. Like in section 7.3 above, we run regressions individually for ability 3 participants and ability 4 participants. Across all regression models, we include a variable called 'Unit Cost' which refers to the unit cost assigned to participant. From Models (2) to (4), we additionally include two independent variables called 'Reveal Decision' which takes value of 1 if decided to reveal and equals to zero if not and an interaction term between 'Other Unit Cost' and 'Other reveal decision'

which measures the other's unit cost when the other paired participant decided to reveal. If the other paired participant decides to reveal it will take 1 otherwise 0. In Model (3), we additionally add 'Risk aversion' as an independent variable, which measures the number of safe options in our lottery task. And lastly, Model (4) controls for the participant's gender, the importance placed on maximizing income, and their understanding of the instructions, in addition to the independent variables from Model (3).

B.4.1 Regression on Low Ability participants Investment Level in Treatment 1 Setting

Dependent Variable	Investment Level of Participants			
	(1)	(2)	(3)	(4)
Unit Cost	-0.10	-0.07	-0.07	-0.05
	(0.12)	(0.12)	(0.12)	(0.12)
Reveal Decision		0.09	0.09	0.09
		(0.06)	(0.06)	(0.06)
Other Unit Cost * Other Reveal Decision		0.03	0.02	0.02
		(0.06)	(0.06)	(0.06)
Risk Averse			0.00	0.00
			(0.02)	(0.02)
Constant	0.47***	0.37**	0.39*	0.41**
	(0.12)	(0.14)	(0.14)	(0.20)
Controls	No	No	No	Yes
N	84	84	84	84

*Note: OLS estimates. Controls include participant's gender, importance to maximize income, and understanding of instructions. Robust standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table B.5 Regression Analysis of Investment Bids of Low Ability Participants in Treatment 1

B.4.2 Regression on High Ability participants Investment Level in Treatment 1 Setting

Dependent Variable	Investment Level of Participants			
	(1)	(2)	(3)	(4)
Unit Cost	-0.01	0.02	0.03	0.03
	(0.12)	(0.13)	(0.13)	(0.13)
Reveal Decision		0.07	0.07	0.06
		(0.07)	(0.07)	(0.07)
Other Unit Cost * Other Reveal Decision		0.02	0.03	0.06
		(0.07)	(0.07)	(0.06)
Risk Averse			-0.02	-0.03
			(0.02)	(0.02)
Constant	0.39**	0.31**	0.38**	0.69*
	(0.13)	(0.15)	(0.16)	(0.25)
Controls	No	No	No	Yes
N	84	84	84	84

*Note: OLS estimates. Controls include participant's gender, importance to maximize income, and understanding of instructions. Robust standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table B.6 Regression Analysis of Investment Bids of High Ability Participants in Treatment 1

B.5 Regression on Investment Level based on Individual Ability in Treatment 2

Like above we take the dependent variable as investment. We ran separate regressions for ability 3 and ability 4 participants Across all regression models, we include a variable

called ‘Unit Cost’ which refers to the unit cost assigned to participant. From Models (2) to (4), we additionally include two independent variables called ‘Reveal Decision’ which takes value of 1 if decided to reveal and equals to zero if not and an interaction term between ‘Other Unit Cost’ and ‘Other reveal decision’ which measures the other’s unit cost when the other paired participant decided to reveal. If the other paired participant decides to reveal it will take 1 otherwise 0. In this treatment, the ‘Other reveal decision’ also encompasses the common knowledge of a participant’s unit cost in the pair and is set to 1. In Model (3), we additionally add "Risk aversion" as an independent variable, which measures the number of safe options in our lottery task. The last model (4) adds additional controls as defined earlier from Model (3).

B.5.1 Regression on Low Ability participants Investment Level in Treatment 2 Setting

Dependent Variable	Investment Level of Participants			
	(1)	(2)	(3)	(4)
Unit Cost	0.05	-0.11	-0.12	-0.12
	(0.12)	(0.15)	(0.16)	(0.16)
Reveal Decision		-0.02	-0.02	-0.02
		(0.08)	(0.08)	(0.09)
Other Unit Cost * Other Reveal Decision		-0.03	-0.05	-0.05
		(0.11)	(0.13)	(0.14)
Risk Averse			-0.01	-0.02
			(0.03)	(0.03)
Constant	0.26**	0.50**	0.59*	0.64*
	(0.12)	(0.18)	(0.31)	(0.37)
Controls	No	No	No	Yes
N	75	35	35	35

*Note: OLS estimates. Controls include participant's gender, importance to maximize income, and understanding of instructions. Robust standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table B.7 Regression Analysis of Investment Bids of Low Ability Participants in Treatment 2

B.5.2 Regression on High Ability participants Investment Level in Treatment 2 Setting

Dependent Variable	Investment Level of Participants			
	(1)	(2)	(3)	(4)
Unit Cost	-0.12	-0.03	-0.01	0.06
	(0.10)	(0.13)	(0.13)	(0.14)
Reveal Decision		-0.01	-0.06	-0.07
		(0.09)	(0.08)	(0.08)
Other Unit Cost * Other Reveal Decision		0.09	0.04	0.02
		(0.17)	(0.14)	(0.15)
Risk Averse			0.05	0.05
			(0.02)	(0.02)
Constant	0.43***	0.37**	0.24*	0.17
	(0.11)	(0.15)	(0.14)	(0.23)
Controls?	No	No	No	Yes
N	75	40	40	40

*Note: OLS estimates. Controls include participant's gender, importance to maximize income, and understanding of instructions. Robust standard errors clustered by participant in parentheses. Significant differences are shown using * p <0.1, ** p <0.05, *** p <0.01.*

Table B.8 Regression Analysis of Investment Bids of High Ability Participants in Treatment 2

B.6 Experimental Instructions

Instructions

Welcome to the Study!

This is an experiment in economic decision-making, funded by the Institute for Global Innovation at the University of Birmingham.

This study aims to gain insights into how individuals make economic decisions. To participate, you must be over 18 years old.

The experiment should not take more than 15 minutes. Please make sure you have enough time at your disposal.

You can earn money by making decisions in the experiment. We will explain how to earn money during the study. Also, you will get £1 guaranteed as a participation fee. Your responses and earnings will be private and anonymous.

Your participation is entirely voluntary, and you retain the option to withdraw at any point during the session. Please note that if you choose to withdraw, you will not receive any compensation from the study.

