# Agent-Based Models of Long-Distance Trading Societies

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## Abstract

Studying historical trading societies helps us to identify the institutions (e.g. rules) and characteristics that lead to their success or failure. Historically, long-distance trading societies, as a more particular example of trading societies, have been established in various parts of the world. Many of these societies were successful in certain aspects, and interestingly, a number of these societies were successful, despite having different characteristics and institutions. This thesis aims to identify some of the institutions and characteristics that contributed to their success.

We use an agent-based simulation model to identify the key characteristics that impacted the success of two long-distance trading societies. The objective of this study is to develop suitable models of these societies that can be used for systematic studies of their characteristics. Two long-distance trading societies studied in this thesis are the British East India Company and the Armenian traders of New-Julfa, both of which flourished during the 17th and 18th centuries. In this thesis, we conduct a comparative study of the two societies, based on historical evidence and contemporary literature that provide empirical support.

Based on the comparative study, we have identified three overarching themes that distinguish these societies: 1) the contractual schemes used and their environmental characteristics; 2) the apprenticeship programmes and vocational schools used; and 3) the institutional mechanisms used. This thesis presents three models developed corresponding to the three themes, based on the presented comparative study of the societies.

The first model developed was based on game theory and simulates the impact of *contractual schemes* and *environmental circumstances* on the two trading societies' success. In the contractual scheme, we assessed the impact of payment

schemes (e.g. profit-sharing), penalties (e.g. dismissal for wrongdoing), and hiring and firing schemes, in the context of open and closed societies, on the success of the society. As a metric of societal success, we considered rule conformity, sustainability, profitability, and improving societal skills.

As a next step, we model the impact of *apprenticeship programmes* and *vocational schools* on the societal success (i.e. maintaining societal skill levels, programme completion rate, and increasing societal income). In this model, we consider the impact of different trader and trainer types (e.g. artisans), along with various policies for managing recruits (e.g. training societal members and hiring from other societies).

In our last model, we extend the beliefs-desires-intentions (BDI) mental architecture to model the impact of *institutional mechanisms* (e.g. fairness) on the success of these societies.

Beyond creating models (methodological contribution) of these societies to demonstrate the influence of characteristics on the success of the societies, our work provides practical contributions, such as a) insights into the positive impact of profit-sharing on a company's profitability; b) the aspects that should be considered to have successful apprenticeship programmes; and c) insights into designing societal rules to deal with societies' lack of transparency.

## Acknowledgements

> "Hafiz, if thou desire the presence (union with God most high) — from him be not absent: When thou visitest thy beloved, abandon the world; and let it go."
>
> Hafiz, translated by Henry Wilberforce Clarke

This PhD, like every other chapters of life, was a passage through which some of my attitudes formed. However, this journey was a long and collaborative one which included exploring ideas new to me. What follows is a concise expression of acknowledgement to the ones who contributed to this thesis in one way or another.

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# 1
# Introduction

The question why some societies are more successful than others has intrigued researchers. Social scientists have noted that underlying institutional mechanisms (e.g. rules) impact this success (Hall & Jones, 1999; Nahapiet & Ghoshal, 1998; Rodríguez-Pose, 2013). This formed the motivation for this thesis.

## 1.1 Motivation

In the investigation of mechanisms to improve economic outcomes of a society, it is important to take into account the characteristics of both the impact of individuals (agents) in terms of their capabilities and roles, as well as organisations (i.e. their policies and strategies). Economies and their underlying mechanisms concern transactions (e.g. a *person* buys or sells items), and decontextualising them from social factors (e.g. political and historical phenomena) is impossible (efforts for contextualisation of economics sometimes called heterodox economics, Brown & Spencer, 2014). To contextualise the economy, we need to choose certain societies and study their mechanisms and characteristics to identify the impacts of those on the economic theory (Colvin & Wagenaar, 2018). In this study, we investigate the institutions (e.g. rules) and characteristics of two historical long-distance trading societies.

Contrasting these societies helps us to answer the *how* and *what* questions. These questions (e.g. what institutions have they utilised?) help us to learn from history in order to improve our understanding of the present and to make better decisions in the future.

The two historical trading societies under study are the British East India Company (EIC, 17th-19th centuries) and Armenian traders of New-Julfa (Julfa, 17th-18th centuries). We choose these two societies because Julfa had similarities with Genoese, Maghribis, and Venetians (all historical long-distance trading societies that used Commenda contracts). Also, the EIC is similar to the Dutch East Indies, and the French East India Company (they monopolised trade between their own country and Asia). Furthermore, in comparison with other societies, we have more data about the EIC and Julfa. The fundamental problems that both societies dealt with involved a) improving profitability and b) the agency problem known as the *principal-agent problem*. The principal-agent problem concerns the dilemma where the self-interested decisions of a party (agent) impact the benefits of the other person on whose behalf these decisions are made (principal). S. A. Ross (1973) was the first to study the problem with a focus on economic aspects of the problem (e.g. impact of payoff). Around the same time, Mitnick (1973) addressed the same topic from the institutional point of view (e.g. rules, see, Mitnick, 2011, for more discussions). Long-distance trade, especially in the historical context, is an example of the principal-agent problem. In the long-distance trading societies, the agents' actions and decisions are not visible to the principals (since they are far away), and self-interested actions of an agent decrease the principal's profits.

The societies studied here have different characteristics (e.g. open versus closed). Also, some of their institutions are different. Some institutions of these two societies help us to identify a better approach for resolving the principal-agent problem; however, other institutions (e.g. the apprenticeship programme) help us to identify some means for improving a system's profitability. These findings can contribute to success in engineering rules and characteristics when designing new societal rules. For this purpose, we use an agent-based modelling approach. The uniqueness of agents helps us to take account of behavioural economics concepts that contradict classical economics assumptions and predictions. In the next section, we state the research questions we address in this thesis.

## 1.2 Research questions and contributions

As already mentioned, the ideas of this thesis are inspired by two historical long-distance trading societies, namely the EIC and Julfa. The questions inspired by the EIC and Julfa are suitable for trading societies facing information opacity (e.g. long-distance traders) where an agent's self-interested decisions (e.g. embezzlement) are not visible to the principal. The higher level question addressed by this thesis is the following:

- What mechanisms facilitated the success of these long-distance trading societies?

To address the question stated above, we investigate different mechanisms and characteristics of the societies using the following three research questions (RQs):

**RQ 1)** How do different *contractual schemes* and differing *environmental circumstances* impact the success of these societies?

**RQ 2)** How do successful societies maintain *skill levels* over time? What are the impacts of employing different mechanisms, including *apprenticeship programmes* and *vocational schools*, on the success of skill development?

**RQ 3)** How do the characteristics of *institutional mechanisms* (e.g. fairness) impact the success of these societies?

To be more precise, we are interested in identifying the mechanisms that helped long-distance traders to be successful from various viewpoints. For this purpose, we have developed general models for trading societies. Then we utilised the specific parameters which can be set for the EIC and Julfan historical traders. Overall, success metrics that we measured here include sustainability of the society, skill levels of agents, rule conformance, and profitability. The three research questions listed above are addressed in Chapters 4–7. More specifically, RQ 1 is covered in Chapter 4. Then Chapter 5 investigates RQ 2. Chapters 6 and 7 extend a mental architecture model and a simulation model, respectively, to address RQ 3.

In what follows, we explain how the different chapters answer the research questions mentioned above. Also, we state what aspects of success are measured in each chapter. Table 1.1 provides an overview of the input parameters (column 2) and the success metrics (column 3) for each of these research questions. It also provides details about what chapters these research questions are associated with (column 4). Below, we provide a brief description of the three models that were developed to answer the three RQs.

First, we model the impact of *contractual schemes* (including contract management) in both societies and the variation of *environmental circumstances* (i.e. mortality rates) on the success of the societies. The aspects of contract that are addressed to answer RQ 1 concern payment and hiring schemes, and the methods utilised for contract management.

We use these to measure their impacts on the different success metrics of a society. In this question (i.e. RQ 1), we assess the impacts of these characteristics on different success

Table 1.1: The characteristics each research question addresses and the success metrics measured by each chapter.

| Research question | Characteristics (input) | Success metrics (outputs) | Chapter(s) that address the question |
|---|---|---|---|
| RQ 1 | Payment scheme<br>Hiring scheme<br>Firing scheme<br>Penalties<br>Mortality rate | Profitability<br>Rule conformance<br>Sustainability<br>Skill levels | Chapter 4 |
| RQ 2 | Trade type<br>Trainer type<br>Recruiting scheme<br>Engagement of schools | Completion rate<br>Skill levels<br>Societal income | Chapter 5 |
| RQ 3 | Fairness of institutions<br>Agents' mobility<br>Mortality rate<br>Apprenticeship | Rule conformance<br>Profitability<br>Changes in rule<br>Monitoring strength | Chapters 6 and 7 |

metrics, including sustainability, profitability, rule conformance, and increasing skill levels. Note that the characteristics and success criteria will be elaborated in detail in Chapter 4.

Second, we model different *apprenticeship schemes* to identify the impact of these on the success of societies. We have considered the impact of characteristics regarding trade type (e.g. potters or engineers), trainer type (e.g. potential employer), recruiting schemes (e.g. using guilds or unions), and the engagement of schools.

To address RQ 2, we use these characteristics to investigate their impacts on the trainees' programme completion rates, their ability to maintain high skill levels, and their impact on increasing societal income.

Finally, we model the impact of institutional mechanisms on the success of these societies. For this purpose, we use a modified cognitive architecture to answer RQ 3. We consider the fairness of institutions, agent's mobility (i.e. moving from one place to another), environmental circumstances, and apprenticeship programmes. The impact of these characteristics on the system is measured through the following outcomes: societal rule conformance, profitability of the organisation, changes made to the rules, and system monitoring strength.

To answer these three research questions, we have developed three models that form the methodological contributions of this thesis. Also, using the simulation, we infer insights that improve our understanding of these societies, which can then be used to engineer modern societies. For instance, the model developed in Chapter 5 can be used to decide about appropriate apprenticeship programmes based on their societal and organisational attributes. Furthermore, modellers can benefit from the cognitive architecture of Chapter 6 to simulate the interaction of agents in a given context. Such applications are elaborated in the following section.

## 1.3 Thesis approach and audience

To answer the stated questions, and to visualise the models, we have used a simulation approach. This research relies on the qualitative data in the form of letters, narrated story, the performance comparison of different societies. As such, the validation of models is performed by using the same information, by comparing the patterns observed in simulations against those observed by historians. As presented in the following chapters, the results from the simulation models aligned with historical data and contemporary evidence from societies chosen in this study. Also, empirical studies conducted by researchers from other fields (e.g. economics) verify the assumptions of the models.

In the simulation and validation procedure, we investigate various characteristics and success metrics shown in Table 1.1. Furthermore, it should be noted that all the models have parameters which are made concrete (i.e. instantiated) which lend themselves for concrete empirical results. Using various methods, such as benefiting from empirical studies, using available historical data, and sensitivity analysis, we find the parameters that correspond to the situation in the EIC and Julfa. To make sure our simulation model mirrors real-world situations reported by historians (i.e. it is valid), we compare our simulation results with reported numbers and patterns.

It should be noted that this thesis work has a trans-disciplinary nature because of investigating historical long-distance trading societies and using social science (e.g. economics and folk-sociology) and psychology to build the models. Based on the extent to which these disciplines have been employed, the following audience may benefit from this work:

- Information scientists: the audience with a knowledge of agent-based simulation, the tools used to build the artificial societies can benefit from the employed methods of this study.

- Social scientists: in particular economists interested in the supply chain management field. This thesis studies two successful long-distance trading societies, as historical examples of supply chains. Although each problem has unique attributes that make it specific in some aspects, the developed models and the findings of Chapters 4 and

7 can help supply chain managers. Also, social scientists interested in studying the impact of institutional mechanisms, such as apprenticeship programmes, guilds, and unions on the society, may benefit from the findings of Chapter 5.

- Historians: Audience interested in comparative studies of historical long-distance trading societies in the early modern era can benefit from built models. This thesis work used information from earlier historical studies to build the models. Also, we have used empirical studies from other disciplines (e.g. sociopsychology) to test some of the historians' beliefs.

- Computer scientists: Computer scientists can use the conceptual cognitive architecture presented in Chapter 6 to model interactions of agents in other contexts.

Finally, it is worth noting that interested researchers can use these models to study other societies, including modern instances, as exemplified in Chapter 5. Furthermore, modellers can use the approach employed in Chapter 4 for other historical long-distance trading societies with similar features (e.g. societies that use commenda contracts),[1] by modifying values of employed parameters, such as the share of profits. Also, researchers can adjust parameter values of Chapter 7 (e.g. costs of conducting apprenticeship programmes) to model modern examples, and they can modify the organisational structure based on the case at hand. The usage of empirical studies in the modelling facilitates exploring examples beyond the historical cases.

### 1.3.1 Refereed publications

The following have resulted from this thesis, respectively:

[1]The contract is a profit-sharing scheme (we describe it in Section 2.2.3). This contract was used during the Middle Ages in Western Europe (see Udovitch, 1962, for a brief review). Studies indicate that it probably originated from the Arabian Peninsula. Note that the origin of this contract is before the 6th century when the Muslims' leader (i.e. Muhammad) worked as a commenda agent in his youth (see Udovitch, 1970, p. 172).

Afshar Sedigh A. H., Frantz C. K., Savarimuthu B. T. R., Purvis M. K., Purvis M. A. (2019) A Comparison of Two Historical Trader Societies — An Agent-Based Simulation Study of English East India Company and New-Julfa. In: Davidsson P., Verhagen H. (eds) *Multi-Agent-Based Simulation XIX* (pp. 17-31). MABS 2018. Springer, Cham.

Afshar Sedigh A. H., Purvis M. K., Savarimuthu B. T. R., Frantz C. K., Purvis M. A. (Under review) An Agent-Based Simulation Study of Different Apprenticeship Societies. *Journal of Artificial Societies and Social Simulation*.

Having stated the research questions, in the next section, we provide an overview of structure of the rest of this thesis.

## 1.4 Thesis structure

This thesis has eight chapters. Chapter 2 provides the historical background related to the two long-distance trading societies, along with a comparison of their institutions and characteristics. Chapter 3 provides the necessary background for understanding the rest of the chapters, including the relevant concepts, foundations, technology, and background.

Chapter 4 simulates the two historical societies in question, using a model developed based on game theory concepts. This chapter investigates the impact of *contractual scheme* and *environmental circumstances* on the success of these trading societies. This chapter also points to some shortcomings of this model that are addressed in Chapters 5, 6, and 7.

Chapter 5 establishes a model for maintaining *skill levels* over time in a society. This chapter also investigates societies other than the long-distance trading societies to evaluate the success of the apprenticeship programmes in societies.

Chapter 6 widens the usual simplified utilitarian agent cognitive architecture by considering certain personal and sociopsychological aspects of humans. The goal of this chapter is to relax the restraints regarding materialistic modelling of agents (i.e. considering only tangible profits/costs in the utility function). The chapter also investigates how this architecture can be used for modelling systems using the two historical trading societies.

Chapter 7 utilises the model developed in Chapter 6 to present results of the impact of *institutions* on agents' behaviour. It also shows how this relates to the success metrics used. Here we relax some assumptions made in Chapter 4 and reassess their results.

Finally, Chapter 8 provides a summary of findings, contributions, and limitations of this thesis. This chapter also discusses future extensions.

# 2

# An overview of the two historical long-distance trading societies

## 2.1 Introduction

In this chapter, we provide an overview of the two historical long-distance trading societies that we explore in the thesis. We use these two contemporaneous societies to explore some important historical institutions (e.g. rules) and societal characteristics (i.e. other aspects) that influenced their performance.

Both societies were active in the 17th and 18th centuries. The long-distance trading societies in question include the British East India Company (1600–1874) — a chartered company (i.e. an association granted exclusive rights of trade by government) — and the Armenian merchants of New-Julfa (1600–1747) — a closed society of traders. Both of them were successful in trade though with significantly different characteristics and institutions. The differences that motivated us for exploring these societies are stated in the rest of this chapter. Given our research questions (see Chapter 1), this chapter aims to provide a comparative background of the two societies with an emphasis on the characteristics and institutions of these societies that are relevant to their economics, especially their contracts and apprenticeship programmes.

The rest of this chapter is organised as follows. Sections 2.2 and 2.3 provide an overview of Julfa and the EIC, respectively. Both of these sections have relatively the same structure. First, we concisely describe the formation of each society (Sections 2.2.1 and 2.3.1, respectively). Afterwards, we describe their important societal characteristics, including their demography (Sections 2.2.2 and 2.3.2, respectively). We continue the description of these societies by investigating their economic institutions, including their contract and payment schemes (Sections 2.2.3 and 2.3.3, respectively). For the importance of skills in the trading societies, we devote a section to investigate the training scheme employed in each society (Sections 2.2.4 and 2.3.4, respectively). We also review the reasons for the decline of each society to complete the narrative (Sections 2.2.5 and 2.3.5, respectively). Finally, in Section 2.4, we compare the characteristics of these two trading societies to form a bigger picture for the comparative models provided in the subsequent chapters.

## 2.2 Armenian merchants of New-Julfa

The Armenian traders of New-Julfa (Julfa) were originally from Julfa, Armenia. They moved into the central parts of Persia (Iran) through a forced displacement by Shah Abbas I (who reigned between 1588 and 1629), a Safavid king (the Safavid dynasty ruled from 1501 to 1736). They formed one of the most successful trading societies in their era that impressed traders of other countries. Their trading society resembles Maghribi traders[1] of the 10th to 11th centuries, in terms of being a religious minority (Christians in a Muslim country), using commenda contracts, having a closed society, and being engaged in long-distance trades. In the following subsections, we state their background, the formation of New-Julfa, their institutions, and the reasons for the decline of this trading society.[2]

### 2.2.1 Displacement of Julfans and the formation of New-Julfa

The displacement of Julfan Armenians was initiated by the Ottoman-Safavid wars of 1603–1618, through which Shah Abbas I aimed to recapture the northern parts of Iran, including Armenia. During this war, the Safavid army faced attacks by the Ottomans (the Ottomans reigned between 1299 and 1922) and understood that they were unable to keep the lands.

[1]Maghribis were a Jewish minority of long-distance traders who operated in a Muslim country. They formed a closed society and operated between the 10th and 11th centuries (see Greif, 1989, for a brief history).

[2]Note that the main resources for the historical account of Julfa are from two theses, namely Herzig (1991) and Aslanian (2007). We also used two Farsi resources, namely Arabihashemi (2016) and Baibourtian (1996).

Consequently, Shah Abbas I used a scorched-earth policy[3] and displaced the residents of those places, including Armenians, to Iran. The displacement caused a dramatic loss of lives and initiated different debates on the intentions of the Shah (i.e. king).[4]

Although displaced people were settled in different places, the people of interest (i.e. Julfans), were first settled in Isfahan (Iran). However, due to some conflicts with locals, Shah Abbas I granted them a land in the south of Zayanderud (a river passing Isfahan) to build their neighbourhood. The unsuccessful attempts of the Shah for silk trade also helped Julfans to gain an informal monopoly of trade.[5] The informal monopoly meant that even though the East India Company (EIC), the Dutch East India Company (VOC),[6] and Muslim merchants were permitted to be engaged in trade, they could not use this right for different reasons.[7]

The mentioned privileges (e.g. granting them a land and informal monopoly) were accompanied by granting Julfans permission to practise their religion and also rule over their neighbourhood (e.g. bulding churches and using their courts). These privileges and permissions are some of the reasons for the formation of New-Julfa. In the next subsection, we investigate some of the societal characteristics of Julfa.

### 2.2.2 Societal characteristics

In this section, we describe the institutions and societal characteristics of the Julfans. These institutions and characteristics helped them to form and maintain a trading society. The main aspects that are covered in this section include Julfan's family firms, their societal demographic characteristics, and the impact of churches and community on governing the

[3]"The act of an army destroying everything in an area such as food, buildings, or equipment that could be useful to an enemy" (Cambridge online dictionary, 2019).

[4]An overview of these debates is presented in Herzig (1991). Also, some information about the old-Julfa can be found in Baibourtian (1996). For a better understanding of Julfans' incentives to stay in Iran, such as their shared religious background and common epic stories, refer to J. R. Russell (1987) and Arakelova (1998), respectively. For information regarding Safavid politics and economics that also impacted Julfan traders refer to Matthee (1999) and Bastani Parizi (2013).

[5]Shah Abbas I also gave Julfans interest free loans in the early years of their trade in Isfahan (Herzig, 1991).

[6]VOC stands for Vereenigde Oostindische Compagnie which can be translated as unified East-Indian company.

[7]Muslims had problems due to their unfavourable religion in Western Europe (i.e. they were not welcome to trade there). Furthermore, after the Ottomans' conflicts with Safavids became worse, the Ottomans did not let Muslims from Iran (i.e. Shia Muslims) use their routes. The EIC had permissions for purchasing royal silks, but the trade was liberalised in 1629 by Shah Safi I (who reigned from 1629 to 1642). The VOC also had problems because of a lack of continuous contact with Iranian markets (Baibourtian, 1996, pp. 45–46).

society. What follows provides an overview of the aforementioned information (for more detailed information see Herzig (1991) and Aslanian (2007)).

#### 2.2.2.1 Family and family firm[8]

> "Their families are very great; for, both sons, nephews, and nieces do dwell under one roof, having all their substance in common: And when the father dieth [sic], the eldest son doth [sic] govern the rest; all submitting themselves under his regiment. [...] In their diet and cloathing [sic], they are all fed and cloathed [sic] alike, living in all peace and they tranquility [sic], grounded on true love and honest simplicity." (Cartwright, 1767, p. 720)

The families played a crucial role in the society. Overall, two factors kept the family firm alive. These include the inheritance rules and intermarriage. *Lawbook of the Astrakhan* (*the Lawbook*, written in the mid 18th century) helps us to understand their rules (e.g. inheritance rules, Herzig, 2007, provides a summary of the commercial laws stated in the book). Based on the Lawbook, the head of family (i.e. father or elder brother) managed all the properties and assets. Also, the inheritance of a person was passed down for six generations (see Figure 2.1). Figure 2.1 schematically shows how the heritage should be equally split among male heirs (the survivors are underlined and are in bold).[9] An heir should ask for independence to control his assets independently. Independence had consequences such as losing all the connections with the family (i.e. the person would lose the permission to use the family reputation in trade and also the possibility of inheriting from other family members). Such rules made a family like a firm where the elder member is its manager (Hakob in Figure 2.1).

These rules, along with intermarriages (marrying cousins), strengthened family bonds and also facilitated the concentration of capital. Note that members of the family could ask for loans but they should pay interests. Other members of the family worked for the firm as commenda agents, and a family firm could be dissolved by declaration of independence of all its members. Thus as stated briefly, Julfa rules led to the formation of family firms by concentration of wealth. In the next subsection, we briefly state how the community and churches contributed to the trading aspects of Julfans.

[8]The descriptions in this section are adapted from Herzig (1991), unless otherwise mentioned.

[9]The daughters received nothing or a small share (e.g. one eighth). Also, if there are two sons or more in a branch, the same sharing scheme as Figure 2.1 may apply there. For instance, in Figure 2.1 if Nathan had two sons, his share of the inheritance was divided equally between his sons.

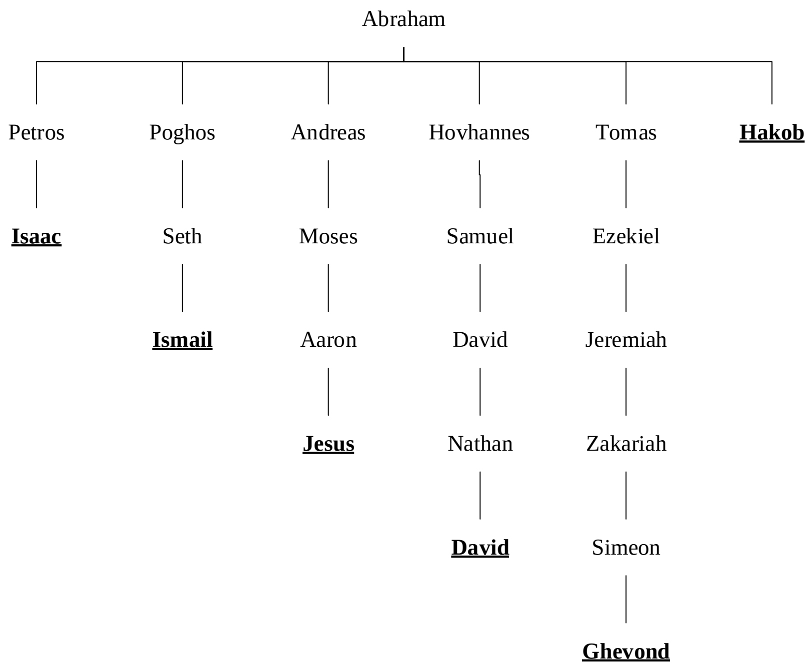


Figure 2.1: A schematic representation of sharing the inheritance of Abraham among his living heirs names in bold and underlined (see Herzig, 1991, p. 161, for more information).

#### 2.2.2.2 Community and church[10]

As stated earlier, Shah Abbas I granted Julfans autonomy to govern their neighbourhood (we address Julfa/New-Julfa as a city). In this section, we describe how Julfans governed their city. The lower level of governors were called Katkhudas (i.e. governors of streets), who were head of the prominent families of the street. The upper level of governors were called Kalantars (mayors) and were chosen by citizens (they functioned like a mayor). He had responsibilities, such as collecting taxes and indicating each household's share in taxes. We describe more functions of these roles later in this section.

Another permission that helped Julfans to govern their network included autonomies granted by governments in the Asian continent. These helped Julfans to establish and enforce their own rules across their trading network.[11] Additionally, Julfans used New-Julfa as a source of **information sharing** and as the final source for **resolving disputes**. All these autonomies and the aforementioned governing levels (i.e. Katkhudas and Kalantar) were

[10]The descriptions of this section are adapted from Aslanian (2007), unless otherwise mentioned.

[11]The EIC in India, Russian governors, and Spanish governors in Manila granted them some rights similar to the ones granted by Shah Abbas I (see Aslanian, 2007, for more information). The importance of this autonomy lies in the fact that regional courts' decisions were mostly based on that region's rules, not Julfans' (e.g. once in Tibet the regional court resolved Julfans' dispute by rolling dice, Aslanian, 2007, p. 268).

employed to establish social administrative means. Aslanian (2007) points to three legal administrative means utilised by Julfans as follows:

- **Assembly of merchants:** It aimed to resolve commercial disputes *inside* New-Julfa. The assembly was comprised of at least 20 members, including the Kalantar, more than nine Katkhudas, and at least three merchants.
- **The portable courts (Jumiat):** It aimed to resolve commercial disputes in *distant places*. It was formed in one of the following ways:
  - If they could find a sufficient number of Julfans, the court only involved Julfans (e.g. four Julfans).
  - If the number of Julfans was insufficient, the court also involved additional invited foreign merchants.
- **Legal assembly:** It aimed to ratify legal papers, to delegate authorities to the attorney, and to approve wills. It involved Katkhudas, Kalantar, and the archbishop of Julfa.

Finally, Julfans could have employed the services of royal police (darogha),[12] for punishing and imprisoning criminals. However, the efficiency of this administrative depended on the Shah's relations with the Julfans. In the next subsection, we state the information-sharing mechanisms of Julfans that made the courts effective by providing evidence.

#### 2.2.2.3 Information-sharing mechanisms

The information-sharing mechanisms in Julfa were diverse. The following are the most important information sharing mechanisms:

- **Churches:** The roles of churches went beyond a worshipping place. They were also places to informally share information.[13] Furthermore, All Savior's Monastery (i.e. the main church of Julfa) was a place for keeping records of contracts and blacklisted Julfans (e.g. persons who were deprived of future trades).

[12] The words dārūḡa, dārūḡa-ūšāgerd, dārūḡaūčī are other pronunciations of the same word. It is a borrowed word from Mongols. They had various roles in different times, from mayors to police. At the time and place in question (i.e. Isfahan as the capital city of the Safavids dynasty), they had a role like the police (see Lambton, 1991, for more information).

[13] When the population of Julfans increased in a city, they established their own churches there (Aslanian, 2007).

- **Letters and qasid (means messenger or runner):** By using letters, Julfans shared information between different network nodes. Couriers (Qasids) were utilised to share urgent information (e.g. sudden changes in business risk). Types of shared information through correspondence are listed below:
  - Information regarding political or social news, along with their impact on business (e.g. change of the ruler in a place).
  - Information related to other merchants and their reputation. This helped the master to find reliable partners and also avoid notorious agents.
  - Information regarding commerce-related issues. This class of information includes the following:
    - A detailed list indicating the current prices of commodities;
    - Current exchange rates, custom duties and road-guard fares.
    - Prices of the items in different places that were an advantage in comparison to other trading societies (e.g. the EIC and the VOC merchants).
  - Up-to-date information regarding business transactions and investments. This class of information was utilised to update the firm's accounts. We can guess this could be used in the same way it was utilised by European merchants in late medieval times (i.e. as valid evidence in court, Aslanian, 2007).
- The assembly of merchants collected information from different parties, and portable courts in other nodes to inform other merchants about cheaters.

Note that for secure communication of commercial information, Julfans used their own dialect rather than Farsi or Armenian (note that Farsi was understood by Julfans; however, it was also understood by Indian and Iranian merchants). Using a particular dialect for communication shows that an agent who wanted to work in Julfa needed to understand, read, and write the Julfan dialect. Because of these limitations and closedness of their society, we explore Julfa's demography in the next subsection.

#### 2.2.2.4 Julfa's demography

As stated earlier, Julfa was a closed society. The closedness of the society had two parts:

- The families formed a closed community of traders (family firm).
- All Julfans used their dialect for business affairs, which other Armenians could not understand.

Table 2.1: Estimated population of Julfa in different periods by different travellers (see Herzig, 1991, pp. 80–81).

| Year | Estimator | Comment | Population (in thousands) |
|---|---|---|---|
| 1606 | Gouvea | | 5 |
| | Iskender Beg | 3,000 households | 15 |
| | Carmelites | 2,000 households | 10 |
| 1626 | Thomas Herbert | | 10 |
| 1637 | Olearius | 3,000 houses | 15 |
| 1642 | Father Sebastian Manrique | conservative | 6 |
| 1660s | Chardin* | 3500 houses | 17 |
| 1677 | John Fryer | 6,000 families | 30 |
| 1712 | Kaempfer | | 30 |

* Chardin referred to it as "the greatest suburb in the world"; Tavernier compared it to a real city.

The aforementioned information indicates the importance of exploring the stability of Julfa's demography for modelling their society. Herzig (1991) compared different reports about Julfa's population during different periods. A summary of those numbers are presented in Table 2.1. Also, Table 2.2 summarises Herzig's (1991) estimation of Julfa population in different periods. As can be seen, the table indicates a steady growth in population that indicates the prosperity and sustainability of the society.

Table 2.2: Herzig's (1991, see p. 81) estimation of Julfa's population in different periods.

| Year | Comment | Population (in thousands) |
|---|---|---|
| 1600–1610 | Based on the demographics' characteristics*. | 5–10 |
| 1625–1650 | | 10–15 |
| 1650s | Abbas II expansion | 20 |
| End of 1600s | | 30 |

*Number of households or houses.

In the next subsection, we provide an overview of the economic institutions of New Julfa.

### 2.2.3 Economic institutions of Julfa

To study the success of any trading society, we should take account of their economic institutions' aspects (e.g. contracts). In this section, we describe the popular contracts in Julfa (i.e. commenda contracts); however, Julfans in limited cases used other types of contracts,[14] such as true partnerships (i.e. partnerships with other firms) and commission-based contracts.[15]

Although Julfans used *muzarba*[16] (i.e. their pronunciation of mudaraba) for commenda contracts, we employ the more familiar term. First, we describe commenda contracts, and afterwards, we include more descriptions specific to the Julfans' contractual rules.

Overall, commenda contracts are profit-sharing contracts where the investor bears the risks of trade, as long as the trading agent does not breach the contract (see Figure 2.2). In the unilateral form of commenda, the agent has a share in the profit, but the investor bears the tangible losses, while the agent loses the time and skill invested (Figure 2.2, disregarding the red dashed lines). The idea of this contract is investing capital by one party, and skills and labours by the other party.

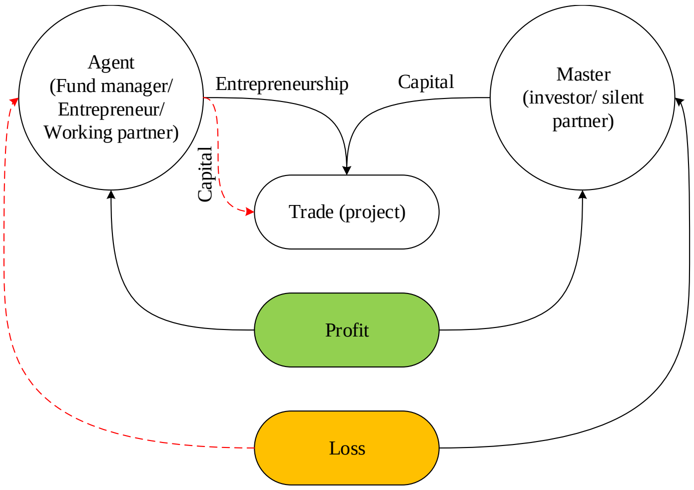


Figure 2.2: A schema of commenda contracts adapted from Jamaldeen (2012, p. 149, Figure 10-1). The red dashed lines belong to the bilateral contract.

Commenda contracts are suitable for combining the skills and labour of an agent with the capital of an investor. In long-distance trades, investors usually used them for reasons such

[14]For more information regarding Julfans economic institutions (see Herzig, 1991, Chapters 4 and 5).

[15]Lane (1963) suggests that a shift from commenda or *colleganza* to commission agency formed in the 14th century in Venice. He continues that the main difference between commission and commenda contract was in the way that the agent was paid. In the newer version, the agent was paid based on the *turnover*. Turnover is defined as "the amount of business that a company does in a period of time" (Cambridge online dictionary, 2019), and it can only be a predictor of profit (i.e. it is not the same as profit, Fairfield & Yohn, 2001).

[16]Note that qirad, muqaradah, mudarabah, mudaraba, and mudharabah are synonymous — the last three are different spellings of the same word (Islamic Banking and Takaful Department, 2012, part B, p. 4, footnote 2).

as avoiding risks of long-distance travels or doing simultaneous trades (i.e. several trades in different places about the same time). The contract is defined in the Lawbook as follows:

> "when someone gives money to another to work, the capital and *two out of three* [emphasis added] parts of the profits go to him, and *the third part* [emphasis added] goes to the worker. Or according to some other arrangement which may be agreed between them." (Herzig, 1991, p. 214, from the Lawbook)

Note that commenda contracts were written contracts that were witnessed by others. Two forms of these contracts are listed below:

- *Unilateral* — Here the investor provided the whole capital, and the agent did not invest any money and only performed the tasks (Figure 2.2, disregarding the red dashed lines).
- *Bilateral* — Here the agent invested his capital as well as his skills (Figure 2.2, including the red dashed lines).

The following lists a summary of the rules mentioned in the Lawbook (note that the master is the investor):

- The agent must follow the instructions of his master, unless otherwise stated (e.g. the master permits the agent to decide on his behalf).
- The agent must provide the account book; otherwise, he may be imprisoned for up to one year. On return, the agent must present all of his belongings (including his luggage) to his master.
- The agent must not conduct trade, except for his master, unless otherwise stated.
- The master should declare the selling/buying prices and the agent must follow them.

Aslanian (2007, p. 269) argues that if courts ruled in favour of one party, the defendant, his family, or his relatives had to pay back the money and accumulated interests. That shows more severe punishments than a simple boycotting for the defendant. In the next subsection, we state how masters attempted to decrease their investment risks by investing in increasing the skill level of agents using an apprenticeship programme.

### 2.2.4 Apprenticeship

The ideal form of the apprenticeship programme in Julfa had two stages, namely school-based training and work-based training. First, we investigate the evidence regarding school-based training. Then we state available evidence regarding work-based training in Julfa.

Note that school-based training is more than just conveying declarative knowledge in the network by means such as printed manuals (e.g. Aslanian, 2007, pp. 179–180, points to one manual in Julfa).

Julfans employed *schools* to teach recruits commercial skills, such as formal writing and solving arithmetic problems. The following passage points to an observation regarding the quality of gained skills in the schools:

> "Hovhannes, son of the priest David [...] was well conversant with the systems of measures and weights in practice in various countries, the different monetary units and the weight of gold and silver each of them contained. *He unerringly solved complicated arithmetical problems relating to the sale of various goods, bank and money transactions, at times quite involved* [emphasis added]. The entries in the ledger abide by accepted principles in book-keeping; the right-hand margins of leaves display expenditures noted after each credit item, while the left hand is taken up by incomes." (Khachikian, 1966, p. 156)

Based on the remaining teaching manuals, the important subjects addressed in their school are as follows:

- Introduction to commerce, including a dialectical discussion, along with some details about the importance of honesty and warnings about trusting strangers;
- Trade routes, important nodes, currencies, and employed units associated with them, exchange rates, and the items one should buy or avoid buying in each node;
- Solving practical and complicated mathematical examples;
- Account-keeping and orderly updating of the general journal.[17]

The work-based training was mostly conducted by families for reasons such as increasing the profitability of the family firm or future-proofing their children. An instance of parents' future-proofing their children is exemplified by a father who took his two sons to work together as commenda agents. The share of profit for the three merchants altogether decreased from 33% to 25%, which indicates some costs for the trainer, regardless of paid wages (i.e. the father, see Herzig, 1991, p. 215).

The other evidence of work-based training is more informal. For instance, Fryer provides information on how masters and wealthy members of society (Khajes) trained their children. See the following passage as an example:

[17] Unlike Aslanian (2007) who used daily financial ledger as a translation for ruznama we proffer to use the word general journal like accountants do. Note that nowadays, in Iran accountants call a general journal, daftar-e ruznama.

> “[T]hey train their Children under the safe Conduct of Experienced Tutors [sic], who instruct them first to Labour [sic] for a Livelihood [sic], before they are permitted to Expend [sic].” (Fryer, 1698, p. 268)

Another instance of work-based training by family members concerns Nikoghos who trained his seventeen-year-old cousin, Zakaria (see Aslanian, 2007, p. 303). The work-based training by family members seems to have been a tradition in Julfa as in the whole Asian continent (Aslanian, 2007, p. 304).

As stated earlier, the apprenticeship programme included both work-based and school-based training. It is rational to assume that in the work-based training provided by the family, apprentices learned some skills, such as pricing the items[18] and negotiation. In the school-based training, they were taught declarative knowledge about the routes and units, as well as academic skills such as solving mathematical problems. In other words, big family firms in Julfa benefited from work-based and school-based training. After stating some reasons for Julfan’s success, in the next subsection, we provide some information on the reason for decline of this society.

### 2.2.5 Decline of New-Julfa

The reason for the decline of Julfa is the subject of debates.[19] Overall, the issues Julfans faced can be summarised as economic issues inside Iran, shahs’ corrupted officials asking for bribes leading to the unpredictability of travel costs, and the Afghans’ war with Safavids that led to the extinction of their dynasty (note that it was caused by a “small band of Afghan tribesmen”, Matthee, 2015). Also, frequent changes of kings after the extinction of the Safavids led to the demand for more taxes (sometimes twice in a year), and famine. Note that Aslanian (2007) and Herzig (1991) suggest that the violence of Nadir Shah Afshar against Julfans was the main reason for the decline of the central node of Julfan’s trading network (i.e. Julfa).

In other words, it was not their economic institutions that caused the decline of the society. At first glance, the reason for the decline might be attributed to not having an independent military to defend the Julfans. However, given their small population size in comparison to Iran, and the costs of maintaining a military, it is difficult to say whether or not having military could have helped.

[18] Armenian families traded gems, diamond, textiles, jewellery, etc. that even nowadays pricing them is not easy.

[19] For such debates and potential reasons for the Julfa decline, see Herzig (1991, pp. 102–108) and Aslanian (2007, pp. 355–369).

Before investigating the next historical long-distance trading society, we wish to summarise information regarding Julfan's institutions by pointing out that the institutions of the Julfa mostly aimed to satisfy their people. The main instances include sharing a significant proportion of profit and utilising adjudication processes to resolve the disputes (courts). Furthermore, they elected the mayor (i.e. Kalantar) democratically (see Aslanian, 2007). These characteristics convince us to assume that Julfans were mostly concerned about the fairness of institutions to control their closed trading society, and to decentralise the governance of the society. The next section explores another long-distance trading society with different characteristics and institutions.

## 2.3 The British East India Company (EIC)

The British East India company (EIC) was established in the last days of 1600 as a Royal Chartered Company (i.e. the Crown granted the company the privilege of the monopoly of trade). Despite its unique characteristics, such as being the first joint-stock multinational company (Seth, 2018), the EIC shared most of its characteristics with other European chartered companies (e.g. monopolising Asian trade). In the 1600s, the Dutch East India Company (VOC) and the French East India Company[20] were also active in India. However, we choose the EIC because we have access to more authoritative English resources and evidence about it. Furthermore, we are interested in this society because the company also coexisted and cooperated with Julfans.[21] It had some contracts with Julfans that permitted them to use the EIC nodes, and also they purchased silk from the Julfan traders. An overview of the EIC's background, its formation, its societal characteristics, economic institutions (e.g. contracts), and reasons for its decline are provided in the following subsections.[22] Note that the EIC's period overlapped with several historical events, such as the Anglo-French War (1778–1783) and the English Civil War (1642–1651). In the following, we investigate the events that had a significant impact on the company's rules or profitability.

[20]It was originally called Compagnie française pour le commerce des Indes orientales translated as *French Company for East India Trade*. It was formed by merging three French long-distance trading companies (Wikipedia contributors, 2018).

[21]Note that Sir Jean Chardin and John Fryer who described Persia and Julfans were the EIC's agents.

[22]The information of this section are mainly from the following resources: Hejeebu (1998), Chaudhuri (1965), Chaudhuri (1978), Marshall (1976), and Erikson (2014).