Kindly take part in the experiment on your own. Please do not work with others.

After reading the information above, confirm your Prolific ID on the next page, which is fundamental for your final payments and indicate your intention to participate on the following page.

You will have 3 [2] attention-check questions. Answer them one by one. You cannot proceed to the next question until you get the current one right. You get four chances to answer each question. If you use up all four chances and still have not answered, you cannot try again. In that case you cannot continue the experiment and you will not receive any compensation. If you answer all the attention-check questions correctly, you can move on the decision-making part of the experiment.

Remember, after you click 'next,' you cannot go back to the previous page. So, be sure you understand everything before you click 'next'.

Please Confirm your Prolific ID

Prolific ID: [Enter Prolific ID]

Do you agree to participate in the study?

Indicate your intention to participate by choosing one of the options below:

- [ ] I agree to participate in the research. Take me to the study.

- [ ] I do not agree to participate. Take me back to Prolific.

General Instructions

This is the main part of the experiment, you will play an economic decision-making game.

Before we proceed, we will explain how the experiment works to ensure clarity and understanding.

[2] 4-for the treatments

Once the experiment starts, you will be matched randomly with someone else who is also participating in the experiment session. Every other participant has an equal chance of being paired with you. You will not know the identity of your paired participant.

Your earnings today depend on the decisions you and your paired participant make. Unless stated otherwise, we will talk about points instead of pounds in the instructions. The conversion rate from points to pounds is 100 points equal to £0.01. Your final earnings from the experiment will be in pounds. You will get the participation fee right after you finish the experiment, and your earnings from the experiment will be paid after a week later once we have calculated earnings for all participants taking part in the experiment.

During the experiment, you might need to wait for your paired participant to decide before moving forward. If 20 minutes elapse while you are on the waiting page, we will consider that your paired participant has left the experiment. In this case, we will terminate your experiment, and your final payment will be calculated as the average of the final earnings of all participants taking part in the session, in addition to the participation fee.

The next page explains the experiment in details. Please read carefully.

Detailed description of the experiment

The experiment has two parts. For the first part known as the contest task, you will have only one [3] stage which is played for a single round.

Here, is how it works: You are endowed with 120 points. You can invest any integer

[3]Two for treatments

number of points from 0 to 120 in your project. Your paired participant also likewise invests integer amount in their project from their endowment of 0 to 120. Depending on both your investments, one project in your pair will succeed. If yours is successful, you earn an additional 120 points; if it is unsuccessful, you earn 0 additional points. The remaining endowment following your investment will be paid to you in the form of earnings.

You and your paired participant will have different innate abilities, which could affect your project's probability (chance) of success. One of you will have ability 4 and the other paired participant will have 3. You will be informed about your own and your paired participant's abilities.

If either one or both of you invests in your projects, then the probability of your project's success is given by the formula below,

$$\frac{\text{your ability} \times \text{your investment}}{(\text{your ability} \times \text{your investment}) + (\text{your paired participant's ability} \times \text{their investment})}$$

For instance, if your ability is 4 and your paired participant's ability is 3, then if you invest 75 points in your project and your paired participant invests 65 points in theirs, the total investment is (4*75) + (3*65) = 495 points. In this case, your project's probability of success is (4*75) / 495 = 0.61, or 61%, and your paired participant's project's probability of success is (3*65) / 495 = 0.39, or 39%.

The computer chooses one participant's project where the probability of being chosen is given by the above formula.

If neither of you invests anything in your projects, and if your ability is 4 and your paired participant's ability is 3, then the probability of success for your project is

$$\frac{\text{your ability}}{\text{your ability} + \text{your paired participant's ability}} = \frac{4}{4+3} = 57\%$$

and the probability of success for your paired participant's project is

$$\frac{\text{your paired participant's ability}}{\text{your ability} + \text{your paired participant's ability}} = \frac{3}{4+3} = 43\%.$$

If your paired participant's ability is 4 and your ability is 3, then the probabilities of success are flipped. The computer then randomly selects one participant's project based on these probabilities of success.

Investing in your project has a cost, but it is private information, so your paired participant will not know your cost. Your cost could be higher, equal to, or lower than your paired participant's. It is randomly chosen from these options: $\{0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5\}$. You will see your cost on your screen.

The cost of investment is denoted by,

$$\text{(unit cost of investment)} \times \text{(your investment amount)}.$$

For instance, if your Unit Cost is 0.8 and you invest 20, your cost of investment is 0.8 times 20, which equals 16.

Note: Your investment and the cost of investing are separate. For example, if you invest 60 points out of 120 and your unit cost is 0.6, it will cost you 0.6 * 60 = 36 points. So, you will have 84 points left (120 - 36) instead of (120 - 60) = 60 points, which will be converted at £0.01 rate and added to your final earnings. [4]

Following the investment decisions of you and your paired participant, your final earnings from the contest part is determined as follows:

Final Earnings = (120−(unit cost)×(investment)+120(if your project is successful)×0.01

[4]Following this, another paragraph will be added based on treatment.

Final Earnings = (120−(unit cost)×(investment)+0(if your project is unsuccessful)×0.01

In the second part, you will play a lottery task with 7 questions. Each time, you will have to choose between two options (Option A and Option B). Option A guarantees you a sure monetary gain of 50 points, while Option B [5] is the lottery. As you progress, you have the potential to win more points. After all 7 questions, one question will be randomly selected, and your final earnings from the lottery task will depend on your choice of that question.

At the end of the experiment, on the results screen, for the first (investment task) part, we will inform you on the success of your project, your project's probability of winning, and details regarding your final payoffs in points and final earnings in pounds. Additional to the details of the investment task, you will also see how much you have earned in pounds from the second (lottery task) part.

Please be patient, as you might have to wait before you can see the outcome of the experiment. Unless you want to voluntarily drop out 'do not close your tab'.

Final Payments from the experiment:

Your final payments from both parts of the experiment are as follows: For the contest part, you will participate in one decision round. We will pay you for this round. From the lottery part, out of the 7 lottery questions we will choose one question at random and will pay you for that question depending on your choice. Additionally, you will receive the guaranteed participation fee. The amount shown on your result screen is your earnings from both parts of the experiment in pounds. On the payment page, you will also see your final payment in pounds, including your earnings from both parts and the participation fee.

[5] See lottery Task table in the end

Please note that if your final payment is less than £1, we will still pay you £1 as your final payment.

To ensure your full understanding of the experiment please respond to the control questions.

After successfully completing the control questions, the actual experiment will start.

Questionnaire: Select the correct alternative for each question

Question 1: If your ability is 4 and you invest 50 points in your project out of your 120 points and your paired participant's ability is 3 and they invest 40 points, what is the probability of success (expressed in percentages) for your project?

1. $\left(\frac{3*50}{(3*50)+(4*40)}\right)*100 = 48.39\%$.
2. $\left(\frac{3*40}{(3*40)+(4*50)}\right)*100 = 37.5\%$.
3. $\left(\frac{4*50}{(4*50)+(3*40)}\right)*100 = 62.5\%$.
4. $\left(\frac{3*50}{(3*40)+(4*50)}\right)*100 = 46.87\%$.

Hint: Use one of the formula below to solve for this question:

Formula 1: If either one or both of you invests in your projects, then the probability of your project's success is given by the formula below,

$$\frac{\text{your ability} \times \text{your investment}}{(\text{your ability} \times \text{your investment}) + (\text{your paired participant's ability} \times \text{their investment})}$$

Formula 2: If neither of you invests anything in your projects, then the probability of your project's success, is given by the formula below,

$$\frac{\text{your ability}}{(\text{your ability}) + (\text{your paired participant's ability})}$$

Question 2: If your ability is 4 and you invest 0 points in your project out of your 120 points and your paired participant invests 0 points as well, what is the probability of success for your project?

1. 57.14%
2. 100%
3. 42.86%
4. 0%.

The same hint from question 1 was displayed in question 2.

Question 3: If your unit investment cost is 0.9, and you invest 60 points in your project while your paired participant invests 70 points in theirs, what is your final payoff from the experiment if your project is unsuccessful?

1. 120 - (0.9*60) = 66 points
2. 240 - (0.9*60) = 186 points
3. 120 - (0.9*70) = 57 points
4. 240 - (0.9*70) = 177 points

Hint: Use one of the formula below to calculate your final payoffs in points from the contest task:

Formula 1: If your project is successful, the payoff in points is given by the formula

below,

$$240 - (\text{unit cost} \times \text{investment})$$

Formula 2: If your project is unsuccessful, the payoff in points is given by the formula below,

$$120 - (\text{unit cost} \times \text{investment})$$

You will now be directed to the experiment. Please remember to click 'next' to proceed.

Treatment:

This game has two stages which we will describe now,

Treatment 1[6]: Now before you invest, you can reveal your private unit cost for free to your paired participant, and they can do the same. If you choose to reveal, click 'reveal' and then 'next'. Your paired participant will see your unit cost along with theirs on their next screen. If you do not want to reveal, click 'not reveal' and then 'next'. In that case, your paired participant will only see their cost on their next screen. Remember, even your cost is not revealed, your participant will still know that your cost is drawn from the interval {0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5} with equal probability. If your paired participant reveals, you will see both costs on your next screen; otherwise, you will only see yours on the next screen and you will know that your paired participant have drawn their cost from the said interval with equal probability. Press 'next' to proceed, but be patient as you may need to wait for your paired participant.

Treatment 2: In your pair, one of you will be randomly chosen, and their cost info will be made public to the other. If your paired participant's cost is made public, your screen will see their cost and your cost. Upon observing this cost information in this case, before you invest, you can choose to reveal your cost for free. If you choose to

[6]This will be absent in the baseline model

reveal, click 'reveal' and then 'next'. Your cost will show on your paired participant's next screen along with their own cost. If you do not want to reveal, click 'not reveal', then 'next', and your paired participant will only see their cost. Remember, even your cost is not revealed, your participant will still know that your cost is drawn from the interval {0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 1.4, 1.5} with equal probability. If you are chosen and your cost is announced, letting your paired participant decide whether or not to reveal their cost. If they reveal, their cost will appear on your screen along with your own cost, otherwise you can see only your own cost and you will know that your paired participant have drawn their cost from the said interval with equal probability. Press 'next' to proceed, but be patient as you may need to wait for your paired participant.

Question 1: Would you find out if your unit cost is higher, for example, your unit cost is 1.5, and your paired participant does not reveal their unit cost?[7]

1. Yes
2. No
3. Maybe

Risk Eliciting

This task involves choosing one of two options (either Option A or Option B), where Option A is always a sure monetary gain and Option B involves a lottery. The decision problems are presented in a table and you need to make a decision in each row. When you make all your decisions for each of the decision problems presented, one of them will be randomly chosen and you will receive the payment according to the resulting outcome from this decision.

[7]This is the additional question for the treatments

Decision	Option A	Option B
1	100% chance of £0.50	50% chance of £0 and 50% chance of £0.80
2	100% chance of £0.50	50% chance of £0 and 50% chance of £1.00
3	100% chance of £0.50	50% chance of £0 and 50% chance of £1.20
4	100% chance of £0.50	50% chance of £0 and 50% chance of £1.40
5	100% chance of £0.50	50% chance of £0 and 50% chance of £1.60
6	100% chance of £0.50	50% chance of £0 and 50% chance of £1.80
7	100% chance of £0.50	50% chance of £0 and 50% chance of £2.00

Table B.9 Lottery Task Table

B.7 Experiment Screenshots

We present some example screenshots observed by some participants while taking part in the experiment. We present first the baseline, followed by treatment 1 and then treatment 2.

Baseline

In the baseline, we present the investment, results, final questionnaire, and Thank You pages below.