### 2.3.1 Formation of the EIC

In 1599, the founders collected the capital to establish the company, and also Shah Abbas I granted British traders permission to trade in Iran. However, the EIC started its trades in the 1600s when Queen Elizabeth I (1558-1603) granted them the royal charter. However, the EIC faced issues, such as rivalry and battles with other European chartered companies and battles with local governors. The following sections concentrate on the economics aspects of this company (i.e. we disregard its wars and battles). The only war we investigate here is the English Civil War[23] because of its impact on the economic institutions of the company (see Section 2.3.3).

### 2.3.2 Social characteristics

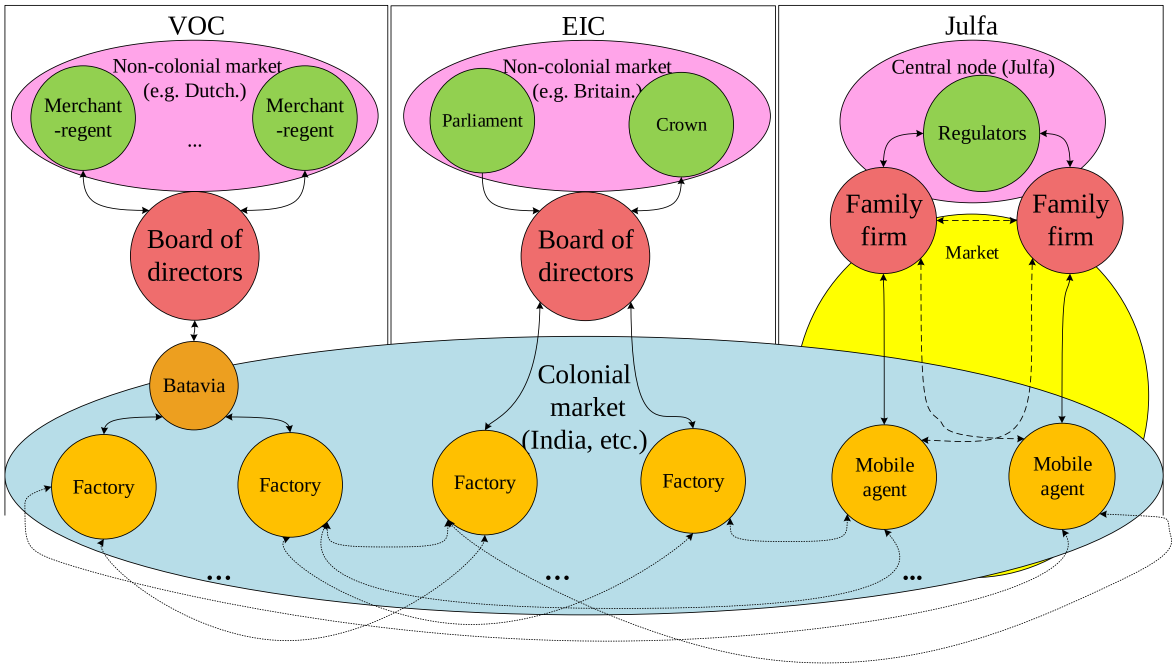


Figure 2.3: A schema of the organisational structure of the VOC, the EIC, and Julfa, and their interconnections.

A society's institutions and characteristics influence its economic performance, and in the EIC certain characteristics led to changes in its institutions and hindered managers in their efforts to control agents' behaviour. Parts of these characteristics were forced by nature (e.g. high mortality rate) and some were consequences of the managerial decisions (e.g. low

[23]This was a fight between supporters of the King and parliament and took place between 1642–51 (although some unrest had been going on in Scotland and Ireland since 1639) (Ohlmeyer, 2019).

wages). The following subsection investigates these institutions and characteristics. In this subsection, we also present some characteristics of the VOC to describe an alternative chartered organisation that was contemporaneous with the EIC.

#### 2.3.2.1 EIC's characteristics and structure

The EIC monopoly had always been at stake by parliament's or the Crown's decisions. Also, the structure of the company provided incentives and ability for agents to hide valuable information from the company (information rent).[24] Here we compare the EIC structure with two other trading societies, namely the VOC and Julfa. Figure 2.3 represents a schema of the organisational structure for the three long-distance trading societies (i.e. the VOC, the EIC, and Julfa). In this figure, the solid lines show the formal relationships, and the dashed-lines shows potential relationships, and the dot-lines are trade relationships. The following compares the structure of these societies in different levels.

- **Regulators (the green circles):** The VOC had concerns regarding the local interests of the regents.[25] These interests sometimes took the place of the company's interests. The EIC faced some additional risks such as a change of rules by the British governors (the Crown and parliament). Julfa had a distributed management (i.e. family firms were ruled by their owners, not by a central director); however, the king's decisions impacted them.
- **The managers (the red circles):** The VOC and the EIC were companies with a centralised management (i.e. board of directors). However, Julfa had a decentralised management of trade because there were several family firms at the same time (i.e. more than one family could trade silk). Furthermore, the EIC was exposed to the trading decisions made by non-partners (i.e. parliament). Note that the Crown had invested in the EIC and could be considered as a partner with some profits. However, the Crown might have permitted the formation of new companies. For instance, in 1635, King

[24]The structure of the EIC comprised of agents who stayed at the same place for a long time. This has provided the information rent on part of agents who stayed at the same place. The incentives of agents is a consequence of a combination of agents' access to the valuable company resources and low payment along with the opportunity of benefiting from such information rents.

[25]For instance, as "the colonial system got underway and state-sponsored corporate bodies like the chartered companies took off, the relationship among metropolitan principals became more adversarial. The VOC, in particular, could act as a state within state-so various Dutch regents complained, or exulted, depending on whether they controlled one of the coveted directorships. But the Seventeen Gentlemen were also the principals of the Dutch East Indies Company, and in that role they confronted the intractable independence of their own colonial agents" (J. Adams, 1996, p. 17).

Charles I did permit the establishment of a new trading company called the Courteen Association (Bogart, 2015).

- **Market (the blue oval, the pink oval, and the yellow circle):** As can be seen, the three companies were engaged in the colonial markets (i.e. places where the EIC and VOC had a duopoly, the blue oval). Also, each company was active in their home countries/nodes (the pink oval). However, Julfans were also engaged in other markets (e.g. French and Italian markets, shown using a yellow circle).
- **Settlements and mercantile agents (orange circles):** The EIC and the VOC had built places called factories for the long-term stay of their mercantile agents (i.e. employees who performed merchandising). A difference between the two is that the VOC had used a managerial centre (Batavia).[26] However, Julfan mercantile agents had moved from one place to another to buy and sell items.
- **Collaboration (dashed-lines and dot-lines):** The mercantile agents of these companies had some formal (i.e. collaboration with companies' explicit permission) or informal collaborations (i.e. performing illegal trades for self-interests or trades on the company's behalf without explicit permissions). This collaboration is indicated in the lower part of Figure 2.3. However, in Jufla, as stated earlier, family firms could start a partnership and also they could have hired each other's mercantile agents (dashed-lines in the upper levels of Julfa).

As can be seen, the EIC had a different organisational structure to Julfa. Now we investigate the issues associated with the adjudication processes in the EIC. The adjudication process in the EIC was ineffective because of the weak monitoring and difficulties with prosecution. For instance, the following passage indicates how some of the Surat council members (i.e. EIC managers in Surat) defended the private traders (i.e. cheaters) in 1620:

> "if some tolleration [sic] for private trade be not permitted none but desperate men will sail our ships." (Factory Records: Miscellaneous, I, 26, 18, February 1620, as cited in Chaudhuri, 1965, p. 87)

Furthermore, company owners could not control and monitor agents' behaviour for the following reasons:

- Mercantile agents could hide their illegal income by spending it inside India.

[26]Batavia was the name of Jakarta, Indonesia, until 1949 (Waworoentoe, 2018). Batavia aimed to control information rent by accumulating information in one place; however, this policy only transferred accumulated information to Batavia (J. Adams, 1996).

- Mercantile agents could remit their money with the help of other companies. For instance, Gaastra (1994) stated that in 1765–1795 around 13% of remittances through the VOC belonged to British agents.[27]

On the other hand, the efficacy of prosecution was low. In other words, in 100 years between 2% and 4% of employees were prosecuted in courts (i.e. about 0.0004[28] of agents per year, Hejeebu, 2005). Furthermore, when company became suspicious of an agent, it took years to investigate and reach a final decision.[29] For this reason, the real punishment given by the EIC was the dismissal of agents for their suspicious behaviour. Indeed, 13.2% of the EIC employees who were hired between 1700 and 1756 in Bengal were dismissed (i.e. about 0.003 per annum; see Hejeebu, 2005, p. 514). For instance, Hugh Barker, an employee with 25 years experience, was fired for the reasons stated in the following passage:

> "We cannot pass by the extravagant price of the raw silk at Casimbazar [sic] and the exceeding badness of the taffetys [sic] from thence. Therefore we may let our servants see that we can distinguish betwixt [sic] them who serve us faithfully and well and those who only pretend to do so we do dismiss the said Hugh Barker from our service." (Hejeebu, 2005, p. 514)

Finally, a counter-intuitive observation concerns a higher number of dismissals for more experienced agents (Hejeebu, 2005). In other words, we can infer that employees in the EIC cheated more as they became more experienced and had more access to company resources. All of these indicate that: a) managers did not have an adequate cooperation with the mercantile agents to monitor their behaviour and b) the EIC owners distrusted their agents and managers.[30] The next subsection provides an overview of the EIC's demography. This helps us to understand one of the reasons for certain policies employed by the company.

[27] 12 million guilders ($f$) out of $f$90,000,000 that equals $13.\overline{3}\%$.

[28] For $x\%$ in $y$ years, it is calculated as $(1 - \sqrt[y]{(1-(x/100))})$.

[29] According to Hejeebu (2005), sometimes the agent died before the final decision. For instance, for a person called Spencer, "the company attempted to revive a complaint nearly two decades after the original incident."

[30] "One of the reasons for that distrust of the factors [i.e mercantile agents] which seems to have been habitual with the Court of Committees was the feeling that they had no means of arriving at the true state of affairs in the Indies unless other factors chose to give information against the delinquent ones [i.e. factors]. Sometimes, one factor more honest than the others would report on the behaviour Of those guilty of *too flagrant abuses* [emphasis added]."(Chaudhuri, 1965, p. 87)

#### 2.3.2.2 The EIC's demography

A main concern of the EIC and other European Chartered companies was the high mortality rate of their agents in India. For instance, Marshall (1976) states that around 60% of employees could not make it back to England, and the survivors looked far older than their real ages. Hejeebu (1998) studied the life expectancy of the EIC's agents between 1700 and 1774 (see Figure 2.4). Figure 2.4 presents the percentage of agents who stayed in the company considering their years of service. Note that the main reason for not working in the next period (five years) was dying and around 85% of agents who were not available in the next period were dead (see Hejeebu, 1998, p. 91, Table 10's footnote).

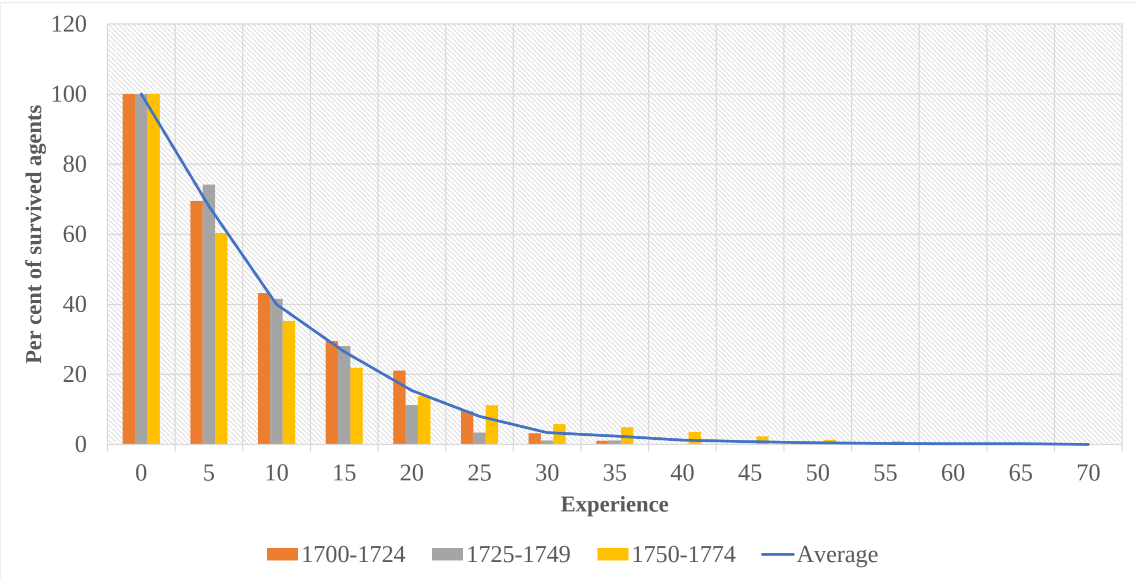


Figure 2.4: Years at service for agents before leaving the company, the x-axis presents years of service, and the y-axis presents the percentage of agents who stayed at the beginning of the period (based on Hejeebu (1998, pp. 90–91, Table 10))

Figure 2.4 does not include the number of agents who died during maritime travel (Hejeebu, 1998, did not include that number). Overall, residual effects of maritime diseases such as scurvy, along with heavy drinking behaviour were some of the reasons for this high mortality rate (Hejeebu, 1998; Marshall, 1997).

To overcome these issues, in 1669 the EIC changed its policy from hiring mature merchants to employing young agents, based on the director's recommendations (O'Malley, 1931, Chapter 10, p. 228). The hired agents were mostly aged between 15 and 19 years (Hejeebu, 1998). Note that when we study the EIC institutions and characteristics (e.g. their apprenticeship programmes), we should also consider such environmental circumstances.

For instance, an incentive for European companies' policies regarding building settlements in their destination could have been to reduce merchants' mortality because of maritime travels. Note that scurvy, that is caused by deficiency of Vitamin C, was first systematically studied by James Lind and his findings were published in 1748. He stated that "I shall here only observe that the results of all my experiments was [sic], that oranges and lemons were the most effectual remedies for this distemper at sea" (Price, 2017, quoted from "A Treatise of the Scurvy", by Lind). The next subsection explores the economic institutions of the EIC.

### 2.3.3 Economic institution

First, we wish to remind the readers that the values stated in this subsection belong to centuries ago (i.e. we should consider the impact of factors such as inflation). The following provides the current *relative value* of £1 in 1700, using two metrics (see Officer & Williamson, 2019, for more information):

- Real price — £147.5. This number indicates the current equivalent purchasing power of £1 for a fixed bundle of goods (i.e. a bundle of goods worth £1 in 1700 is now worth £147.5).
- Labour earnings — £2181. This number 'measures an amount of income or wealth relative to the wage of the average worker.' In other words, a person who was paid £1 to perform a task in 1700, is paid £2181 to do the same job.

As can be seen, the value of £1 changes, based on time and other factors (purchasing power versus labour earnings). We mentioned this as a gauge for readers to know that when we say a merchant could transfer about £2,000 from India, it means that with the same money, he could buy a car worth about £295,000 now. However, considering the average wages, his income was equal to about £4,362,000 now.

The following provide an overview of the main economic institutions that impacted the company:

- **The monopoly of trade:** As stated earlier, the company was formed through a monopoly privilege. However, for the structure of the company, this privilege was at stake through decisions of parliament or new partnerships formed by the Crown.
- **Contracts:** The contracts indicate the economic institutions that were employed by the company to manage the mercantile agents. In the following details, we investigate how the contractual scheme of the company evolved over time.

**Flexible commissioning (1600–1609):** First, agents worked as commission agents — the commission rate was between 2.5% and 4% (see Chaudhuri, 1965, p. 75). They also had permissions for private trade for a maximum of £25 for certain items or they had a share in the company profit.[31]

**Fixed wages (1610–1640):** The most popular method for paying wages to agents who lived in India was 33% in cash, and the rest, or most of it, was credited as company shares.[32] Table 2.3 provides some evidence of the wages during this period. Note that factors function the same as the mercantile agents. Also, there is evidence that indicates masters failed to control the agents' behaviour during this time. These difficulties were twofold and they are ascribed below:

- Agents did not follow the provided commands from managers about the company's desires. For instance, in 1628, some agents postponed maritime travel using excuses regarding dangers from the Portuguese fleets. This frustrated the managers and they clarified that this kind of behaviour should not be repeated.[33]
- The agents had extravagantly spent company funds. For example, in one case, the managers were frustrated because the agents sent a mission to the Court of Golconda to secure the company's concessions at a cost of about £4,000 (Chaudhuri, 1965, p. 87).[34]

Overall, it is believed that agents had formed a coalition to cover their frauds and only extremely harsh violations might have been reported (Marshall, 1976).

**Transition period (1660–1700):** In the 1660s, the company granted permission for private trade to the agents. The reasons for granting such a permission were twofold, a) an

[31]The differences between commission and commenda contracts are stated in footnote 15.

[32]Note that in commenda contracts the agent has a share in profits made by his skills. However, this policy means that the agent bore the risks of mistakes and fraudulent behaviour of other agents.

[33]The directors' reaction was as follows:

> "[T]he factors put not the fault in cowards why that ship comes not home this year, for they themselves either will not understand or will not follow their commission, ... in one particular point of advice from hence to Surat wherein direction is given to dispeed [sic] away one or more ships in November and not to stay to come in fleets unless the second ship may be ready within 14 days." (Court Book, X, 219-20, 15 January 1628, as cited in Chaudhuri, 1965, p. 86)

[34]The directors' response was as follows:

> "You have to the life expressed your own vanity, folly, and riot unto those people, and wasted so much of our estate in such a lavish manner as if we sent our ships and monies hither for you to make shows and pagents [sic] for those people to scorn at." (Letter Book, I, 127, 27 October 1636, as cited in Chaudhuri, 1965, p. 87)

Table 2.3: The early evidences for wages in the EIC based on Chaudhuri's (1965, p. 84) discussions

<table>
<tr><th>Rank</th><th>Wage</th><th>Comment</th></tr>
<tr><td>Low-skilled</td><td>£10</td><td>Nathaniel Courthope</td></tr>
<tr><td>Junior factor</td><td>£40</td><td rowspan="2">In 1614, for instance, Hugh Fraine, a Spanish agent, was paid £20. His wage increased by £20 a year and reached £100 after 5 years.<br>In another case, William Kent was hired with a wage of £50. His wage rose to £100 for the rest of his service.</td></tr>
<tr><td>Senior factor</td><td>£150–£200</td></tr>
<tr><td>President</td><td>£500</td><td>In 1633 Methwold was paid this much.</td></tr>
</table>

idealogical shift took place in Britain,[35] and b) after the English Civil War (1642-1651) some of the company's agents were added to its board of directors. This addition caused an injection of new attitudes and led to granting permissions for private trade. Figure 2.5 presents the total value of items imported from the Asian continent between 1664 and 1760. The immediate effects of granting permissions for private trade are identified through a drop in the EIC's imports from India to about 0. Furthermore, in 1691, parliament granted permission to some traders to form a rival company called the New East India Company.[36] The formation of this rival company also led to a decrease in the imports of the EIC (see Figure 2.5).

**New contracts (1700–1750):** Hejeebu (2005) conducted a study on the EIC's contracts between 1700 and 1750. Based on the available information, granting permissions for private trade was used by the company to reduce the company's costs (i.e. wages). The third row of Table 2.4, indicates the new wages. The new wages decreased drastically. For instance, before the 1660s, a junior factor was paid £40; however, based on the new contract, a senior merchant was paid £40 (see wages in Table 2.3 and Table 2.4). In other words, the new contract changed the main source of the agents' income from paid wages to private trade and cheating. Table 2.4 compares the wages (the third row), and the average remittances (money sent) in the EIC (the fourth row).

Based on the available evidence, to penalise agents, the company had access to remittances and also had the signed bonds. However, as stated earlier, agents could use other companies like the VOC to transfer their money if they felt unsecure about the company's

[35] According to Erikson (2014), "[m]any contemporaries of the Company argued that monopoly privileges were in violation of the common law and [the] Magna Carta."

[36] The company was officially called the English Company Trading to the East Indies (Bohun, 2008). For more information on the impact of the company on the EIC, see Erikson (2014, p. 63) and Hejeebu (2016, p. 37).

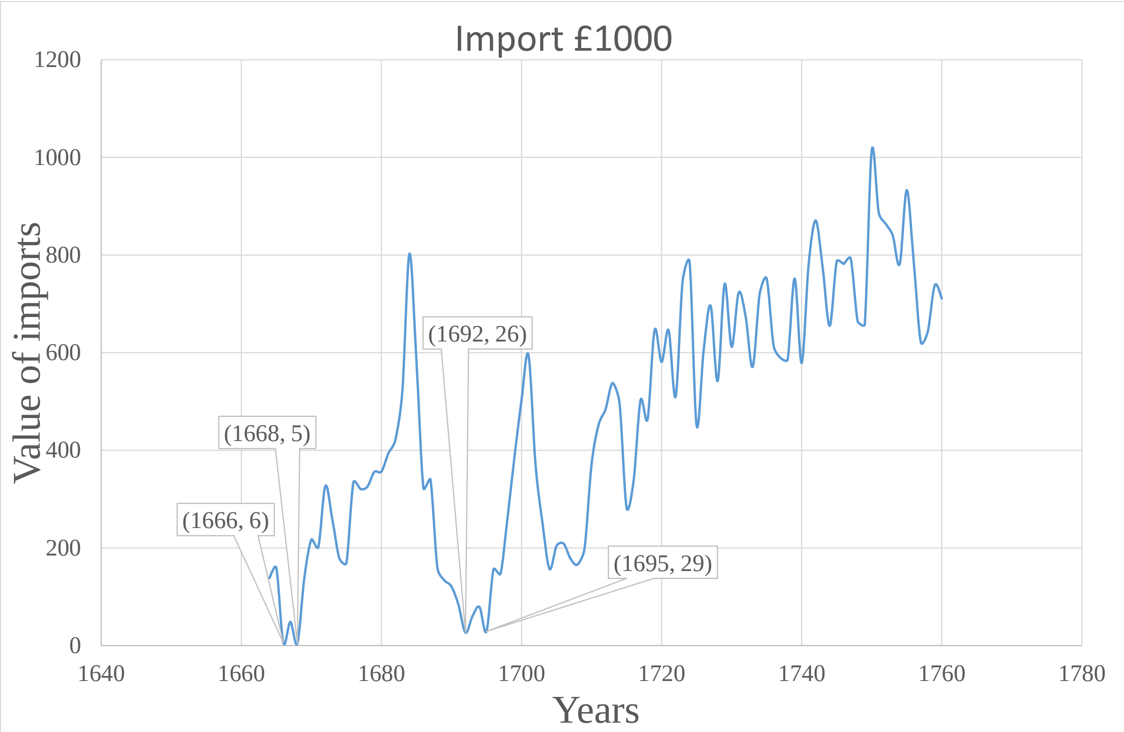


Figure 2.5: Total value of imported items from Asia (i.e. India, China, and South-East Asia, based on Chaudhuri (1978, pp. 508–510, Table C.2)). Labels — i.e. (x,y) — show the year and the value of imports, respectively.

Table 2.4: Remittance from India by the EIC's agents and their wages (see Hejeebu, 2005, p. 502 and p. 519)

| Experience | 1–5 | 6–10 | 11–15 | 16–20 |
|---|---|---|---|---|
| Title* | Writer | Factor | Junior merchant | Senior merchant |
| Annual payment | £5 | £15 | £30 | £40 |
| Remittance per year** | £139 | £406 | £1416 | £2297 |

*The titles change, based on experience and factors are low experienced mercantile agents.

** Note that this includes income from private trade and cheating, less expenditures in India.

future actions based on their observations. Also, although the value of signed bonds was significant (e.g. £500 for a writer), in several years before the EIC dissolution, some agents could pay some sureties to sign their bonds, thereby, getting around the purpose for which the bond was originally created.[37] More importantly, there is no evidence of using these

[37]Hejeebu (2005, footnote 43) explains that a market of guarantors was formed behind the EIC office. In one case, the same person signed 50 bonds for different agents during 15 years (see Hejeebu, 2005, p. 506,

bonds to punish the cheaters. The next subsection investigates the methods employed by the company to improve the skills of its agents.

### 2.3.4 Training

In this subsection, we investigate both aspects of the apprenticeship programmes in the EIC, namely school-based training and work-based training. As stated earlier, in the early years of its establishment, the company only hired experienced agents. At the end of 1660s the company changed its policy to hiring young agents and sending them to India. The first group of young people were from a particular school that was known for having commercial courses in its regular programme.[38] This policy did not persist, and after 1694, the company officially started to hire writers (i.e. agents with some information on keeping accounts).[39] The writers learnt the local dialect in tutelage provided by a company tutor. However, in practice, the educational skills of the agents were not taken seriously, as explained in the following passage:

> "Even after the duties of the Company's servants had ceased to be purely commercial [i.e. after 1682], the only educational qualification required for admission to the Service was a rudimentary commercial training: a certificate that the applicant for a nomination had gone through a *regular set of merchants' accounts* [emphasis added] was the only test." (O'Malley, 1931, p. 230)

Note that in the last years of the company's life (i.e. 1800), a specialised course was proposed by Wellesley to address the concern about "administering an empire".[40] However, the course was not approved by the board for being **too costly**.[41]

footnote 43).

[38]The school's name was Christ's Hospital; O'Malley (1931, p. 228) said "[agents] were mostly obtained from Christ's Hospital, the well-known blue-coat boys' school, which had the advantage of giving its scholars some commercial training."

[39]In 1682, a rule was passed in the EIC that only the ones who could keep the accounts were eligible to be hired.

[40]The course was supposed to cover philosophical and general topics about ethics, civil and international law, and history, along with the Indian language, history, customs, habits, Hindu and Islamic laws, and religion. Note that based on the topics, this course was not designed for commercial purposes, but was designed to control, manipulate, and govern Indian society for the benefits of the *empire*. This ambition ironically led to the EIC's dissolution in 1874 and after that the Crown formally became the ruler of India in 1854 (Kaul, 2011; Sahni, 2013).

[41]The EIC board accepted that colleges can be used for teaching languages, and after 1854 when Britain governed India, the college was employed for the same purpose. However, the evidence suggests that even learning languages was not practised well (O'Malley, 1931, p. 234).

Overall, as stated above, the commercial skills were not taken seriously. In other words, after the 1660s, the agents were trained by experienced merchants inside India during work in the first five years (i.e. the duration of this organisational role).[42] Furthermore, the incentives of trainers in the EIC were not the same as Julfans'. In the EIC, the tutors were forced to train other agents, while in the Julfa, family members trained their relatives for their firm's profits.

As stated in this subsection, there is no convincing evidence that agents had adequate school-based training (except for employees of the end of the 1660s). In other words, there is only evidence for a work-based training that was not effective. This influenced the company when they changed their policy from hiring experienced merchants to young and inexperienced recruits (i.e. after 1660s). The next subsection provides an overview of the reasons for the decline of the EIC.

### 2.3.5 Decline of the EIC

Hejeebu (2016) divides the life-cycle of the company into four periods to investigate the transformation of the EIC. These periods include 1600–1660, 1660–1745, 1745, and 1745–1784. Note that after 1784, the company was gradually dissolved by parliament by limiting its directors' powers and empowering militaries. The first period is 1600–1660, during which, the company decided to establish residencies in India. The second period is 1660–1745. During this period, the company faced crises for different reasons, such as its defeats in battles with Aurangzeb (Indian Mughal king) and the emergence of a rival company in Britain (the New East India Company). The third period is during 1745, when the EIC had an unwanted war with its French counterpart because of the Britain-France opposition. The last period is 1745–1784. In this period, the army had conflicts with merchants and also merchants did not obey the orders of the board of directors. These conflicts caused parliament's involvement in company's decisions (i.e. conflicts between managers, the board, and parliament), and finally, the company was dissolved in 1854.[43]

However, an aspect that is not addressed by Hejeebu (2016) is the gradual decline of the EIC's monopoly power. This decline was caused by a) granting permissions for private trade to employees and b) its integration with the New East India Company (i.e. two companies

[42] Note that five years is a too optimistic estimation because they had to do their tasks, such as writing some copies of letters and learning the language of locals. Furthermore, the main task of trainers was merchandising (i.e. in practice, the training time was much less than five years).

[43] There is some debate that before 1854, the EIC no longer existed. For instance Marx (1853) says "So far, the East India Company has, since 1833, no longer existed but in name and on sufferance."

worked as a whole). The latter led to an increase in the supply of items in the British market that made the monopoly of trade useless. Figure 2.6[44] indicates that after integration (i.e. 1709), although the company had an increasing trend of imports, it faced occasional losses (i.e. 1722 and 1718).

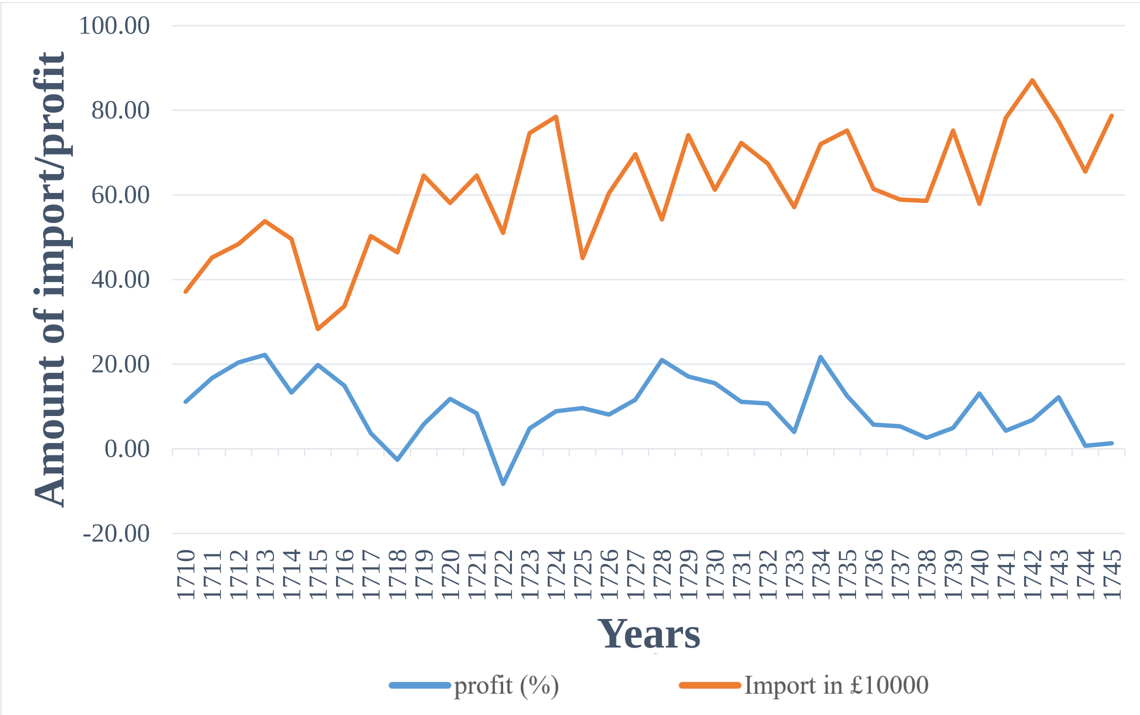


Figure 2.6: A comparison between the EIC imports and profits (based on Chaudhuri, 1978, pp. 508–510 and 440, Table C.2 and Table A.26)).

In the next section, we provide a summary of the two trading societies' institutions and characteristics.

## 2.4 Comparison of the two trading societies

As stated at the beginning of this chapter, we aim to compare two successful trading companies to explore reasons for their success. The EIC was successful mostly because of its monopoly, and Julfa was successful even in a competitive environment.

Table 2.5 presents some of the differences between the EIC and Julfa. Columns "EIC" and "Julfa" indicate whether a characteristic/institution was available in the society. The

[44]Chaudhuri (1978) provided information on the EIC profits for 1710–1745. Because after 1709 the account books were more organised.

Table 2.5: A comparison between characteristics and institutions of the EIC and Julfa

| Characteristics/institution | EIC | Julfa | Studied | Chapter |
|---|---|---|---|---|
| Apprenticeship | Weak | Strong | Yes | 5 and 7 |
| Mortality rate | High | Low | Yes | 4, 6, and 7 |
| Closed | No | Yes | Yes | 4 |
| Adjudication | Not in effect | Yes | Yes | 4, 6, and 7 |
| Profit-sharing | No | Yes | Yes | 4, 6, and 7 |
| Societal collaboration in monitoring | No | Yes | Yes | 4, 6, and 7 |
| Mobile agents | No | Yes | Yes | 6 and 7 |
| Risk-sharing | No | Yes | No | - |
| Improving social network by marriage | No | Yes | No | - |

column "Studied" indicates whether the identified attribute was considered in this study. Finally, column "Chapter" indicates the number of the chapter that addresses the attribute. Note that all of these characteristics do not have the same weight in impacting the success of these societies. The following provides a summary of the two societies' characteristics and institutions, starting with Julfa.

The Julfans were a closed society of traders with rules that helped the concentration of wealth in a family (i.e. their inheritance law). They also used intermarriage to strengthen their family bonds and sometimes used marriage to improve their social networks. They used commenda contracts[45] to manage their trades. They shared a significant amount of profit, and the master bore most of the trade's risks. Because in Julfa agents were responsible for buying and selling items, they did not stay in one place for a long time. Moving in their networks and profit-sharing incentivised them to search for new opportunities. To manage their contracts they had two types of courts, namely an assembly of merchants and portable courts. The portable courts were formed in distant places to accelerate dispute resolution. Julfa's population growth convinces us of their prosperity. Also, it can be understood that they did not face a high mortality rate. The low mortality rate of the company, and also the fact that the investor bore risks of losses, convinced Julfans to invest in maintaining a high societal skill level by conducting apprenticeship programmes. Also, certain characteristics (e.g. family firms) convinced Julfans to collaborate in monitoring and reporting suspicious behaviours of merchants. This monitoring and reports were completed by other means of information sharing, such as archiving the name of blacklisted agents in the Churches.

The main issue that the EIC faced from the beginning was a high mortality rate. This made the managers use an open scheme for recruiting merchants. Also, to control the mortal-

[45]In this study when we say commenda contracts, we refer to bilateral commenda contracts.

ity rate of the maritime travels and for better access to the market, they established factories (warehouses) in their trading nodes. These establishments were the places where their agents stayed for a long time. Although their contracts evolved over time, their agents never had a share in the profit made for the company (the agent did not even know about the amount of profit made). Another issue that the EIC was involved with was regarding monitoring their agents and enforcing the rules. In fact, sometimes managers defended cheaters against the board of directors. Finally, the high mortality rate and profit that was guaranteed by monopoly deterred the company owners from investing in apprenticeship programmes.

Having presented the background of the two long-distance trading societies, in the next chapter, we underline the technological infrastructure and concepts used to model these two historical trading societies.

# 3

# Background, foundations, concepts, and employed technology

## 3.1 Introduction

In this chapter, we provide an overview of the concepts, foundations, and technologies employed in this thesis to model the trading societies described in the earlier chapter. We underline the infrastructures of the models that are the main contribution of this thesis. We present concepts underlying agent-based modelling and simulation, fuzzy sets, social institutions, and psychological and sociopsychological mechanisms and theories. We use these concepts in the context of the two historical long-distance traders. The rest of the chapter is organised as follows. Section 3.2 reviews the technologies and tools used to model different aspects of these societies. These are used to develop models of agent interactions. Section 3.3 presents relevant concepts with respect to the domain of this study (i.e. managing long-distance traders) concerning social institutions (i.e. the rules of the game) and economics. Section 3.4 provides a review of another aspect of humans (i.e. psychology and sociopsychology) that we make use of in this thesis. Finally, Section 3.5 provides a summary and an overview of the relevance of those concepts to this thesis.

## 3.2 Technologies and modelling approaches

In this section, we state the technologies and modelling approaches employed in the following chapters. The technological concepts include agent-based social simulation and fuzzy sets. The modelling approaches focus on methods associated with agency and include the belief-desire-intention (BDI) model, game theory, and CKSW (Purvis et al., 2014)[1] frameworks.

### 3.2.1 Agent-based social simulation

To model complex systems, we usually divide the system into agents — i.e. its components such "that each of them *produces a particular effect by its action*" (Cambridge online dictionary, 2019). When we use such an idea to simulate social interaction, it is called *Agent-Based Social Simulation* (ABSS). In other words, ABSS concerns the interaction of three fields of research, namely social science, agent-based computing, and computer simulation. ABSS can be defined as "the use of agent technology for simulating social phenomena on a computer" (Davidsson, 2002).

In what follows, we concentrate on the aspects related to the agent-based simulations (ABS), and we investigate social aspects in Section 3.3.1 and Section 3.4.

First, we should clarify what we mean by agents in this context. Agents are autonomous, self-contained, and social entities (Macal & North, 2009). In other words, agents are autonomous entities that interact with one another and their environment. According to Macal and North (2005), agents possess the following characteristics which make them suitable candidates for simulation of the human decision-making processes.

- They are defined such that one can distinguish them based on their characteristics or set of rules.
- They can interact with one another or the environment.
- They have some objectives or goals and make decisions according to them.
- They are autonomous and can make independent decisions.
- They are flexible and can modify their behaviour by learning.

According to Banks et al. (2010), in general, there exist two reasons for discrete-event system **simulation**. The first reason is imitating a system behaviour based on the historical data to investigate "what if" scenarios about the real-world system. The second reason is to

[1]CKSW stands for Commander-Knowledge-Skill-Worker. It is described in Section 3.2.5.

predict the system's performance while designing it. Gilbert and Troitzsch (2005) suggested some additional reasons for social simulation, such as a better understanding of the system, prediction, substituting certain capabilities of humans, training, and formalisation. In social science, formalisation, prediction, and an understanding of the system are the benefits of simulation, and also simulation is a suitable alternative for expensive experiments of policies on society.

However, one should note that as Davidsson (2002) suggested, simulation of social phenomena may require estimations of many parameters that may be difficult to estimate, but when done well, it helps to understand the consequences of a new policy.

### 3.2.2 The BDI mental architecture

As stated earlier, we use agents to divide a complex system into smaller action components. Also, an agent impacts the system by its decisions. A challenge in agent-based simulation is modelling the agents' decision-making process (i.e action deliberation, Balke & Gilbert, 2014). A class of studies that investigates such a challenge employs the beliefs-desires-intentions (BDI) cognitive architecture. The BDI is an agent cognitive architecture that is developed, based on the concepts stated by Bratman (1987).[2] Bratman et al. (1988) employed the idea to model resource-bounded agents' reasoning. This model and its extensions became popular in the community in a decade (Georgeff et al., 1999). Figure 3.1 presents a simple BDI cognitive architecture. Below, we provide a brief definition of beliefs, desires, and intentions based on Bordini et al. (2007) and Bratman et al. (1988):

- **Beliefs:** This set contains an agent's information about the world. It also indicates the attitude of the agent towards the usefulness of the actions.
- **Desires:** This set indicates what an agent *possibly* would like to do. As a result, desires *potentially* influence an agent's actions.
- **Intentions:** This set indicates an agent's decision on *committing* to a possible course of action. Note that Bratman considers intentions as practical attitudes with commitments to act. In other words, intention goes beyond desires by embarking upon doing certain actions. He suggested that the idea regarding intentions should be taken seriously "on its own terms, without trying somehow to reduce it to ordinary desires and beliefs." [3]

[2]Zimmerman and Bratman (1989) provide a brief review of Bratman's (1987) definition of intention and its correlation with plans and practical reason.

[3]For a review of ongoing discussions regarding Bratman's (1987) definition of intention, see Setiya (2018, Section 4).

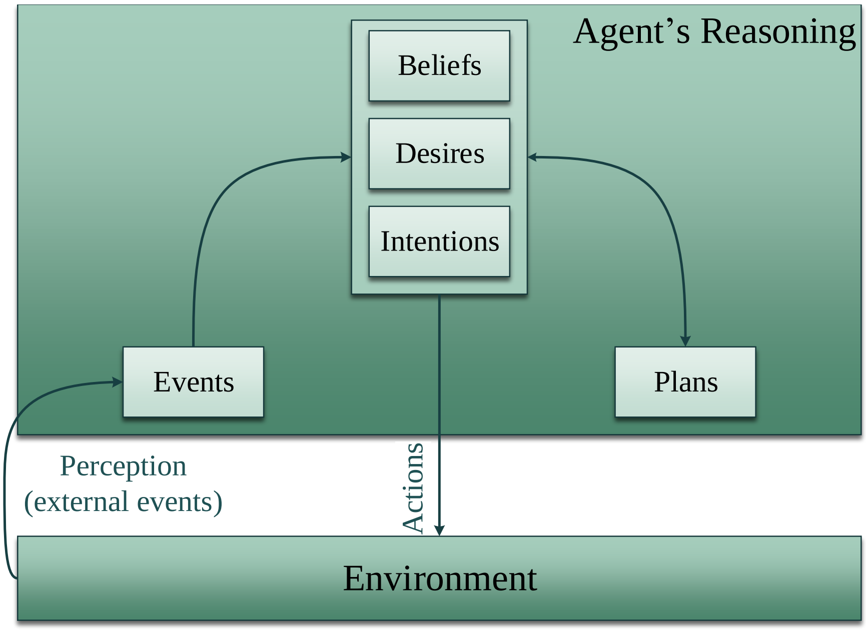


Figure 3.1: The BDI cognitive architecture.

In Figure 3.1 plans are "intentions writ large". Plans update the intentions through providing the next alternatives or a change in the bigger picture. Also, a change in intentions impacts the plans. For instance, suppose we *intend* to travel to city A. In addition, suppose that we consider two forms of travel, namely air travel and a road trip. Note that each form needs a different *plan* (i.e. sequence of actions), such as buying a ticket or checking the car. Suppose we decide to book a flight because we do not like driving. Afterwards, we do not consider the sequence of actions (plan) related to booking a flight.

Now we explain the impact of the beliefs and desires using the former example. In that example, our *desire* impacted our reasoning by reducing the associated weight to the road trip. Also, we took a decision, based on a set of plans that we *believed* that we can successfully use to travel to city A (e.g. we did not consider walking). Bratman et al. (1988) noted that although it is possible for us to change our plans based on changes in our beliefs, plans "should be relatively resistant to reconsideration and abandonment."