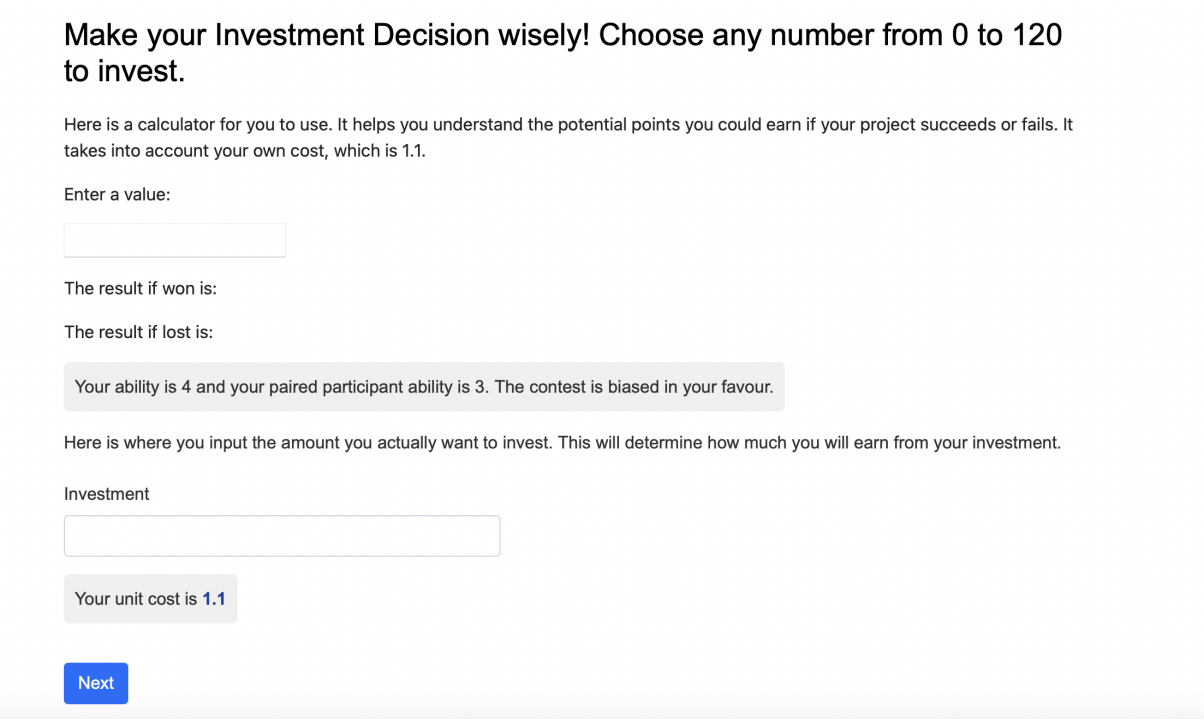

Figure B.1 Investment Page in Baseline.

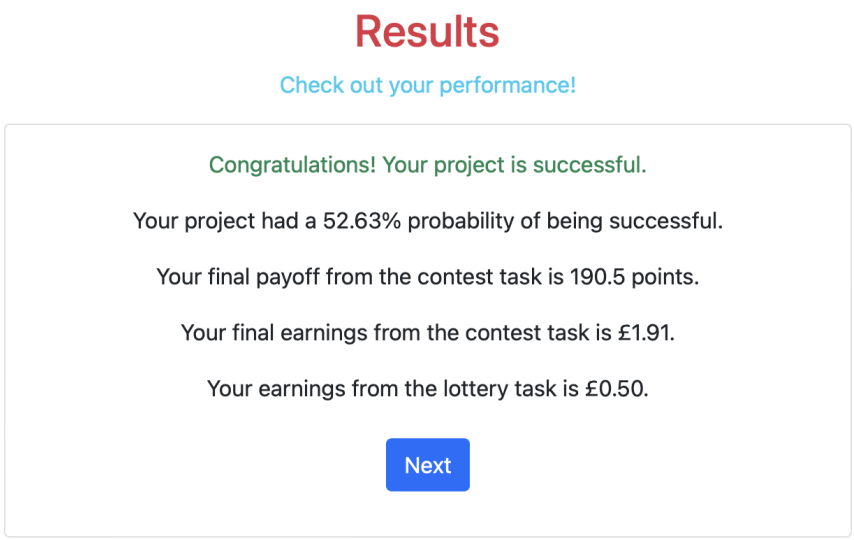

Figure B.2 Results page displayed to the participant when their project is successful.

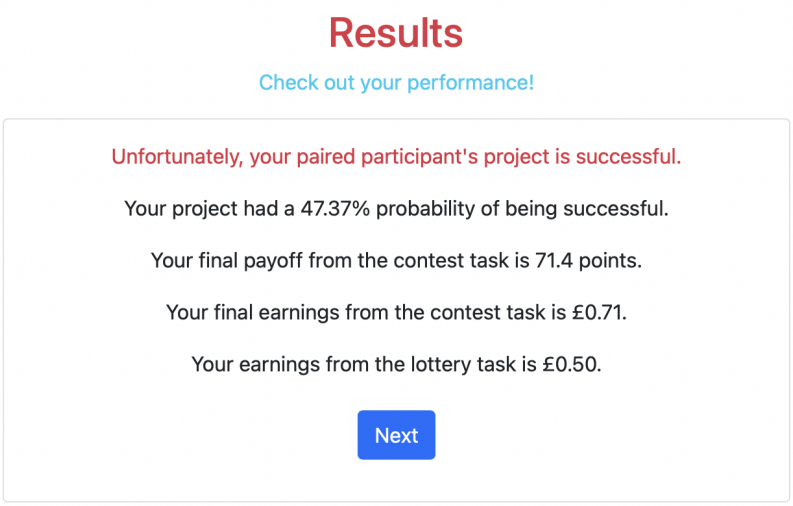

Figure B.3 Results page displayed to the participant when their project is unsuccessful.

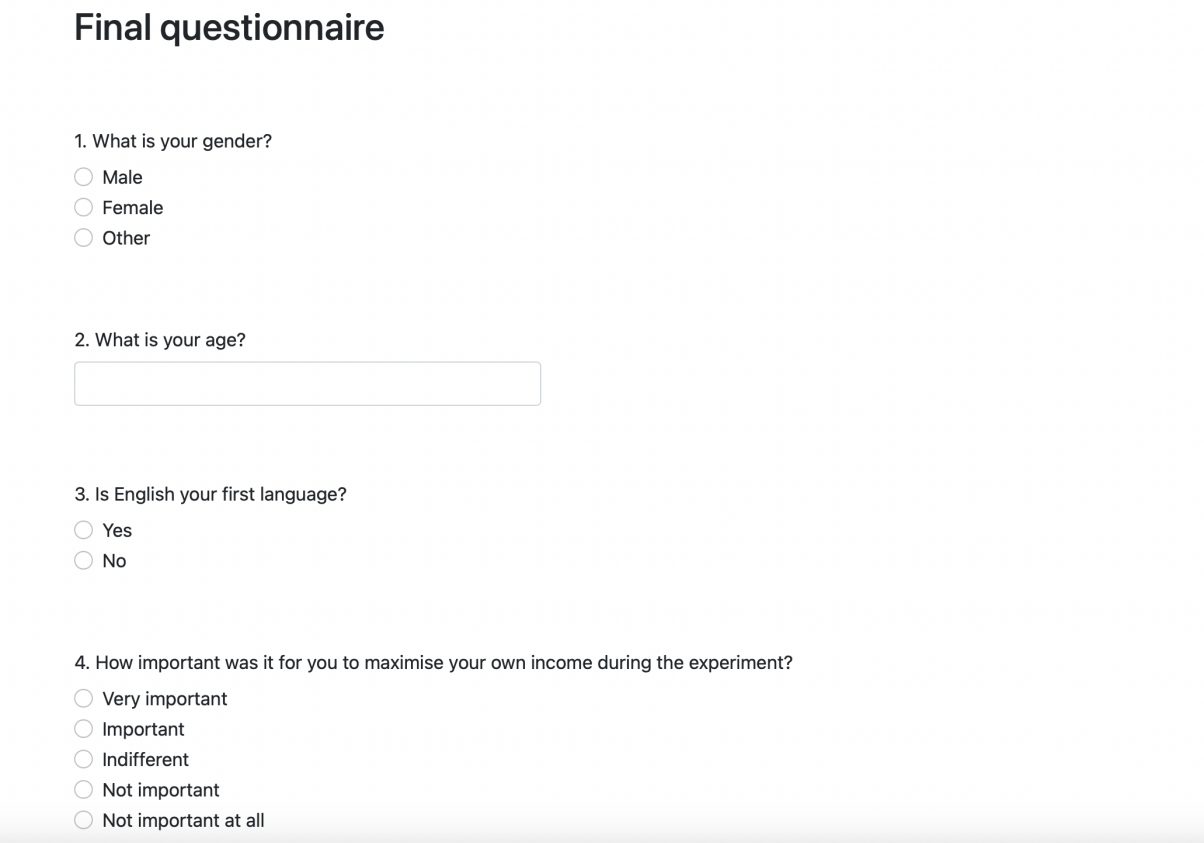

Figure B.4 Final Questionnaire 1-4.

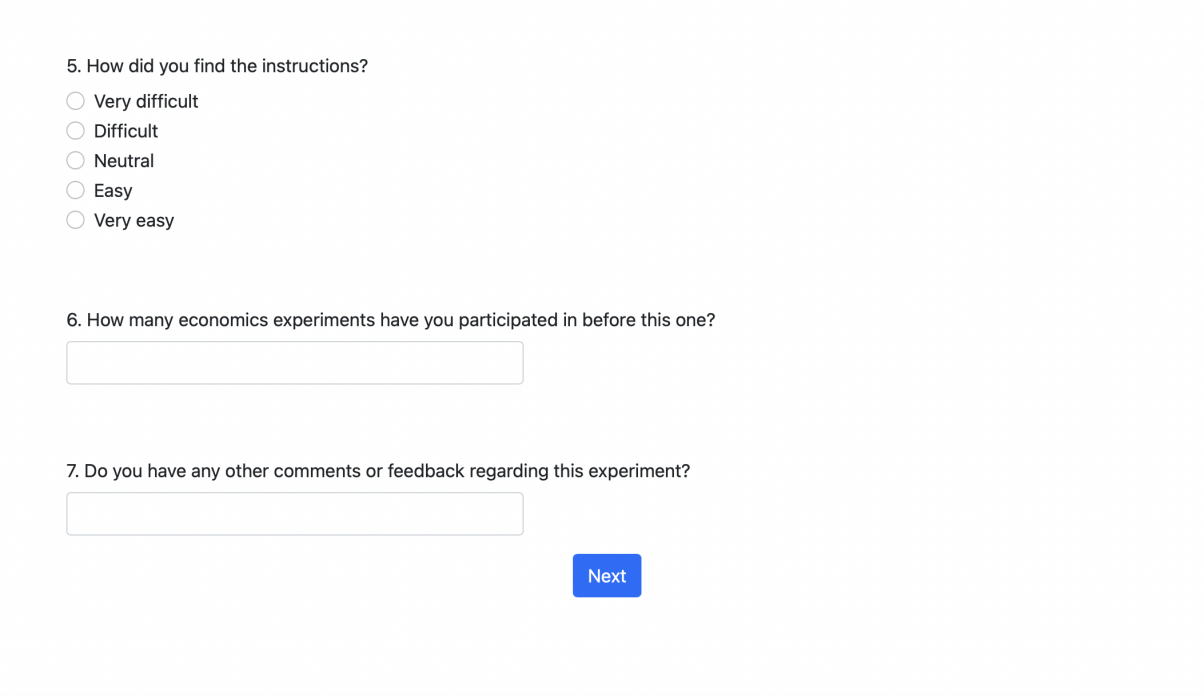

Figure B.5 Final Questionnaire 5-7.

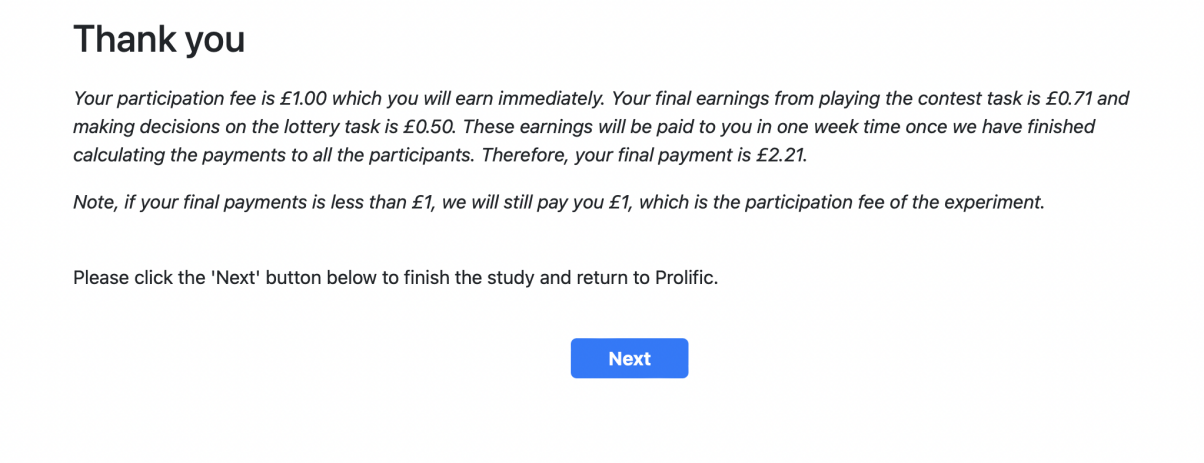

Figure B.6 Final Earnings Page displayed to participants.