Several researchers have employed the BDI cognitive architecture for modelling agents (Caillou et al., 2017; Jo et al., 2004; Taillandier et al., 2012). Two well-known extensions of the BDI cognitive architecture include the EBDI and the BRIDGE. Pereira et al. (2008) and Jiang et al. (2007), presented the EBDI (eBDI) architecture, based on the idea of Pereira et al. (2006) who took account of the impact of *emotions*. Dignum et al. (2009) proposed a beliefs-response-intentions-desires-goals-ego (BRIDGE) model for policy making. However, in this model, agents are not bound to be rational; for instance, Dignum et al. (2009) argued that "preferences for rational versus rule following procedures differ across cultures" (Dignum et al., 2009, p. 147). This model has a notion of "law of nature" that overrules agents' decisions that makes it hard to extend the results of a simulation to other cases. Criado et al. (2010, 2011) also presented a formalisation of BDI (n-BDI) to take consideration of norms and their internalisations. The strength of these works lies in modelling and formalising agents' decisions on following norms.

In Chapters 6 and 7, we present an extension of the BDI cognitive architecture, considering the impact of personality, and also we consider the dynamics of beliefs associated with agents in the model. In Sections 3.4.1 and 3.4.2, we describe the additional psychological and sociopsychological foundations we have employed to extend the BDI cognitive architecture.

### 3.2.3 Fuzzy sets

As stated in the earlier subsection, an agent's actions are impacted by its beliefs. Sometimes these beliefs involve some uncertainties that can be modelled using the notion of fuzzy sets. Zadeh (1965) presented the idea of fuzzy sets as a class of objects with a degree of membership ranging between zero to one. The degree of membership of $X$ in set $A$ indicates the possibility of $X$ to be a part of $A$ (see, Figure 3.2). As suggested by Zadeh (1965), the idea is suitable in cases where there are ambiguities. These can be exemplified using the example of a 'class of *tall* men', as opposed to a 'class of men' and a 'class of men taller than 180 cm' — note that in the example of a 'class of *tall* men', the adjective *tall* is a source of ambiguity. This idea of fuzzy sets that accommodates ambiguities contributed to different scientific areas, such as engineering, mathematics, and operations research (Dubois & Prade, 2015). Zadeh (1978) developed this idea to represent possibilities as opposed to probability. Overall, linguistic uncertainties are *possibilistic*, not *probabilistic*.

To distinguish possibility from probability, one should note that in probabilistic instances, when an observation is made, uncertainty disappears. In other words, the statement is clear and the sequence of events makes the outcome uncertain. For instance, say we bet on a pocket of a roulette wheel[4]. The uncertainty of whether we are lucky is resolved after the ball stops spinning. However, in the example of a 'class of *tall* men', visiting a person

[4]Note that the word 'possibility' is also used to refer to epistemic probabilities such as Dempster–Shafer's theory. Such theories do not represent the vagueness of words, but represent how far an agent believes the proposition holds given the available evidence. Such possibilities represent probabilities estimated based on rough evidence and do not model difficulties associated with the vagueness of words (e.g. one may have an epistemic estimation for ones bet and call it 'possibility').

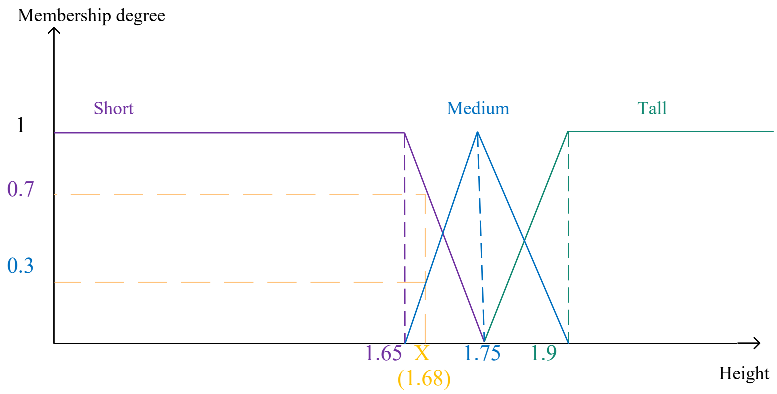


Figure 3.2: An example of granules and fuzzy numbers.

does not remove the source of uncertainty. For instance, Figure 3.2 shows an example that we have met a person who is X meters tall, and we are not sure if he is short or medium. Zadeh (1978) stated that the possibility concerns the "meaning" of information in lieu of its *measure*. An application of using possibility and meanings is in fuzzy reasoning (e.g. in rule-based systems with *if-then* rules, Izquierdo & Izquierdo, 2018; Karaboga & Kaya, 2019).

Zadeh (1979, 1999) presented ideas about information granularity and computing with words. *Information granularity* concerns the uncertainty of information for reasons such as linguistic approximation (e.g. tall men). "Computing with words" addresses using these approximations for doing some computations (e.g. number of tall men in a class). The fuzzy set is a candidate for modelling such situations. We use the example of a 'class of tall men' to explain granularity and computing with words. Note that for the uncertainty associated with the definition of tall (i.e. the label used to identify the granule), the number of tall men is also a fuzzy number. In other words, we might be sure that at least five persons are tall. However, also, we might think that three others are possibly tall. A fuzzy set is a good candidate to model certain rules that have ambiguous terms (e.g. minor offences) in their guidelines[5] and

[5]An instance is the following from The Code for Crown Prosecutors of England. "The majority of cases prosecuted by the CPS [i.e. Crown Prosecution Service] are charged by the police, and many of these will include minor offences. When reviewing police-charged cases, prosecutors should consider whether a prosecution is the most appropriate disposal. Where a prosecutor decides that a charged offence should be dealt with by way of a caution or conditional caution (or any other OOCD [i.e. Out-Of-Court Disposal]), the police should be advised and [...] the proceedings should be terminated" (Director of Public Prosecutions, 2017). What follows defines a *minor* offence. "In many cases of minor offending the loss or harm is minor, and the seriousness and consequence of the offending is [sic] low-level" (Director of Public Prosecutions, 2017). Also, Ostrom's (1990, p. 90, Table 3.1) fifth principle concerns "graduated sanctions" where these sanctions depend on "the seriousness and context of the offense."

also observations that suggest people sometimes do not label a violence as a crime (Brennan, 2015).

We also state fuzzy concepts regarding the utilisation of granules for grading data. Again, we use height of people as an example. Say we want to classify people into short, medium, and tall. For doing so, we assume that a man taller than $1.9\ m$ is tall, and a man shorter than $1.65\ m$ is short. Using fuzzy terms, the degree of membership of height $1.65\ m$ to label short is 1 — i.e. without a doubt such a man is short (see Figure 3.2). We also assume that a man who is $1.75\ m$ is of medium height. Suppose one asks us whether a man who is $1.7\ m$, is short, medium, or tall. The fuzzy set models such phenomena. Here we have three granules (short, medium, and tall) and different heights. The possibility of a certain height to be a member of a granule is presented in Figure 3.2. Given former assumptions, we think person X who is $1.68\ m$ might be short or medium, but we are sure he is not tall. Furthermore, we think that the possibility of being short is more than X being medium (see Figure 3.2). To be more precise, the degree of memberships of 1.7 in short and medium sets are 0.7 and 0.3, respectively (see Figure 3.2).

We can use these concepts to model the ambiguity associated with real-world phenomena, such as the severity of an action taken, the seriousness of a violation, the dirtiness of clothes, or the warmness of the weather. In Chapters 6 and 7, we use the idea to model mapping of a violation to an agent's understanding of its seriousness.

### 3.2.4 Game theory

Cudd (1993) suggests that game theory, as a subset of studies addressing rational choices by rational agents, is inspired by developments of three ideas listed below:

- Rationality equals utility maximisation.
- Probability theory can express rational beliefs/expectations.
- Rational agents employ a strategy for interaction.

The philosophy of some of these ideas dates back to Aristotle (e.g. utilitarian decisions). However, the game theory as a mathematically formalised method of *decision-making* was presented by von Neumann (1928) and then elaborated in the book "Theory of Games and Economic Behavior" (von Neumann & Morgenstern, 1953).[6] Because of the contributions of Nash (1950a, 1950b, 1951, 1953) — that made it possible to find a stable solution (i.e. Nash

[6]Note that apparently Zermelo (1913) investigated the first instance of a two-players game (using a chess example) to find the time it takes a player to win when s/he is in a winning position (See Schwalbe & Walker, 2001, for more discussions).

equilibrium) — and other scientists (e.g. Aumann), this field of study became popular (see Gambarelli & Owen, 2004, for more discussions). Several researchers employed this method in conjunction with agent-based simulation (Adami et al., 2016; Hill et al., 2004; Luo et al., 2016).

There are several types of games considered by game theorists, such as infinitely long, continuous, non-cooperative, asymmetric, sequential, and imperfect information games. We only state the main concepts that we use in this thesis. To do so, we consistently use two games. The first one is the Stag Hunt game inspired by a story told by Rousseau[7] on hunting a deer (Skyrms, 2001). The second game is the Ultimatum game presented by Güth et al. (1982). Figure 3.3 shows payoff matrices of the Stag Hunt game and the Ultimatum game. In the Stag Hunt game, two players decide on cooperation to hunt a 'Stag', and one may leave one's post to hunt a 'Hare' so that the payoff for both players decreases (i.e. it is rational to cooperate). In the Ultimatum game, a player (proposer) is endowed with a total amount of money ($T$, $\$6$ in our example). He proposes a share of that money ($P$) to another player (responder). The responder either accepts or rejects the offer. The utility functions associated with proposals are presented in Figure 3.3. For simplicity, we considered two policies, namely fair ($\$3$) and unfair offers ($\$1$) — i.e. we changed the continuous policy into discrete.

<table>
<tr><th colspan="4">A numerical example of a<br>Stag Hunt game</th></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Hunter 1</td></tr>
<tr><td>Stag</td><td>Hare</td></tr>
<tr><td rowspan="2">Hunter 2</td><td>Stag</td><td>$(a, a)$<br>$(\$3, \$3)$</td><td>$(c, b)$<br>$(\$0, \$2)$</td></tr>
<tr><td>Hare</td><td>$(b, c)$<br>$(\$2, \$0)$</td><td>$(d, d)$<br>$(\$1, \$1)$</td></tr>
</table>

<table>
<tr><th colspan="4">A discrete instance<br>of an Ultimatum game</th></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Responder</td></tr>
<tr><td>Accept</td><td>Reject</td></tr>
<tr><td rowspan="2">Proposer</td><td>Fair</td><td>$(P_F, T - P_F)$<br>$(\$3, \$3)$</td><td>$(\$0, \$0)$</td></tr>
<tr><td>Unfair</td><td>$(P_U, T - P_U)$<br>$(\$5, \$1)$</td><td>$(\$0, \$0)$</td></tr>
</table>

Figure 3.3: The Stag Hunt and the Ultimatum games' payoffs and policies

First, we describe the Stag Hunt game. Figure 3.3 (left) models the game. In this game, if both hunters abide at their posts, each has a payoff of $\$3$. However, if only one hunter

[7]The game is explained by Rousseau (1993, first published in 1755). He says: "If a deer was to be taken, every one saw that, in order to succeed, he must abide faithfully by his post: but if a hare happened to come within the reach of any one of them, it is not to be doubted that he pursued it without scruple, and, having seized his prey, cared very little, if by so doing he caused his companions to miss theirs."

leaves his post and hunts a hare, he has a payoff of $\$2$ and the other hunter earns nothing. If both hunters leave their posts and hunt hares, the payoff for each of them decreases to $\$1$.

Now we describe the Ultimatum game presented in Figure 3.3 (right). Assume we endow Patrick (the proposer) with $\$6$ (i.e. $T$). He should propose a share of $\$6$ to Robin (the responder). Suppose Patrick considers a proposal of $\$5$ (i.e. sharing $50\%$) is a fair proposal — i.e. $(P_F, T - P_F) = (3, 3)$. He also can propose $\$1$ as an unfair amount — i.e. $(P_U, T - P_U) = (5, 1)$. On the other hand, Robin may have a different understanding of a fair proposal (e.g. $60/40$). If Patrick proposes $\$1$ and Robin wants to punish him for such an unfair proposal, he rejects it and both will gain nothing — i.e. $(0, 0)$. However, Patrick may propose $\$2$, and Robin may find it better than nothing and hence, may accept the offer. In that case, the payoffs would be $\$4$ for Patrick and $\$2$ for Robin. In what follows, we state some types of games.

**Incomplete information games** are the games where players do not have complete information about each other's positions, strategies, or an estimation of the chances of choosing such strategies. The Stag Hunt game is studied under both complete/incomplete information — e.g. payoffs can be randomly generated (Xue, 2003). In the Ultimatum game, the proposer knows his proposal but not the other players' policy (i.e. the responder policy). In such situations, uncertainty in the game and new information (e.g. the responder is sensitive to the fairness of proposal) may change the strategy from a fair to an unfair proposal (or otherwise).

**Zero-sum games** are the games in which winners' gains are equal to the loss of losers. In the Stag Hunt game both of the hunters can increase their payoffs by cooperation (i.e. both gain). In the Ultimatum game, when the responder rejects, both lose. However, in most gambling games, the winner gains his bet along with others' bets — i.e. they are zero sum — (the winner's gain equals the losses of the rest). Another example of a non-zero-sum game is accepting bribes and manipulating company prices. In such a situation, the loss of the company exceeds the gains of its employee.

**Non-cooperative games** are the games in which individuals compete to improve their payoffs. In such cases, to enforce the commitments, there should be some punishments. The Stag Hunt game is a cooperative game. The Ultimatum game is a non-cooperative game, because increasing the payoff of a player means the loss for the other.

**Asymmetric games** are the games in which two players have a different set of actions or payoffs. In other words, if $u_i$ and $a_i$ are utility function, and the action for player $i$, respectively, $u_1(a_1, a_2) \neq u_2(a_2, a_1)$ for at least a pair of actions $(a_1, a_2)$ (Osborne, 2003). The Stag Hunt game is a symmetric game. However, the Ultimatum game is an asymmetric game because two players may have different expectations (e.g. the proposer may think a $\$2$

proposal would be accepted, while the responder rejects such a proposal). Such an idea was the topic of Kagel et al. (1996).

**Sequential games** are the games where players do not take actions simultaneously (e.g. chess). The Stag Hunt game is a non-sequential game in which all hunters can simultaneously leave their positions. The Ultimatum game is a sequential game where players' positions in the game impact their sequence (i.e. being responder or proposer).

In conventional employments of game theory by economists, agents only consider dollars in their utility functions (Gintis, 2009; Gintis et al., 2005). For instance, Greif (1993) investigated the impact of Commenda contracts for Maghribi traders using a complete-information game. Also, Greif (2008) believed that Maghribi traders did not use any courts for dispute resolution. These ideas are revised and tested in Chapters 4 and 7.

However, we can include other costs/rewards in the utility function (e.g. feeling bad for an instance of immoral conduct). In Chapter 4, the utility function of agents is comprised of dollars. However, in Chapters 6 and 7, we extend the utility function of agents to go beyond material utility consideration and include some mental and social costs for violating rules.

### 3.2.5 The CKSW framework for simulation

Agents' roles impact organisational performance. For example, some top-level managers assign a human resource (HR) management department to manage employees and assign appropriate roles to them. However, HR managers categorise roles based on the company's field of activity (e.g. engineering) and responsibilities of an agent (e.g. industrial design), along with the agent responsibility in the organisation hierarchy (e.g. manager). This kind of modelling increases the number of agent types. For instance, Ghorbani et al. (2013) used the same concept to categorise agents in a computer recycling system based on their roles in the society and their activities (worker, government representative, dealer, and professional recycling company). This kind of detailed role modelling increases the model complexity that may not assist with obtaining a more clear bigger picture of the organisation. For this purpose (i.e. making a more clear bigger picture), we should study methods of ruling, acquiring, and sustaining knowledge and skills in societies (i.e. their key meta-roles).

CKSW (*Commander-Knowledge-Skills-Worker*) is a meta-model that helps modellers to decompose agents in a society based on their key meta-role characteristics (Purvis et al., 2014). These meta-roles are stated below:

- **Commander** (C): It addresses all participants that are empowered with ultimate authority and have an impact on society by policymaking.

- **Knowledge** (K): This category deals with the impact of knowledge and information on the system. Therefore it involves all agents who hold, transmit, or manage information. One should note that a key attribute of knowledge is its communicability through language (know-what).
- **Skills** (S): This category is used to represent agents who are known for their skills in society (e.g. artisans who make jewellery and pottery). Note that unlike knowledge the skills are difficult to communicate and much more so to apply (know-how). Because of this, a relatively long-term master-pupil engagement in the form of an apprenticeship is necessary to transfer the skill.
- **Workers** (W): This category represents members of the society who are not rich in skills and information. They too are not empowered with authority, and they use different processes such as training or education to become a person of other types (Commander, Knowledge, or Skill). Note that these agents may possess certain skills, but those skills are not of use in the community (e.g. making potteries in a garrison).

The CKSW model has been used in social simulation (Jahanbazi et al., 2015, 2016). In this thesis, we utilise the CKSW meta-roles in our simulation. In Chapter 4, we model interactions between Commanders and Skilled agents, and we consider the impact of Knowledge in the system. In Chapter 5, we model apprenticeship programmes as an institutional mechanism for skill transfer to turn Workers into Skilled agents. In that chapter, we also investigate the impact of Knowledge and additional institutional mechanisms (e.g. interventions of the Commander), on the performance of apprenticeship programmes. In Chapters 6 and 7, we use the same meta-roles to model and simulate rule-following in the system.

## 3.3 General social modelling

Here we state concepts relevant to this study, namely social institutions and economic concepts. These concepts are important to investigate because they indicate decision-making logics of different agents, given their meta-roles in the society.

### 3.3.1 Social institutions

To clarify what we mean by social institutions and their importance, we use North's (1990) definition:

> "Institutions are *the rules of the game* [emphasis added] in a society or, more formally, are the humanly devised constraints that shape human interaction. In consequence they structure incentives in human exchange, whether political, social, or economic." (North, 1990, p. 3)

Note that these interventions have different formality levels. North (1991) clarified the aforementioned concern by categorising institutions as formal (e.g. laws and constitutions) and informal (e.g. sanctions and traditions). Institutions are critical components of society due to their influences on the incentives of "players". Scholars also present other definitions; however, we use North's (1990, 1991) definition of institutions. Acemoglu (2006) modelled emergence and persistence of "non-growth enhancing" institutions. Also, North (1990) suggested that stability is the main role of institutions:

> "The major role of institutions in a society is to *reduce uncertainty* [emphasis added] by establishing a stable (but *not necessarily efficient*) [emphasis added] structure to human interaction." (North, 1990, p. 6)

Institutions is the topic of several investigations. As a popular instance, Crawford and Ostrom (1995) provided a "grammar of institutions" to classify rules, norms, and shared strategies. Ostrom (2009) also categorised word guidelines[8] as presented below (See, Figure 3.4):

- **Shared strategies** (conventions) are defined as instructional guidelines.
- **Norms** are morals, values, and guidelines prescribed by the community's culture.
- **Rules** are enforced guidelines regarding prohibitions, permissions, and requirements.
- **Physical laws** are principles that can be tested such as Newton's first law about inertia.

To clarify the difference between the concepts stated above, we employ the suggested syntax of grammar (ADICO) proposed by Crawford and Ostrom (1995) that has five components as follows:

- Attributes (A): This indicates whom that institutional statement addresses (e.g. a group of people or organisations).
- Deontic (D): This is the modal verb indicator that distinguishes prohibition, permission, and obligation.

[8]Note that Ostrom (2009) starts with some discussions about Max Black's categorisation of rules and uses the term *rule* in her classification as a general concept representing rules, norms, physical law, and convention. However, for simplicity, we use the *guideline* to refer to common usages of the term *rule*.

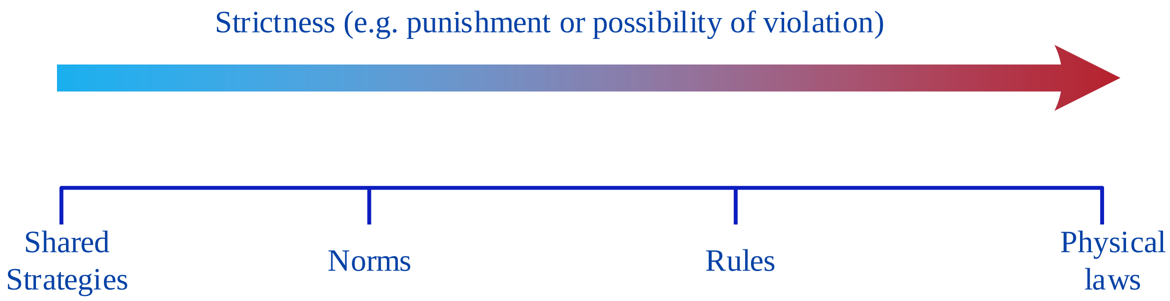


Figure 3.4: Institutions and their strictness.

- Aim (I): It indicates the outcome or action associated with the Deontic component.
- Condition (C): This indicates the conditions under which the Deontic component applies (when or where).
- Or else (O): It indicates the consequences of breaking the institutional statement.

*Conventions/shared strategies* include Attributes, Aims, and Conditions (AIC). *Norms* have an addition of the Deontic component to strategies (ADIC). The *rules* are the complete statement that clarify the consequences of not following them (ADICO). The following presents example statements representing the aforementioned concepts:

- Convention: A person (A) uses his right hand (I) when he shakes hands (C).
- Norm: A person (A) *must* (D) be fair (I) when he trades (C).
- Rule: A witness (A) *must not* (D) lie (I) when he testifies under oath (C) *or else* the witness will be charged for the crime of perjury (O).

As can be seen, the norms and rules differ in terms of the certainty of punishment. As Ostrom (2009) suggested, the consequences should have three qualifications, namely: a) it should be supported collectively, b) the exemptions should be addressed by other rules or norms, and c) there should be an efficient monitoring system to punish or report the actions. Note that Ostrom (2009) suggested that rules do not necessarily need government intervention.[9]

Sproule-Jones (1993) divided "rules into the two categories of rules-in-use and rules-in-form." The point made is that rules-in-use (followed rules) in some provinces might be rules-in-forms (unfollowed rules that do not have any effect on behaviour) in others.[10] There exist

[9]Julfa is an example of such systems, as stated in Chapter 2.

[10]He also states that rules can "possess both an instrumental and an intrinsic value" (see Ostrom, 1995, for a review of the book).

some obstacles in the path of a law in becoming a rule-in-use (Cole, 2017). Some instances of these obstacles include laws contradicting with strong norms or activities of monitoring agents who filter the rules based on their interpretations. The latter issue can lead to a change in institutions so that the law is interpreted or mediated differently or even neutralised. Cole (2017) also suggested that when a law does not become a rule-in-use, it neither means that the conflicting norms are superior, nor that the law is faulty. For instance, the 14th and 15th Amendments of the US Constitution that aimed to provide the same rights for former slaves were not fully enforced until 1954 (Patterson, 2005). Cole (2017) stated that the hardships of enforcing such a law were because of the norms backing racism. In other words, although there are reasons racism is not justified (i.e. it deprives a minority from their rights), it was strong enough to revoke the superior Constitution.

In the following chapters, we address the impact of institutions (e.g. rules) on societies. Also, in Chapter 4, Chapter 6, and Chapter 7, we address the impact of monitoring. Chapter 7 investigates circumstances under which a law becomes a 'rule-in-use' or a 'rule-in-form' by permitting monitoring agents to interpret the law differently.

### 3.3.2 Economics and behavioural economics

The definition of economics is both simple and impossible. It is simple if we agree with certain definitions (e.g. "an inquiry into the nature and causes of the wealth of nations," Smith, 1904), and it is relatively impossible if we want to use a definition that addresses critics concerns. Finley (1999) stated that when Hutcheson, a teacher of Adam Smith, wrote a "Short Introduction to Moral Philosophy;" he did not discuss matters such as property and contracts as a part of '*oeconomicus*' (i.e. economics). Instead, he stated the duties of family members and servant and masters, since, based on its origin, economics meant organising households. However, Thomas Carlyle defines it as the *dismal science*, and a non-abusive definition would be studying the ways that society utilises its scarce resources (Bishop, 2004).

However, economics might be abusive. The abusive part of economics lies in the principles, the ways and methods which are suggested to handle the system, and scarcity itself. For instance, a criticism of economy concerns some ideas of Adam Smith (i.e. the father of modern economics). In *Invisible Hands*, he suggested that the efficiency of resource utilisation is improved by adopting self-interest in a free market (Bishop, 2004). Different studies address the inferred selfishness of this argument and the matter of scarcity (i.e. economists plan to manage the scarcity or sometimes augment it).

For instance, Ruggiero (2013) addressed some statements such as the following passage:

> "It is not from the benevolence of the butcher, the brewer, or the baker that we expect our dinner, but from their regard to *their own self-interest* [emphasis added]. We address ourselves *not to their humanity* [emphasis added] but to their self-love, and never talk to them of our own necessities, but of their advantages" (Smith, 1904, p. 14)

Ruggiero (2013) claimed this suggests that "the selfishness should be the pivotal variable orienting our action, irrespective of how destructive this might be." Then he continues, although it is unclear whether or not Adam Smith meant to justify entrepreneurial crimes, "contemporary criminal entrepreneurs 'learn' the techniques and rationalisations of their conduct directly from Adam Smith". An example of augmenting scarcity is *Agricultural Adjustment Administration* that urged farmers to destroy excessive crops or reduce production during the recession to boost prices (The US Congress, 1933). Fite (1962) stated that farmers had different ideas about the deal and accepted reducing production out of desperation.

In the following subsections, first, we provide a review of relevant concepts of classical and neoclassical principles (i.e. the ones we used in this study), and also some concerns expressed by behavioural scientists.

#### 3.3.2.1 Microeconomics and macroeconomics

Microeconomics deals with the micro-level of economy concerning individuals' economic behaviours such as decisions regarding consumption, pricing, and wages. However, macroeconomics concerns issues at an aggregate level, such as unemployment and inflation. Governments mostly employ some means (i.e. macroeconomic policies) through taxation, controlling interest rates, and public spending.

The ideas employed from microeconomics in this study is the market's equilibrium for wages; this is depicted in Figure 3.5. In this figure, the dot-dashed blue line is the curve associated with the new demand that we will use in our example. As shown in Figure 3.5, the equilibrium happens when supply curve intersects demand curve (i.e. for a given price quantity demanded equals the quantity supplied). To have a sense of the market's equilibrium, we use an example of ice cream prices. The curve suggests that the company increases the prices to increase their profits; however, more prices means less purchasing power (i.e. less demand). The equilibrium is the prices where the quantity of demand equals the quantity of supply (e.g. the number of customers equals the number of ice creams produced). As noted before, the dot-dashed blue line indicates the new demand curve after a decrease in demand (e.g. demand curve for ice creams in winter). This decrease causes a new equilibrium (the green line) with lower prices because of the extra supply (see Mankiw, 2017, Part II, for more explanations). We should point out that this is a simplified version of market mechanisms. For instance, we only consider the price in this curve and not profits. However, a company produces items when its profit margin (price less costs) is positive.

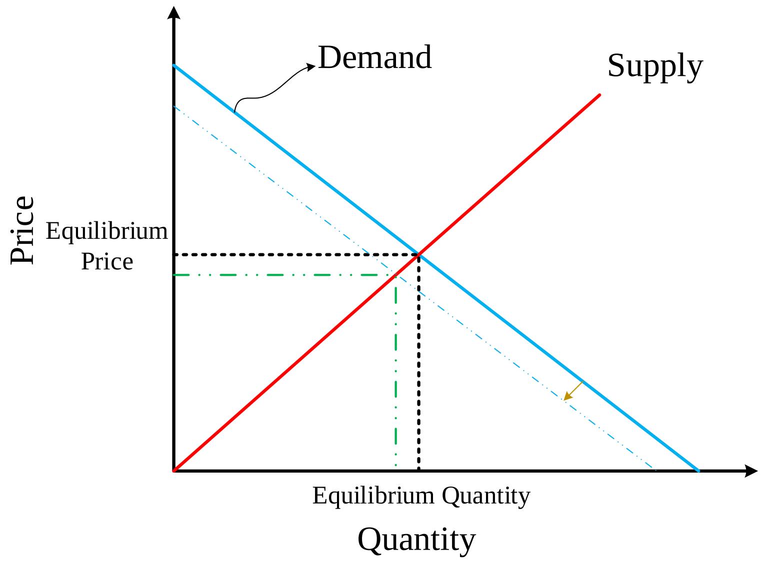


Figure 3.5: The market's equilibrium.

Another economic concept we used in this study concerns the Gross Domestic Income/ Product (GDI/GDP). This subject is important for measuring in the context of macroeconomics. As stated earlier, macroeconomy concerns the economy as a whole. GDI/GDP estimates the output of the economy in a given period of time. Furthermore, it can be used to estimate government revenue by income taxes.[11]

These concepts are utilised primarily in Chapter 5, which investigates apprenticeship as a means for controlling the unemployment of youth. Furthermore, we use a refined version of market equilibrium in that chapter for modelling the dynamics in wages. We also measure the contribution of apprenticeship programmes to the GDI. This helps us to identify the macro impact of programmes on the country's economy and also the improvement of the government's expected income.

#### 3.3.2.2 Behavioural economics

Behavioural economics compounds the impact of other aspects influencing decision-making, such as cognition, psychological characteristics, and culture. Gintis (2009) states, in general,

[11] One should note that more GDP does not always mean more governmental revenues because of the role of factors such as tax rate.

that in behavioural decision-making, *rationality* is not equal to *selfishness*. Otherwise, sociopaths, who are the most selfish would be considered as rational beings. Agreeing upon such ideas (e.g. agents are not always selfish) points to a need for a reassessment of economics theories (e.g. profit maximising agents). First, we investigate some of the lab studies that contradict classical and neoclassical economic theories. Then we state some of the solutions provided by behavioural economists that we have used in this study.

Utilising sociopsychology findings regarding cognitive dissonance (see Section 3.4.2), Akerlof and Dickens (1982) proposed a model to show why workers in hazardous industries (e.g. a PhD holder working in a nuclear plant) believed their work is safe. In other words, well educated employees in a nuclear site denied the hazards to themselves. However, in their model there exists a crucial assumption that states "beliefs once chosen persist over time". Although this assumption contradicts some lab studies about cognitive dissonance (i.e. changes in beliefs; see Festinger & Carlsmith, 1959; Izuma et al., 2010; van Veen et al., 2009, for some examples), their study promotes a more sophisticated economic model of the world by letting agents have different understandings. In other words, they brought earlier models closer to real-world instances by considering different classes of agents where a class of them accepts to work in a hazardous situation.

Benartzi and Thaler (1995) stated that a reason for the puzzling outcome in financial markets is because of investors' *myopia*. In other words, although the investors are aware of the long-term profit of their investments, they may sell some stocks for a short-term decrease in prices.[12] This myopia contradicts investors' use of a discount factor for a long-term horizon.

Instances where biases impact cognitive decision-making were studied by Tversky and Kahneman (1974) and Kahneman and Tversky (1979). These studies indicated that people use heuristics that introduce predictable errors due to matters such as inconsistent preferences based on the appearance of the offers. This phenomenon is known as the *framing effect*, where, for example, a person prefers to buy a \$5 item with a 20% discount ($\$5 \times 0.8 = \$4$) rather than buy the same item from another retailer who sells it for \$3, but has a 33% surcharge for credit cards (again $\$3 \times 1.33 = \$4$)[13](see Rieger et al., 2016, for a recent survey).

Another instance that contradicts the economists' expectations relates to lab studies of the Ultimatum game (see Section 3.2.4 and Figure 3.3). Most lab studies indicate that offers are usually between 40% and 50% of granted money and also half of the offers below 20%

[12]This change in plan is interesting in stock markets because the inventors know that some changes are short-term and seasonal (i.e. will not impact the long-term profit).

[13]The results were formalised in the latter study as *prospect theory*, that states that psychological loss aversion is not linear; hence, expected *small* losses are ignored when dealing with a big gain (e.g. lotteries).

are rejected. These contradict the combination of selfishness and utility maximisation (in terms of money) of players based on which a) the proposer (Patrick in the example of Section 3.2.4) should make small offers, and b) the responder (Robin in the example of Section 3.2.4) should accept any offer (Debove et al., 2016). Other scholars also studied the importance of fairness. For instance, J. S. Adams (1965) and J. S. Adams and Freedman (1976) investigated the impact of fair distribution of income on people's behaviour (e.g. their efforts in the company). They indicated that agents modify their efforts in the company based on their perception of fairness of the company. For instance, van Dijke et al. (2019) stated how distributive and procedural justice (i.e. fair dispute resolution) incentivise an agent to voluntarily pay taxes.

Several researchers used behavioural economics to build agent-based models (e.g. see Bonein et al., 2016; Hashimzade et al., 2014; Šperka & Spišák, 2013). We use concepts of behavioural economics in all the chapters. However, in particular, we will investigate the impact of fairness on society members' behaviour and some concepts of prospect theory in Chapters 6 and 7. The concept of the agent's myopic decisions is considered in Chapters 4–7.

## 3.4 Psychological and sociopsychological aspects

As stated earlier, this thesis concerns agent modelling of the social interaction of traders. Here we investigate some psychological aspects of humans which can be incorporated into an agent model, such as the impact of personality on decision-making and the impact of society on their psychology (i.e. sociopsychological aspects).

### 3.4.1 Impact of personality

As stated in the BDI cognitive architecture in Section 3.2.2, an aspect of agents is their beliefs about actions. The ambitious idea is that attributing people's behaviour to their personalities might be as old as human culture. However, we know that Plato (429?–347 BC) in his republic (Plato, 1991, written around 380 BC) emphasised the importance of four cardinal virtues (i.e. wisdom, courage, moderation, and justice) to distinguish three classes of inhabitants along with their associated tasks, namely the producers, the auxiliaries (army men), and the guardians (rulers) (see Frede, 2017, for more discussion about Plato's ethics).

In an influential work, Jung (1976, first published in German in 1921) suggested personality types are a means of identifying people's *general attitudes*, as well as attitudes about life, using the concept of *function types*. Jung (1976) mostly focused on describing personalities and their impacts on a person's behaviour, and Myers (1962) inspired by Jung provided a manual to identify personality types. The Myers-Briggs Type Indicator (MBTI) not only provides a manual to identify personality types, but it also contributes to the classification by considering the impact of auxiliary functions. Before publishing the manual, Katharine Briggs published several papers, for instance, "Meet Yourself", that provides an outline of Jung's personality types (see Geyer, 1995, for a history of the formation of the MBTI).

Jung (1976) believed a person directs libido (i.e. psychic energy) or general interests *consciously* based on his/her *general attitudes*. General attitudes indicate this aspect of personality by classifying agents into two groups, namely people who direct their psychic energy to the outer world (i.e. are Extraverted) or direct it to the inner world (i.e. are Introverted).[14] Jung (1976) also emphasised the importance of *psychological functions* that an agent uses in his/her cognitive processes. However, in Jung (1976), he mainly concentrated on dominant functions (i.e. functions employed consciously), but MBTI also considers the impact of auxiliary functions (i.e. functions employed unconsciously).

Since its introduction, MBTI has been widely used in different studies, such as decision-making (Hough & Ogilvie, 2005; Hunt et al., 1989; Su-li & Ke-fan, 2010), learning and teaching contexts (S. E. Cooper & Miller, 1991; Radwan, 2014), and team formation (Farhangian et al., 2014, 2015c; L. Zhang & Zhang, 2013). Furthermore, the reliability and validity of the MBTI is shown by scholars in different domains (Capraro & Capraro, 2002; Randall et al., 2017; Thompson & Borrello, 1986). However, one should note that the MBTI is not the only framework for personality classification. Some other methods to classify the personalities and cultural dimensions include the five-factor model or Big 5 (McCrae & T. Costa, 1987), the California Psychological Inventory (CPI) (Gough, 2000), and organisational cultures (Hofstede et al., 1990). Furthermore, a class of studies is devoted to finding the correlations between different classification schemes' dimensions. In this thesis, we choose to use the MBTI method of personality classification for its popularity in academic use (Andrejczuk et al., 2018; Farhangian et al., 2016, 2015a; Salvit & Sklar, 2011). However, we benefit from the findings of Big 5 and CPI when required.

In this study, we employ the MBTI method to model agents' cognition, and also the way that they apply weights to the different beliefs. We will investigate in more detail about personality in Chapters 6 and 7 when we propose our extension of the BDI cognitive architecture.

[14] Jung (1976) believed that the unconscious compensates for the conscious' shortcomings. Here he indicated unconscious attempts to clarify the other side of the world to a person (e.g. outer world for introverts).

### 3.4.2 Sociopsychological concepts

Aristotle believed that the human being is a political animal who needs a state and "he who by nature and not by mere accident is without a state, is either a bad man or above humanity" (Aristotle, 1999, p. 5). From his belief, we can infer that he believed that society and people have mutual impacts on each other. Some of these mutual influences are easy to understand (e.g. winning the elections by more votes). However, others need more detailed studies (e.g. why social discrimination has negative impacts or why a significant number supported Trump and not the other candidates (Pettigrew, 2017)). The latter issue concerns the sociopsychological aspect of humanity (i.e. how society impacts our thoughts, feelings, and behaviours). What follows includes some examples of these social influences on psychology.

In a study on the impact of society on psychological positions and judgments, Bandura et al. (1961) indicated that children imitate aggressive models of adults when they are exposed to such behaviours. Afterwards, Milgram (1965) studied the situation where A asks B to hurt C (using an electric shock). The findings were shocking; although most subjects were against hurting a person, many of them obeyed the authority or were even eager to administer the extremest hurts. The results indicated a significant divergence from the prediction of surveyed people. An explanation for such a behaviour is that person B transfers responsibilities to authority. Haney et al. (1973) aimed to identify whether reported brutality of guards was a consequence of their personality or the prison's situations. They divided some volunteers with stable personalities into two groups, namely mocked guards and mocked prisoners. The mocked prisoners were treated like criminals from the time they were arrested. The mocked guards were also allowed to use any non-violent measures (e.g. push-ups) to maintain the order. The study was stopped in just six days because of the abusive behaviour of the mocked guards over the mocked prisoners.[15]

Overall, as tested by different scholars, and also exemplified by the examples provided above, the impact of society and situations goes beyond a quick change in moods (e.g. deliberative torturing in Bandura et al.'s (1961) study). Furthermore, Thibaut et al. (1974) indicated that procedural justice (i.e. fair dispute resolution procedures) impacts the incentives of people about the long-term association with a social group. In other words, the fairer dispute resolutions of a group are, the more its members plan for long-term association with it. Furthermore, Tyler (1997) stated that the internalisation of obligations of a group by members took place because they found the rules *legitimate*. However, as Tyler (1997) indicated in his study, people follow the rules only under certain conditions (i.e. only when they are convinced about the legitimacy of the rules).

[15]The video and more discussions are available at `https://www.prisonexp.org/slide-1.htm`.

Another class of studies concerned changes in agents' behaviour through their choices. Festinger and Carlsmith (1959) tested the cognitive dissonance by paying some people to misguide another person about a tedious task (i.e. telling the person that a task was interesting when in fact it was boring) and after that, they asked them what their real feeling about the tasks was. The results indicated that the members of the group that were paid one-dollar to lie to new participants — say that task was interesting — increased the attractiveness of the task for themselves (i.e. they rated the task to be more interesting than the control group).[16] Because of cognitive dissonance, it is hard for a person to keep two inconsistent attitudes together. For instance, in the previous test, it was hard for participants to admit to themselves that they were cheap liars (i.e. they misguided others for just a dollar), so they changed their attitude about the attractiveness of the test. However, when the participants were paid more, they did not feel cheap and might have felt shrewd (i.e. they did not experience cognitive dissonance). Festinger and Carlsmith's (1959) experiment was repeated by different scholars (Chapanis & Chapanis, 1964; J. Cooper, 2007; Egan et al., 2007; Shultz & Lepper, 1996). As suggested by Aronson and Aronson (2007), this simple theory — cognitive dissonance — has extensive applications. The findings of cognitive dissonance are applied to explain behaviours or change them in different fields. For instance, they impacted J. S. Adams's (1965) theory for payment (Miner, 2005, Chapter 9), they were used for water and energy conservation (Dickerson et al., 1992; Kantola et al., 1984), and it was also employed to explain irrational behaviours of investors (Chang et al., 2016).

In Chapters 4, 6, and 7 of this thesis, we use some of these ideas in the forms of self-justification and change in beliefs. In particular, in Chapters 6 and 7, we investigate the influential characteristics that are controllable by a commander (e.g. legitimacy of rules).

## 3.5 Summary and relevance

As already stated, this study uses agent-based social simulation to model two historical long-distance trading societies. Given the subject, we model the mutual impact of economic and social concerns on agents' behaviour. For this purpose, we use institutions to model eco-

[16]They divided the participants into three groups: control (i.e. unpaid), one-dollar (this group was paid one-dollar), and twenty-dollars (this group was paid twenty-dollars). They asked the paid groups to lie to a girl that the test was fun (i.e. they paid them to lie). Then they asked the participants the question about the attractiveness of the test. The notable part is that two participants told the girl that the test was boring, but they were paid to say otherwise (both were paid one-dollar). Three participants did not accept the offer (two from the twenty dollars group, and one from the group that was paid one-dollar). A participant felt guilty and asked for the girl's phone number to explain he was asked to lie to her (he was paid one-dollar).

Table 3.1: The stated concepts and technologies and the chapters they are used

| Concepts and technologies | Chapters | | | |
|---|---|---|---|---|
| | 4 | 5 | 6 | 7 |
| ABSS | ✓ | ✓ | ✓ | ✓ |
| Social institutions | ✓ | ✓ | ✓ | ✓ |
| Fuzzy sets | | | ✓ | ✓ |
| Game theory | ✓ | | | |
| CKSW | ✓ | ✓ | ✓ | ✓ |
| BDI | | | ✓ | ✓ |
| Personality | | | ✓ | ✓ |
| Sociopsychological | | | ✓ | ✓ |
| (Neo)Classical economics | | ✓ | | |
| Behavioural economics | ✓ | ✓ | ✓ | ✓ |

nomic and social devised constraints. We also make use of the evidence from psychological and sociopsychological studies to model the impact of external societal factors on an agent's behaviour. We also utilise a folk-sociological model to distinguish agents' meta-roles that relate to their power over the system and the influence of the system on them.