Treatment 1

Here, we present only the reveal decision page and the investment page, as the remaining pages are identical to those in the baseline.

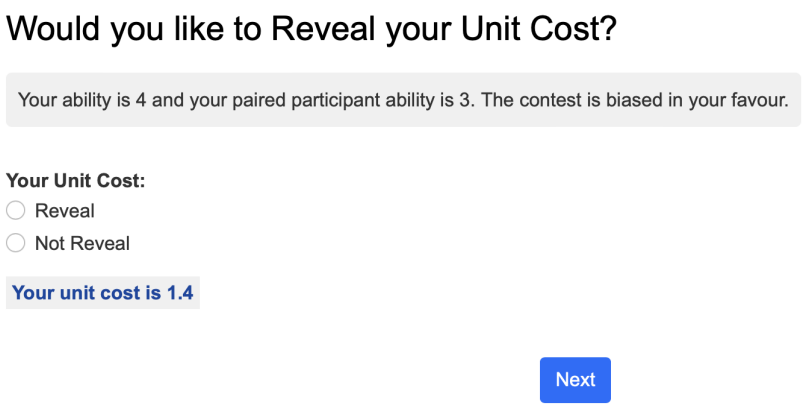

Figure B.7 Reveal Decision for a High-ability Participant in Treatment 1.

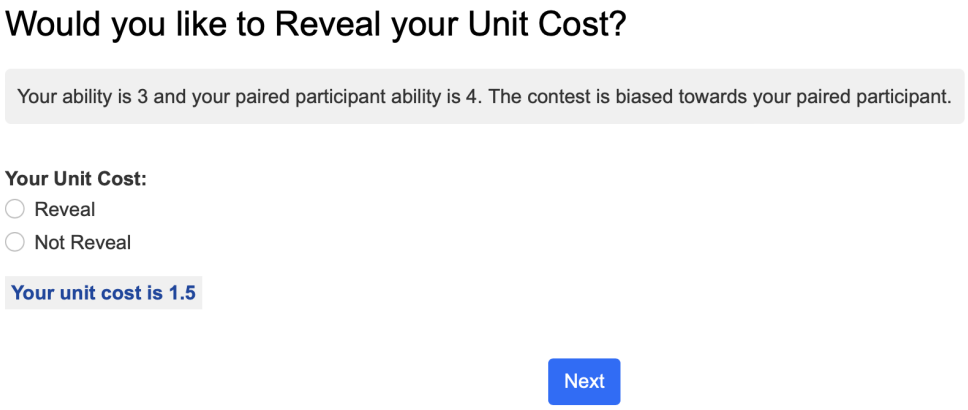

Figure B.8 Reveal Decision for a Low-ability Participant in Treatment 1.

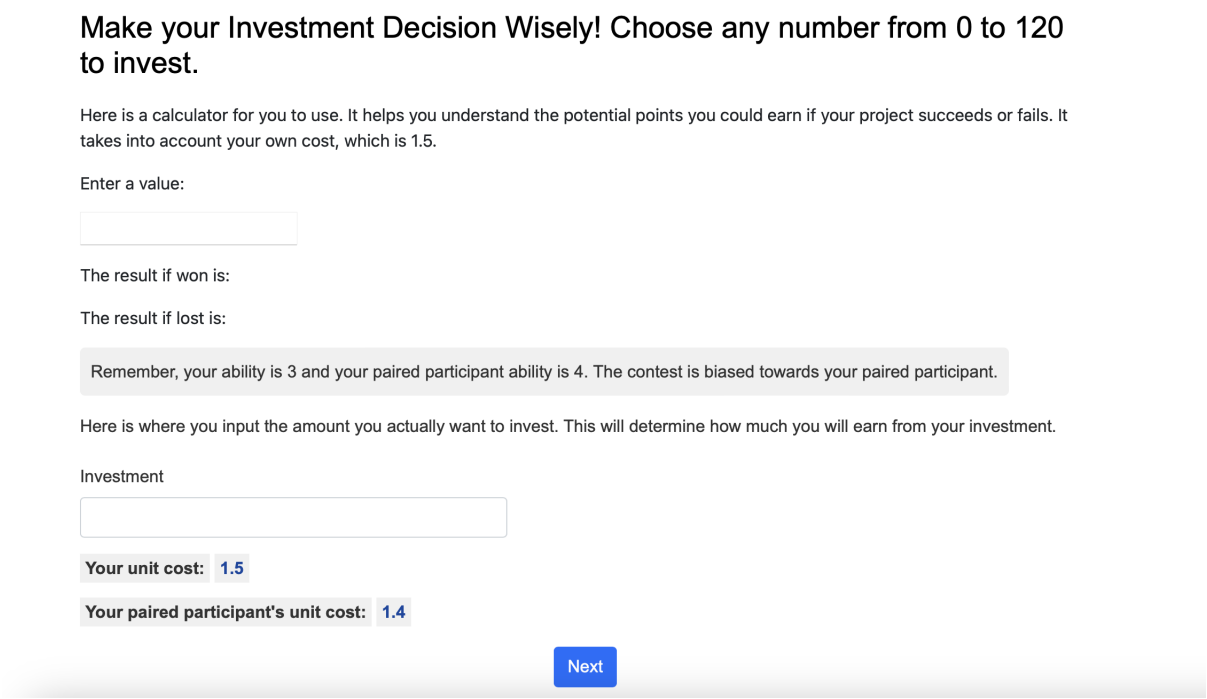

Figure B.9 Investment Page for a participant when the other has revealed information in Treatment 1.