To model the impact of psychological and sociopsychological aspects on an agent's decision, we propose a refined version of the BDI cognitive architecture. Furthermore, in the BDI cognitive architecture, we will use fuzzy sets to reflect the influence of the ambiguity of meaning on an agent's cognition. We also employ some concepts of behavioural economics in agents' decision-making processes to bring them closer to real-world instances. Table 3.1 provides an overview of the concepts employed in this thesis, along with their associated chapters. Note that we elaborate the relevant concepts in the appropriate chapter. After stating the relevant concepts and technologies, in Chapter 4, we model the contractual schemes of these societies to answer the first research question.

# 4

# Impact of the contractual schemes and environmental circumstances on the success of societies

## 4.1 Introduction

In a collaborative and distributed environment, international companies face information opacity that often leads to information asymmetry. Nowadays, international companies try to overcome this problem by using real-time information infrastructures. Challenges associated with such a class of problem are commonly referred to as the "*principal-agent problem*" (Holmstrom & Milgrom, 1991). This problem concerns two parties engaged in a deal where an *agent* (e.g. mercantile agent) is expected to pursue his *principal*'s (master's/director's) benefits. The agent's decisions and actions are hard to monitor. Particularly in long-distance trades, issues such as power delegation to agents (e.g. access to company resources) and absence of transparency (e.g. justifications for spendings) are inevitable. Such phenomena are incentives for an agent's use of company resources for his own self-interests. Henceforth, we refer to any selfish behaviour that imposes some costs to the principal as ***cheating***. Furthermore, in this chapter, the term agent refers to mercantile agents and the model that we construct concentrates on their behaviour.

Note that agents are valuable organisational resources because their gradual skill improvement leads to a company's increased profitability. On the other hand, retaining skilled agents who cheat imposes costs on the organisation. We study these effects by modelling some aspects of the British *East India company* (EIC) and *Armenian merchants of New-Julfa* (Julfa). These societies were long-distance traders that pursued their benefits by delegating some rights to agents in remote places. What makes the comparison of both systems appealing is their evident co-existence in the Indian subcontinent, with the EIC managers identifying the Julfa traders as superior. As a result, the EIC granted Julfans the same privileges as British merchants in order to "alter and invert the ancient course of their trade to and from Europe" (Ferrier, 1973, p. 50). This chapter, along with the following chapters, aims to unlock some of the secrets of this *ancient course*. In this chapter, we consider environmental circumstances in terms of the societal mortality rate. Also, the contractual scheme consists of the following characteristics:

- *Hiring scheme*: This aspect indicates whether or not the organisation considers hiring an agent from outside of the known agents (i.e. **closedness** versus openness of society).
- *Firing scheme*: This aspect indicates directors' sources of suspicions and also how the disputes against suspected agents were settled (**adjudication** processes).
- *Payment scheme*: The **payment scheme** concerns the revenue of both the organisation and the agent.
- *Penalties*: It indicates the **punishment** for a revealed fraud.

We employ agent-based simulation to study the two long-distance trading societies. Note that in this chapter, we use a relatively simple game theory approach for agents' decision-making. Based on the game and agents' conformity, we form four different scenarios. The outcomes of these scenarios are measured using four metrics. These metrics include sustainability, rule conformance (e.g. percentage of cheaters and experience of cheaters), profitability, and societal skill level.

First, we describe the simulation model for a base scenario (i.e. scenario 1), then for each succeeding scenario we clarify how the base model is modified. The rest of this chapter is organised as follows. Section 4.2 takes a comparative look at the EIC and Julfa. Section 4.3 states how these systems are modelled and the reasons behind the chosen parameters. Section 4.4 presents and describes the simulation results. Finally, Section 4.5 sums up the findings and proposes future directions.

## 4.2 Review of systems

In this section, we provide an overview of the two historical long-distance trading societies, and then we compare them with respect to five characteristics of the EIC and Julfa. The characteristics are listed below:

1. **Societal mortality rate:** The mortality rate helps us to simulate the demography of the EIC and Julfa and answer a crucial question about the capability of the EIC to create a closed society of traders.
2. **Closedness of society:** This indicates the nature of the system in attracting a workforce (open versus closed).
3. **Adjudication processes:** This aims to decrease errors associated with punishing the innocents. We call the process of going through evidence and decision-making regarding suspicious behaviours the "adjudication processes".
4. **Payment scheme:** This characteristic indicates companies' payment schemes in terms of fixed salary versus profit-sharing.
5. **Punishment:** This deters agents from cheating by imposing some costs on them.

**The East India Company (EIC):** The EIC was formed in 1600 based on the monopoly of trade between Asia and Britain, granted by Queen Elizabeth I, and was active until the mid-19th century (Seth, 2012). One of the first problems that the EIC faced concerned finding experienced agents to perform long-distance trades.[1] Therefore they used an *open* workforce scheme for subsequent years, where any worker from Britain was allowed to join.

**Armenian merchants of New-Julfa (Julfans):** Julfans were originally from Old-Julfa in Armenia. They had inheritance rules that created strong family bonds (Herzig, 1991). They also used informal institutions to control society. These kinds of social bonds and sharing the same background were some of the reasons behind having a *closed* workforce society in Julfa.

Note that both societies hired males as agents (therefore we focus on men in societies). What follows states the differences in characteristics for the EIC and Julfa.

**Societal mortality rate:** An issue that the European chartered companies faced in Asia was a decrease in the life expectancy of agents. An EIC's employee on average worked not even past his 30s — i.e. 15 years of service time (see Section 2.3.2.2). On the other hand,

[1] For instance, a record belonging to 1619 indicates that the company's search for two eligible merchants led to only one choice of a merchant who had lived in Spain for several years (Chaudhuri, 1965).

there are no discussions about such a problem for the Julfans, neither in their correspondence nor in historical contexts. On the contrary, we see a persistent demographic for the residents of New-Julfa they had a low mortality rate.

**Closedness of society:** As mentioned earlier, the EIC had an open scheme of hiring. The company used contracts, signed bonds, and references obtained from others to ensure the agents' trustworthiness. On the other hand, Julfans was a closed society of traders sharing the same background (i.e. being from old-Julfa) and city of residence (i.e. New-Julfa). They had and used their own dialect that was different from other Armenians living in Iran. Note that in a closed society, a child observes and learns system characteristics such as monitoring strength before being hired as an agent, given that fired agents were not exiled after punishment (i.e. they just could not trade). The Julfans had several monitoring means, such as correspondence between traders who had information on agents' trustworthiness and prices in trading nodes (see Chapter 2 for more information). Also, they could collect information using their main church archives or informally during meetings in local churches (Aslanian, 2007). Finally, in Julfa, an agent had to hand over everything he had with him upon his return, including his personal luggage and clothing, which made it difficult for him to hide his illegal revenue from his master (henceforth, director) (Herzig, 1991). The strong social relationships convince us to assume that non-cheaters in Julfa put in their efforts to sustain the order inside their society. The intuition for such efforts has already been stated by Socrates in his court defence (The Apology of Socrates by Plato, 2008, was originally written about 399 BC):

> "[...] Which is better, to live among bad citizens, or among good ones? [...] Do not the good do their neighbours good, and the bad do them evil? [...] And is there anyone who would rather be injured than benefited by those who live with him?" (Plato, 2008)

**Adjudication processes:** Another difference between these two societies concerns the methods they used to handle suspicious behaviours. The closedness of Julfan society and permissions granted by Persian Kings to establish their own institutions were some reasons for having local courts and rules. They also had autonomy outside of Iran and established churches of their own in their frequently visited cities (Aslanian, 2007). Moreover, they had two kinds of institutions for resolving disputes, namely the assembly of merchants and portable courts. In Julfa, adjudication processes were rigorous and they effectively identified cheaters. However, in the EIC, directors felt that a large number of cheaters were present in the system, despite limited reports from trading settlements (Chaudhuri, 1965). The EIC directors used a performance-based means for identifying cheaters and skipped adjudication processes (Hejeebu, 2005).[2] This introduces the likelihood of punishing an honest agent for his bad performance. Also, it introduced a surprising firing pattern (i.e. more experienced merchants were fired in higher positions despite their higher revenue).[3]

**Payment scheme:** Some relaxations of the EIC monopoly between 1660 and 1700 that followed from the English Civil War (1642–1651) persuaded the EIC directors to pay low nominal salaries[4] and grant agents the privilege of private trade (the right of trade in the intra-Asian market, Erikson, 2014). As a result, the EIC agents sought other sources to increase their revenue and counted on private trade as their real salary (Hejeebu, 1998). In Julfa, on the other hand, directors used commenda contracts (an open-ended contract with substantial profit-sharing of about 30% in Julfa, Herzig, 1991). A popular form of commnda contracts is bi-lateral contracts, where agents can also invest their capital in the same trade. In essence, the EIC traders were salaried and had the opportunity to perform private trade. In Julfa, commenda contracts as a profit-sharing scheme were used.

Table 4.1: System specification based on EIC and Julfa societies

| ***Characteristics*** | **EIC** | **Julfa** |
|---|---|---|
| Nature of the workforce | Open | Closed |
| Payment design | Private trade | Commenda |
| Mortality rate | High | Low |
| Adjudication chance | No | Yes |
| Punishment | Dismissal + unutilised bond | Paying costs + interest by agent or extended family or they were excluded from trade |

**Punishment:** The EIC discouraged employees from cheating by asking them to provide a signed bond of at least £500 (Hejeebu, 2005) and punished cheaters by dismissing them in case of suspicion. However, in Julfa, one of the frequently used ways of punishment was asking a cheater, or his core or extended family, to pay back the incurred costs and cumulative interests. If they refused to pay, they would be boycotted by traders. This evidence suggests that these consequences of cheating were harsh (a merchant writes to his brother: "I would rather chuse [sic] to dye [sic], than for them to [blot my] name out of the list," Aslanian, 2007, pp. 248–249).

[2]"We cannot pass by the extravagant price of the raw silk at Casimbazar [sic] and the exceeding badness of the taffetys [sic] from thence. Therefore we may let our servants see that we can distinguish betwixt [sic] them who serve us faithfully and well and those who only pretend to do so, we do dismiss the said Hugh Barker from our service." (See, E/3/106 letter to Bengal 23 Jan 1735, para. 138, as cited in Hejeebu, 2005, p. 514)

[3]Around £1000 (see Hejeebu, 2005, Table 1-3).

[4]£5 to £40 versus £50 in Britain.

As stated earlier, these two societies had differences in the nature of workforce societies, payments, mortality rates, adjudication processes and monitoring, and punishment (see Table 4.1 for differences). In the next section, we model the effects of the differing characteristics of these systems on their success, using an agent-based simulation.

## 4.3 Simulation model of two systems

Following the earlier description of differences between the two trader societies, here we present a model for investigating the impact of the aforementioned characteristics on societal success. For this purpose, we first state the assumptions, and then we present the procedures employed for simulating these societies. Finally, we state the reasons for the chosen simulation parameters.

### 4.3.1 Model assumptions

To model the EIC and Julfa, and systematically investigate the impact of the aforementioned parameters, we use a game theory scheme. As stated in Chapter 3, there are games with different properties; what we use here is a non-cooperative, asymmetric, sequential, and imperfect information game (see Section 3.2.4 for a definition of these).

One of the characteristics associated with the principal-agent problem concerns the costs of self-interested actions of an agent for the principal. The agents can make profits by cheating, and the directors define punishments to control it. Such games are non-cooperative games (i.e. players do not have common strategies). The game is also asymmetric because directors and agents have different strategies (here we only present a game for agents who play with "nature" — i.e. there is no strategic decision in directors' actions). This is a non-zero-sum game because punishments such as firing would not compensate for the losses of the company. The game is sequential, and agents are the ones who perform the first action. In addition, when there is no adjudication, the game is an imperfect information game because agents are not sure about the consequences of their honest actions.

Figure 4.1 presents the base game (i.e. scenario 1) that agents play. In this game, agents have two potential actions (i.e. to cheat or to be honest). On the other side, because of an inherent lack of transparency due to long-distances, the director cannot identify the actions and may suspect an agent's action incorrectly. In Figure 4.1, "C" and "NC" indicate cheat and not cheat, respectively. Furthermore, the directors' *suspicions* are indicated by vertical labels, and the agent's *actual* action is indicated horizontally. The left table indicates punishments and rewards associated with each state (i.e. an agent's action and the director's response), and the right table indicates the probabilities of the director's response to actions learnt by an agent over time.

**(a) Utility for actions**

| | | Director's Suspicion | |
|---|---|---|---|
| | | Cheat (C) | Not Cheated (NC) |
| Actual | C | $CI - P$ | $CI + \alpha \times FI$ |
| | NC | 0 | $\alpha \times FI$ |

**(b) Actions' probability**

| | | Director's Suspicion | |
|---|---|---|---|
| | | Cheat (C) | Not Cheated (NC) |
| Actual | C | $cpc$ | $1 - cpc$ |
| | NC | $ppnc$ | $1 - ppnc$ |

Figure 4.1: Game that potential cheaters play (the base scenario)

Agents decide on their actions based on parameters, which include cheating income (CI), future income (FI), discount rate $(\alpha)$, and punishment (P). Moreover, the effectiveness of institutions has an effect on their decision-making. In other words, the probability associated with each situation (system state) affects the agent's behaviour. Therefore agents estimate the probability of getting fired in different situations. These probabilities are listed below for an agent:

- Probability of getting punished for cheating (pc);
- Probability of getting punished for bad performance when he cheated (ppc);
- Probability of getting punished for either bad performance or cheating when he cheated (cpc);
- Probability of getting punished for bad performance when he did not cheat (ppnc);

The $cpc$ stated above is the complement of the probability of an agent not getting fired based on a) his bad performance and b) his action being identified as cheating. This statement is mathematically expressed as follows:

$$cpc = 1 - ((1 - pc) \times (1 - ppc)) \tag{4.1}$$

Figure 4.1 shows how agents decide on their actual actions based on the consequences of those actions and their estimations regarding the director's suspicion (i.e. the director's actions). Note that sometimes although agents did not cheat, the director may still think they cheated based on their bad performance. Figure 4.1a shows the utility obtained (punishment or reward) of each state (e.g. an agent cheats and the director identifies the action). Figure 4.1b shows an agent's estimation of the probability of each state, given his action.

To test the impact of different punishment schemes, agents' perceptions of the consequences of cheating, and their conformity to the simulation output, we have employed four different simulation scenarios. The first and the third simulation scenarios test the impact of punishment schemes by attributing them to either the type of contract used or employing adjudication processes. The second scenario extends Scenario 1 by assuming that the punishments beyond firing are only enforceable by courts. The last scenario extends Scenario 1 to model the impact of conformity. These scenarios are listed below:

Scenario 1) *Contract-based punishment*: This is the base scenario stated above. In this scenario, we attributed the punishment to the contracts. In other words, when commenda contracts are used, the cheaters should pay cheating income along with the interest.

Scenario 2) *Only dismissed for bad performance*: Here Scenario 1 changes so that suspected cheaters are only expelled when there is no evidence (i.e. suspects do not pay back their income of cheating).

Scenario 3) *Court-based punishment*: In this scenario, we change Scenario 1 by assuming that the type of punishment is related to using courts. In other words, when there are no adjudication processes, commenda contracts have a punishment like that of the EIC (i.e. signed bonds).

Scenario 4) *Conformity*: In this scenario, we extend Scenario 1 by assuming that a part of society (impressionable agents) consider cheating in their utility function when they observe a certain number of cheaters.

The difference between Scenarios 1 and 2 lies in the consequences of performance-based punishments (in Scenario 2 suspected cheaters only lose their job). In Scenario 3, the punishments (e.g. fines) of Scenario 1 are decided by the courts (i.e. punishment is not attributed to the payment scheme). In Scenario 4, we extend Scenario 1 by considering morally impressionable agents (conformity). In other words, these agents justify their actions if the number of observed cheaters exceeds a certain threshold.

### 4.3.2 Algorithms

Here we present a model that investigates the effects of the stated characteristics in Section 4.2 on societal success. To do so, we assume that some agents play a game with incomplete information, wherein they decide to cheat (Myerson, 1982). The rest of the society are those who would not cheat at all. Moreover, directors aim to maximise profits by employing different payment, punishment, and firing schemes.

**Algorithm 4.1:** Managerial level decisions (directors)

```
1  Identify and fire cheaters based on observations
   /* Observations is a function of agents' cheating level and chance of
      identification (see Table 4.3, last row)                                */
2  if there is no adjudication process then
3  |   Measure performance of agents, based on their experience and update their record using discount
   |     factor
4  |   Fire worst performers with higher access to company resources, i.e. junior merchants, senior
   |     merchants, or council members (more than 12 years experience).
5  end
6  if workfoce society is open then
7  |   Hire people so the population is stable
8  else
9  |   Hire all agents aged 15
10 end
11 CurrentCapital ← ∑_{∀Agents} DirectorCapital in the hands of agents
12 ROR ← CurrentCapital / OldCapital
13 OldCapital ← CurrentCapital
14 Redistribute capital
   /* It takes place based on the number of new recruits, fired, and deceased
      agents.  First, directors allocate 100 units to each new recruit, then
      the remainder of accumulated capital is distributed among other
      merchants, considering their current access to the company's capital ---
      the current access of an agent is defined as the amount of capital or
      resources currently allocated to the agent, see Algorithm 4.2          */
```

We assume that these trader societies are managed by a director entity (an abstraction for all decision-making entities in a society). The steps performed by a director are indicated in **Algorithm 4.1**. This algorithm shows how the managerial level of a system works. The firing of cheaters takes place as a function of the effectiveness of the monitoring mechanisms (line 1). Monitoring depends on available information on agents' behaviour that is a function of an employee's loyalty to the company. We assume that closedness of the workforce society increases loyalty and information transparency due to the social bonds and informal and formal measures of information exchange. Another firing scheme is associated with the lack of an adjudication process (e.g. in the case of EIC), and agents are expelled based on their performance (lines 2–5). Then we consider directors who have different hiring schemes. In an open society, agents are hired to stabilise the population of traders, and in a closed society, all agents aged fifteen years are hired (lines 6–10). The total capital in the society is the sum of the capital available to all agents (line 11). The Rate of Return (ROR) is the ratio of current capital to old capital (line 12). The director updates his old capital for the next run (line 13) and redistributes the capital from fired and deceased agents to recruits and experienced agents. The allocated capital to new recruits is 100 units, and the rest is distributed to experienced agents, based on their current access to the director's resources (line 14).

**Algorithm 4.2** represents a brief overview of the operational details of an agent in the society (agent *A*). Agent *A* grows 1 year older, and based on the mortality rate associated with his age, he may die with a certain probability, and also he stops working, if he is fired. In a closed society a fired agent continues his presence in the system but cannot trade any more. This assumption was inspired by Julfa institutions (i.e. they did not exile cheaters from the society). We employ it to prevent a closed society from artificially becoming extinct (line 1). Some agents quit the company for a healthier life back home when they face a high mortality rate (lines 2–4). The rest of the algorithm is applicable for all working agents (line 5 indicates this concept). Agent *A*'s skill (s) linearly improves during the first ten years until he reaches his maximum attainable skill (line 6). In a closed system, agent *A* reproduces another agent (male child) while he is aged between 21 to 55 with a certain probability until he either has the maximum possible number of children or he dies (lines 7–16). Each new born agent has totally new random values for parameters (i.e. an offspring will not inherit a bad reputation, a bad skill, or a cheating tendency).

We set the cheating costs imposed on the system at zero (line 17). A potential cheater decides to cheat based on this utility function (lines 18–32). Agent *A* estimates his expected utility based on a) the form of the contract, b) the considered time horizon, and c) the cumulative capital in subsequent iterations. To take account of future income, agent *A* considers no revenue at the moment ($I(0)$). He also takes account of his capital and the director's capital using dummy variables (i.e. Mcap and cap, line 19). Then he calculates his expected income at time $t$, based on the assessed average income $(aai)$, plus the average attainable income for skill $(aais)$ multiplied by his degree of skill $(s)$ for the considered time horizon (lines 20–25). Agent *A* considers the near future in this calculation — in our simulation it is 6 years. Then agent *A* calculates the net present value of his expected utility, using his discount factor (line 26).

Cheating is considered as a random manipulation $(RM)$ of what are considered to be the details of trade (e.g. purchasing other items) with a linear correlation to its visibility. The randomness represents random opportunities for price manipulation. The magnitude of the

**Algorithm 4.2:** An agent's operational details

Increase Age by 1 year, die randomly considering mortality rate for age, and get fired based on the director's policy.

**if** *workforce society is* ***open*** *and mortality rate is* ***high*** **then**

  leave work with $40\%$ chance $\times$ associated mortality rate according to age

**end**

**if** $age >= 15$ and not *fired* **then**

  **if** *age* $\in [16, 25]$ **then** increase skill $(s)$ by $10\%$ of maximum attainable skill

  **if** *workfoce society is closed* **then**

    **if** *(*$21 \leq$ *Age* $\leq 55$*)* **then**

      **if** *the number of children* $<$ *maximum* **then**

        **if** *rand()* $\leq$ *ReproductionChance* **then**

          Create a new person with age $\leftarrow 0$ and random parameters

          Increase the number of children by 1

        **end**

      **end**

    **end**

  **end**

  Cheating cost $\leftarrow 0$

  **if** *potential cheater* **then**

    `/* Calculate expected utility, based on director's and agent's capital, using Cap and Mcap as dummy variables; */`

    cap$(0)$ $\leftarrow$Mycapital, $I(0) \leftarrow 0$, for commenda Mcap$(0)$ $\leftarrow$ DirectorCapital otherwise Mcap$(0)$ $\leftarrow 0$, and $t \leftarrow 1$.

    **while** $t \leq 6$ **do**

      $I(t) \leftarrow (aai + aais \times s)\times$ $[0.3\times$ Mcap $(t-1)$ + cap $(t-1)]$

      cap$(t)$ $\leftarrow$ cap$(t-1) + I(t-1)$

      Mcap$(t)$ $\leftarrow (aai + aais \times s) \times 0.7\times$ Mcap $(t-1)$

      $t \leftarrow t + 1$

    **end**

    Discounted utility $(\alpha \times FI) \leftarrow \sum_{i=1}^{6} \alpha^i \times I(i)$

    Consider a random manipulation $(RM)$, $CI \leftarrow RM$ for commenda and $CI \leftarrow G(< RM)$ for others.

    Learn $pc$, $ppc$, $ppnc$, and effectiveness of bond $(eb)$.

    **if**

    $(pc+ppc)\times(CI-eb\times pc\times P)+(1-pc-ppnc)\times(CI+\alpha\times FI) > (1-ppnc)\times\alpha\times FI$

    **then**

      CheatingCost $\leftarrow RM$

    **end**

  **end**

```
33      if Commenda then
34          total ← ((Rand(aai) + Rand(aais) × s)× DirectorCapital) − CheatingCost
35          DirectorCapital← 0.7× total
36          My capital← 0.3× total + RM
37      else
38          DirectorCapital ← DirectorCapital +((Rand(aai) + Rand(aais) × s)× DirectorCapital)
              − CheatingCost
39          Mycapital← Mycapital +((Rand(aai) + Rand(aais) × s)× Mycapital) + CI
40      end
41  end
42  if leaning is considered then
43      if the number of observed cheaters > threshold and agent is impressionable then
44          Convert to potential cheater
45      end
46  end
```

correlation reflects the degree to which the unwanted manipulation is correlated with the ease of its identification. In commenda contracts, a cheater's profit is as much as the manipulation, because the agent buys and sells items. A salaried agent's profit of cheating is in the form of accepting a gift from other parties to change the orders[5] (line 27). Afterwards, agent *A* updates his estimations of the probabilities of different states, based on his observations, *a priori* knowledge, and the effectiveness of bonds — if he is salaried — (line 28). Consecutively, agent *A* may decide to cheat based on expected utility (lines 29–31). Agent *A* updates his capital as well as his director's capital (lines 33–41). Note that the increase in the director's capital directly affects the director's profits that is a function of the payment scheme and the cheating costs incurred because of agent *A*. For commenda contracts, the director's profits decrease by $30\%$ due to the profit-sharing. Finally, in scenarios where some agents are impressionable (i.e. some agents may turn into potential cheaters), if agent *A* observes a certain number of cheaters in his connections, he also considers cheating (lines 42–46).

### 4.3.3 Simulation parameters

In this section, we state the parameters employed in our simulations. A simulation run is initialised with a predefined population with different ages and random *a priori* knowledge of

[5] The most frequent reported forms of cheating in the EIC were embezzlement, reselling an agent's items, and accepting gifts — e.g. choosing the best gift giver (Marshall, 1976).

Table 4.2: Punishment, reward, and learning for the base scenario

| Parameter | Learning means | Note |
|---|---|---|
| Future revenue | Asking other agents | |
| Chance of being punished as a cheater | Observation | Discount past parameters |
| Chance of getting fired for bad performance | Observation | Discount past parameters |
| Chance for cheating | Observation | Discount past performance |
| Effectiveness of bond | Observation | Bayesian |
| Punishment in commenda | Contract | Revealed cheating + Interest |

associated probabilities for each state. The age structure of the initial population is defined in a way that it reflects the associated mortality rate. To do so, we fitted an exponential function on data as suggested by Frol'kis (1982). Then based on: a) the population of a given year, b) the percentage of deceased agents, and c) the assumption that the societal population did not have any trend recently (i.e. increasing or decreasing), the number of agents in the subsequent years is identified. The results of this procedure are depicted in Figure 4.2. In this figure, the x-axis indicates the age and the y-axis indicates the number of agents. The blue lines are associated with high mortality rates and the orange lines indicate low mortality rates. Also, Equation 4.2 shows the fitted exponential functions.

$$MortalityRate(age, rate) = \begin{cases} 0.0736 \times e^{(0.01035 \times age)}, & \text{if } rate = High \\ 0.0033 \times e^{(0.0478 \times age)}, & \text{if } rate = Low \end{cases} \tag{4.2}$$

For each iteration, which equals a year, agents update their assessments of the effectiveness of different institutions — for instance, the probabilities of a cheater or non-cheater being fired. The main parameters that an agent learns are shown in Table 4.2. The following states the parameters that were fixed in our simulation and the reasons for choosing these numbers.

**Weighting factor:** Agents weight past estimation using $0.3$ weight due to the one year lag and the obsolescence of past information. The only exception for this learning method relates to not-executed bonds. We know of no bonds that were paid upon the fault (confiscated) in the EIC based on accumulated data; therefore agents increase their belief about the ineffectiveness of these bonds with more evidence (they use a Bayesian inference for a Bernoulli probability distribution that assesses the probability of confiscating bonds). For all cases, agents stick with *a priori* knowledge, if they do not observe anything new. In the base scenario (i.e. Scenario 1), we ascribed punishment and bonds to contract form, so: a) in commenda contracts (e.g. Julfa), identified cheaters are punished, based on the cheating and accumulated interests (they know it once they start the contract) and b) in other contracts (e.g. the EIC), cheaters are dismissed and the bond is not confiscated (they learn this paying back by observation). Note that in commenda contracts, only Judges can ask cheaters to pay the interests.

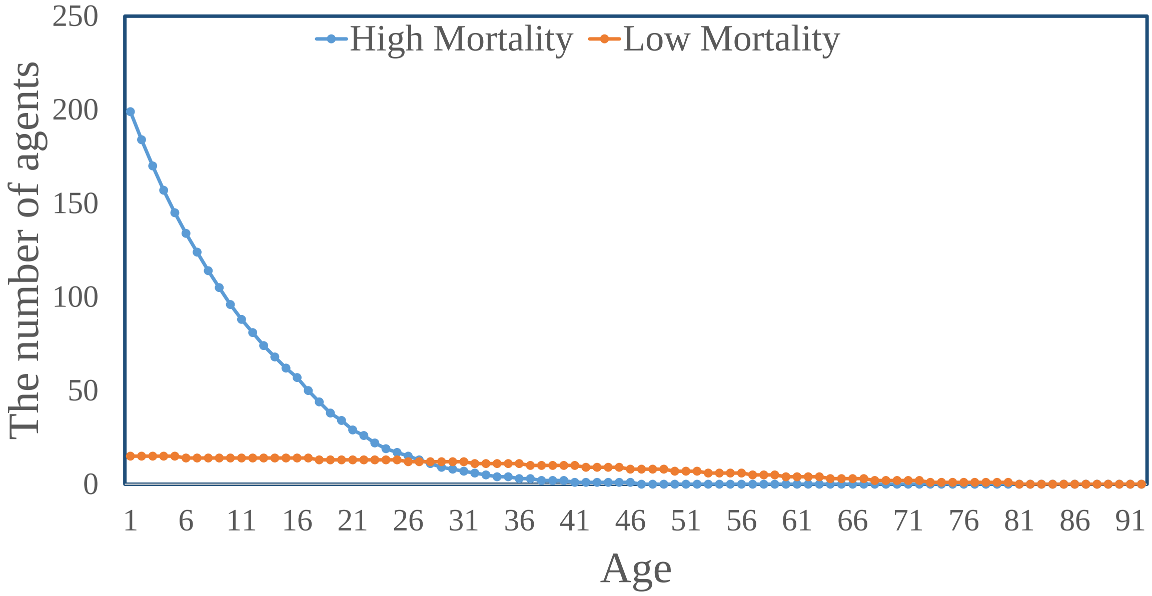


Figure 4.2: Age structure for systems with a) low mortality rate and b) high mortality rate.

The **population** is defined, based on the approximate population of these societies. In Julfa, approximately 800 traders (directors and agents) were active in the 17th century (Aslanian, 2007) and in the EIC, based on the number of factories[6] and their population, the number of agents was estimated to be 500. To perform a comparative evaluation, we used 500 agents for both societies. The mortality rates, their functions, and the reproduction rates for the two societies were obtained from various sources (Aslanian, 2007; Frol'kis, 1982; Hejeebu, 1998; Hollingsworth, 1957).

**Discount factor:** This is used to calculate the net present value of money. Systems with high mortality rates have a high discount factor because of mortality risks — in such societies the net present value of money reaches $1\%$ in 10 years. Moreover, in Julfa, this was estimated based on the reported customary interest rates ($\alpha \approx 10\% \rightarrow (1/1.1) \approx 90\%$, Herzig, 1991) as an indicator of the average societal discount factor.

**Years:** Each agent has a finite time horizon (6 years) for calculating his utility function. This number of years is employed to parametrise our model. Note that we did not consider a longer time horizon (e.g. 20 years) because of the observations made by behavioural

[6]For a list of these factories in India see (Robins, 2017), Map 2 (p.65).

scientists (Kim & Zauberman, 2009; Muradoglu & Harvey, 2012; Pedneault et al., 2017).

Table 4.3: Simulation parameters

| Name | Description | Distribution | Value(s) |
|---|---|---|---|
| Weighting factor | Weight of past information | Constant | 0.3 |
| Population | Mature population (regardless of children) | Constant | 500 |
| Maximum number of boys | Low mortality rate<br>High mortality rate | Constant | 1.4<br>10.4 |
| Discount factor | Low mortality rate<br>High mortality rate | Normal<br>$(\mu, \sigma)$ | (0.9,0.033)<br>$(0.63, 0.12)$ |
| Years | Agent's myopia | Constant | 6 |
| Revenue | Basic income for trades | Uniform | $(0.05, 0.1)$ |
| Skill-based revenue | Linear function of skill | Uniform | $(0, 0.1)$ |
| Potential cheater rate | Chance of being a potential cheater | Constant | 0.5 |
| Proportion to fire | Fired per run for bad performance (no adjudication process) | Constant | 0.008 |
| Skill | Maximum attainable skill | Uniform | $(0.5, 1)$ |
| Chance of identifying $a\%$ manipulation | By agents with direct link | Uniform | $(0, a)$ |
| | By directors in a closed society | Beta | $(1, 5, 0, a)$ |
| | By directors in an open society, discounted by $1\%$ for employees' disloyalty | Uniform | $(0, a)$ |

**Revenue:** Based on the approximated ROR associated with the EIC during 1710–1745, revenue rate (i.e. ROR) on average increases $9.74\%$.[7] In our model, we also assume that a minimum revenue can be made by trade because of monopoly privileges. Therefore in our model the revenue rate is uniformly distributed in $(0.05, 0.1)$. Additionally, to model the impact of skill on the profits made in the society, we consider **a skill-based revenue** with a maximum of $0.1$ that depends on the situation — it is random — and the agent's skill level (i.e. lower skills make lower profits). In other words, it has a continuous uniform distribution in $(0, 0.1)$.

**Potential cheater rate:** We assumed that the chance for an agent to be opportunistic is the same as that of being honest (i.e. 50-50).

**Proportion to fire:** This indicates the proportion of fired agents per run for their bad performance. We know that about 13.2% of the EIC employees who were hired between 1700 and 1756 in Bengal were dismissed (i.e. about 0.003 per annum, see Section 2.3.2.1). In our model, we considered it a little bit higher (i.e. 0.008 per annum) to take account of a slightly higher number of fired agents in other settlements and the impact of missing data.

[7] A detailed table is provided in (Chaudhuri, 1978), Table A.26 (p.440).

**Skill:** An agent has a maximum attainability for skill. We assume that an agent has at least an average attainability that makes him interested in trading. The maximum attainability for an agent is uniformly distributed in $(0.5, 1)$.

**Chances of identifying cheaters:** The agents identify their friends' cheating (i.e. connected agents) randomly. Note that the more manipulation there is, the more visible it is. For this purpose, we assumed that the probability that a friend identifies $a\%$ manipulation is uniformly distributed in $(0, a/100)$. In a closed society (e.g. Julfa), agents collaborate in monitoring and report each other's behaviours. Also, the directors have other means (e.g. checking an agent's luggage and other agents' reported prices) to verify the reports. For these reasons, we assumed that the directors identify manipulations better and, we use the beta distribution[8] for this purpose. In an open society (e.g. the EIC), directors have weak monitoring means and the agents are not as loyal to the system as closed societies. Also, we know that in the EIC during 100 years between 2% and 4% of employees were prosecuted in courts (i.e. about 0.0004 of agents per year, see Section 2.3.2.1). For these reasons, we assumed that a cheating behaviour is rarely identified by directors (i.e. we used a coefficient of $1\%$ for this purpose).

To operationalise our model, we assumed that each agent starts with 100 units of money from the director's capital and 10 units of money of his own capital for local trades. Also, we assumed that an agent has approximately 20 random connections with other agents that he can observe and learn from (inspired from Dunbar's number, see Carron et al., 2016; Zhou et al., 2005). Therefore a new employee creates around 20 random connections to other agents in the system — the connection is lost once a person leaves the society. Finally, the bonds are 50 units of money for agents with one to five years of experience, 100 for agents with six to eight years of experience, and 150 for more experienced agents (inspired from stepwise bound with a significant amount of the EIC; see Hejeebu, 2005).

## 4.4 Simulation results

We conducted experiments with sixteen simulated societies by varying four characteristics. However, in this section, we describe simulation results for *ten* societies out of sixteen simulated societies. We only report two societies with high mortality rates (i.e. the EIC and its

[8] A beta distribution is a flexible continuous probability distribution to model events in a finite interval (see S. M. Ross, 2010, pp. 218–219). $Beta(\alpha, \beta, c, d)$ indicates the beta distribution with parameters $\alpha$ and $\beta$ in the interval $(c, d)$. Note that when the two parameters are 1 (i.e. $\alpha = \beta = 1$), the distribution transforms to the Uniform distribution in $(c, d)$.

closed counterpart), and skipped the others, because we already know that a higher discount factor — because of a high mortality rate — decreases directors' profits by increasing the opportunistic behaviours of the agents (Baker & Miceli, 2005; Mastrobuoni & Rivers, 2016). We employed these examples with a high mortality rate to a) represent the EIC better and b) test whether the EIC was able to form a closed society of traders. This helps us to identify a crucial factor impacting these two societies' sustainability. We state this result at the end of this section.

We have utilised *NetLogo* to perform our simulation (Wilensky, 1999). We also used 30 different runs to simulate each system and then averaged their results. Moreover, we assume each iteration reflects a year. The number of iterations in this simulation is bounded to 200 — both systems used these institutions and lasted for around 150-200 years.[9] We gradually change characteristics of EIC to get closer to Julfa to examine their effects on the success of these societies. Based on these combinations, we study the success of these systems using four metrics, namely sustainability, reducing the percentage of the cheaters, improving the skill of people, and making more profits. It is worth mentioning that we did not add punishment compensations when calculating societal revenue (i.e. ROR), because we are concerned with trade income. Also, such consequences have adjudication costs and the probability of losing in court — note that adding such factors makes the simulation more complicated. Table 4.4 shows characteristics for the ten simulated societies and the real societies they represent (given in parenthesis). Note that we did not explicitly include punishment in Table 4.4 and considered its impact by varying scenarios.

In Table 4.4, the configurations (i.e. societies) are identified by two letters associated with characteristics, namely *LM, Co, Cl*, and *Ad* that represent **L**ow **M**ortality rate, using **Co**mmenda contracts, **Cl**osedness of societies, and having **Ad**judication processes, respectively. We used a Boolean index to indicate whether such an attribute is included (i.e. 1) or not (i.e. 0). Likewise, in Table 4.4, a tick indicates that the society includes that attribute, and a cross indicates the society does not include that attribute. In the following sections, we state results associated with simulation scenarios. Note that the model representing Julfa has a value of 1 (tick in Table 4.4) for all the four characteristics, and the one representing the EIC has a value of 0 (cross in Table 4.4) for the same characteristics. The models in the middle are stereotype societies with varying characteristics.

**Impact of characteristics on societal sustainability:** As stated earlier, we have conducted the closed counterpart of the EIC to test whether they were able to use a closed

[9]The EIC legalised local trades for agents in the late 17th and early 18th, and Julfans were active for less than 200 years.

Table 4.4: Configuration of different systems

| Characteristics | $LM_0Co_0Cl_0Ad_0$ (EIC) | $LM_0Co_0Cl_1Ad_0$ | $LM_1Co_0Cl_0Ad_0$ | $LM_1Co_0Cl_0Ad_1$ | $LM_1Co_0Cl_1Ad_0$ | $LM_1Co_0Cl_1Ad_1$ | $LM_1Co_1Cl_0Ad_0$ | $LM_1Co_1Cl_0Ad_1$ | $LM_1Co_1Cl_1Ad_0$ | $LM_1Co_1Cl_1Ad_1$ (Julfa) |
|---|---|---|---|---|---|---|---|---|---|---|
| Low mortality rate | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Commenda | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ |
| Closed | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Adjudication | ✗ | ✗ | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ |

society hiring scheme (e.g. family and relatives of directors). For this purpose, we considered a closed community of traders with the same mortality rate as the EIC. Furthermore, to have a stable population, we had to assume that a trader has **around 21 babies with** $70\%$ **probability of having a child per year**. This indicates that, given the high mortality rate, any attempts to hire from a closed society could be the biggest obstacle to sustainability of trade.

In the next subsection, we present the simulation results associated with the base Scenario (Scenario 1).

### 4.4.1 Scenario 1: Contract-based punishment

This scenario is the base game presented in Figure 4.1. The following represents the utility function of a cheating associated with the societies lacking adjudication:

$$U(Cheat) = cpc \times (CI - P) + (1 - cpc) \times (CI + \alpha \times FI) \tag{4.3}$$

The utility function for an honest action in both societies is as follows:

$$U(Honest) = (1 - ppnc) \times \alpha \times FI \tag{4.4}$$

A potential cheater decides to cheat when $U(Cheat) > U(Honest)$. Note that having adjudication processes removes the probability of getting fired for bad performance; hence, in Equations 4.1 and 4.3, the $ppc$ and $ppnc$ equal zero.

In the following subsection, we include the results for the impact of the societal configuration on rule conformance.

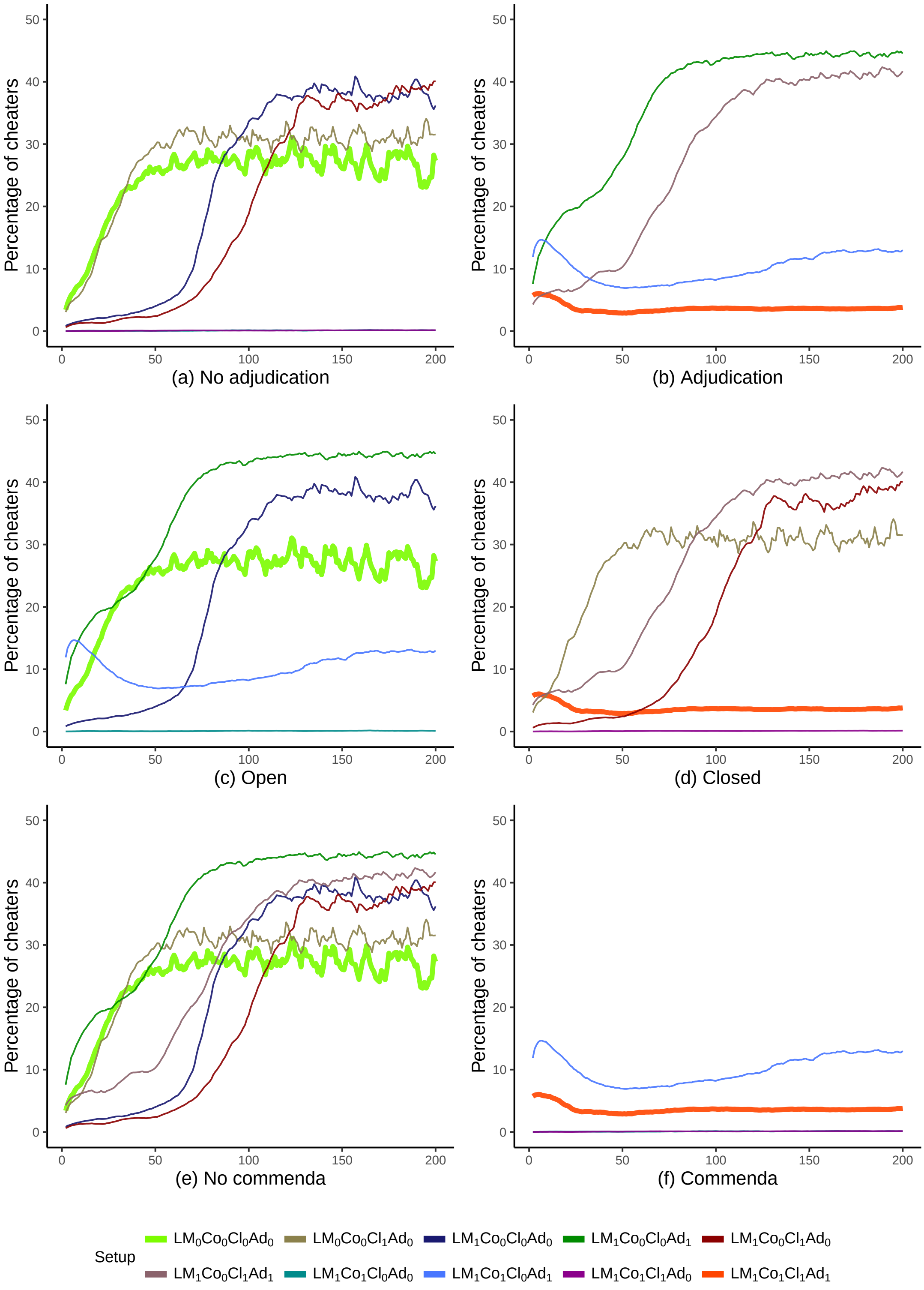


Figure 4.3: Percentage of cheaters in a society, where the x-axis is the number of years and the y-axis is the percentage of cheaters in a society (Scenario 1). Note that $LM_1Co_1Cl_0Ad_0$ and $LM_1Co_1Cl_1Ad_0$ are both zero — in (a) and (f) they are overlapped.