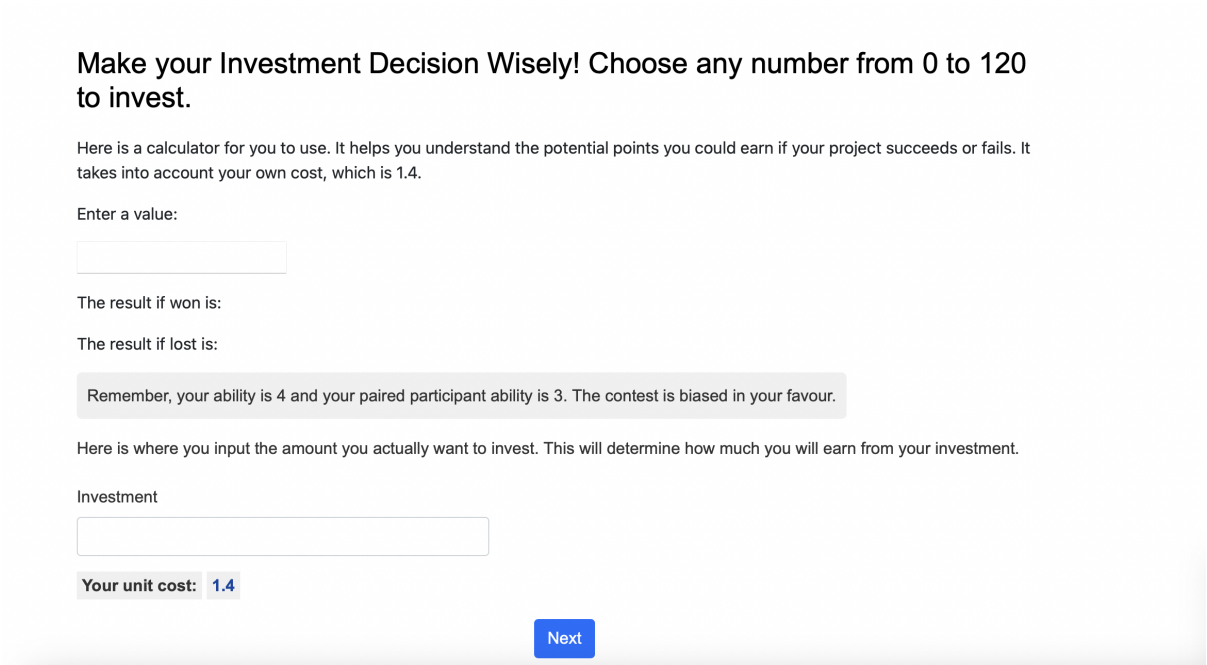

Figure B.10 Investment page for a participant when the other has not revealed information in Treatment 1.

Treatment 2

As in Treatment 1, in Treatment 2 we present the common knowledge cost information page, the reveal decision page, and the investment page, as the other pages are identical to those in the baseline.

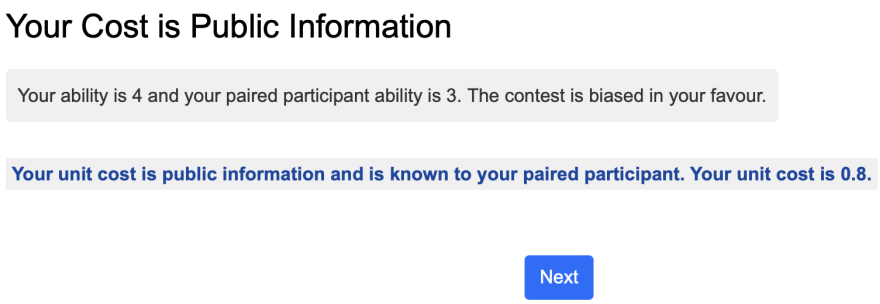

Figure B.11 Cost information when Common Knowledge page as seen by a participant in Treatment 2.

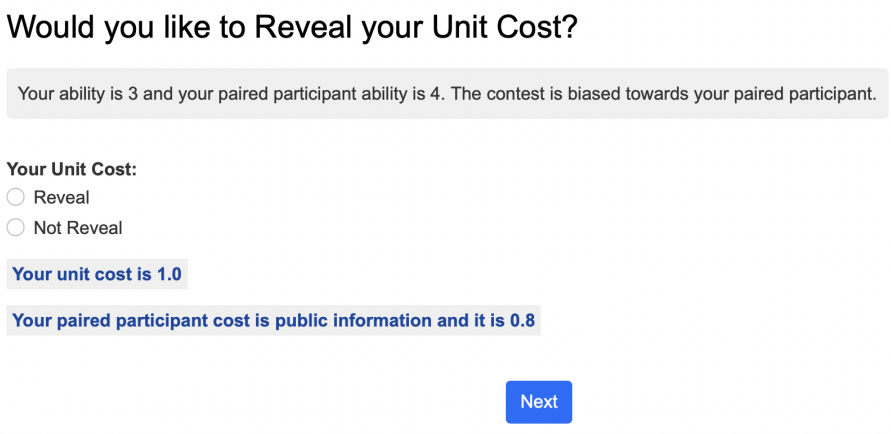

Figure B.12 Reveal Decision page of the other participant in Treatment 2.

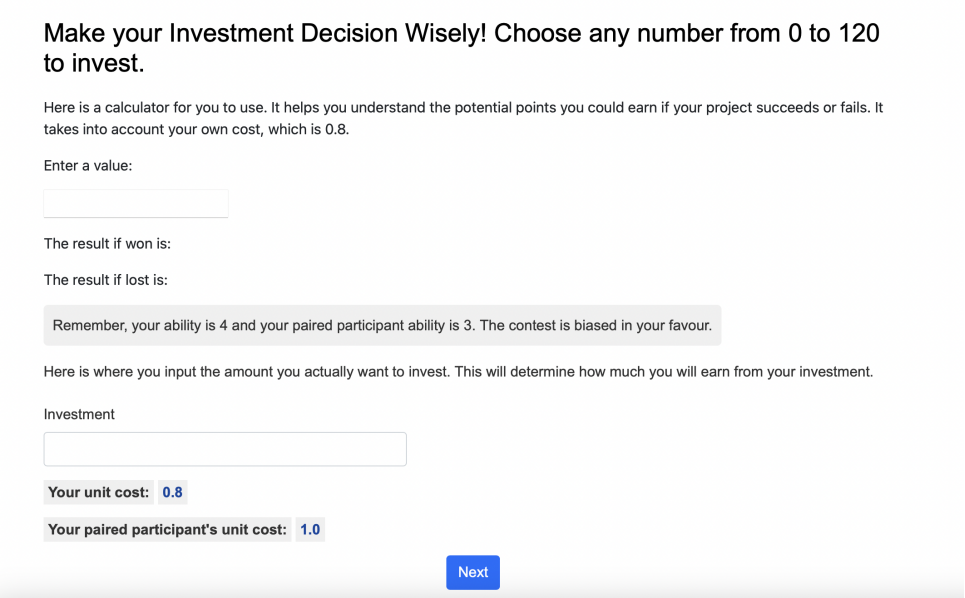

Figure B.13 Participant's investment decision page when their paired participant's cost has revealed in Treatment 2.