#### 4.4.1.1 The impact of societal configuration on rule conformance

Now we state the results of simulation runs for **Scenario 1**, which are given in Figure 4.3. The goal of this subsection is to compare the cheating behaviours among different societies during 200 iterations (years). The x-axis of this figure represents the number of years since the system's establishment and the y-axis indicates the percentage of cheaters in the society (Figures 4.3a-4.3f). In these graphs, horizontal pairs group the simulated societies based on having (right) and not having (left) a characteristic (i.e. lines are repeated in each pair of characteristics). Furthermore, the EIC and Julfa are highlighted with thicker lines (green and red, respectively).

**Percentage of cheaters:** As can be seen, having adjudication processes (Figures 4.3a-4.3b) deters agents from cheating (i.e. societies with $Ad_0$ has a lower number of cheaters than their $Ad_1$ counterparts). Closedness of society (Figures 4.3c-4.3d) does not control agents' inclination towards cheating significantly. This indicates that in societies with lower payments and mild punishments, agents take the risk of cheating (i.e. $Co_0$). However, it should be emphasised that this number is cumulative (i.e. cheaters remain in closed systems). As can be seen, there are fewer cheaters in systems run by commenda contracts (Figure 4.3f) than salaried agents (Figure 4.3e). This indicates the impact of this profit-sharing on agents' behaviour.

What follows presents the Kendall statistical test[10] to measure the impact of the characteristics on agents' inclinations towards cheating. Note that as stated earlier, a higher discount factor — caused by a higher mortality rate — increases the agents' opportunistic behaviour in the society. Consequently, we only used data of low mortality rates in the statistical tests:

- The impact of commenda contracts on agents' inclination towards cheating is statistically significant, negative, and moderate ($\tau = -0.59$). This indicates that a combination of profit-sharing mechanisms (e.g. $30\%$ sharing) and stronger punishments for more serious cheating deters agents from cheating.
- The correlation between closedness of the society and the prevalence of cheating is negative and weak ($\tau \approx -0.13$ and $p\text{-}value \approx 0$). This indicates that the closedness of the society — a better monitoring — weakly hampers agents' inclination towards cheating.
- The correlation between agents' inclination towards cheating and having adjudication

[10]We did not use the Spearman test because of the presence of ties caused by 0/1 characteristics. We also did not use the Pearson test because of the trend in the observation and different variances (i.e. they are not homogenous and normal).

processes is positive ($\tau \approx 0.37$ and $p\text{-}value \approx 0$). Note that not having adjudication processes means performance-based firing. Consequently, this correlation[11] shows that performance-based firing moderately deters agents from cheating.

To summarise, the commenda contract — which includes significant profit-sharing — and closedness of society deterred agents from cheating. Note that a counter-intuitive finding is adjudication processes' failure to deter agents from cheating (described more in Section 4.5).

**Experience of cheaters:** After stating the impact of characteristics on agents' inclination towards cheating, we state the trend of cheating behaviour based on the agent's experience. Figures 4.4a to 4.4e present boxplots for the percentage of cheaters that are present in societies who had experience of less than four years, between four and six years, between seven and nine years, between ten and twelve years, and more than or equal to thirteen years, respectively. Figure 4.4f presents the boxplot for the percentage of agents who were fired for cheating (independent of experience). In these plots, a diamond represents the *average* of simulation results and the red dots are outliers.

As can be seen, in closed societies ($Cl_1$) stronger monitoring mechanisms help the society to identify and fire most of the cheaters. Also, in the open counterpart of Julfa (i.e. $LM_1$ $Co_1Cl_0Ad_1$), an increase in experience decreases the inclination towards cheating because of an increase in expected profit (see Figure 4.4a versus Figure 4.4b-4.4e) — as can be seen in Figure 4.4f, almost none of the cheaters were fired (see $LM_1Co_1Cl_0Ad_1$). This result indicates the importance of bilateral commenda contracts that increase the profits of agents more than the nominal share (30% in this model) by providing the opportunity for investments of accumulated profits. Another interesting result belongs to Julfa without commenda contracts ($Co_0$) using an open society ($Clo_0$) — i.e. society $LM_1Co_0Cl_0Ad_1$. As can be seen in Figures 4.4a and 4.4e, accumulation of experience has a negative impact on agents' inclination towards cheating. This also emphasises the importance of profit-sharing contracts disregarding monitoring strength. This increase in the number of experienced agents who are inclined towards cheating provides some insights for us to understand why the EIC used a performance-based firing scheme.

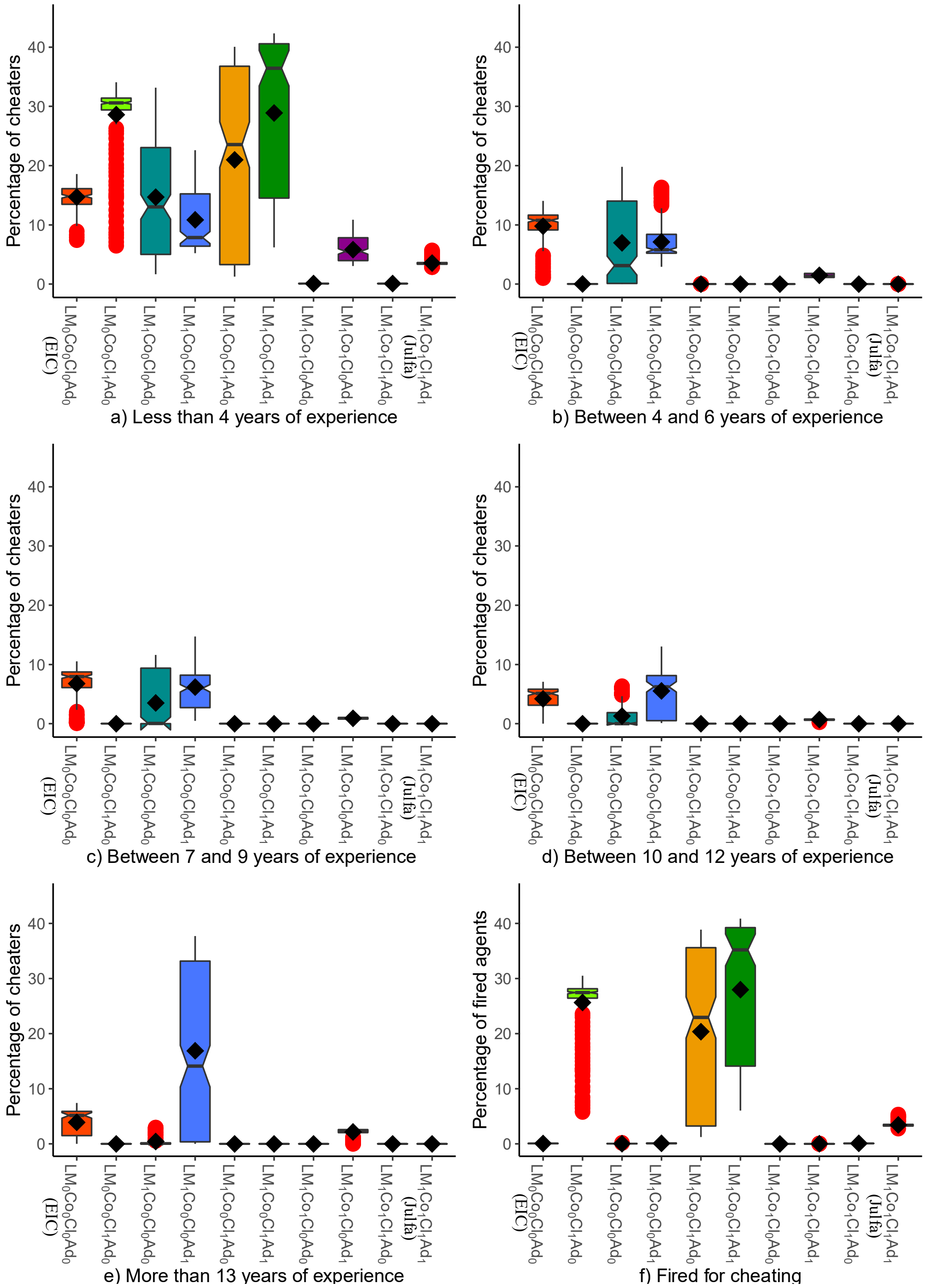


Figure 4.4: Boxplot of percentage of cheaters with respect to experience (a-e) and fired agents (f). In boxplots a-e, the y-axis represents the percentage of cheaters. In boxplot f, the y-axis represents the percentage of agents fired for cheating.

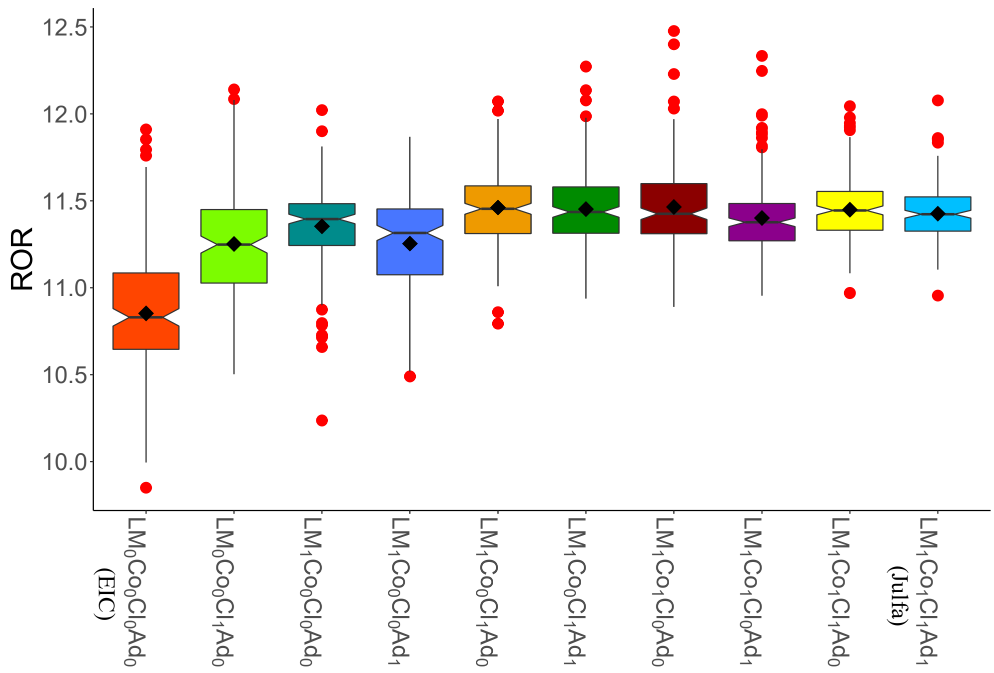


Figure 4.5: The boxplot of the obtained ROR of simulation results for different system settings (Scenario 1).

#### 4.4.1.2 The impact of societal configuration on the profits made by directors

In this subsection, we study the impact of the system's characteristics on the directors' ROR (see Figure 4.5). As can be seen in Figure 4.5, the simulated Julfa ($LM_1Co_1Cl_1Ad_1$) has a better ROR than the simulated EIC ($LM_0Co_0Cl_0Ad_0$). In addition, for societies with a low mortality rate ($LM_1$), there are higher RORs in societies with commenda contracts ($Co_1$) or in a closed society ($Cl_1$) than in the other societies ($Co_0Cl_0$). In the following, we use a Kendall statistical test to measure the correlation between the characteristics and the directors' ROR.

- The correlation between employing commenda contracts and the ROR is positive and weak ($\tau \approx 0.06$ and $p\text{-}value < 0.004$). This correlation indicates that the combination of profit-sharing as proposed in commenda contracts (30% profit-sharing) and punishments based on the seriousness of cheating have a weak and positive impact on the directors' ROR.

[11] For the strength of coefficients we have used Dancey and Reidy's (2017, p. 182, Figure 6.7) interpretations. Also, see Akoglu (2018, Table 1) for other metrics. For absolute values of correlation, zero and one are none and perfect correlations, respectively. Also, the intervals for weak, moderate, and strong correlations are $(0, 0.3)$, $(0.4, 0.6)$, and $(0.7, 0.9)$, respectively.

- The closedness of the society has a positive, weak, and statistically significant correlation with the ROR ($\tau \approx 0.13$ and $p\text{-}value \approx 0$). This indicates that closedness of the society weakly improves the ROR through better monitoring and therefore reduces agents' inclinations towards cheating.
- The correlation between the ROR and having adjudication processes is weak and negative ($\tau \approx -0.08$) and is statistically significant ($p\text{-}value \approx 0.0001$). In other words, given the assumptions of this scenario, we note that having adjudication processes weakly decreases profitability by keeping non-cheaters with a low performance in the system.

As stated above, two out of the three characteristics had a positive impact on the directors' ROR (closedness of society and using commenda contracts). The obtained correlation associated with using adjudication processes was weak. Furthermore, it can be seen that if the EIC were to become a closed system, it would have a slightly higher ROR (See Figure 4.5 $LM_0Co_0Cl_0Ad_0$ versus $LM_0Co_0Cl_1Ad_0$).

Finally, overall, using commenda contracts has a positive impact on the societal ROR. In other words, this sharing scheme pays itself back by deterring agents from cheating. On the other hand, a combination of closedness and a low mortality rate (all societies identified by $LM_1$ and $Cl_1$) improves profitability. The EIC's policy, disregarding the impact of mortality rate, is not a superior policy. In other words, society $LM_1Co_0Cl_0Ad_0$ (i.e. the simulated EIC with a low mortality rate) only outperforms society $LM_1Co_0Cl_0Ad_1$ (i.e. Julfa without commenda contracts with adjudication processes).

In the next subsection, we discuss the impact of characteristics on societal skill level.

#### 4.4.1.3 The impact of societal configurations on societal skill level

Figure 4.6 presents the societal skill level for different configurations. As can be seen, the societal skill of the simulated EIC is relatively the same as Julfa (the agents attained about 75% of a full skill level). Overall, not using adjudication processes helps the society to improve their skills (i.e. all societies with $Ad_0$). This is intuitive because lacking adjudication processes leads to the removal of low-skilled agents (they are suspected of cheating). Below, using a Kendall statistical test, we examine the correlation between the considered characteristics and the societal skill level.

- Employing commenda contracts has a weak, positive, and statistically significant correlation with the societal skill level ($\tau \approx 0.19$ and $p\text{-}value \approx 0$). Using these contracts,

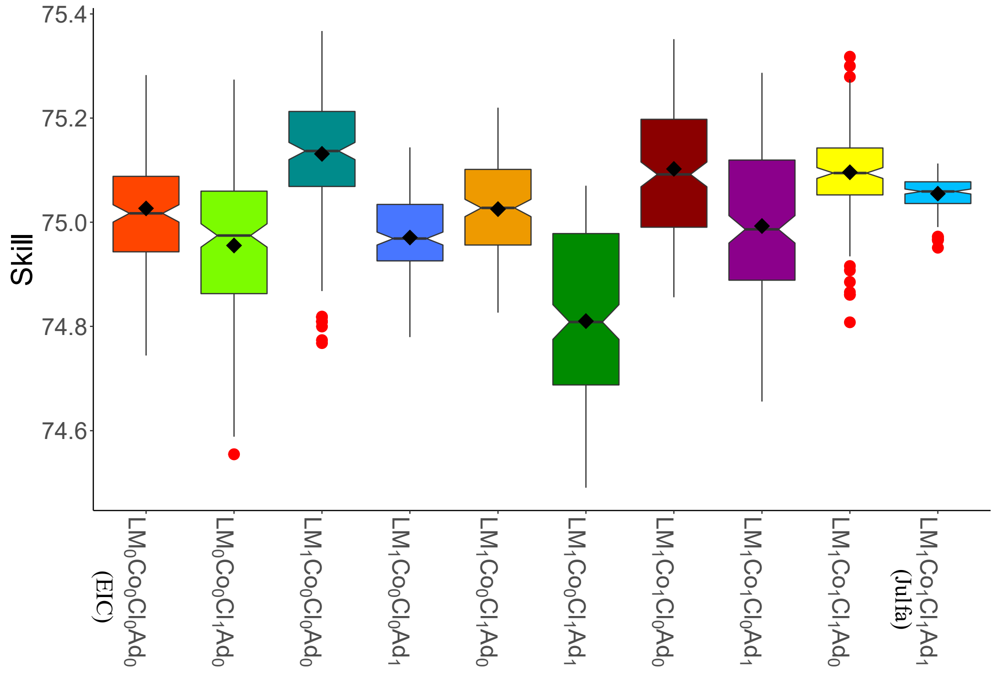


Figure 4.6: The boxplot of the societal skill associated with different system settings (Scenario 1).

agents have a lower inclination towards cheating, and lacking adjudication processes increases the societal skill level by filtering out low-skilled agents.

- The correlation between the closedness of the society and the societal skill of agents is negative and weak ($\tau \approx -0.1$), and is statistically significant ($p\text{-}value \approx 0$). This is because in closed societies a high number of low-skilled agents are hired for the hiring scheme used.
- The combinations of societal skills (average of skill levels of a society) and using adjudication processes have a moderate, negative, and statistically significant correlation ($\tau \approx -0.35$ and $p\text{-}value \approx 0$). This correlation indicates that performance-based firing has a moderate positive impact on filtering out low-skilled agents. Note that we can infer that some of (if not a majority of) the fired agents, based on the low performance, were not the worst cheaters, but they had lower skills than their peers.

Overall, only using commenda contracts had a positive impact on the societal skill level. However, this can be because of performance-based firing.

Finally, the worst societal skill level belongs to society $LM_1Co_0Cl_1Ad_1$ (i.e. the Julfa without commenda contracts), where no profits are shared, low-skilled agents are introduced into the system, and only cheaters are fired. In such a system, low-skilled agents remain as long as they do not cheat. The best societal skill belongs to $LM_1Co_0Cl_0Ad_0$, which is the simulated EIC with a low mortality rate. Other societies with a high societal skill level are societies that use a profit-sharing contract and lack adjudication processes ($Co_1$ and $Ad_0$). These results suggest that Julfa's characteristics considered here do not improve a societal skill level. In the next subsection, we model a situation under which cheaters are only expelled if a performance-based metric is used.

### 4.4.2 Scenario 2: Only dismissed for bad performance

This scenario is a revised version of the game associated with the base scenario (Equation 4.3). The new game is presented in Figure 4.7. Here the potential cheater considers two distinguished punishments based on the source of the director's suspicion. If the director uses performance-based metrics to identify a cheater (with the probability of ppc), he only fires the agent (i.e. there is no additional punishments). However, if there is some evidence regarding the agent's cheating (with the probability of pc), he gets fired and is punished by having to pay additional penalties decided by contracts. Note that in the base scenario, the agent assumed that when the director suspected him for his low performance, the director could collect evidence (i.e. an agent's cheating would have been revealed). What follows presents the game considered by a potential cheater in societies lacking adjudication processes:

**(a)Punishment and Rewards**

| Actual | Director's Suspicion: Cheat (C) | Director's Suspicion: Not Cheated (NC) |
|---|---|---|
| C | $CI - P \mid CI$ | $CI + \alpha \times FI$ |
| NC | $0$ | $\alpha \times FI$ |

**(b)Actions' probability**

| Actual | Director's Suspicion: Cheat (C) | Director's Suspicion: Not Cheated (NC) |
|---|---|---|
| C | $pc \mid ppc$ | $1 - cpc$ |
| NC | $ppnc$ | $1 - ppnc$ |

Figure 4.7: The game that potential cheaters play (Scenario 2). In the top left cells, "|" separates sources of the director's suspicion. The left arguments refer to when the director has some evidence and those on the right refer to when the director suspects the agent just for his bad performance.

$$U(Cheat) = (pc \times (CI - P)) + (ppc \times CI) + ((1 - cpc) \times (CI + \alpha \times FI)) \tag{4.5}$$

The utility function for an honest action is the same as before:

$$U(Honest) = (1 - ppnc) \times \alpha \times FI \tag{4.6}$$

Similar to Scenario 1, a potential cheater decides to cheat when $U(Cheat) > U(Honest)$, and having the adjudication processes sets the $ppc$ and $ppnc$ to zero in Equations 4.1 and 4.3, respectively.

#### 4.4.2.1 The impact of societal configurations on rule conformance

In this subsection, we describe the simulation results for Scenario 2 shown in Figure 4.8. The x-axis of this figure represents the number of simulation iterations and the y-axis indicates the percentage of cheaters (Figure 4.8a-4.8f). This scenario also shows that adjudication processes (Figure 4.8a-4.8b) have a negative impact on agents' inclinations towards cheating (i.e. $Ad_0$ has a lower percentage of cheaters than their $Ad_1$ counterparts). And societies $LM_1Co_0Cl_0Ad_0$ and $LM_1Co_0Cl_1Ad_0$ had a change in their percentage of cheaters in comparison with Scenario 1. Note that most of the patterns observed by this scenario have no or slight changes in comparison with Scenario 1. Below, we present the results of the Kendall statistical test, emphasising what have been stated:

- The impact of commenda contracts on agents' inclination towards cheating is the same as Scenario 1 ($-0.59$ and $p\text{-}value \approx 0$).
- The correlation between closedness of the society and the percentage of cheaters is almost the same as Scenario 1 ($\tau \approx -0.14$ and $p\text{-}value \approx 0$).
- The correlation between the percentage of cheaters and having adjudication processes is positive and the same as Scenario 1 ($\tau \approx 0.37$ and $p\text{-}value \approx 0$).

As stated above, the correlations between the percentage of cheaters and the system's characteristics is almost the same as Scenario 1. In the next subsection, we state the results associated with the director's profit based on this scenario. Note that the patterns for the results associated with the experience of cheaters were almost the same as **Scenario 1**; hence, we do not report them here.

#### 4.4.2.2 The impact of societal configuration on the profits made by directors

The patterns of the ROR associated with this scenario were almost the same as Scenario 1 (see Figure 4.5); hence, we did not include its visualisation. Below, we report the results associated with the performed Kendall statistical test that emphasises this similarity:

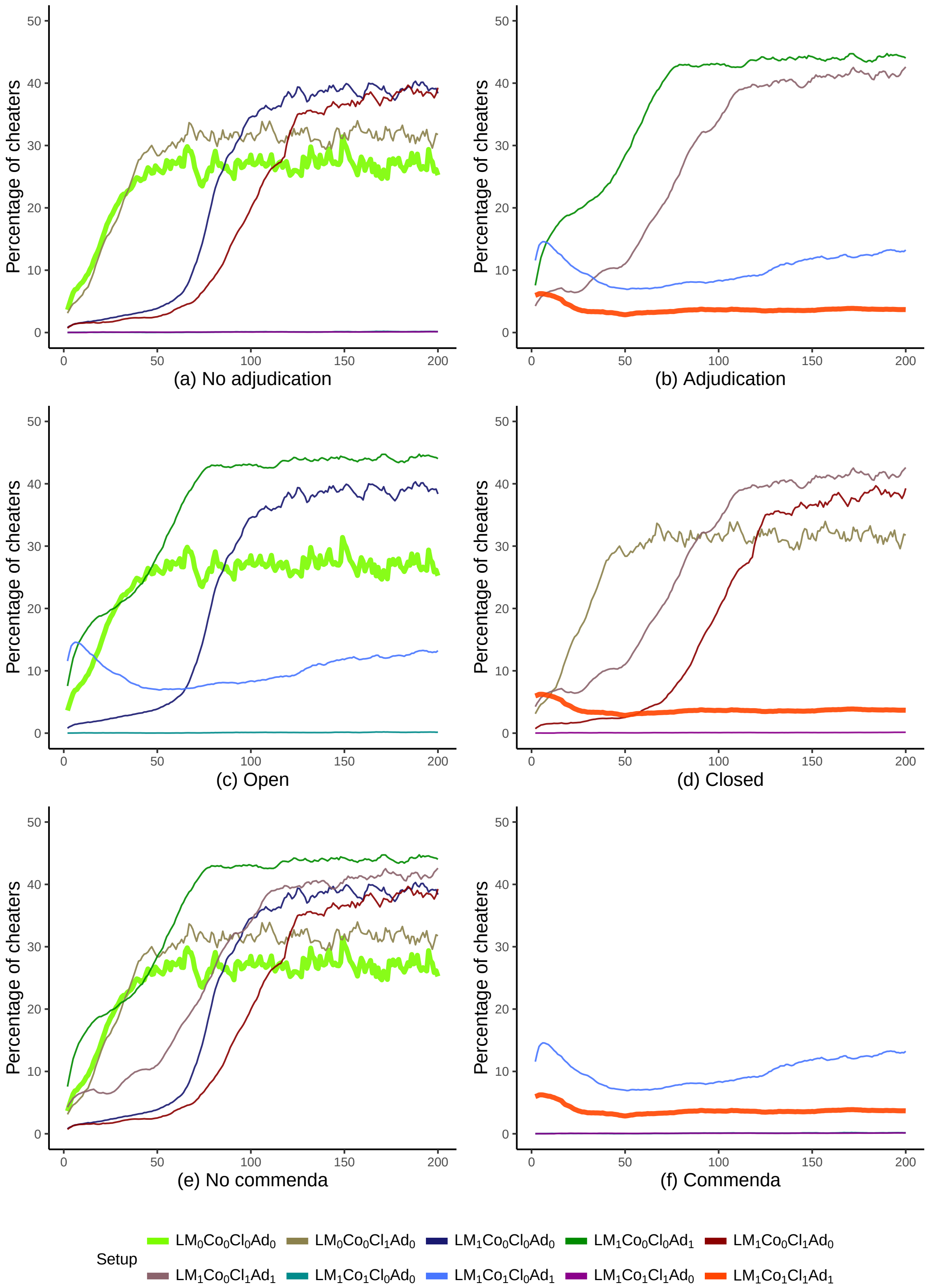


Figure 4.8: Percentage of cheaters in a society, where the x-axis is the number of years and the y-axis is the percentage of cheaters in a society (Scenario 2).

- The correlation between the ROR and employing commenda contracts is almost the same as that of Scenario 1 ($\tau = 0.14$ and $p\text{-}value \approx 0$).
- The correlation between the ROR and closedness of society is the same as what was obtained for Scenario 1 ($\tau \approx 0.14$ and $p\text{-}value \approx 0$).
- The correlation between the ROR and having adjudication processes is similar to Scenario 1 ($\tau \approx -0.08$ and $p\text{-}value \approx 0$).

As stated above, similar to **Scenario 1**, closedness of society and using commenda contracts had positive correlations with the profitability of the system. Furthermore, the correlation between having adjudication processes and the ROR was negative (as that of **Scenario 1**). In the next subsection, we describe the results associated with the impact of this scenario on the societal skill level.

#### 4.4.2.3 The impact of societal configurations on the societal skill level

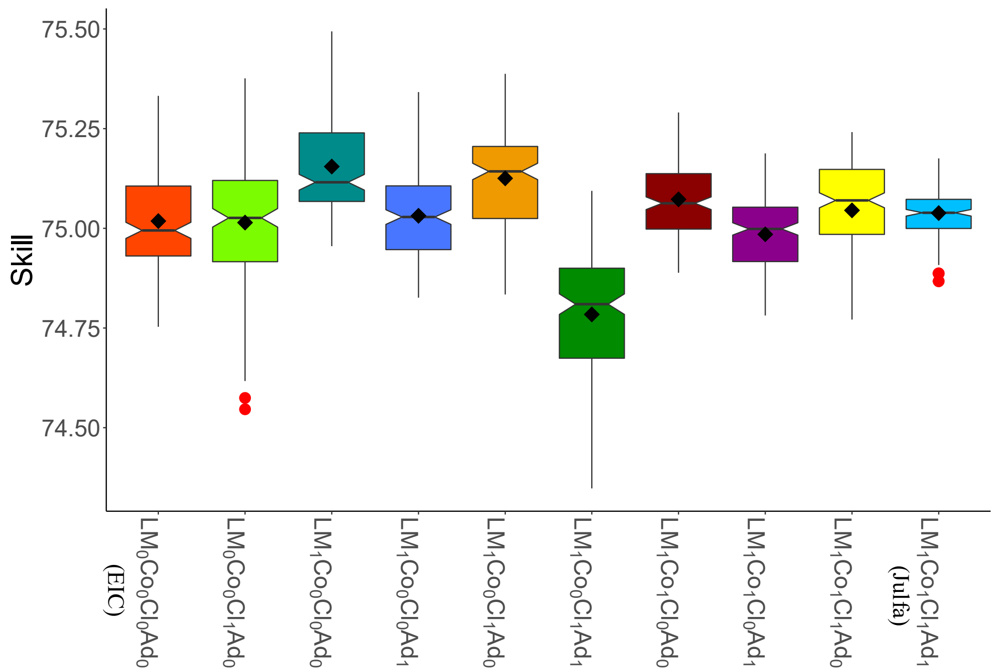


Figure 4.9: The boxplot of the societal skill level associated with the simulation for different system settings (Scenario 2).

Figure 4.9 presents the societal skill level associated with different configurations. As can be seen in this figure, the societal skill level of the simulated EIC is almost the same as Julfa (75). Overall, not having adjudication processes helps the society to improve their skills (i.e. all societies with $Ad_0$ outperform their $Ad_1$ counterparts). This is intuitive, because lacking adjudication processes leads to the removal of agents with lower skills — they used performance-based firing that filters out lower skilled agents. What follows reports results associated with a performed Kendall statistical test to examine the correlation between considered characteristics and the societal skill level.

- Employing commenda contracts has a statistically insignificant, weak, and negative correlation with the societal skill level ($\tau \approx -0.02$ and $p\text{-}value > 0.2$). This means we cannot be sure that this correlation is not a random observation.
- The correlation between closedness of the society and the societal skill of agents is similar to Scenario 1 ($\tau \approx -0.11$ with $p\text{-}value \approx 0$).
- The societal skill level and having adjudication processes has almost the same correlation as Scenario 1 ($\tau \approx -0.37$ with $p\text{-}value \approx 0$).

The correlations between both closedness of society and having adjudication processes, and the societal skill were the same as Scenario 1. However, the correlation between employing commenda contracts and the societal skill level was statistically insignificant and negative, which means it might be a random observation. In this scenario, the worst and the best societal skill levels are associated with $LM_1Co_0Cl_1Ad_1$ (Julfa without commenda contracts) and $LM_1Co_0Cl_1Ad_0$ (the EIC with a low mortality rate in a closed society), respectively.

The next subsection presents another revision of Scenario 1 wherein the type of punishments is decided by courts instead of by the type of contracts.

### 4.4.3 Scenario 3: Court-based punishment

This scenario is another revision of the base game (Scenario 1). Here we attribute types of punishments to employing adjudication processes. In other words, a society lacking adjudication processes uses punishments similar to those of the EIC (i.e. signed bonds and firing) and its agents use the utility function of Equation 4.3. Note that in Scenario 1, if a society had adjudication processes and no commenda contracts, its punishment was similar to those of the EIC (signed bonds); however, in this scenario, the same society has punishments similar to those of Julfa (paying back cheating income in addition to interest). The next subsection presents results of rule conformity for different configurations.

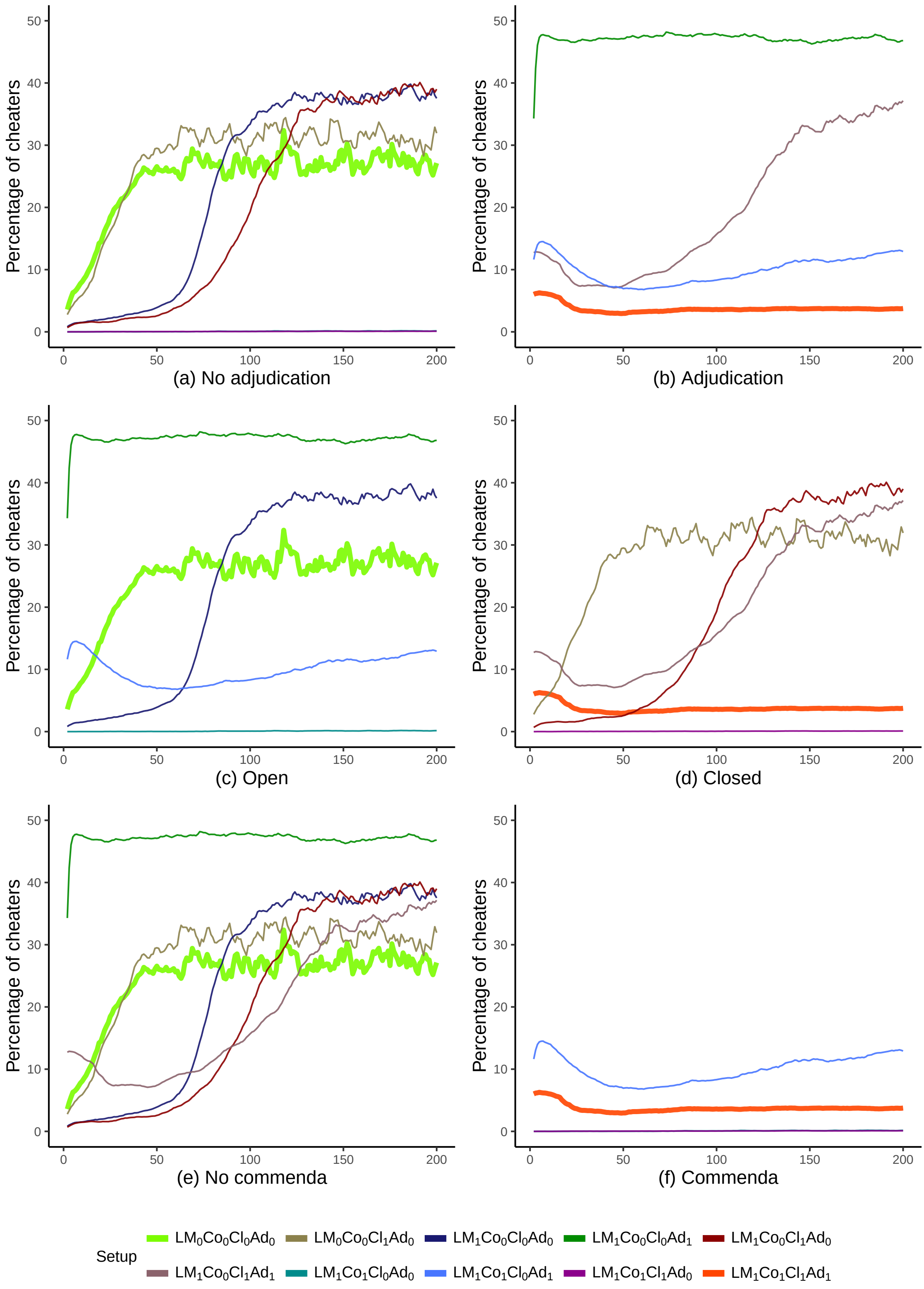


Figure 4.10: Percentage of cheaters in a society, where the x-axis is the number of years and the y-axis is the percentage of cheaters in a society (Scenario 3).

#### 4.4.3.1 The impact of societal configuration on rule conformance

In this subsection, we state the results of simulation runs for Scenario 3, indicated in Figure 4.10. As can be seen, the change in the punishment had a substantial impact on society $LM_1Co_0Cl_0Ad_1$ (i.e. the EIC with an adjudication process and a low mortality rate). Note that this change in pattern that indicates the deterrent impact of signed bonds also indicates the reason the EIC asked for a signed bond and skipped adjudication processes. The bonds — although they were not confiscated — had a substantial value that prevented some potential cheaters from cheating for a while (i.e. until they had learnt about its uselessness). On the other hand, the firing itself is a preventive punishment for commenda contracts, such that the patterns associated with $LM_1Co_1Cl_0Ad_0$ and $LM_1Co_1Cl_1Ad_0$ (i.e. simulated Julfa with no adjudication processes disregarding closedness of society) did not change. In what follows, we present the results of the Kendall statistical test to assess the influence of the considered characteristics on agents' inclinations towards cheating:

- The impact of using commenda contracts on the agents' inclination towards cheating is similar to Scenarios 1 and 2 (i.e. $-0.58$ with a $p\text{-}value < 0.0001$).
- The correlation between closedness of society and the prevalence of cheating has decreased compared to Scenarios 1 and 2 ($\tau \approx -0.18$ and $p\text{-}value < 0.0001$).
- The correlation between agents' inclination towards cheating and having adjudication processes is positive and similar to Scenarios 1 and 2 ($\tau \approx 0.36$ and $p\text{-}value < 0.0001$).

As stated above, the correlations are relatively similar to those of **Scenarios 1** and **2**, except for a decrease in the correlation between closedness of society and the percentage of cheaters. Overall, punishments employed by the EIC and Julfa seem to be properly devised based on their payment schemes.

After stating the impact of the system's characteristics on agents' inclination towards cheating, we only report the trend of cheating behaviour associated with $LM_1Co_0Cl_0Ad_1$ (i.e. the only society with a change in the cheating pattern) for Scenarios 1 and 3. Figure 4.11 represents the boxplot of the experience of cheaters. As can be seen, Scenario 3 has a lower percentage of cheaters with a low experience (less than three years) compared to Scenario 1. However, an increase in the experience of agents, increases agents' inclination towards cheating for Scenario 3 compared to Scenario 1. Note that in Scenario 3, agents know that directors are not able to identify their cheating easily (i.e. the society is open), they are not fired for their bad performance, and the company does not ask for signed bonds. In the next subsection, we state the directors' profits based on different configurations.

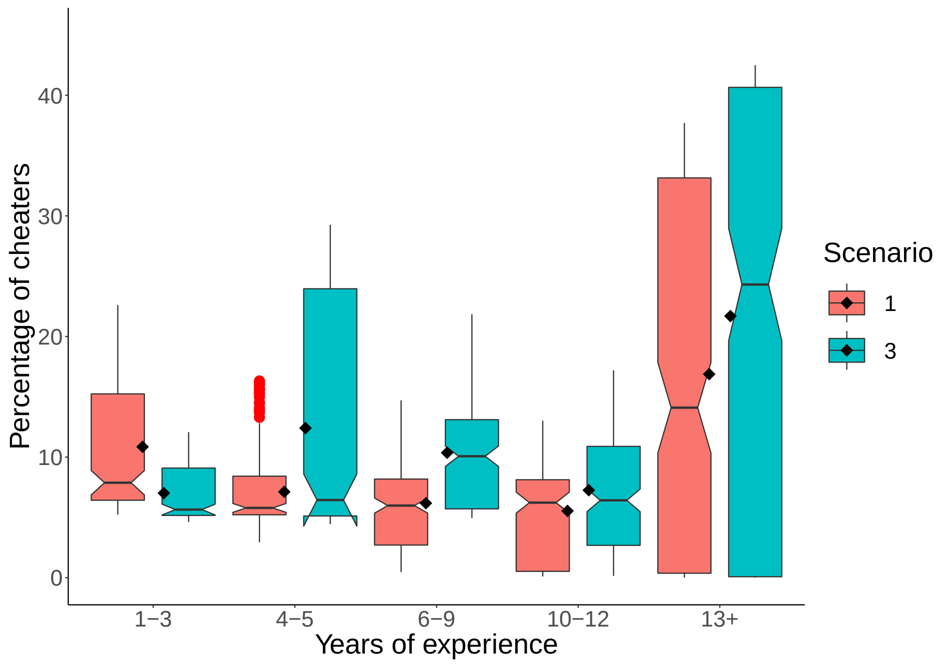


Figure 4.11: Boxplot of the percentage of cheaters in $LM_1Co_0Cl_0Ad_1$ for Scenarios 1 and 3 with respect to the experience.

#### 4.4.3.2 The impact of societal configuration on the profits made by directors

In this subsection, we do not provide a visualisation of the directors' ROR because the patterns did not change compared to Scenario 1 (see Figure 4.5).[12] Below, we report values associated with the Kendall statistical test to measure the correlation between the characteristics and the ROR.

- The correlation between employing commenda contracts and the ROR is also similar to Scenarios 1 and 2 ($\tau \approx 0.16$ with a $p\text{-}value < 0.0001$).
- The correlation between the closedness of the society and the ROR is also similar to Scenarios 1 and 2 ($\tau \approx 0.14$ and $p\text{-}value < 0.0001$).
- The correlation between the ROR and having adjudication processes is weak and negative ($\tau \approx -0.04$). Also, this correlation is on the edge of significance ($p\text{-}value \approx 0.06$). In other words, statistically speaking, we are not very confident about the impact of using adjudication processes on directors' ROR.

In general, this scenario, similar to **Scenario 1**, indicated a positive correlation between both closedness of society and commenda contracts with directors' profits. However, this

[12]Note that there was a decrease in profitability of the $LM_1Co_0Cl_0Ad_1$, but it was still much better than the EIC.

time, the significance of correlation between using adjudication processes and the ROR was weaker.

#### 4.4.3.3 The impact of societal configurations on the societal skill level

In this subsection, we do not provide any visualisations; however, a brief description of Kendall statistical tests is presented below:

- The correlation between using commenda contracts and the societal skill level is statistically insignificant, weak, and negative ($\tau \approx -0.03$ and $p\text{-}value > 0.15$). This indicates that commenda contracts, coupled with stricter punishment, improve the societal skill (i.e. Scenarios 1 and 2).
- The correlation between closedness of the society and the societal skill level is weak and on the edge of significance ($\tau \approx -0.04$ with $p\text{-}value \approx 0.06$). This value increases in comparison with Scenarios 1 and 2.
- The societal skill level of agents and having adjudication processes have the same correlation as Scenarios 1 and 2 ($\tau \approx -0.42$ with $p\text{-}value < 0.0001$).

As can be seen, under this scenario, all three characteristics have a negative impact on the societal skill of the system. However, the only statistically reliable result is firing, based on the performance. In the next section, we briefly explore another extension of Scenario 1.

### 4.4.4 Scenario 4: Conformity

In this scenario, we extend Scenario 1 by considering agents' conformity — they consider cheating based on the number of cheaters observed. For this purpose, we assume that agents are divided into three subgroups with the same size (Tyran & Feld, 2002, points to the emergence of such a phenomenon in real-world scenarios). One group always follow the rules, the second group is potential cheaters, and members of the third group turn into potential cheaters, if they observe a number of cheaters more than a threshold (Algorithm 4.2 lines 39-43). This threshold is randomly generated for each agent separately. Note that for this scenario, we only report the percentage of cheaters (i.e. agents cheated) and potential cheaters (agents consider cheating in their utility function). We do not consider the rest of the results, because we still use the utility function and characteristics of Scenario 1.

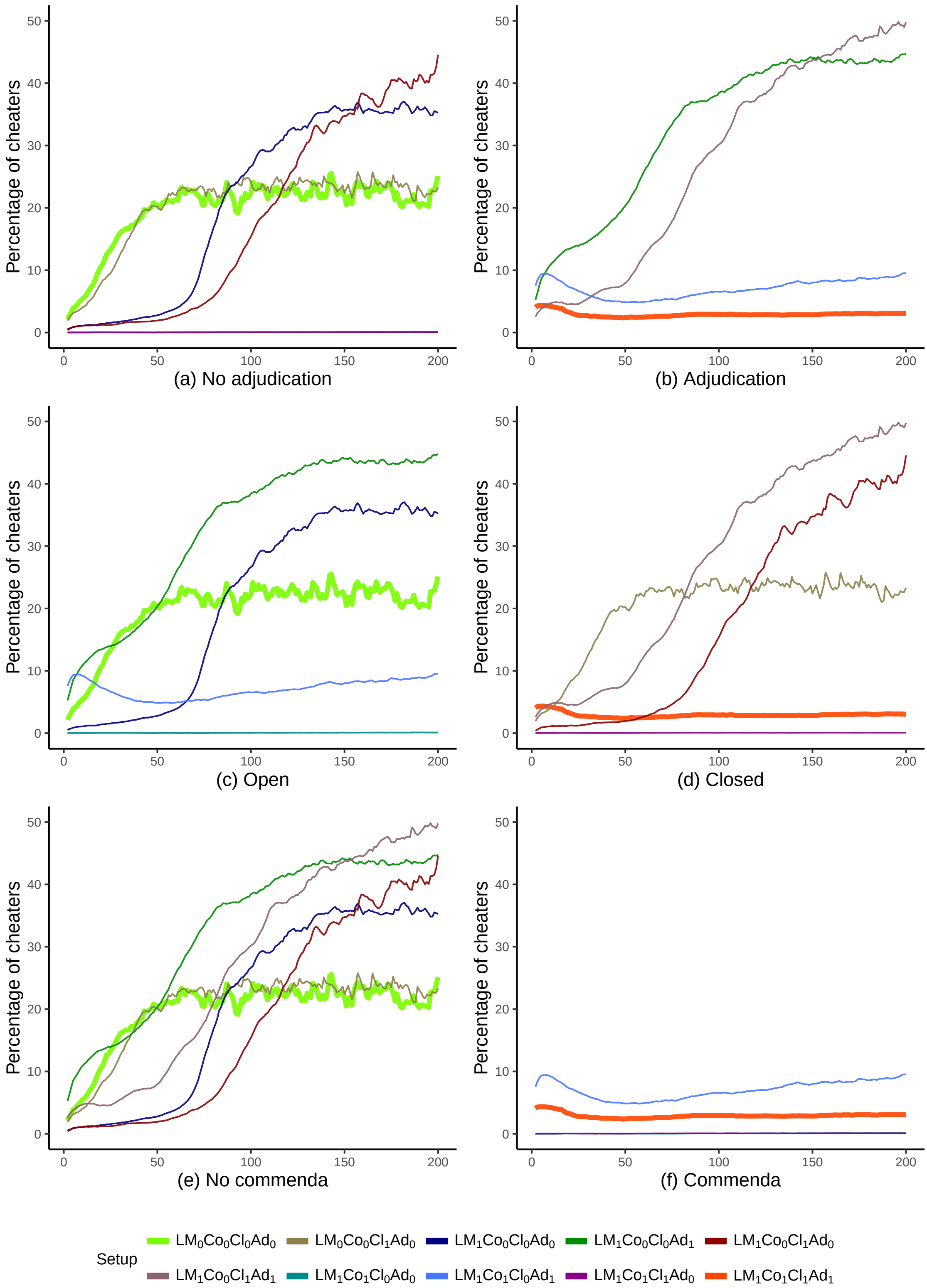


Figure 4.12: Percentage of cheaters in a society, where the x-axis is the number of years and the y-axis is the percentage of cheaters in a society (Scenario 4).

#### 4.4.4.1 The impact of societal configuration on the percentage of cheaters

Figure 4.12 shows the percentage of cheaters for different configurations. As can be seen, the societies without commenda contracts have a change in the patterns in comparison to Scenario 1 (i.e. two closed societies have an increasing trend in cheating, namely $LM_1Co_0$ $Cl_1Ad_0$ and $LM_1Co_0Cl_1Ad_1$). In these two societies, the cheaters remain in the society after getting fired, and some agents consider cheating as an acceptable behaviour because of the availability of the high percentage of cheaters (i.e. agents consider cheating if they think their behaviour is not acceptable). When a society has adjudication processes, the agents cheat sooner, because they assume there is a lower probability of punishment (i.e. they are not punished for bad performance). What follows presents the correlations between the inclination towards cheating and different characteristics:

- The impact of commenda contracts on the agents' inclinations towards cheating is similar to those of Scenarios 1, 2, and 3 (i.e. $-0.58$ with a $p\text{-}value \approx 0$).
- The correlation between closedness of the society and the popularity of cheating is almost similar to those of Scenarios 1, 2, and 3 (i.e. $\tau \approx -0.09$ with $p\text{-}value \approx 0$).
- The correlation between the inclination towards cheating and having adjudication processes is the same as Scenarios 1, 2, and 3 ($\tau \approx 0.37$ and $p\text{-} \approx 0$).

Note that this similarity of correlations was predictable because in this scenario, the agents conform to the behaviour observed. This act based on the prevalence of cheating may increase the number of cheaters, but it would not influence the correlations. In the next subsection, we assess the impact of the conformity on changes in the agent's policy (i.e. considering cheating as a potential policy).

#### 4.4.4.2 The percentage of potential cheaters

Changes in the agent's behaviour, considering conformity (justifying cheating based on popularity), is presented in Figure 4.13. In this figure the straight green line indicates $33\%$ (i.e. the expected minimum of potential cheaters). As can be seen, in all societies, except for $LM_1Co_1Cl_0Ad_0$ and $LM_1Co_1Cl_1Ad_0$ (i.e. the EIC with commenda contracts and a low mortality rate and Julfa without adjudication processes), some agents changed their policy to be a potential cheater (the percentage of potential cheaters is greater than 33%). Note that as shown in Figure 4.12, in some societies (all societies with $Co_1$) the actual percentage of cheaters is lower than the percentage of potential cheaters — about 10% versus more than $33\%$ (see, Figures 4.12f versus 4.13f). In two cases, the numbers of agents who conform to

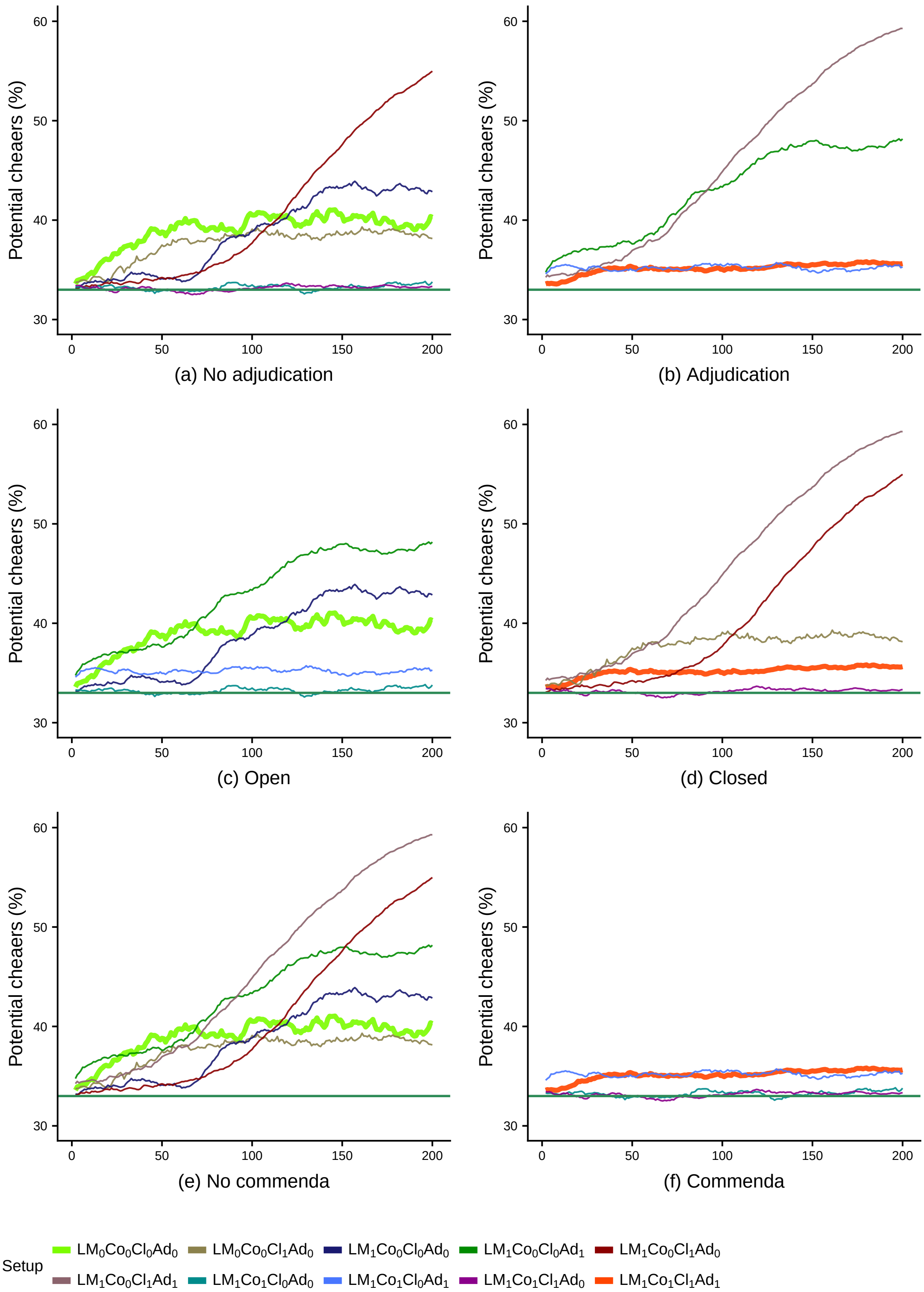


Figure 4.13: Percentage of potential cheaters in a society, where the x-axis is the number of years and the y-axis is the percentage of potential cheaters in a society (Scenario 4).

the cheaters' policy increased — by turning into the potential cheaters. More specifically, in societies $LM_1Co_0Cl_1Ad_0$ and $LM_1Co_0Cl_Ad_1$, the ratios of potential cheaters increased to $60\%$ and $55\%$, respectively. This indicates the negative impact of not sharing profits in a closed society on agents' policies (i.e. they consider cheating in their policy). In the next section, we provide a discussion about the findings of this chapter based on the studied scenarios.

## 4.5 Discussion

This chapter has built a model to simulate the impact of contractual schemes and environmental circumstances on the success of a society. Also, it sheds light on what happened in the two historical long-distance trading societies, namely the EIC and Julfa, along with other hypothetical societies created based on their characteristics. The simulation revised Greif's (1993) model[13] by considering an additional punishment and by using an incomplete information game. This study aimed to investigate the effects of some characteristics of the EIC and Julfa on their success.

Before further discussion, we wish to point out the relevance of the results associated with our representations of the EIC and Julfa with the real societies. Because of the lack of quantitative data, we rely on comparative information provided by merchants who visited both societies. Below, we provide an overview of our simulation results that reflects relevant historical observations:

- **Sustainability:** Our simulation model reproduced a demographically sustainable closed society for Julfa as was observed by historians (see Tables 2.1 and 2.2). Also, for the EIC, our model pointed to the concern that convinced company owners to use an open scheme for hiring agents (it was impossible to establish a closed society for them).
- **Rule conformity:** A common belief among historians and directors of the EIC concerns a prevalence of cheating (for instance, see Chapter 2, footnote 30). Furthermore, evidence concerning dishonest behaviour in Julfa is limited (Aslanian, 2007). The simulation results demonstrate the same situation. In other words, we observe a significant difference between the percentage of cheaters in the EIC and Julfa, with a higher prevalence of cheating in the EIC.
- **Profitability:** Our simulation was successful in reproducing the average ROR obtained by the EIC (i.e. around $10\%$) despite cheating prevalence (see, Chaudhuri, 1978, Table

[13] Greif's (1993) model concentrated on profit-sharing as the main reason for deterring agents from cheating.

A.26, p. 440). Although the simulation results show a lower volatility in the directors' ROR, this can be caused by reasons other than agents' cheating (e.g. changes in the quantity of demand in Britain). The results for Julfan's directors' profits are slightly more than that of the EIC. Although we do not have precise information for the ROR in Julfa, we know that the Julfans continued their policy for more than one century, despite being aware of the EIC's contracts (i.e. they did not find their approach to be less profitable).

Note that the two historical long-distance trading societies were examples of societies facing the principal-agent problem. In other words, in both of them, the principal (master/director) delegated power to an agent. Also, the agent had the potential to make profits by pursuing self-interest in lieu of his mater's interests. What follows states the general results obtained, given the considered characteristics (including hypothetical societies).

**Mortality rate:** To stabilise the population in the society $LM_0Co_0Cl_1Ad_0$ (closed counterpart of the EIC with the same mortality rate), we used trial and error observed that increasing the maximum number of agents from 1.4 to 10.4 stabilises the population (i.e. around 21 children with $70\%$ probability of having one child per year). These numbers show why the EIC could not afford to incorporate a closed system, especially if we consider the assumption's severity (i.e. having 21 children in 30 years while agents are working in a foreign continent). These numbers also emphasise that the Julfans had a low mortality rate (with high mortality rate they could not sustain a closed society).

**Commenda contracts:** The results suggest that it is rational to share a significant amount of profit to control the cheating behaviour of agents. This finding is emphasised by the positive correlation between commenda contracts and the ROR for all considered scenarios — the marginal difference in the values of ROR convinces us that at least it controls the cheaters without any additional costs. Furthermore, different scenarios for punishment indicate that a combination of sharing profits and depriving the cheaters from future collaborations deters agents from cheating.

**Closedness of society:** The most significant impact of closedness of society was on the identification of cheaters. In other words, a system lacking satisfactory rewards eventually faces a large number of cheaters, even with a strong monitoring means. Even though agents in such societies may know they would be identified, they take the risk of cheating and try their luck.

**Adjudication processes:** Another result of this study showed a negative and strong correlation between using adjudication processes and societal skill level. This finding, coupled with marginal differences between the skills of the agents in different societies, calls for a future study on the characteristics which caused the noticeable differences in skills that even convinced the EIC directors to grant Julfans privileges the same as British agents, as quoted in the introduction. A counter-intuitive result of this simulation is related to the deterrent impact of not using adjudication processes on agents' inclination towards cheating. This outcome should be examined further using other methods.

Using Scenario 4, we assessed the impact of system characteristics on a society where part of its agents may turn into potential cheaters based on the number of cheaters observed. This showed that the combination of closedness of society and not using commenda contracts has the most impact of agents' inclination towards becoming a potential cheater. This emphasises the importance of commenda contracts for closed societies like Julfa.

In general, the results of simulation indicate the effect of limited information about a system on the agent's decision-making, as suggested by the rational choice perspective (Monroe, 2001; Simon, 1985). For instance, we observe the impact of low payment schemes on agents' cheating in order to make fast and easy money. On the other hand, the point that profit-sharing (performance-based payments) persuades agents to work better is a phenomenon observed in other studies (Haubrich, 1994). Based on the results of this simulation, payment should be a function of both agents' access to the company's resources and his performance. Otherwise, good monitoring, disregarding having adjudication processes and punishment, cannot control cheating behaviour (this is assessed in Scenarios 1-3). Moreover, in creating a closed collaborative society, some simple parameters, such as environmental circumstances (mortality rate) impact a closed society's sustainability such that neglecting them leads to social failure.

Furthermore, considering the wealth of society (the idea proposed by Adam Smith), cheaters in societies with commenda contracts do the least harm. This is because cheating with high profits (e.g. stealing the director's money) was unpopular in societies with commenda contracts, while a popular form of cheating in a society without commenda contracts involved manipulating of organisation's profits by accepting gifts (i.e. soft bribes; see proportion of cheaters in Figures 4.3e, 4.8e, 4.10e, and 4.12e versus Figures 4.3f, 4.8f, 4.10f, and 4.12f, respectively). Accepting soft bribes changes the game into a non-zero-sum game that leads to a social loss of profits (i.e. yields marginal profits for agents in comparison to large losses for company); however, our results and historical evidence show this was popular among agents.

As stated earlier, there are some limitations to our current work. This simulation neglected the psychological effects of fairness (e.g. using adjudication processes) that are discussed in studies such as Thibaut et al. (1974). We also assumed that the profit of local trades conducted by agents is the same as that which is monopolised by the company. Relaxing this assumption may increase the cheating rates in society. Also, the results could not simulate a higher societal skill of Julfans in comparison to the EIC agents. In the next three chapters, we address the effects of apprenticeship programmes and the impact of the fairness of institutions on agents' behaviour. In particular, the next chapter studies the impact of apprenticeship programmes and vocational schools on the success of society.

# 5

# Impact of apprenticeship programmes and vocational schools on the success of societies

## 5.1 Introduction

This chapter studies apprenticeship as an important tool of skill transfer throughout human history. We extend our study of the two historical trading societies by analysing an additional historical case, i.e. old Britain (1300s–1600s), along with two contemporary schemes of apprenticeship (i.e. those of modern Britain and Germany), to learn the reasons for better performance of some societies than others. This chapter identifies important characteristics for apprenticeship programmes based on the patterns of the investigated societies.

To clarify the subject, we wish to briefly define apprenticeship. Apprenticeship refers to a set of activities and technical training provided by a skilled practitioner in which inexperienced participants learn a profession or art (Hamilton & Hamilton, 1993). Also, as already stated in Section 3.2.5 of Chapter 3, this institution helps a society to turn people with the Worker meta-role into people with the Skill meta-role. Skill transfer is a time-consuming task in which an unskilled individual develops skills under the supervision of professionals. The incentives for apprenticeship are diverse: sustainable development (UNESCO-UNEVOC, 2006, p.9), fighting youth unemployment (Plug & Groot, 1998), and increasing productivity (King, 2009), to name but a few. Also, the importance of apprenticeship is identified by historians. For instance, Riello (2009) suggests that the Indian subcontinent lost its market share in 50 years (i.e. from the 1760s to 1810s) due to the opportunities for Europeans to gradually attain relevant trading skills, and he attributes this as an important reason for British economic advancement in addition to the industrial revolution.

Nowadays the importance of apprenticeship programmes is emphasised in many countries. However, there are different frameworks for apprenticeship programmes, such as work-based training and dual systems (i.e. a combination of schools and work-based training; see Davy & Frankenberg, 2018). Despite the relative success of programmes in terms of the number of skilled agents and increasing profitability, some apprenticeship programmes are accepted as more efficient. Also, there are several studies on formalising apprenticeship programmes (Allais, 2012; Palmer, 2009).

In this chapter, we employ agent-based simulation to improve our understanding of the mechanics that made some apprenticeship programmes such as the Julfan and the German more efficient. To achieve this general objective, we employ intuitive numbers based on available shreds of evidence (e.g. discussions and economic studies), and we avoid employing numbers drawn from specific industries or societies. The reasons for such an approach are as follows:

- We face different systems from geographical and historical points of view;
- Specific numbers for one industry are also influenced by locally specific factors such as exports and imports of products, the mortality rate, and immigration or emigration rates associated with that industry, and the time and society in which it is located.

Beyond historical societies, other studies conducted in Britain and Switzerland emphasise the importance of apprenticeship programmes in the modern context (Fuller & Unwin, 2003; Müehlemann et al., 2009). It has been noted that Germany has a successful apprenticeship programme where companies invest in training apprentices (Büchel, 2002; Franz & Soskice, 1994). This programme has worked well enough so that it has limited the unemployment rate for under 25-year olds to around 6.7 per cent, versus 17.3 per cent across the EU (Jacobs, 2017). The performance of the German model convinced 18 countries to ask for the German government to help to set up the same scheme, and German companies also initiated their foreign apprenticeship projects (Jacobs, 2017).

In this chapter, we compare the utility of various apprenticeship societies that help transfer skills through generations. As stated in Chapters 2 and 4, Julfans had higher skills than the EIC agents. Also, Chapter 4 indicated that this higher skills level cannot be attributed to the Julfan's contractual scheme. This chapter improves our knowledge about the reasons for Julfan's higher skill levels by investigating some important institutional characteristics employed in various apprenticeship societies.

Note that this chapter addresses apprenticeship for two distinct types of trades with different incentives for training (i.e. artisans and manufactures/traders). Although Julfans were known for their long-distance trading societies, they had artisans or worked with artisans who produced items traded. Furthermore, we use manufacturers as a metaphor for traders because of more contemporary studies on them.

The rest of this chapter is organised as follows. Section 5.2 concisely reviews these societies and identifies their differences. Section 5.3 describes the modelling approach used to simulate these systems. Sections 5.4 and 5.5 present the results of the simulations for manufacturers and artisans, respectively. Finally, Section 5.6 discusses the findings of this chapter and provides future directions.

## 5.2 A review of five systems

In this section, we proceed towards modelling apprenticeship programmes. What follows provides an overview of apprenticeship programmes in five different societies, namely Julfa, Germany, old Britain, the EIC, and modern Britain. Then we compare these systems with respect to six characteristics. These characteristics which are identified, based on the similarity of patterns in historical and contemporary apprenticeship programmes and verified by related studies, are listed as follows:

1. **Trade types:** The type of trade helps us to identify important characteristics of training societies. We choose two trades based on the historical cases associated with relatively simple tasks.[1] These trades can be categorised into two types:
    - **Artisans:** These are trades that can be done individually using body parts skillfully.
    - **Manufacturers:** These are any trade (e.g. production systems or long-distance trades) for which some skilled agents are hired to perform tasks for masters. These skills concern handling complexities of systems and using machinery instead of body parts.

[1] We believe that other trades (e.g. the service sectors) can be modelled using concepts of this simulation by selecting relevant characteristics from two given trade types.

2. **Access hurdles:** These hurdles take place in the form of asking for prepayments for training (e.g. premiums) in this chapter we refer to them as prepayment.
3. **Guilds and unions:** These institutions have a restrictive influence on systems by limiting the number of skilled agents by using different means (i.e. limiting the number of apprentices or authorised skilled agents).
4. **Trainer type:** The types of trainers have some impact on the quality of the programme. We address two types of trainers:
   - **Companies:** The company trains an apprentice as a potential employee.
   - **Contractors:** Independent contractors perceive the training apprentices as a source of income.
5. **Schools:** Utilisation of schools (e.g. high schools) is a means of transferring knowledge and academic skills (e.g. analysing).
6. **Openness:** Openness of the society is a characteristic that facilitates leaving the community in the middle of the programme to work in other communities with high demand.

### 5.2.1 Societies' background

In what follows, we describe the characteristics of the five societies, and how these societies possess the characteristics mentioned above.

**Old Britain:** In the old British apprenticeship system (AD 1300s-1600s) guilds were in effect that limited skilled agents from joining the workforce society and made apprentices pay premium costs for training (Wallis, 2008). Also, bigger cities (e.g. London) hosted recruits from smaller towns who frequently left the system once they had adequate skills to work on their town.

**Armenian merchants of New-Julfa (*Julfa*):** Armenian merchants of New-Julfa were originally from old Julfa in Armenia. They re-established a trader society in New-Julfa (near Isfahan, Iran) after their forced displacement in the early 17th century. Due to their complicated inheritance rules that created tight bonds within extended families (Herzig, 1991), they formed a closed society that was run by strong social norms instead of formal rules. Based on the historical data, these traders are known to have had a "merchant school" (Aslanian, 2007, p.171) around the 1680s. A more general apprenticeship system was active in Julfa and Persia (old Iran) to transfer skills in society, wherein skilled agents employed the labour of apprentices and trained them instead of paying high wages. In Julfa, apprenticeship programmes took place informally by family members or relatives who hired or recommended trained apprentices.

**The EIC:** During roughly the same period (AD 1500s-1800s), a parallel system was active in Britain. The British contemporary counterpart of Julfa (i.e. the British *East India Company* (EIC, AD 1500s-1800s)) had a totally different perspective about managing the society. The EIC hired inexperienced apprentices, asked them to provide signed bonds, and sent them for trading to India to be trained by fellow merchants on a voluntary basis. The incentives of trainers for good training is questionable for reasons such as time spent on a task without any provisioned profit (i.e. they trained for immediate income).

**Modern Britain:** In the contemporary era, Britain has used a different scheme for apprenticeship programmes. A survey of this system around 2001 referred to the method as a "*Training Market*" (Ryan & Unwin, 2001). During this time the government employed contractors and a subsidy-based system to compensate the training costs incurred. For paying contractors, the government used a weighting system to rank and pay contractors based on the skill requirement of the society, the trainer's performance (i.e. how many apprentices were trained and how successful they were in finding a job), and the difficulty-level of the target skill.

**Germany:** The other contemporary apprenticeship system which is studied extensively is the German dual apprenticeship system (Franz & Soskice, 1994). These programmes combine teaching technical knowledge in public schools coupled with work-based training provided by certified trainers (i.e. companies). In these programmes, the government invests in providing public schools, and work-based training is provided by companies or individuals. Next, we state the characteristics of these systems in detail. In the following sections, we describe the characteristics of the system mentioned at the beginning of the section.

### 5.2.2 Characteristics and institutions

This section provides an overview of the aforementioned societies with respect to the characteristics stated earlier, namely trade type, access hurdles, workforce restriction (i.e. guilds and unions), trainer type, schools, and the openness of society.

#### 5.2.2.1 Trade type

First we divide systems into two sub-systems based on the trade, similar to the German apprenticeship programme, by using distinct terms. In the contemporary German apprenticeship programmes, two different terms "*Handwerk*" (meaning crafts) and "*Industrie*" (meaning industry) are employed to distinguish different systems. We use 'artisans' and 'manufacturers' to separate these two systems. These trades have different requirements for skills, and trainers have distinct incentives for training.

**Artisan:** An artisan, such as a wood-carver or a hairdresser, trains a potential competitor but can employ trainee services during apprenticeship. For these reasons, in some societies, artisans consider those services insufficient for compensating for the costs, and ask for some payments from apprentices. In addition, some artisans use guilds as a means of restricting trained agents from getting into the system to guarantee the stability of wages in the future. These trades do not require complicated skills for analysis, computations, etc. that are provided by school-based training, and the artisans are the only ones who are eligible to train others (i.e. contractors cannot replace the artisans).

**Manufacturer:** Alternatively, a trader's or manufacturer's trainee does not compete with apprenticeship providers, unlike a trained artisan. For instance, setting up a factory or starting long-distance trades require a large amount of capital when compared to a salon or to buying tools and working at home. Therefore a trained apprentice is a potential employee (not a competitor as in the case of an artisan). The fact that companies have future benefits in training apprentices is a reason for companies to train agents without asking agents for prepayment. These benefits include negotiating for paying slightly less wages than community norms, hiring the best-trained agents, and providing training in some specific skills required for that particular company.

Furthermore, the companies do not have any incentives for limiting the number of trained skilled agents; hence they do not need to have any guilds. However, there are some societies that limit the number of trainees to benefit apprentices (e.g. avoiding a significant drop in wages or losing incentives for participating in apprenticeship programmes), a phenomenon we study later. Note that these trades require complex knowledge and skills that may require school-based training. Furthermore, these skills can also be transferred by employing third-party trainers (i.e. contractors).

Based on the aforementioned arguments, we assume that it is in the vested interest of manufacturers to put in their best efforts to train apprentices that may potentially work for them. This logic shows itself in efforts put forward to transfer all skills to the apprentices. On the other hand, in the artisan training domain, the disinclination to train artisans is observed by Chardin in Persia:

> "There it is indeed that Knowledge must be stolen; for the Master thinking on the Profit he may reap by his 'Prentice [sic], more than on teaching him his Trade,

doth [sic] not trouble himself much with him, but employs him only in those things that relate to his Profit.” (Chardin, 1720, Chapter XVII, p. 261)

To model these systems we divide our model system into the trade types, **artisans** and **manufacturers**. Then we choose the most influential characteristics for each society, based on the above-mentioned statements. These characteristics are as follows (Tables 5.1 and 5.2 represent these characteristics for each trade type):

- **Manufacturers'** characteristics:
  - *Trainer type*,
  - *School*,
  - *Openness of society*.
- **Artisans'** characteristics:
  - *Access hurdles*,
  - *Workforce restrictions*,
  - *Openness of society*.

Table 5.1: System specification based on different societies for **manufacturers**

| **Characteristics** | **Julfa** | **Old Britain** | **The EIC** | **Germany** | **Modern Britain** |
|---|---|---|---|---|---|
| ***Trainer type*** | Not a contractor | Not a contractor | Contractor* | Not a contractor | Contractors |
| ***School*** | Yes | No | No | Yes | No |
| ***Openness of society*** | No | Yes | Yes | No | No |

*In the EIC, employees trained other agents as a responsibility, so they did not have any provisioned profits in good training and only faced costs of spending more time.

Table 5.2: System specification based on different societies for **artisans**

| **Characteristics** | **Julfa and Iran** | **Old Britain** | **The EIC** | **Germany** | **Modern Britain** |
|---|---|---|---|---|---|
| ***Access hurdles*** | No | Yes | Yes | No | Yes |
| ***Workforce restrictions*** | No | Yes | Yes | No | Yes |
| ***Openness of society*** | No | Yes | Yes | No | No |

#### 5.2.2.2 Access hurdles (for artisans only)

Based on the historical evidence of some systems, we note that some societies had entry conditions for apprentices by asking them for premiums to compensate for training costs and as a bond to guarantee reliable behaviour on the part of apprentices.

However, Chardin's (1720)'s travelogue shows no evidence of such requirements in Julfa and more generally, in Persia (i.e. old Iran). Instead, trainers paid wages to the apprentices based on their age and skill, and both parties could freely terminate the programme. An example was a contract involving a family of three agents in Julfa, where agents were paid a lesser extent than was the norm, i.e. it imposed some costs on the father who was the trainer of his two sons.[2] In contrast, in old Britain, some rules prohibited masters from paying apprentices during some periods, and it was a norm to ask apprentices to compensate training costs by paying a premium upfront (Wallis, 2008). This rule (i.e. asking for a premium) could have been an effect of guild power in old Britain. The significant result of asking for a premium was on limiting participants' access to apprenticeship programmes from less-prosperous individuals.

In the EIC, the masters at the headquarters asked employees for a bond signed by two insurers and paid their employees a lower wage than labourers. Furthermore, like other companies in Britain, they only fired agents for bad behaviour[3] (Hejeebu, 2005). In more recent instances (i.e. German apprenticeship programmes and modern apprenticeship programmes in Britain), sometimes there is a payment for eligible apprentices, and there is no evidence of asking for payments from young apprentices[4] (Franz & Soskice, 1994; Ryan & Unwin, 2001). In this chapter, the effect of asking for a premium is abstractly considered in two ways:

- Asking for prepayments in the form of a premium limits the number of participants who can afford to pay the costs for an apprenticeship. Therefore only agents from upper-class families can participate in programmes (the top three deciles).
- These payments are considered as imposed costs by agents in their decision-making about the profitability of programmes.

[2] A father and his two sons entered into a commenda contract (wherein profits are shared between the agent and the principal) and asked for 25% share of the profit (instead of 33%) and part of the profit went to the sons (Herzig, 1991).

[3] They fired agents, not for bad performance, but because they suspected them of cheating. Moreover, the agents had privileges such as private trades and tax exemption inside India, and some of the effects of these items were studied in Chapter 4.

[4] In contemporary British apprenticeship programmes, there is an age restriction for subsidising participants.

#### 5.2.2.3 Workforce restriction (for artisans only)

Here we investigate the impact of two general types of labour market intermediation, namely craft guilds and unions. The craft guilds are associations formed by artisans to follow and secure their mutual benefits (Epstein, 1998; Lis & Soly, 2019). The unions are formed by employees to regulate employers' behaviour (Autor, 2008). These two associations have several impacts on the labour market and some of them are stated here.

One of the prominent effects of **guilds** is *restricting skilled* people from practising their abilities by having exclusive legal privileges for performing that specific action (Ogilvie, 2014). For instance, in old Britain, this power over the market was a way to restrict trained people from being "freemen" and had adverse effects on trainees finishing apprenticeships (Wallis, 2008).[5] However, based on Chardin's observations, no evidence of guilds is available for most skills in Iran (including Julfa):

> "Whoever is about to set up a Shop in any Trade, goes to the Head of the Trade, gives his Name and Place of Abode to be set down in the Register, and pays some small Fee for it. The Head never enquires of what Country the Tradesman is, nor who was his Master, nor whether he understands his Trade. The Trades likewise have no Restrictions, to hinder one from incroaching [sic] upon another. A Tinker makes Silver Basons [sic], if they are bespoke; every one undertakes what he pleases, and they never Sue one another upon that account." (Chardin, 1720, Chapter XVII, p. 260)

Due to the liberalisation of the workforce market in Germany, guilds no longer exist. However, in Britain, the effect of guilds is still present in forms of either guilds themselves or livery companies,[6] especially in the form of creating a lot of unnecessary bureaucracy or difficult exams for skilled people before letting them into the market.

Unions are a means of introducing another kind of restriction in workforce societies. Some unions attempt to regulate wages in a competitive labour market wherein agents are employees of other companies (e.g. in a manufacturer's society)[7]. For instance, Johnston

[5] Epstein (1998) suggested that the craft guilds sustained skilled labours by providing apprenticeship; however, historical evidence indicates that they sometimes had a negative impact (Wallis, 2008).

[6] For instance, see Gwyther (1992) for a report on the power of livery companies in London and Thomas et al. (2013) for a study about guilds in the UK. An example of a guild's website is `https://www.wsd.org.uk`.

[7] Note that "[u]nions have historically solved collective action problems among atomistic workers by organizing collective bargaining, sanctioning employers for misconduct, and regulating employers' hiring and dismissal policies" (Autor, 2008).

and Hancké (2009) stated how unionised societies that were active under the European monetary union, could negotiate for excessive wage increases when there was a loss of employment. Therefore the difference between unions and guilds was inherited from their incentives. Guilds are established in favour of trade profitability, while unions defend the profits of employees at some costs for trades. Therefore a guild's policy is to control the number of skilled agents who can work in the system (i.e. some skilled agents are not permitted to work). However, unions attempt to protect and improve their members interests by means such as stabilising wages. This attempt has consequences such as controlling the number of unemployed agents by regulating the number of apprentices.

#### 5.2.2.4 Trainer type (for manufacturers only)

Based on the analysis of the literature on these systems, we find that some systems had certain types of trainers in apprenticeship programmes (contractors or potential employers). In Julfa, masters (the ones who were the primary owners of the trade) were the ones who trained and monitored the performance of agents. Their simultaneous training and evaluation helped them to identify talented and trustworthy apprentices, especially if masters wanted to hire them. On the other hand, in old Britain, once apprenticeship programmes began, the training could be terminated if apprentices were untrustworthy.

In Germany, the nature of apprenticeship programmes is more complicated. Apprentices learn technical knowledge (henceforth *academic skills*) in public schools (henceforth *education/school*) and they are assessed there. At the same time, there is also work-based training that takes place by *certified companies or craftsmen*. After finishing the process, apprentices gain a ***qualification***. The qualification is strongly controlled for an agent to be eligible to practise a profession. In Germany, some freedom in the programme design lets companies give training in some specific skills needed for employees to work in these companies, along with more general skills. This makes participation in such programmes more attractive for both large and small companies (Franz & Soskice, 1994). Finally, in the modern British programmes, a cost-efficient scheme was designed for training. They subsidised technical trainers, who mostly employed contractors, in addition to some public trainers, based on a scoring scheme that consists of the following:

- the skill requirement,
- the complexity of the skill training,
- the number of trainees combined in a ratio with the ones who find a job.

Moreover, work-based training took place in a company willing to provide a work environment for trainers (mostly small companies). This method created some issues such as tendencies to sacrifice quality of teaching for quantity (since they are paid for quantity) and trainers were inclined towards simpler skills that are easy to teach. In this work, we distinguish between training provided by contractors (the ones involved in the modern British programme) and non-contractors (i.e. *companies* as future potential employers). It should be noted that the contemporary British apprenticeship system officially uses contractors for training apprentices. Furthermore, in the EIC the training was done by more experienced agents at the destination. The method employed in the EIC worked as in modern Britain, because there was no motivation for trainers to train their apprentices well.

#### 5.2.2.5 Schools (for manufacturers only)

An important attribute of systems is associated with their emphasis on the use of schools (e.g. high school and colleges) for academic skills and training purposes. Schools' impact on system performance is twofold. On the one hand, they are a source of declarative *knowledge* (i.e. facts, information, and descriptive knowledge) transfer. This knowledge can be obtained by studying in schools much more easily than in work-based situations. The importance of knowledge is observed in some historical cases, as well as modern instances. For example, Julfans not only provided a pamphlet containing trade information (e.g.routes and conversion of units), but also had a specialised school for training recruits (see Chapter 2).

In the literature, there are arguments about the impact of declarative knowledge on the improvement of learning skills. For instance, Ahlum-Heath and Di Vesta (1986) investigated the impacts of "*know-what*" (i.e. knowledge) on gaining skills associated with solving complex problems by asking some participants to verbalise why they perform certain actions. Their observations suggest that controlled verbalisation accelerates the gaining of problem-solving skills. Some studies suggest that improvements in declarative tactical knowledge facilitate skills transfer[8] (Anderson, 1982; Williams & Davids, 1995).

In addition, a school attendee obtains some *skills* through education (academic skills). For instance, in Julfa a trader should have basic skills in arithmetic and formal writing before he was considered for employment (Aslanian, 2007). In modern contexts, these skills are essentially more extensive. One of the reasons schools are more efficient in transferring academic skills is the time and effort invested by experts to design an appropriate and comprehensive educational system. Therefore in designing courses students' and the industry's diverse capabilities and requirements are considered, and the training is concentrated on developing skills that could be transferred to other contexts.

[8] Declarative tactical knowledge is a combination of information about rules, tasks, objectives of the game, etc. which is overall knowing what to do (Américo et al., 2017).

The importance of different degrees of the aforementioned skills on performance in various fields are stated in Stasz and Brewer (1999, Chapter 3, pp. 15-36). They suggest companies that face more frequent changes in their production processes need agents with technical skills obtained in schools. Such issues, along with limited availability of time and resources at hand in a work-based training environment, call for an independent structure to form and enhance academic skills. This point was neglected in old Britain, the EIC, and the apprenticeship system employed in Britain in 2001, i.e. the schools were not a compulsory part of programmes.

#### 5.2.2.6 Openness versus closedness (for artisans and manufacturers)

Another important attribute of apprenticeship systems concerns the ratio of apprentices that leave the system to work in other communities. This attribute is affected by three characteristics:

- Probability of finding a job with better payments in other places which motivates some agents to leave programmes sooner to work in other communities;
- Reputation for having high skills so that agents can work in other places with higher payments;
- Reputation of programmes that attracts apprentices from other communities.

Henceforth, we call societies providing such opportunities as ***open for training***. These societies train agents that may leave the community to work elsewhere. Some cities in old Britain were open for training (e.g. London (Wallis, 2008)), but Julfa was a totally closed system, where apprentices were only employed within their society. Due to the availability of apprenticeship programmes in Germany and Britain (in most cities) and its availability to their own residents, they are considered to be closed (i.e. the trained apprentices stay in the same community for some years).

However, another definition of openness is the availability of agents from other communities (e.g. countries) to work for lower wages than the norm in the community under study (i.e. ***openness for working***). Openness for working is considered as a scenario in our modelling. To summarise, when a society trains apprentices who may leave, it is open for training. Furthermore, when companies of a society have the opportunity to find trained agents from other communities, it is open for work. Henceforth, by openness we mean that the system is open for training (unless stated otherwise).

Tables 5.1 and 5.2 show selected characteristics based on the trade type and specifications of various societies considered in this work. Note that the availability of these characteristics is considered to be neither good or bad, but we consider them with respect to their impact on the decisions made by trainers and apprentices.

Summarising the characteristics associated with the systems, first, we have divided apprenticeship programmes based on the *trade type* (i.e. artisans versus manufacturers) for a better understanding of the societies' characteristics. Then the *openness* of the society has been considered for both trade types. For complicated industries such as manufacturers, we have addressed the impact of two other characteristics: the use of *schools* in imparting knowledge and academic skills and, *trainer type* that can be a trainer contractor or a company that trains potential employees. For apprenticeship programmes in an artisan trade, we have investigated the impact of an *access hurdles* (i.e. asking for prepayment such as a premium) and the *restrictive influence* of guilds by limiting the number of authorised skilled agents.