[8]

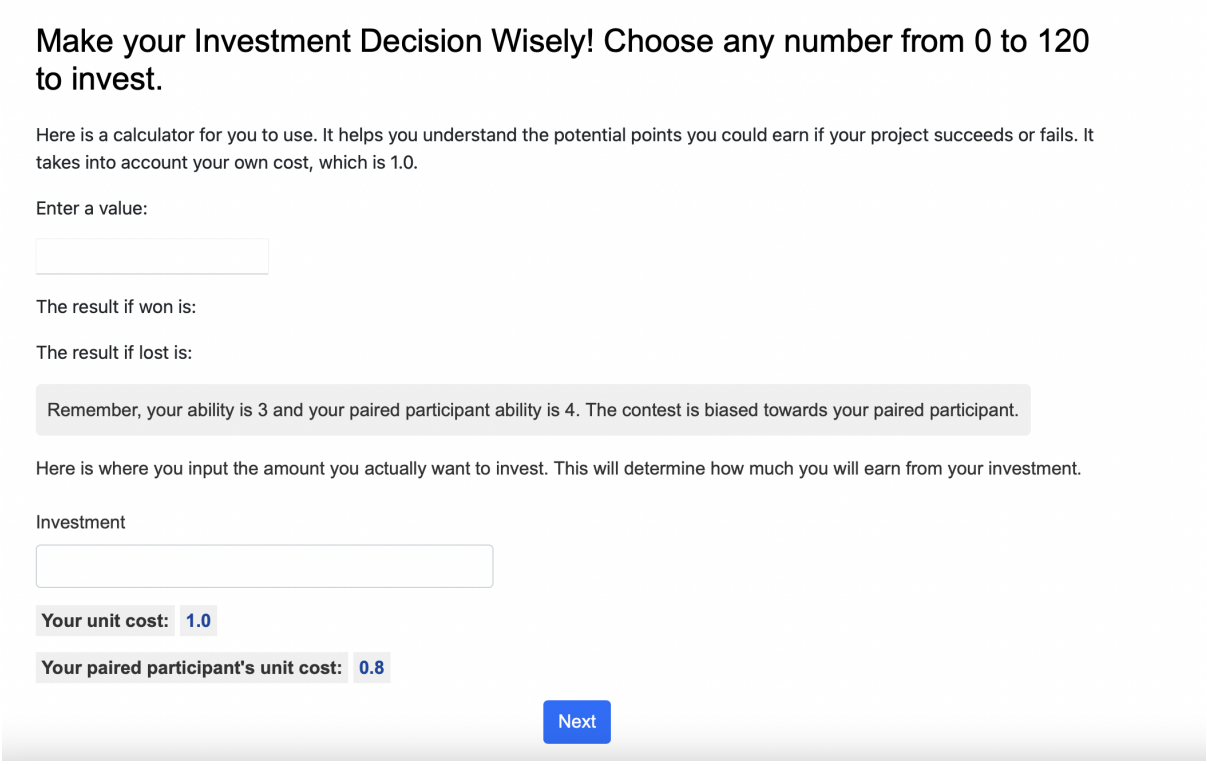

Figure B.14 Participant's investment decision page when their paired participant's cost is common knowledge in Treatment 2.

[8]Note when the other paired participant has not revealed in Treatment 2 then paired participant unit cost will not be visible on the screen.

Appendix Three

Chapter 3 Appendix

C.1 Policy of the Re-elected Incumbent

The voter payoff function after substituting the functional forms from equation 1 can be written as follows,

$$V = (1+3\theta)\Big[y - \frac{y^2}{2}\Big(2 - \frac{\theta}{2}\Big)\Big] + \gamma y$$

$$V = (1+3\theta)\Big[y - \frac{y^2}{2}\frac{(4-\theta)}{2}\Big] + \gamma y$$

Simplifying we get,

$$V = (1+3\theta+\gamma)y - \frac{y^2}{2}(1+3\theta)\frac{(4-\theta)}{2}$$

Maximising voter payoff function V w.r.t the policy of the incumbent y we get,

$$\frac{\partial V}{\partial y} = (1+3\theta+\gamma) - \frac{(1+3\theta)(4-\theta)}{2}y$$

Setting the above equation equal to 0 and simplifying we get, the optimal policy adopted by the incumbent,

$$y^* = \frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)} \tag{C.1}$$

C.2 Voter Indirect Utility

Substituting the optimal policy y^* adopted by the re-elected politician in the voter payoff function we get the indirect utility function,

$$V^* = (1+3\theta)\Big[y^* - \frac{y^{*2}}{2}\Big(2-\frac{\theta}{2}\Big)\Big] + \gamma y^*$$

$$V^* = (1+3\theta)\Big[y^* - \frac{y^{*2}}{2}\frac{(4-\theta)}{2}\Big] + \gamma y^*$$

$$V^* = (1+3\theta+\gamma)y^* - \frac{y^{*2}}{2}(1+3\theta)\frac{(4-\theta)}{2}$$

$$V^* = (1+3\theta+\gamma)\Big[\frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)}\Big] - \frac{1}{2}\Big[\frac{2(1+3\theta+\gamma)}{(1+3\theta)(4-\theta)}\Big]^2(1+3\theta)\frac{(4-\theta)}{2}$$

$$V^* = \Big[\frac{2(1+3\theta+\gamma)^2}{(1+3\theta)(4-\theta)}\Big] - \Big[\frac{(1+3\theta+\gamma)^2}{(1+3\theta)(4-\theta)}\Big]$$

$$V^* = \Big[\frac{(1+3\theta+\gamma)^2}{(1+3\theta)(4-\theta)}\Big] \tag{C.2}$$

C.3 Politician Indirect Utility

The politician indirect utility can be obtained by plugging y^* in the politician payoff function $v = (1+3\theta)\Big[y - \frac{y^2}{2}\frac{(4-\theta)}{2}\Big] + \alpha\gamma y + r$. By calculating we obtain,

$$v^* = \Big[\frac{(1+3\theta+\gamma)(1+3\theta+\gamma(2\alpha-1))}{(1+3\theta)(4-\theta)}\Big] + r \tag{C.3}$$