## 5.3 Simulation model of two types of traders

Following the description of apprenticeship characteristics, in this section, we present an integrated model for investigating the impact of the six characteristics of the aforementioned societies on their success in training apprentices. This model is a general representation of an apprenticeship system that is built, based on numbers inspired by available evidence, discussions, or empirical figures (e.g. the Pareto principal). In this simulation, we consider two types of agents (i.e. trainers and apprentices) and two types of trades (i.e. manufacturers and artisans). Apprentices are agents who participate in the programme to attain skills, while trainers are agents who participate for diverse motivations.

The motivations of trainers to participate in the programme are based on the trade and their type. In a manufacturing trade where apprentices are potential employees, the company (i.e. potential employer) trains for future profits, earned by the skills of trained agents. However, in the same trade, the contractors train an apprentice for income from the training. Therefore the former (i.e. company) has a motivation for good training, but a contractor wants to reduce the costs of training by modifying the quality of training. On the other hand, artisans train the agents for their income during the programme and sometimes based on community pressure. Before continuing with the model description, let us state some assumptions we made for representatives of the different apprenticeship systems.

### 5.3.1 Model assumptions

There are some assumptions in this model that should be clarified before further descriptions of simulation. These assumptions include system characteristics that impact the expected profits of trainers and apprentices. Therefore we cover the following:

- parameters that are considered in connection with the calculation of expected profits;
- the importance of schools and their impact on different **manufacturing** companies;
- the attainability of work-based and academic skills that represent separate aptitudes which are independent of each other;
- utility functions employed in this chapter;
- reasons for changes in wages.

In this model, both apprentices and trainers calculate their expected profits over a finite horizon by taking into account a discount factor $(\alpha)$ for anticipated income. A finite horizon reflects the myopic decision-making of agents caused by workforce turnover observed in countries such as Germany (Franz & Soskice, 1994). For manufacturers, as formerly discussed, we consider two skills to be obtained (i.e. school-based and work-based skills) that are essential for a good performance for employees in companies. To model the effects of skills on the outcome of companies, we use the idea of Franz and Soskice (1994) in a way that would be applicable for a discrete scenario. The output of a skilled worker $(y)$ is given by:

$$y = f(ed, s_{wb}), \tag{5.1}$$

wherein $ed$ and $s_{wb}$ are skills obtained in school-based and work-based training, respectively.

In our work, we also use Howard Gardner's *Multiple Intelligence* (MI) theory (Howard, 2011) as a framework for the two skills stated above. Gardner argues that IQ is an insufficient measurement of intelligence of an individual.[9] He proposes the idea of MI that splits the intelligence into eight or nine categories (see Howard, 2011, p. xv). He stated that individuals may be strong in certain types of intelligence and be weak in others. In this chapter, differentiation among *Logical-Mathematical*, *Bodily-Kinesthetic*, and *Linguistic* intelligence emphasises the separation of agents' ability to acquire different aspects of skills in school-based and work-based training.

We use the above-mentioned idea by assuming that attainability for work-based skills and school-based skills is different per individual. Some studies suggest that motivation

[9] Howard (2011, p. 19) argues "intelligence tests rarely assess skill in assimilating new information or in solving new problems. This bias toward "crystallized" rather than "fluid" knowledge can have astounding consequences".

(henceforth, *passion*) and achievements are positively correlated (Subotnik et al., 2011). For instance, Kusurkar et al. (2013) indicated positive correlations among *autonomous motivation* (i.e. motivation from within the student), study strategy, and average grades. In our model, the effect is twofold:

- more passionate agents have a higher chance of enrolling in an apprenticeship (i.e. they are persistent in finding a trainer);
- passion causes the apprentice to practise more, and hence, gain skills faster than non-persistent ones.

Some evidence from the German apprenticeship system in the 1980s suggests that some sectors faced deficiencies in the availability of apprenticeship vacancies (Franz & Soskice, 1994, see Table 2).[10] These deficiencies show the importance of being persistent and passionate (e.g. accept to wait for a while) to get into an apprenticeship system.

To model these systems, we consider the following characteristics: *attainability*, *motivation*, *training policy*, and the *trainer's ability to transfer skills* (investigated further when simulation parameters are described). We model these characteristics from 0 to 1, where 0 represents not having the attribute and 1 represents full possession of this attribute.

In our model, the degree of acquired work-based skills falls into three categories that are denoted by discrete numbers (these parameters represent weights for $S_{wb}$ in Equation 5.1). These discrete numbers reflect classifications of skilled agents, based on the predefined thresholds (e.g. shopfitter and cabinet maker) as follows:

- *Excellent (E)* which is denoted by a value of 2, wherein the acquired work-based skill is more than or equal to 0.75. These agents are the ones whose skill acquisitions are in the upper half of the required skill range (i.e. from $0.75$ to $1$),
- *Adequate (AD)* which is denoted by a value of 1, wherein the acquired work-based skill is more than or equal to 0.5 but less than 0.75. These are the agents whose skill acquisitions are in the lower half of the required skill range,
- *Inadequate* which is denoted by a value of 0, wherein the acquired work-based skill is less than 0.5.

For academic skills, we use two categories by employing Boolean numbers. This classification again reflects the scenarios, such as having or not a high-school diploma and is as follows:

[10]Note that being passionate can also be reflected in choices among different programmes in real-world situations, i.e. agents choose the programmes that are more interesting for them. However, a low birth rate in societies with an ever-growing demand for skilled workforce can harm the overall performance of the society.

- *Academic (A)* which is denoted by a value of 1, wherein the apprentice's acquired academic skill is more than or equal to 0.5. This skill is important to analyse the complexities of the system and to adapt to the associated complexities.
- *non-academic (N)* which is denoted by a value of 0, wherein the apprentice's acquired academic skill is less than 0.5. Lacking this skill is not costly for small companies that have routine procedures.

Overall, we have six combinations of academic and work-based skills such that two of them have no benefits for employers. Those two are agent types with inadequate work-based skills (irrespective of whether or not they have adequate academic skills). In the model, we consider two kinds of companies for manufacturers, namely large and small:

- large companies/traders: These are the leaders in the manufacturing/trading area (e.g. electrical technicians for maintenance sectors in a car manufacturing company such as BMW or General Motors and large trading families in Julfa). They have complicated production systems or trade in valuable items, and their employees need some level of education to understand and handle those complexities (see Section 2.2.4).
- Small companies/traders: These are companies, such as household wiring and small shops which are engaged with less complicated technologies and invest less in infrastructure and tools or do trades which are not engaged in luxurious and international trades that need complex computations (e.g. a lot of conversion to compare prices in different countries).

To compute the total amount of income generated in a society by employing apprentices trained by a system, we model certain utility functions. What follows are utility functions to abstractly model income generated by a manufacturing system that hires apprentices (large and small companies). Items produced by large companies have an income function which is given by:

$$U_{Manufacturers}(large) = (a_{MB} \times s_{wb}) + (b_{MB} \times s_{wb} \times ed) \tag{5.2}$$

where $ed$ represents academic skills and can be 0 or 1. Values for $ed$ which are 0 or 1 indicate not having or having academic skills, respectively. Furthermore, $s_{wb}$ can have one of the values $0, 1, 2$ for inadequate, adequate, and excellent work-based skills, respectively. There are two parts to the right side of the equation. The first part shows the role of a work-based skill in developing a product. The second part shows how academic skills, combined with work-based skills, can improve the value of the item manufactured in a company or decrease the wastage produced by agents. As will be described in the *simulation parameters* *section* (see Table 5.3), the higher ratio of $b_{MB}$ to $a_{MB}$ emphasises the value of school-based skills for large manufacturing companies. This shows the importance of investments made by these companies to use complicated machinery that can only be utilised by employing educated and skilled agents, and the lack of academic skills that increases wastage of items and hence, reduces the company's productivity.

Now we describe the utility functions for small companies. The small-company utility function in the manufacturing section is defined as:

$$U_{Manufacturers}(Small) = (a_{MS} \times s_{wb}) + (b_{MS} \times ed \times Boolean(s_{wb})) + (c_{MS} \times Boolean(s_{wb})) \tag{5.3}$$

where $Boolean(s_{wb})$ presents the binary function and is $0$ for inadequate work-based skills and $1$ for adequate or excellent work-based skills. There are three parts to the right-hand side of this equation. The first part of this equation shows that having more work-based skills ($s_{wb}$) improves item values to a limited extent ($a_{MS}$). For small companies with limitations such as having simple machinery, using low or medium quality raw materials, or having limited capital to be engaged in luxury trades, the improvement of the income for possessing more skilled agents (i.e. $a_{MS}$) is small. The second part shows that the combination of academic and work-based skills can offer a certain value in these companies that for the same reasons as before are also small. The third part ($c_{MS} \times Boolean(s_{wb})$) shows that finding an agent who can work with simple machinery can contribute to some profit margins ($c_{MS}$ shows this coefficient). Note that for small companies, due to the simplicity of the manufacturing process, this part should have a significant share in profit margins.

As stated earlier, **artisans'** academic educations do not influence the quality of the final product directly. This assumption is a direct result of the fact that the focus of such skills is on how one can utilise his body parts (e.g. hands) skilfully. Therefore an artisan does not need academic skills, and the utility functions are defined as:

$$U_{Artisans}(large) = (a_{AB} \times s_{wb}), \tag{5.4}$$

for large companies, and:

$$U_{Artisans}(Small) = (a_{AS} \times s_{wb}) + (b_{AS} \times Boolean(s_{wb})) \tag{5.5}$$

for small companies. In these equations, $s_{wb}$ is $0, 1, 2$ for inadequate, adequate, and excellent work-based skills, respectively. Moreover, $Boolean(s_{wb})$ is $0$ for inadequate work-based skills and $1$ for adequate or excellent work-based skills. The utility function for large companies shows the impact of a high degree of skills on the quality of final products when they have a complicated nature (e.g. tapestries). In contrast, high skills cannot improve the quality of less complicated items (e.g. dyed cotton) significantly. Note that as stated earlier, for artisans, the size of the company does not reflect the market share, but it indicates the importance of investments (e.g. purchasing high quality raw materials) on their future income. Therefore we have a higher number of small companies that produce ordinary items and a small number of large companies that produce luxurious items.

Another assumption of this model is related to wages and factors that influence them. One of the main assumptions stated in the field of *labour economics* concerns the correlations between demand and supply in the market (Borjas, 1999). These statements suggest that there is a correlation between labour supply, demand, and wages, such that an excessive supply of the labour force initiates a drop in wages and vice versa, and there is a tendency for the labour market to reach an equilibrium in the long run (see Section 3.3.2.1 for market equilibrium). On the other hand, there is some empirical evidence for *stickiness of wages* that suggests that wages are not adjusted quickly based on labour market behaviour for various reasons (see Blinder & Choi, 1990; Kahn, 1997). This issue (i.e. stickiness of wages) and its influence is addressed in our model by considering a threshold (stickiness threshold) for excess supply and demand below which there is no effect on the wages.

### 5.3.2 Algorithms

The simulation model is split into three executive procedures. The first procedure is executed with the societal level set-up, including the creation of an appropriate society as artisans or a manufacturing society. The second procedure covers the decision-making of trainer agents. The third algorithm describes the procedure of individual apprentices. In each run, these procedures are executed in sequence. Note that all loops run once per iteration.

**Algorithm 5.1** presents the steps of the societal level of the simulation. We assume that in each iteration of the simulation (which is one year), $1000$ new agents are introduced into the apprentice system with random characteristics, and the ones who do not find a trainer leave the society at once (line 1).

Then we divide the system based on the trade type. If the trade deals with artisans, a trainer can accept a new apprentice once the recruited agent's training has been completed (i.e. once every three years). The number of years reflects apprenticeship programmes duration in modern and some historical contexts.[11] In each iteration, a fraction ($R\%$) of skilled

[11] In the German and British instances, programmes duration is three years. In the EIC, after five years, the agents were promoted to factors (i.e. merchants). Note that in the EIC case, apprenticeship programmes were not full-time because the agents already had some tasks to do.

**Algorithm 5.1:** Societal level set-up

/* AP and Waited will be used in the Apprentice's algorithm. */

Create 1000 new agents with random motivation, attainability, and academic skill per run ($AP$ and $Waited \leftarrow 0$)

/* $R$ indicates the demand for new artisans by community members. P-, is a general indicator of probability. For instance, P-Excess-Supply indicates probability of excess supply. $W_i$ stands for wage associated with skill $i$. Stickiness threshold indicates the impact of stickiness of wages; */

**if** *Artisan* **then**

  $Demand_i \leftarrow R\%$ of number of artisans possessing skill $i$

  **if** *Guild* **then**

    P-Excess-Supply $\leftarrow 0$

  **else**

    /* Wages are between their minimum and maximum levels. Also, they are more than wages for lower skill levels. */

    Update P-Excess-Supply

    **if** $\text{Supply}_{\text{Excellent}} \geq \text{Demand}_{\text{Excellent}} + StickinessThresholdshold$ **then** $W_{Excellent} \leftarrow \max\{W_{Excellent} - 1, W^{max}_{Adequate} + 1\}$

    **if** $\text{Supply}_{\text{Adequate}} \geq \text{Demand}_{\text{Adequate}} + StickinessThresholdshold$ **then** $W_{Adequate} \leftarrow \max\{W_{Adequate} - 1, W^{max}_{Adequate}\}$

  **end**

  **if** $\text{Demand}_{\text{i}} \geq \text{Supply}_{\text{i}} + StickinessThresholdshold$ **then** $W_i \leftarrow \min\{W_i + 1, W^{max}_i\}, i \in \{Adequate, Excellent\}$

  Update probability of finding job for each skill

  /* The probability is 1, if there is a deficiency in the labour market for a skill. If there is a surplus supply of skills, the probability is calculated by dividing supply by demand of the company for that skill. Also, agents use a weighting factor for combining historical data with current information. */

**else**

  /* The manufacturers are addressed here. */

  Demand for skilled agents $\leftarrow$ number of companies that did not participate in training apprentices and find it profitable to search from the workforce market.

  Update probability of staying, finding job for each skill, and the number of agents hired based on training

  **if** $\text{Demand}_{\text{i}} \geq \text{Supply}_{\text{i}} + StickinessThresholdshold$ **then** $W_i \leftarrow \min\{W_i + 1, W^{max}_i\}$, $\forall_{skill}$

  **if** $\text{Supply}_{\text{i}} \geq \text{Demand}_{\text{i}} + StickinessThresholdshold$ **then** $W_i \leftarrow \max\{W_i - 1, W^{max}_{i-1} + 1\}$

**end**

/* $N_{ij}$ and $Value_{ij}$ indicate the number and value of items produced by companies with size $i$ (i.e. large or small) that possess agents with skill $j$ (we use associated cell number, e.g. the excellent and academic skill cell number is 5), respectively. */

20 Update overall profit (GDI) of the society based on demand, supply, and value of products that are manufactured, as shown in Table 5.3, using $GDI = \sum_{\forall i} \sum_{\forall j} N_{ij} \times Value_{ij}$

agents are required to replace deceased or retired individuals (lines 2-3).

Furthermore, as mentioned before, the guild prevents an excess supply of skilled agents (lines 4-5). If there is no guild and the surplus supply of skilled agents exceeds its supply in addition to the *stickiness threshold*, the wages for that particular skill decrease by 1 (lines 6-10). In contrast, if the demand for a skill exceeds its supply and the *stickiness threshold*, the wages increase by 1 (lines 11). Finally, the probability of finding a job will be updated in the society, based on the number of unemployed agents, demand for each skill, and weighting information (line 12).

On the other hand, when the system deals with manufacturers (i.e. an apprentice is trained to be potentially hired by the company), the demand and procedures for skilled agents are relatively different (line 14). In a society where contractors train agents, demand represents the number of companies that find it more profitable to wait and hire employees from the existing apprenticeship society where the employees have already acquired skills, rather than hiring just academically educated agents and training them during work (line 15).

Afterwards, wages associated with skill $i$ ($w_i$) are updated, based on the excess supply or demand, and we assume only large numbers of supply or demand can increase or decrease the wages in society (i.e. deviations of around 30% of potential demand) (lines 16-17). Finally, the outcome of the whole apprenticeship programme is decided, based on the degree of skill possessed by hired apprentices (i.e. supply) and the size of the company that hired them (i.e. demand by small or large companies) and their impact on the value of produced items. These two parameters (i.e. skill of apprentices and type of companies) are utilised to calculate the value of produced items by these skilled agents in the form of the Gross Domestic Income as presented in Table 5.3 (i.e. GDI (line 20 )).

**Algorithm 5.2** represents the trainers' decision-making. Note that as mentioned before, artisans and manufacturers societies have different incentives for training; hence, they are addressed separately in this algorithm. If some premium is paid by apprentices, it will be taken into account (lines 1). Then the trainers are divided, based on the nature of the skill (i.e. artisans (lines 2-7) or manufacturers (lines 8-16)). For artisans, the decision to participate in an

**Algorithm 5.2:** Trainer's algorithm

/* Maximise your profit based on your attribute */

**if** *Apprentice pays Premium* **then** Premium $=$ paid premium **else** Premium $= 0$

/* $\alpha$ is a discount factor. $y$ indicates years, for employers/trainees it is 6 and for artisans/contractors it is 3 (i.e. their training horizon). */

/* g and b indicate good and bad quality of training, respectively. */

/* 'labour'is the value of simple tasks performed by apprentices. */

**if** *Artisan* **then**

  $\mathrm{ExpectedProfitOfGoodTraining} = \sum_{y=1}^{3}(\mathrm{labour} \times \alpha^{y}) - (\mathrm{P\text{-}Excess\text{-}Supply_g} \times (\mathrm{lost\text{-}profit(Excess\text{-}Supply)}))$

  $\mathrm{ExpectedProfitOfBadTraining} = \sum_{y=1}^{3}(\mathrm{labour} \times \alpha^{y}) - (\mathrm{P\text{-}Excess\text{-}Supply_b} \times (\mathrm{lost\text{-}profit(Excess\text{-}Supply)}))$

  $\mathrm{ExpectedProfitOfTraining} = \mathrm{premium} + \max\{\mathrm{ProfitOfBadTraining}, \mathrm{ProfitOfGoodTraining}\}$

  $\mathrm{ExpectedProfitOfNotTraining} = 0$

**else**

  /* The manufacturers are addressed here. */

  **if** *Apprentice is a Potential Employee* **then**

    /* $\mathrm{P_{Stay}}$ indicates probability of staying at the company and $f(ed, s_{wb})$ indicates functions associated with academic and school-based skills ($ed$) and work-based ($S_{wb}$), e.g. Probability (Finding($s_1, s_2$)) is the probability of finding an educated agent with excellent work-based skills. */

    /* $w_i$ indicates wages for skill $i$, wherein $i$ indicates different skills (e.g. excellent work-based and academic skills) */

    $\mathrm{Profit\ of\ Training} \leftarrow \mathrm{P_{Stay}} \times \sum_{y \leftarrow 1}^{6}(\mathrm{profit}(f(ed, s_{wb}))(y) \times \alpha^{y} - \mathrm{costs\ of\ training}$

    $\mathrm{profit\ of\ Not\ Training} \leftarrow \max\{\}$

  **else**

    /* Contractor */

    /* $p_{si}$ and $\mathrm{Cost}_i$ ($i \in \{g, b\}$) indicate probability of finding a job and the costs of *g*ood or *b*ad quality of training, respectively. */

    $\mathrm{ExpectedProfitOfGoodTraining} \leftarrow p_{sg} \times \mathrm{Subsidy} + \sum_{y \leftarrow 1}^{6}(\mathrm{Subsidy} \times \alpha^{y}) - \mathrm{Cost}_g$

    $\mathrm{ExpectedprofitOfBadTraining} \leftarrow p_{sb} \times \mathrm{Subsidy} + \sum_{y \leftarrow 1}^{6}(\mathrm{Subsidy} \times \alpha^{y}) - \mathrm{Cost}_b$

    $\mathrm{ExpectedProfitOfTraining} \leftarrow \max\{\mathrm{ProfitOfBadTraining}, \mathrm{ProfitOfGoodTraining}\}$

    $\mathrm{ExpectedProfitOfNotTraining} \leftarrow 0$

  **end**

**end**

**if** (ExpectedProfitOfTraining) $>$ (ExpectedProfitOfNotTraining) **then**

  **if** *(ExpectedProfitOfGoodTraining)* $\geq$ *(ExpectedProfitOfBadTraining)* **then** train good **else** Train bad

```
    else
21  |  Do not train
22  end
    /* Find best apprentices                                   */
23  if Trainer = company then
24  |  if the trainer trained an apprentice and at least one apprentice remains then
25  |  |  Hire the best apprentice
26  |  else
27  |  |  if already hired an Educated Agent then do not hire, or else hire one agent from waiting
    |  |    pool of apprentices that optimises trainer utility
28  |  end
29  end
```

apprenticeship is based on three factors, namely:

- income from labour work during the apprenticeship programme;
- costs incurred by wages decrease due to the excess supply in the workforce market;
- premiums paid by apprentices.

Based on these factors, an artisan calculates the expected income of good training, bad training, and abstaining from training (lines 3-6). On the other hand, manufacturers have a different kind of motivation for training apprentices. They first decide what actions to take (i.e. do not train or provide good or bad training). We divide trainers into two subsets, namely *potential employers* and *contractors*. Potential employers are trainers who hire from their trained pool, while contractors provide just the training (i.e. they do not hire). Quality of training has a direct impact on potential employers' future income, so they make decisions based on:

- the probability of finding a skilled person from already trained agents ($\mathrm{Probability}$ $(\mathrm{Finding\ Skill})$);
- the costs of hiring educated agents and then training them during work;
- the profits of providing good training to an agent.

The profit of good training is decided, based on the probability of an apprentice staying until the end of apprenticeship programmes (lines 8-10). Furthermore, contractors only consider incomes from subsidies in two ways: a) a subsidy paid, based on the number of apprentices trained and b) a subsidy paid based on the trained agents who found a job. Contractors can decrease costs by slightly reducing the quality of training (e.g. hiring low-quality tutors) (lines 12-15). Then based on their calculated profits, trainers decide how to train (lines 18-21). Finally, companies who trained agents will hire the best one (if anyone is left) or they hire academically-educated agents to train them during work (lines 23-29).

**Algorithm 5.3** provides an overview of how agents decide about their attendance in an apprentice programme. First, agents who can afford the programme will update their costs; if there is no premium, then everyone can afford to participate (lines 1-4). Then agents check to see if it is profitable to attend an apprenticeship programme or if it is better to start working in the labour market directly as unskilled labourers (line 5). The rest of the algorithm is about apprentices who attend the programme. Note that if the number of apprentices who find attending the programme profitable exceeds the maximum capacity, the apprenticeship system chooses the ones who are more passionate (i.e. motivated) with a higher chance (line 6).

Then the system checks to find eligible agents (i.e. agents who decided to continue with the programme and who have not completed their apprenticeship period (AP), and then updates their APs (lines 7-8). The eligible agents first increase their apprenticeship experience and set their speed of learning(s) to 1 (line 9). Then the speed of transferring skills to an agent is updated based on the company's size, its training policy, and the apprentice's passion, and whether or not attending school is compulsory (lines 10-12). An example of such a procedure for a contractor who has a policy of 'good' training in a society without compulsory schools for a passionate apprentice (who did not attend school this year) with a work-based attainability of $x$ can be calculated as $s = (\mathrm{s}_{\mathrm{small}} \times \mathrm{s}_{\mathrm{NoKnowledge}} \times \mathrm{s}_{\mathrm{passion}} \times \mathrm{work\text{-}BasedAttainability})/3 = (0.85 \times 0.9 \times 1 \times x)/3 = 0.255 \times x$ (for employed factors see Table 5.3).

Furthermore, the availability of schools introduces the possibility of having more educated agents — unavailability of school reduces this opportunity to agents who pursued the education voluntarily (with a totally random chance — 50% — per run) (lines 13-19). When the society is open, each agent may leave the system with a probability of 10%[12] (line 20). Moreover, an apprentice may find it more profitable to leave the apprenticeship due to the reductions in demand for skilled labour (lines 21), and with a probability of 20%, 50%, or 80% (which is varied in the experiments) the agent checks to see if it is more profitable to leave sooner and use their current skill in their employment (lines 22).

It is essential to emphasise that agents estimate their provisioned skills optimistically and assume they can attain skills faster than before (10% faster).[13] Finally, at the end of

[12]Wallis (2008, see p. 840) provided such level of decline in perusing programme for old Britain.

[13]For instance, Grossman and Owens (2012) indicates that participants felt they are unlucky and their score

their training, apprentices search for a job and at most wait for two years (i.e. at most while

should be higher by about 10%.

**Algorithm 5.3:** Apprentice's algorithm

/* Note that based on the societal level set-up $AP$ and $Waited$ have an initial value of 0 for new agents. */

**if** *did not attend apprenticeship* **then**

  /* check affordability, no premium means no hurdle */

  **if** *Premium should be paid* **then if** *family class = High* **then** affordable?← yes & $prem \leftarrow PaidPremium$

  **else** affordable?← yes & $prem \leftarrow 0$

**end**

/* Agents search for a place and decide whether to attend or not. */

/* $W_{\text{Skill}}$ and $W_{\text{EstimatedSkill}}$ denotes wage for acquired and estimated work-based and school-based skills. */

**if** *Not attending &* $((\sum_{y \leftarrow 4}^{6}(\alpha^y \times ((\text{p}_{\text{FindingJob}} \times W_{\text{Skill}}) + (1 - \text{p}_{\text{FindingJob}}))) - prem) \geq (\sum_{y \leftarrow 1}^{6} \alpha^y))$ **then** Profitable ← yes

**if** *Number of agents with (Profitable = yes) > capacity* **then** Choose appropriate number of agents with higher scores.

/* The system associates scores to each agent. These scores are generated based on their passion. Then it chooses agents with higher scores. */

/* Henceforth, only apprenticeship attendees are considered. */

**if** "Apprenticeship period" (AP) $\leq 3$ & not an 'unsuccessful apprentice" **then**

  $AP \leftarrow AP + 1$

  /* Training speed (s) may decrease (e.g. for trainer's policy). */

  /* 'work-based'and 'academic'skills increase based on attainability and trainer's skill and policy. */

  $s \leftarrow 1$

  **if** *Trainer ≠ LargeCompany* **then** $s \leftarrow s \times 0.85$

  **if** *Trainer'sPolicy ≠ GoodTraining* **then** $s \leftarrow s \times 0.9$

  **if** *Passion ≤ 0.5* **then** $s \leftarrow s \times 0.9$

  **if** *School* **then**

    Work-BasedSkill ← $((\text{Work-BasedAttainability}/3) \times s)+$ Work-BasedSkill

    AcademicSkill← $((\text{AcademicAttainability}/3) \times s)+$ AcademicSkill

  **else**

    /* $\#random\ 1$ means generating random float in $(0, 1)$ interval. */

    Work-BasedSkill ← $((\text{Work-BasedAttainability}/3) \times 0.9 \times s)+$ Work-BasedSkill

    **if** $\#random\ 1 \leq 0.5$ **then** AcademicSkill ← $((\text{AcademicAttainability}/3) \times s)+$ AcademicSkill

  **end**

20 **if** $Open$ & $\#random\ 1 \leq 0.1$ **then** leave

21 **if** $(\sum_{y \leftarrow 3+AP}^{6}(\mathrm{p}_{\mathrm{FindingJob}} \times \mathrm{W}_{\mathrm{EstimatedSkill}}) \times \alpha^{y}) < \sum_{y \leftarrow 1}^{6} \times \alpha^{y}$ **then** unsuccessful apprentice (leave)

`/* c is defined as percentage who check profitability of leaving the programme (20%, 50%, or 80%) */`

22 **if** $\#random\ 1 < C$ & $(\sum_{y \leftarrow 1}^{6}(\mathrm{p}_{\mathrm{FindingJob}} \times \mathrm{W}_{\mathrm{Skill}}) \times \alpha^{y}) < \sum_{y \leftarrow 3+AP}^{6}(\mathrm{p}_{\mathrm{FindingJob}} \times \mathrm{W}_{\mathrm{EstimatedSkill}}) \times \alpha^{y})$ **then** Search for job

23 **else**

24 **if** *(Do not have a job & successful apprentice) or search for job* **then**

25 Compete to find a job to fulfill demands based on skill (i.e. join the waiting pool)

26 **if** *#random 1* $< 0.5\times$ *Waited* **then** Leave **else** Waited ← Waited + 1

27 **end**

28 **end**

$0.5 \times waited < 1)$[14] and when they cannot find any jobs, they leave the waiting list to pursue other labourer jobs afterwards (lines 24-28).

### 5.3.3 Simulation parameters

In this section, we state the important parameters used (see Table 5.3) in this simulation and the reasons for choosing the values presented. Note that for both apprenticeship trades (i.e. artisans and manufacturers) we used 300 iterations as a representative for the most duration that we knew lasted in different societies (old Britain's apprenticeship programmes was active between 1500 to 1800).

**The number of potential apprentices:** The simulation creates 1000 new agents per iteration. This number shows the birth rate in a society that introduces new persons who potentially can attend the apprenticeship programme.

**Attainability:** In our simulation model, we assume that the degree to which agents can acquire different types of skills (i.e. work-based and school-based) are not similar and we call those degrees attainabilities. Apprentices should have a minimum attainability level for a work-based skill to be qualified to enrol in an apprenticeship programme. Therefore we assume that agents have the ability to acquire the minimum required work-based skills if they

[14] Worthen (2002) stated that the Workforce Development committee recommended that enrolling every two years for plumbers' apprenticeship programme is inefficient because "[high school graduates] won't wait around 2 years."

Table 5.3: The simulation parameters

| No. | Name | Comment | Distribution\parameter | Values |
|---|---|---|---|---|
| 1 | Number of potential apprentices | Per run | Constant | 1000 |
| 2 | Attainability | For work-based skill<br>For academic | Uniform | (0.5, 1)<br>(0, 1) |
| 3 | Passion | To learn the skill | Uniform | (0, 1) |
| 4 | Number of companies | Large : Small | Pareto principle | 20 : 80 |
| 5 | Utility function (artisans)*<br>Large:Small | E<br>AD | $a_{AB} = 10$<br>$a_{AS} = 1.5, b_{AS} = 10$ | 20 : 13<br>10 : 11.5 |
| 5 | Utility function (manufacturers)*<br>Large : Small | A E<br>A AD<br>N E<br>N AD | $a_{MB} = 5, b_{MB} = 10$<br>$a_{MS} = 2, b_{MS} = 2$<br>$c_{MB} = 8$ | 30 : 14<br>15:12<br>10:12<br>5:10 |
| 6 | Speed of training | Large : Small companies<br>Good : Bad training<br>School : No school | Constant | 1 : 0.85<br>1 : 0.9<br>1 : 0.9 |
| 7 | Speed of learning | Passionate ($\geq 0.5$)<br>Not passionate ($< 0.5$) | Constant | 1<br>0.9 |
| 8 | Academic skills | School<br>No school | Constant<br>Probability per run | 1<br>0.5 |
| 9 | Initial wages (artisans)* | E<br>AD | Adapted, based<br>on situation | 11<br>7 |
| 10 | Initial wages (manufacturers)* | A E<br>A AD<br>N E<br>N AD | Adapted, based<br>on situation | 10<br>8<br>4<br>3 |
| 11 | Stickiness threshold | Indicates<br>changes in labour<br>supply/demand that do<br>not impact the wages | Constant | 30** |
| 12 | Discount factor ($\alpha$) | All agents | Normal ($\mu, \sigma$) | (0.9, 0.033) |
| 13 | Years<br>(considered for calculating profit) | Constant | - | 6 |
| 14 | Maximum waiting time (years) | To search for jobs | Constant | 2 |
| 15 | Weight of past information | Apprentices<br>Companies | Constant | 0.3<br>0.5 |

* Note that A and N indicates having and not having academic skills, respectively. Also, E and AD indicates possessing excellent and adequate work-based skills, respectively.

**We check the impact of this parameter on simulation in Scenario A of manufacturers (see Table 5.7).

put sufficient effort into apprenticeship programmes (i.e. 0.5) for a work-based skill. Therefore the work-based attainability for qualified agents has a continuous uniform distribution in the interval (0.5, 1)).

However, the attainability of academic skills is independent of work-based skills and has a continuous uniform distribution in the interval (0, 1). The minimum attainability of 0 reflects the fact that agents may not have any interests or intelligence for school-based training, but they attend that programme because it is a compulsory part of the programme. Note that we employed continuous parameters for attainability to facilitate gradual increments of them in the simulation.

**Passion:** In the simulation model, each agent has a passion to learn the new skill. This number is randomly generated from the $(0, 1)$ interval.

**The number of companies:** One of the parameters that impacts demand in the labour market is ***ratio of companies***. We assumed the ratio of small companies to large companies in a society to be $4:1$, inspired by the *Pareto principle*. This ratio complies with infrastructure to residential building companies presented by the Ministry of Business, Innovation and Employment (2017).[15] Furthermore, Geerolf (2017) indicates that under certain production functions and assumptions that are not very restrictive, the *Pareto Principle* is upheld.[16] In our study, we only use the rate as an indicator for the ratio of large to small companies, not a representation of their market share.[17]

**Utility function — artisans:** As stated earlier, different trading societies have different utility functions. Overall, two points impact these utilities, namely the size of the company (i.e. large or small) and the trade type (i.e. artisan or manufacturing). Overall, a large company has a high potential to make profits for the investments made on providing advanced production processes or buying high-quality raw materials. In an artisan-trading society, the large and small companies are metaphors for budget spent on raw materials by an artisan when producing an item based on their target market (i.e. part of the community is more prosperous and hence, can afford more luxurious items). This phenomenon is also considered in the form of the proportion of demands in a society (i.e. the percentage of prosperous

[15]Estimated based on figures in New Zealand see Figure 3-8, (pp. 9-12).

[16]Overall, the *Pareto principle* expresses Vilfredo Pareto's statement who experimentally observed the ratio of persons with an income more than $x$ can be modelled as $Cx^{-\alpha}$, wherein $C$ and $\alpha$ are constants (Arnold, 2015, p. 1). This dominance of some companies over market is known as the 80/20 rule by economists, exhibiting phenomena that around 80% of values are produced by 20% of society. This behaviour is also expressed as "probability of measuring a particular value of some quantity varies inversely as a power of that value" (Newman, 2005).

[17]Some studies such as Brynjolfsson et al. (2011), suggest revisions on 20% market share (i.e. long tail phenomenon) but these revisions are questioned in other empirical studies (Zhong & Michahelles, 2013).

families in a community is limited; hence, the demand for items provided by high-skilled agents is less). Attempts of low-skilled agents for producing decorative items lead to more wastage costs due to their limited ability to perform complicated tasks. On the other hand, high-skilled agents cannot benefit from their skills to perform advanced tasks when their target market includes average families who cannot afford expensive items. The values of items are calculated based on Equations 5.4 and 5.5, and the parameters presented in Table 5.3. For instance, the value of an item produced by an agent with adequate skills ($s = 1$) in a small company is obtained as $a_{AS} \times 1 + b_{AS} \times 1 = 1.5 + 10 = 11.5$ using Equation 5.5.

**Utility function — manufacturers:** In a manufacturing society, the advanced production process means more frequent changes in the process. The academic skills are required to handle these frequent changes in equipment and help the employees to predict some what-if scenarios by utilising their information and analysing skills obtained in schools (Stasz & Brewer, 1999). Note that having low work-based skills or not having school-based skills lead to a significant loss in large companies for producing scrapped items and opportunity loss, despite remarkable depreciation costs. Furthermore, small companies utilising simple production processes can benefit from work-based and school-based skills obtained by agents to a limited extent. The values are obtained based on Equations 5.2 and 5.3, and the parameters presented in Table 5.3. For instance, the value of an item produced by an agent with adequate and academic skills ($s = 1$ and $ed = 1$) in a large company is obtained as $a_{MB} \times 1 + b_{MB} \times 1 \times 1 = 5 + 10 = 15$, using Equation 5.2.

Furthermore, as stated earlier, in some manufacturing apprenticeship schemes, some ***Contractors*** were employed to train agents. We assume that contractor processes are similar to that of small companies (i.e. they do not invest in providing resources for an advanced learning environment). Furthermore, note that we know that in the modern apprenticeship in Britain mostly small companies were interested in providing work-based training. This implies it is not profitable for large companies to invest in training apprentices. Both small companies and contractors use simple procedures; therefore we have assumed that the maximum transferred skill (to an apprentice) is limited to $85\%$. The lower chance of training highly skilled agents is a consequence of the company's limited resources (i.e. trainer's skills and available tools) that decreases the quality of training.

**Speed of training and learning:** As stated in the algorithms, training and learning speeds are modified, based on the quality of training and the agent's characteristics. We assumed that the lack of the following worsens *speed of learning* and *the speed of the training*, and reduces these by $10\%$:

- Passion (e.g. practising beyond the necessary);

- Good training (i.e. putting all efforts towards transferring skills to apprentices);
- Declarative knowledge (i.e. providing guidelines and required rules by experts before starting work-based training).

We have considered small numbers (i.e. 10% reduction) to study the impact of the aforementioned parameters on the speed of learning. The reasons for this small reduction are as follows:

- If the deviation is significant, especially for the passion and quality of training, then it can be recognised by third parties such as the government, unions, and the trainer, and they will interfere to rectify the system.
- Knowledge exclusion by not having attended school can be compensated by providing some guidance during work-based training, but it is time-consuming. This time-consumption slightly decreases the overall quality of training by decreasing the available time for work-based training.
- If small numbers indicate significant impacts, increasing them would not show anything new.

**Academic skills:** Another important attribute of the apprenticeship programmes for manufacturing societies is the engagement of ***schools***. If systems lack formal schools as a compulsory part of programmes, each apprentice with the probability of 50% gains academic skills per iteration. This percentage reflects arbitrary decisions on attending schools voluntarily made by agents per run, based on their perception about their academic skills and value of such skills.

As mentioned before, in manufacturing societies, contractors are paid for training apprentices. However, ***training costs*** for artisans and manufacturing companies are a concern that should be addressed. Based on arguments provided by Franz and Soskice (1994) and Wallis (2008), there are two reasons artisan-trainers accept apprentices despite the apparent costs:

1. There are benefits of manual labour provided by the apprentices, at the beginning of apprenticeship along with additional profits associated with their services for acquired skill during their apprenticeship. Wallis (2008) proposes some necessary tasks that are useful in the workplace such as delivery, cleaning, and shop watching that could be done by apprentices and suggests that youth in old Britain might have gained some other useful skills, i.e. work-related or general chores, by training provided by their parents.

2. Franz and Soskice (1994) mention an additional reason for artisans to accept apprentices. They note there are reasons net costs of training are negligible or negative (i.e. it can be profitable considering the aforementioned incomes). Also, if there exist small costs, especially in small towns, being from the same social circles and knowing the parents of an applicant puts some pressures on artisans to accept applicants. Overall, social circles and friends and family put pressures on artisans to accept these marginal costs to create a good reputation.

In our model, we considered a small proportion of costs for manufacturers in addition to negotiation privileges for them (i.e. they pay lower wages than the norm of society for that particular skill). For those artisans who accept apprentices, the motivation for training apprentices is to create a good reputation in addition to utilising apprentice services that also result in some marginal profits.

**Initial wages — artisans and manufacturers:** Another crucial element for having a stable system is paid wages and expected profits of apprenticeship programmes. Former studies indicated that if these numbers are not chosen correctly, the system fails.[18] Note that these numbers are chosen, based on the following conditions, by considering utility functions of companies (to avoid making a system unprofitable and eventually fail). Two requirements of agents' wages that we considered are:

- The wages for a high level of skills should be more than a lower level of skills (e.g. an educated agent with excellent work-based skills is paid more than his uneducated counterparts).
- The wages cannot exceed the price of the item produced using the same skill for both large and small companies (i.e. companies need to have enough income to pay wages).

The openness of the system in terms of being open for training worsens the programme completion ratio. Some may join the apprenticeship system, but may exit earlier to work where a low level of skills is required.[19] Another impact of the openness of the system is addressed in one scenario of manufacturers where some skilled agents from other communities may join the system to work for companies (which will be stated in the next section).

**Stickiness threshold:** This number shows the excessive labour supply or demand for skilled agents beyond which wages in the labour markets change. In other words, wages do not adjust to the market equilibrium for values below this number. For example, if 100

[18] Franz and Soskice analytically indicated the importance of these costs and their trade-off — see (Franz & Soskice, 1994), Section 3.1, (pp. 16-17).

[19] A 15% decrease in leaving programmes is observed for cases where the number of cities in which that particular skill could be utilised was limited to 3 (see Wallis, 2008, p. 844).

agents are employed and 29 agents are unemployed in a society, the wages do not change. In our model, we have considered 30 as the stickiness threshold; however, we test the impact of other values on the model in one of the manufacturing scenarios (Scenario A, Table 5.7).

**Discount factor and number of years:** Another parameter that impacts trainers and apprentices' expected profits of the programme is their discount factor and provisioned horizon. The agents use a discount factor to calculate the net present value of future income in a finite horizon (6 years). The number of years reflects the high workforce turnover observed in Germany, the high mortality rate in the EIC, and overall, the time inconsistency of expectation observed in studies such as Ainslie (2015). For a discount factor for money, we used evidence available from Julfa (Herzig, 1991). Herzig (1991) suggested that the interest rate norm in Julfa was around 10% per annum. This number suggests how Julfans mentally discounted the value of money.

Another important factor of apprenticeship programmes is their ***duration***. The number of years in apprenticeship programmes is inspired by modern programmes (i.e. 3 years) to make results more applicable. However, this assumption does not comply with some historical cases such as old Britain and Persia, but is essential in modern contexts where there are minimum age constraints to enter programmes and the availability of alternative programmes with three years duration.

**Maximum waiting time:** After completing the programme, agents will search for jobs and will not stay unemployed for more than two years (i.e. they will stay in the system for at most two years), and the chance of leaving the waiting pool in the first and second years (if they are unemployed) is 0.5 and 1, respectively. These figures are employed to reflect concerns, such as living cost requirements and family pressures (see also footnote 14).

However, in manufacturing systems run by companies, some of the trained apprentices are ***hired*** by companies. If manufacturers train some agents, they hire the qualified agent who possesses the highest degree of skill (i.e. they do not hire agents from the labour market). The reasons for such a decision are listed below:

- Pressures imposed by society and unions that expect companies to hire their apprentices if they need some skilled agents.
- The employees of a company also expect the company to hire one of the trainees because of the friendship bonds formed during the programme.
- The company has a vested interest in hiring its own apprentices, because they attain specific skills that are important for the company, and they are familiar with specific procedures inside the company that are not known to outsiders.

In addition, estimations of ***probabilities*** in the system are based on globally known information about the number of hired agents, agents' skills, the number of trainers, and trainers' current policy to decide about participating in apprenticeship programmes, and the quality of training. For the number of hired agents and number of traders, we know that currently, countries have official reports on their skills shortages, and unemployment rates, etc. that are indicators for agents to decide the next iterations. In older contexts, for lower population per community, rumours and observed shortages are means that agents can use for an estimation about those figures.

**Weight of past information:** Furthermore, we parametrise agents' learning and their behaviours as follows. The agents' skills and the trainers' current policy are numbers that can be assessed by asking former trainers and references in both contemporary and historical instances. Apprentices discount past information using a weight of 30% for past and a weight of 70% for recent information. This reflects the importance of recent information for apprentices, because they do not monitor the system for a long time. On the other hand, companies use a 50% weight for recent information and past information. Note that companies keep a better track of past information than apprentices, because companies are active in the system for a longer time than apprentices. Therefore we used a different weighting for companies to abstractly reflect their experiential differences that stem from their long term activity in the system.

Trainers estimate the impacts of changing their training policy from good to bad, or hiring from already educated people, based on known parameters. In other words, they assume if they change their policy from good quality to bad quality training, the chances for agents to obtain high skills decreases by 10%. For hiring already educated agents, large companies assume that an agent has a 45% chance of having excellent skills, 45% of having adequate skills, and 10% of having inadequate skills after training. This assumption is based on predicted low motivation for learning new skills by already hired agents on their obtained skills.

Therefore a manufacturer predicts a hired agent obtains adequate and excellent skills with a probability of $0.5 \times 0.9 = 0.45$, wherein $\mathbf{0.5}$ is estimated, based on the agents' attainability that is continuously and uniformly distributed in (0.5,1) and the thresholds for different levels of skill, i.e. $0.5$ and $0.75$.[20] Also, $\mathbf{0.9}$ indicates reductions in the speed of learning because of a lack of motivation. Furthermore, inadequate skills are obtained with the probability of

[20]Note that the probability of $X$, where $x_1 < X < x_2$, which follows a uniform distribution in $(a, b)$, is calculated as $(x_2 - x_1)/(b - a)$ (see Equation 5.6). Here it is calculated as $(0.75 - 0.5)/(1 - 0.5) = 0.5$ and $(1 - 0.75)/(1 - 0.5) = 0.5$, for probabilities of adequate and high work-based skills, respectively.

$0.1$ (i.e. $1-$ aforementioned skills).

In Sections 5.4 and 5.5, we provide results of this simulation for manufacturers and artisans, respectively. We have utilised *NetLogo* to perform our simulation (Wilensky, 1999). We also used 30 different runs for each system and then averaged their results. Moreover, we assume each iteration reflects a year.

## 5.4 Results of apprenticeship for manufacturers

In this section, we describe the results of the simulation for manufacturers, considering eight different combinations of three characteristics (indicated in Table 5.1), namely:

- Engagement of schools;
- Openness of the system (for training);
- Trainer type (i.e. companies or contractors)

Table 5.4 indicates characteristics for the eight simulated societies and societies they represent. The set-ups (i.e. societies) are identified by a prefix (M.) that represents the trade type of *manufacturing*. Additionally, each society can be identified by the first letter of the characteristics, namely *S, O, C* that are representatives of compulsory *school*, ***o**penness* of the system, and ***c**ompany* trader, respectively. We used a Boolean index to indicate whether such an attribute is included (i.e. 1) or not (i.e. 0). Likewise, in this table a tick indicates that the society includes that attribute, and a cross indicates the society does not include that attribute.

Table 5.4: Set-ups for apprenticeship in manufacturers

| Characteristics | $M.S_0O_0C_0$ (Modern Britain) | $M.S_0O_0C_1$ | $M.S_0O_1C_0$ (EIC/old Britain) | $M.S_0O_1C_1$ | $M.S_1O_0C_0$ | $M.S_1O_0C_1$ (Julfa/Germany) | $M.S_1O_1C_0$ | $M.S_1O_1C_1$ |
|---|---|---|---|---|---|---|---|---|
| School | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ |
| Open | ✗ | ✗ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Company | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ |

Moreover, we assumed 20%, 50%, or 80% of agents (in different experiments) might check for job opportunities during their apprenticeship, and may leave the programme if they find checking for the job more profitable. These numbers (i.e. 20, 50, 80) are chosen to cover representative values in a continuum of values from 0% to 100% to see if they have a significant impact on the outcome of the system. In simulation, we considered three scenarios, namely:

Scenario A) Training a sufficient number of agents, i.e. unions impose pressures to limit the number of agents to the labour demand;

Scenario B) No union in effect, i.e. the number of apprentices attending programmes can be significantly more than the provisioned demand;

Scenario C) Openness for working, i.e. the community attracts and accepts agents from other communities for reasons such as having a better economy or facing skill shortage.

The unions are the means to try to defend workers' interests such as guilds in an artisan's society with different means. The impact of unions is studied under *Scenario A* for manufacturers, where unions or the government regulates the number of companies that are eligible to train apprentices. Moreover, the only case where manufacturers put up some barriers was that of the EIC where the headquarters asked for signing bonds by two insurers. This impact is not studied in our model, because those bonds could have been signed by totally unknown people (see Hejeebu, 2005, footnote 43).

Note that the threshold used for the stickiness of wages is considered to be 30. Results regarding the impact of changing stickiness thresholds associated with labour supply and demand on different systems performance are studied in *Scenario A*. Furthermore, for simplicity, we use ***academic*** and ***non-academic*** as shorthand for *having* and *not having* the ***school-based skill***, respectively. For ***work-based skills***, we use ***excellent*** and ***adequate*** and will not explicitly mention ***work-based skills*** anymore.

What follows presents the aforementioned scenarios. The first scenario is the base scenario (inspired from the German apprenticeship programmes), and then, we systematically explore how more liberal scenarios impact apprenticeship programmes. The aim of this systematic exploration is to identify the extent to which workforce liberalisation impacts the market in terms of apprenticeship programmes.

### 5.4.1 Scenario A for manufacturers: Train to satisfy the labour market demand

In Scenario A of apprenticeship programmes, societies invest in training to minimise the number of unemployed agents. This scheme addresses two issues raised by the excessive training of apprentices, namely:

1. exorbitant rates of unemployment for that particular skill that is a concern for unions;

2. training costs imposed on the system due to the investment of public services, such as schools, and payments to contractors.

To address these issues, we assume each contractor has a capacity to train 12 apprentices per year (i.e. they train $20\%$ more apprentices than what the labour market needs to address the openness of the society), and when companies initiate training, small companies will not participate in training (i.e. the system starts by training 100 apprentices). They may add to the system when there is some vacant capacity for training, e.g. some large companies are not interested in participating. Note that at most, **6 small companies** can participate in training in the next iterations when all large companies accept apprentices to reduce the risks of skill shortages.[21] The capacity for contractors is defined to reflect government boundaries on paying subsidies to limit the total number of trained agents. Training by larger companies and limitation are a reflection of the following:

- the higher tendency for agents to be trained by companies with a better reputation;
- government intervention to enhance the reputation of the apprenticeship system (e.g. the German government let certain certified companies train apprentices that limits the number of companies that participated in the programme (Ryan & Unwin, 2001)).

As can be seen in Table 5.5 and based on the Pareto principle, the maximum number of apprentices per run can be calculated as $10 \times 12 = 120$ for systems run by contractors and $(20 \times 5) + (6 \times 1) = 106$ for systems run by large and small companies.

Table 5.5: The additional simulation parameters for Scenario A

| Name | Comment | Distribution | Values |
|---|---|---|---|
| Number of contractors | | Constant | 10 |
| Number of companies | Large:Small | Constant | 20:80 |
| Capacity for training | Large companies | Constant | 5 |
| | Small companies | | 1 |
| | Contractors | | 12 |
| Maximum number of apprentices | Companies | Capacity $\times$ maximum number of participants | 106 |
| | Contractors | | 120 |
| Probability of leaving the system* | When system is open (per run) | Constant | 0.1 |

*Stated in footnote 12.

The capacity for manufacturers is obtained based on their expectations from the system and trade-offs between costs and benefits. In a system benefiting from school training, it

[21] We know in German apprenticeship programmes, only eligible companies could participate in training that indicates some interventions to control training an excessive number of apprentices (Franz & Soskice, 1994). This number can be optimised for a real-world scenario.

is expected that half of the students obtain enough academic skills based on a continuous uniform distribution of the academic attainability of students. The chances of obtaining excellent work-based skills is $50\%$, considering the distribution of agents' attainability and the required degree of skill. In other words, an agent needs to obtain $0.75$ of skill, while the attainability has a continuous uniform distribution in the range $(0.5, 1)$, which means half of the trainees have the chance to obtain excellent skills. Note that when $x$ follows $U(a, b)$, i.e. $x$ follows a continuous uniform distribution in $(a, b)$, we have from S. M. Ross (2010, p. 195):

$$P(x \geq c) = \begin{cases} 0 & c \leq a \\ \dfrac{b-c}{b-a} & a < c \leq b \\ 1 & b < c \end{cases} \tag{5.6}$$

Wherein $P(x)$ is the probability of $x$. Therefore we have:

$$P(s_{wb} \geq 0.75) = \frac{1 - 0.75}{1 - 0.5} = 0.5 \tag{5.7}$$

Due to the fact that academic and work-based skill attainability are independent, a random agent with a chance of $25\%$ can have academic and excellent work-based skills altogether, i.e. he has $50\%$ chance of obtaining academic skills, and considering the former probability, we have $0.5 \times 0.5 = 0.25$. Therefore on average, having four apprentices leads to having one desirable trainee if that one is passionate and finishes the programme. This part is calculated, based on the *geometric* random variable expected value. This distribution is appropriate to calculate the probability of one success for any trial of games or experiments, such that each trial has a Boolean-value outcome such as tossing a coin. Let $p$ be the probability of success and the number of required successes is one; then the expected value of the number of trials $X$ can be obtained as (S. M. Ross, 2010, pp. 157–159):

$$\mathrm{E}(X) = \frac{1}{p}, \tag{5.8}$$

and in our model it equals $1/0.25 = 4$. However, there is a chance that having four apprentices would not lead to having a desirable agent. Some reasons are apprentices leaving the programme before completion or a company's inability to find an apprentice who has the best skills with a chance of $(1 - 0.25)^4 \approx 0.32$. This probability is calculated based on the attributes of *geometric* probability distribution and its formula for the number of runs $(x)$ being more than $n$ (S. M. Ross, 2010, p. 156):

$$P(x > n) = \sum_{i=n+1}^{\infty} P\{X = i\} = \sum_{i=n+1}^{\infty} p(1-p)^{i-1} = (1-p)^n. \tag{5.9}$$

On the other hand, for requirements and costs associated with training, the manufacturers cannot accept many apprentices, so *five* apprentices are considered to be the maximum capacity for apprenticeship programmes.

The capacity of small companies is defined based on their small budget and workshop space. However, since there is not much difference among incomes obtained by different skills, and the risks only concern the probability of the apprentice leaving the programme or training an apprentice with an attainability lower than $0.6$ — then in this case, the risks of (i.e. probability for) not finding an ideal agent is around the same number for small and large companies. The chance for small companies is $(0.6 - 0.1)/(1 - 0.5) = 0.2$, and for large companies, it can be calculated as $0.75^5 \approx 0.24$. Note that we increased large companies' maximum capacity to five.

The capacity of contractors is calculated using a simple approach. For contractors, most training costs are covered by the government, and to cover the rest of the costs, it is enough that some of their apprentices find jobs. In the current scenario, this capacity is defined to avoid significant differences between the overall capacity of systems run by contractors and companies (see Table 5.5). However, due to the lower quality of training for contractors that is a consequence of their limited investments, we assumed that the government and unions let them have slightly more capacity (i.e. maximum of $120$ versus $106$). Note that either the government had to accept this increase in capacity or grant significant subsidies to trainers to establish much more complicated processes that were not affordable for small companies.

Table 5.6 presents observed *programme completion* and the *Gross Domestic Income (GDI)* produced by apprenticeship programmes for each type of society (see Table 5.4) based on different tendencies for apprentices to check for jobs before finishing the programme. To study the success of each apprentice system, we first analyse the percentage of attendees who finished apprenticeship programmes. The result based on this metric is suggested by Ryan and Unwin (2001) as an indicator for the efficacy of the German apprenticeship programmes against its British counterpart.

#### 5.4.1.1 Impact on programme completion

As can be seen in Table 5.6, the four top successful systems using this metric (for all probabilities of checking for a job — 0.2, 0.5 and 0.8) are systems $M.S_0O_0C_1$, $M.S_1O_0C_1$, $M.S_1O_0C_0$, and $M.S_0O_0C_0$ where the systems are closed ($O_0$). Moreover, when more agents are looking for a job during training, the completion rate decreases drastically. We used non-

Table 5.6: Programme completion ratio and the GDI for different set-ups considering Scenario A (mean ± standard deviation)

| **Part 1 (Societies $\mathbf{M.S_0O_0C_0}$–$\mathbf{M.S_0O_1C_1}$)** | | | | | |
|---|---|---|---|---|---|
| **Set-up** | **Probability of checking for job** | $\mathbf{M.S_0O_0C_0}$ (modern Britain) | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_0O_1C_0}$ (EIC/ old Britain) | $\mathbf{M.S_0O_1C_1}$ |
| ***Programme completion (%)*** | 0.2 | 65.7 ± 5.9 | 77.6 ± 5.4 | 39.4 ± 3.6 | 44.6± 3.5 |
| | 0.5 | 45.9 ± 4.1 | 52.4 ± 4.2 | 27.9 ± 2.5 | 32.0 ± 2.7 |
| | 0.8 | 29.5 ± 2.6 | 31.1 ± 2.2 | 18.1 ± 1.7 | 21.6 ± 1.8 |
| ***GDI*** | 0.2 | 724 ± 64 | 888 ± 56 | 379 ± 35 | 361 ± 57 |
| | 0.5 | 554 ± 50 | 670 ± 49 | 279 ± 26 | 269 ± 34 |
| | 0.8 | 379 ± 35 | 372 ± 36 | 179 ± 18 | 204 ± 21 |
| **Part 2 (Societies $\mathbf{M.S_1O_0C_0}$–$\mathbf{M.S_1O_1C_1}$)** | | | | | |
| **Set-up** | **Probability of checking for job** | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ (Julfa/ Germany) | $\mathbf{M.S_1O_1C_0}$ | $\mathbf{M.S_1O_1C_1}$ |
| ***Programme completion (%)*** | 0.2 | 72.4 ± 4.7 | 77.5 ± 3.7 | 43.4 ± 2.6 | 46.3 ± 2.6 |
| | 0.5 | 45.8 ±2.7 | 49.5 ± 2.1 | 28.3 ± 1.7 | 32.5 ± 1.5 |
| | 0.8 | 24.9 ± 1.5 | 25.6 ± 1.4 | 16.4 ± 0.9 | 20.9 ± 1.2 |
| ***GDI*** | 0.2 | 1215 ± 58 | 1264 ± 45 | 740 ± 34 | 830 ± 33 |
| | 0.5 | 907 ± 35 | 973 ± 29 | 554 ± 25 | 672 ± 25 |
| | 0.8 | 599 ± 31 | 627 ± 26 | 361 ± 21 | 494 ± 25 |

parametric tests[22] to investigate the impact of the percentage of agents who checked for a job during their programme on the programme completion ratio. The test indicates that an increase in job-seeking behaviour significantly decreases the percentage of agents who finished the programme. Based on these test results, we can conclude that a given society having some rules or norms that persuade agents to finish the programme will improve programme completion. For simplicity henceforth, we mainly present and describe results related to the case of 20% agents checking job opportunities.

Now we state in detail the results of the percentage of agents who finished the programme for each of the eight simulated societies. As can be seen in Figure 5.1 (a-f), the systems (with 0.2 probability of checking for a job) producing the highest completion ratio are societies $M.S_0O_0C_1$ and $M.S_1O_0C_1$ where the systems are closed (i.e. $O_0$) and companies train the apprentices (i.e. $C_1$). Moreover, $M.S_0O_1C_0$ and $M.S_1O_1C_0$ are systems with the least num-

[22]We employed Kruskal-Wallis and Pairwise Mann-Whitney tests as post-hoc analysis due to the non-homogeneity of variances that was identified by the Fligner-Killeen test.

ber of apprentices who finished the programme (see Figure 5.1, c). This result emphasises the adverse effect of the combination of openness (i.e. $O_0$) and contractor trainers (i.e. $C_0$) on the decisions made by trainers about finishing the programme.

Now let us focus on the systems similar to the German apprenticeship programme and Julfa which is system $M.S_1O_0C_1$. It can be observed that this system is working well as anticipated, with 77.5% completing the apprenticeship. Moreover, the result is consistent with observations for the German system.[23] However, this consistency stems from some other factors in the German system (i.e. the requirement to complete the programme to earn a qualification) which is considered in this model as the probability of checking for jobs (see the second column of Table 5.6).

We know that in countries such as Britain, such a rule was not in effect and one can even assume that contractors may encourage trainees to search for a job during the programme to earn their subsidies faster. Therefore such societies are highly likely to behave worse (see Table 5.6 results associated with a higher probability of checking for jobs). Furthermore, in cases where tendencies to leave the programme are high (e.g. 80% of apprentices check for jobs), the absence of academic education encourages trainees to stay until the end of the apprenticeship programme. This phenomenon can be seen in societies which lack compulsory schools that are identified by $S_0$ ($M.S_0O_0C_0$, $M.S_0O_0C_1$, $M.S_0O_1C_0$, and $M.S_0O_1C_1$), versus societies with compulsory schools that are identified by $S_1$ ($M.S_1O_0C_0$, $M.S_1O_0C_1$, $M.S_1O_1C_0$, and $M.S_1O_1C_1$) that is caused by slower training, which causes concerns about inadequate skills at the end of the programme and which convinces apprentices to terminate the programme sooner.

We also conducted a Wilcoxon Rank Sum statistical test to identify the impact of the studied characteristics on finishing the programme. The test indicates the importance of:

- the closedness of society (i.e. the combination of closed systems identified by $O_0$ ($M.S_0O_0C_0$, $M.S_0O_0C_1$, $M.S_1O_0C_0$, and $M.S_1O_0C_1$) outperforms the combination of open systems identified by $O_1$ ($M.S_0O_1C_0$, $M.S_0O_1C_1$, $M.S_1O_1C_0$, and $M.S_1O_1C_1$);
- the engagement of schools (i.e. systems with compulsory schools identified by $S_1$ ($M.S_1O_0C_0$, $M.S_1O_0C_1$, $M.S_1O_1C_0$, and $M.S_1O_1C_1$) outperforms systems without compulsory schools identified by $S_0$ ($M.S_0O_0C_0$, $M.S_0O_0C_1$, $M.S_0O_1C_0$, and $M.S_0O_1C_1$);
- training by companies — societies identified by $C_1$ ($M.S_0O_0C_1$, $M.S_0O_1C_1$, $M.S_1O_0$

[23] Around 75% of apprentices finish the programme in Germany (Ryan & Unwin, 2001).

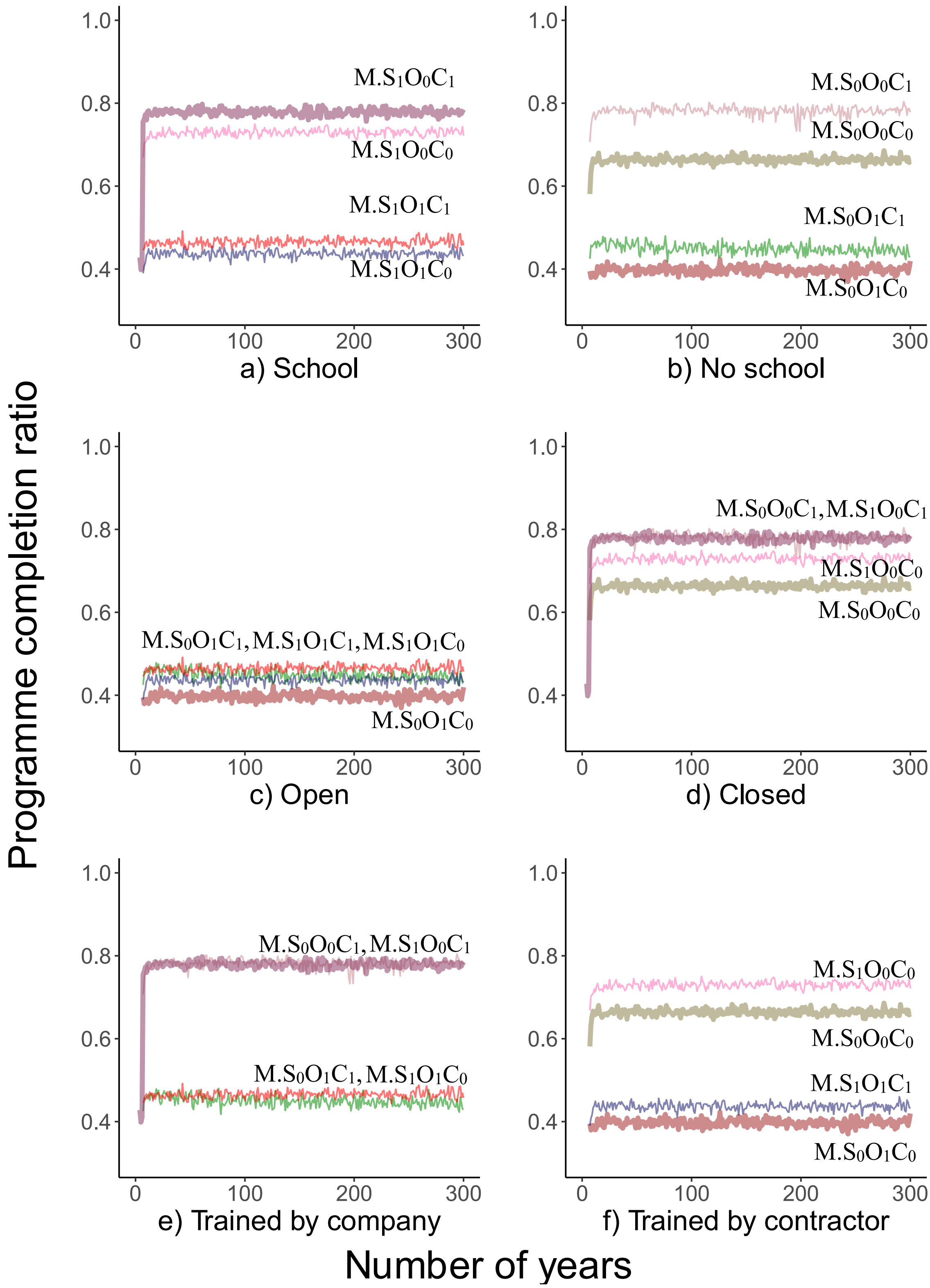


Figure 5.1: Programme completion ratio for different set-ups (a-f).

$C_1$, and $M.S_1O_1C_1$) — results in better performance than training by contractors — systems identified by $C_0$ ($M.S_0O_0C_0$, $M.S_0O_1C_0$, $M.S_1O_0C_0$, and $M.S_1O_1C_0$).

The aforementioned factors increase the percentage of agents who finished the programme ($p < 0.01$ for all tests) when 20% of agents were looking for a job during the programme. Finally, when more agents check for jobs during an apprenticeship (i.e. 50% and 80%), the impact of the engagement of schools in apprenticeship programmes on programme completion changes from positive to negative with $p < 0.01$ (i.e. decreases completion rate). This change is predictable, considering the combination of two factors, namely:

- faster work-based skill development in societies that benefit from schools;
- tendencies for agents who acquired some levels of skills (e.g. adequate work-based skills) to look for jobs.

#### 5.4.1.2 Impact on the GDI

Another method to measure the success of apprenticeship programmes is using the Gross Domestic Income (GDI) of the society, based on items manufactured by hired apprentices (see Table 5.6 and Figure 5.2). First, we compare the correlation between programme completion and the GDI based on the numbers presented in Table 5.6. The outcome of Spearman tests *for different societies* shows more than weak positive correlations between the GDI and the percentage of agents who finished the programme (i.e. the values of correlation are 0.83 for 20% and 0.44 for both the cases where 50% and 80% of the agents who checked for jobs ($p < 0.01$)). These indicate that an increase in the tendency for checking for jobs, decreases the average effectiveness of remaining apprentices who completed programmes; hence, the correlation between the GDI and completion ratio decreases.

However, a moderate correlation with the higher percentage of agents who look for a job (for 50% and 80%) is an indicator of the inappropriateness of the utilised metric by Ryan and Unwin (2001) (i.e. under certain circumstances, an increase in the GDI has not accompanied an increase in the percentage of agents who have finished the programme, e.g. see Table 5.6, $M.S_0O_1C_0$ versus $M.S_0O_1C_1$). Using a non-parametric test to investigate the impact of the percentage of agents who checked for a job during apprenticeship indicates that an increase in job-seeking behaviour significantly decreases the GDI. Based on these test results, again, the importance of having some rules or norms for persuading agents to finish the programme is emphasised. As stated earlier, for simplicity, henceforth, we only present and describe results related to the case of 20% of agents checking for job opportunities.

As can be seen, societies $M.S_1O_0C_0$ and $M.S_1O_0C_1$ have a higher GDI (see Table 5.6) than other systems wherein compulsory schools are engaged in the programme (identified by $S_1$), and these societies are closed ($O_0$). Now switching to Figure 5.2, we can see that changes in other characteristics of apprenticeship programmes when companies are responsible for training apprentices (identified by $C_1$) vary the GDI drastically — i.e. the GDIs of systems $M.S_0O_0C_1$, $M.S_0O_1C_1$, $M.S_1O_1C_1$ are much lower than $M.S_1O_0C_1$ (see Figure 5.2). The best performance of the system is obtained by society $M.S_1O_0C_1$, the best replicate of Julfa and Germany. This increase in performance is a result of the engagement of schools ($S_1$), training by companies as potential employers ($C_1$), and fewer tendencies to leave the system during the programme ($O_0$). However, when the assumption of using school or closedness of a system is relaxed, the performance decreases drastically (i.e. systems $M.S_0O_0C_1$, $M.S_0O_1C_1$, and $M.S_1O_1C_1$). Figure 5.2 shows that:

- systems $M.S_1O_0C_0$ and $M.S_1O_0C_1$ have the highest GDI;
- systems $M.S_0O_1C_1$ and $M.S_0O_1C_0$ (the EIC) have the lowest GDI;
- systems $M.S_0O_0C_0$, $M.S_0O_0C_1$, $M.S_1O_1C_0$, and $M.S_1O_1C_1$ perform similarly.

The Kruskal–Wallis and Pairwise Wilcoxon Rank Sum statistical tests indicate that the GDI of all societies is statistically different ($p < 0.01$ for all tests) when 20% of agents are looking for a job during the apprenticeship programme.

To have a better analysis, we also conducted a Wilcoxon Rank Sum statistical test to identify the impact of studied characteristics on the GDI of the societies. The test indicates the importance of:

- the closedness of society (i.e. a combination of closed systems identified by $O_0$ ($M.S_0O_0C_0$, $M.S_0O_0C_1$, $M.S_1O_0C_0$, and $M.S_1O_0C_1$) outperforms the combination of open systems identified by $O_1$ ($M.S_0O_1C_0$, $M.S_0O_1C_1$, $M.S_1O_1C_0$, and $M.S_1O_1C_1$));
- engagement of schools (i.e. systems with compulsory schools identified by $S_1$ ($M.S_1O_0C_0$, $M.S_1O_0C_1$, $M.S_1O_1C_0$, and $M.S_1O_1C_1$) outperform contrasting systems ($M.S_0O_0C_0$, $M.S_0O_0C_1$, $M.S_0O_1C_0$, and $M.S_0O_1C_1$) altogether);
- being trained by companies (i.e. systems identified by $C_1$ ($M.S_0O_0C_1$, $M.S_0O_1C_1$, $M.S_1O_0C_1$, and $M.S_1O_1C_1$) perform better than systems identified by $C_0$ ($M.S_0O_0$ $C_0$, $M.S_0O_1C_0$, $M.S_1O_0C_0$, and $M.S_1O_1C_0$) as a whole, wherein contractors train agents).

The above-mentioned characteristics significantly increase the GDI of the society ($p < 0.01$ for all tests), regardless of the percentage of agents who look for a job during the apprenticeship programme (i.e. for 20, 50, and 80 per cent).

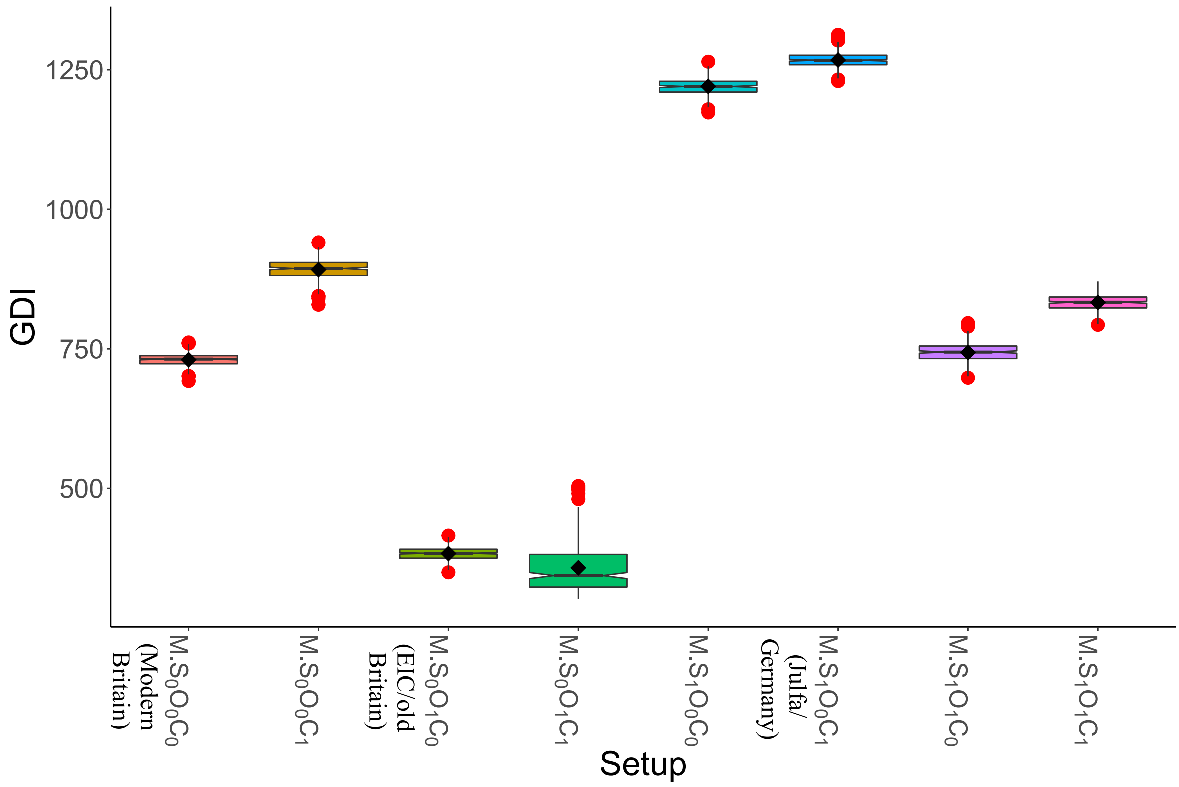


Figure 5.2: Boxplot of the GDI acquired by apprentices programmes under different set-ups; the red dots present outliers and a diamond indicates the mean.

#### 5.4.1.3 Impact of excess supply and demand — stickiness threshold

The stickiness threshold is the threshold at which excess demand/supply causes changes in wages. We vary the stickiness threshold for demand/supply to examine its impact on different simulation results, namely:

- profitability (GDI);
- the programme completion ratio;
- wages.

To do so, we systematically varied the initial number of the stickiness threshold for stickiness of wages (i.e. 30 surplus/shortages skills in labour market) by:

- using an extreme point (i.e. 1);
- halving it (15);
- doubling it (60).

As can be seen in Table 5.7, for different combinations of set-ups and stickiness thresholds, these changes do not significantly change the percentage of agents who finished the programme nor the GDI. Furthermore, these stickiness thresholds have various impacts on

Table 5.7: The GDI and the programme completion ratio for different set-ups with respect to the stickiness threshold associated with the market tolerance towards excess demand and supply (mean ± standard deviation).

**Part 1 (Societies $\mathbf{M.S_0O_0C_0}$–$\mathbf{M.S_0O_1C_1}$)**

| Set-up | Stickiness threshold | $\mathbf{M.S_0O_0C_0}$ (modern Britain) | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_0O_1C_0}$ (EIC/ old Britain) | $\mathbf{M.S_0O_1C_1}$ |
|---|---|---|---|---|---|
| ***Finished programme (%)*** | 1 | 65.8 ± 5.9 | 77.6 ± 5.6 | 39.3 ± 3.5 | 44.7 ± 3.8 |
| | 15 | 65.9 ± 5.6 | 77.9 ± 5.8 | 39.4± 3.7 | 44.5± 3.6 |
| | 30 | 65.7 ± 5.9 | 77.6 ± 5.4 | 39.4 ± 3.6 | 44.6± 3.5 |
| | 60 | 65.2 ± 5.9 | 76.6 ± 6.2 | 39.4 ± 3.6 | 44.6 ± 3.7 |
| ***GDI*** | 1 | 725 ± 66 | 885 ± 59 | 380 ± 35 | 372 ± 58 |
| | 15 | 725 ± 62 | 896 ± 60 | 380 ± 37 | 357 ± 55 |
| | 30 | 724 ± 64 | 888 ± 56 | 379 ± 35 | 361 ± 57 |
| | 60 | 735 ± 68 | 898 ± 68 | 380 ± 36 | 374 ± 74 |

**Part 2 (Societies $\mathbf{M.S_1O_0C_0}$–$\mathbf{M.S_1O_1C_1}$)**

| Set-up | Stickiness threshold | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ (Julfa/ Germany) | $\mathbf{M.S_1O_1C_0}$ | $\mathbf{M.S_1O_1C_1}$ |
|---|---|---|---|---|---|
| ***Finished programme (%)*** | 1 | 72.1 ± 4.8 | 77.6 ± 3.5 | 43.4 ± 2.9 | 46.2 ± 2.3 |
| | 15 | 72.3 ± 4.6 | 77.4 ± 3.3 | 43.5± 2.6 | 46.3± 2.4 |
| | 30 | 72.4 ± 4.7 | 77.5 ± 3.7 | 43.4 ± 2.6 | 46.3 ± 2.6 |
| | 60 | 71.7 ± 4.3 | 76.9 ± 3.6 | 43.4± 2.8 | 46.3 ± 2.3 |
| ***GDI*** | 1 | 1209 ± 58 | 1265 ± 41 | 740 ± 37 | 830 ± 30 |
| | 15 | 1213 ± 55 | 1265 ± 41 | 741 ± 35 | 829 ± 32 |
| | 30 | 1215 ± 58 | 1264 ± 45 | 740 ± 34 | 830 ± 33 |
| | 60 | 1205 ± 52 | 1297 ± 48 | 742 ± 37 | 831 ± 31 |

wages (Table 5.8). As predicted, an increase in a stickiness threshold leads to a decrease in wages for some societies (e.g. $M.S_0O_0C_1$ when the stickiness threshold is 60). The only system that faces no changes in wages is $M.S_0O_1C_0$, which possesses the least number of skilled agents in the system (see Table 5.9).

Table 5.8: Wages for different set-ups with respect to the stickiness threshold associated with the market tolerance towards excess demand and supply (mean ± standard deviation).

**Part 1 (Societies $\mathbf{M.S_0O_0C_0}$–$\mathbf{M.S_0O_1C_1}$)**

| Set-up | Stickiness threshold | $\mathbf{M.S_0O_0C_0}$ (modern Britain) | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_0O_1C_0}$ (EIC/ old Britain) | $\mathbf{M.S_0O_1C_1}$ |
|---|---|---|---|---|---|
| ***Wage non-academic and adequate*** | 0.1, 15, 30 | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 |
| | 60 | 4.0 ± 0.1 | 3.9 ± 0.0 | 4.0 ± 0.1 | 4.0 ± 0.1 |
| ***Wage non-academic and excellent*** | 0.1, 15 | 8.9 ± 0.4 | 8.9 ± 0.4 | 8.9 ± 0.4 | 8.9 ± 0.4 |
| | 30 | 8.9 ± 0.4 | 8.8 ± 0.6 | 8.9 ± 0.4 | 8.9 ± 0.4 |
| | 60 | 6.3 ± 0.2 | 5.7 ± 0.1 | 8.9 ± 0.4 | 8.7 ± 0.7 |
| ***Wage academic and adequate*** | 0.1, 15, 30 | 11.0 ± 0.2 | 11.0 ± 0.2 | 11.0 ± 0.2 | 11.0 ± 0.2 |
| | 60 | 10.4 ± 0.2 | 9.7 ± 0.1 | 11.0 ± 0.2 | 10.9 ± 0.2 |
| ***Wage academic and excellent*** | 0.1, 15, 30 | 13.0 ± 0.2 | 13.0 ± 0.2 | 13.0 ± 0.2 | 13.0 ± 0.2 |
| | 60 | 12.6 ± 0.2 | 11.7 ± 0.1 | 13.0 ± 0.2 | 13.0 ± 0.2 |

**Part 2 (Societies $\mathbf{M.S_1O_0C_0}$–$\mathbf{M.S_1O_1C_1}$)**

| Set-up | Stickiness threshold | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ (Julfa/ Germany) | $\mathbf{M.S_1O_1C_0}$ | $\mathbf{M.S_1O_1C_1}$ |
|---|---|---|---|---|---|
| ***Wage non-academic and adequate*** | 0.1, 15, 30 | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 |
| | 60 | 3.8 ± 0.0 | 3.7 ± 0.0 | 4.0 ± 0.1 | 4.0 ± 0.1 |
| ***Wage non-academic and excellent*** | 0.1, 15, 30 | 8.9 ± 0.4 | 8.9 ± 0.4 | 8.9 ± 0.4 | 8.9 ± 0.4 |
| | 60 | 5.4 ± 0.1 | 5.4 ± 0.1 | 8.9 ± 0.5 | 8.8 ± 0.5 |
| ***Wage academic and adequate*** | 0.1, 15 | 11.0 ± 0.2 | 11.0 ± 0.2 | 11.0 ± 0.2 | 11.0 ± 0.2 |
| | 30 | 10.6 ± 0.3 | 10.9 ± 0.3 | 11.0 ± 0.2 | 11.0 ± 0.2 |
| | 60 | 9.2 ± 0.1 | 9.2 ± 0.1 | 10.9 ± 0.3 | 10.4 ± 0.4 |
| ***Wage academic and excellent*** | 0.1, 15 | 13.0 ± 0.2 | 13.0 ± 0.2 | 13.0 ± 0.2 | 13.0 ± 0.2 |
| | 30 | 13.0 ± 0.2 | 12.9 ± 0.3 | 13.0 ± 0.2 | 13.0 ± 0.2 |
| | 60 | 11.4 ± 0.1 | 11.1 ± 0.1 | 13.0 ± 0.2 | 12.5 ± 0.4 |

#### 5.4.1.4 Impact on wages and the number of skilled agents

We investigated the impact of apprenticeship programmes on two other parameters, namely:

- workforce society wage stabilisation;
- number of skilled agents (different types of skilled agents shown in Table 5.9).

Table 5.9 shows the total number of skilled agents, including the apprentices who are still attending apprenticeship programmes. As can be seen, the number of educated agents with excellent skills has the highest value in $M.S_1O_0C_1$ (61.1), and that is more than the total number of skilled agents in societies $M.S_0O_1C_0$ and $M.S_0O_1C_1$. Overall, societies with compulsory schools that are identified by $S_1$ ($M.S_1O_0C_0$, $M.S_1O_0C_1$, $M.S_1O_1C_0$, and $M.S_1O_1C_1$) outperform other systems in developing skilled agents (combination of work-based and academic skills, see *Total Skilled* shown in Table 5.9), which indicates the importance of the engagement of schools in the apprenticeship programme (three of them benefited from schools).

The only counterexample is society $M.S_0O_0C_1$, where *companies provide training, and the system is closed*, which is better compared to societies $M.S_1O_0C_1$ and $M.S_1O_1C_1$ that have *open* societies (i.e. $O_1$). System $M.S_0O_1C_0$ (the EIC) has more poorly skilled agents in comparison with society $M.S_1O_0C_1$ (Julfa), considering all combinations of work-based and academic skills as stated by Fryer (1698) (as we quoted in the introduction).

Table 5.9: Statistics for work-based and academic skills attained under different set-ups when 20% of agents check for jobs (mean ± standard deviation)

**Part 1 (Societies $\mathbf{M.S_0O_0C_0}$–$\mathbf{M.S_0O_1C_1}$)**

| **Set-up** | $\mathbf{M.S_0O_0C_0}$ (modern Britain) | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_0O_1C_0}$ (EIC/ old Britain) | $\mathbf{M.S_0O_1C_1}$ |
|---|---|---|---|---|
| ***Non-academic and adequate*** | 68.4 ± 6.1 | 67.2 ± 4.3 | 45.7 ± 4.0 | 34.9 ± 5.7 |
| ***Non-academic and excellent*** | 4.3 ± 0.4 | 26.8 ± 1.1 | 2.8 ± 0.3 | 12.6 ± 2.1 |
| ***Academic and adequate*** | 3.8 ± 0.4 | 6.9 ± 0.6 | 2.5 ± 0.3 | 3.4 ± 0.6 |
| ***Academic and excellent*** | 0.4 ± 0.4 | 16.2 ± 0.5 | 0.2 ± 0.1 | 1.8 ± 0.6 |
| ***Total Skilled*** | 76.9 ± 6.1 | 117.1 ± 4.5 | 51.2 ± 4.0 | 52.7 ± 6.1 |

**Part 2 (Societies $\mathbf{M.S_1O_0C_0}$–$\mathbf{M.S_1O_1C_1}$)**

| **Set-up** | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ (Julfa/ Germany) | $\mathbf{M.S_1O_1C_0}$ | $\mathbf{M.S_1O_1C_1}$ |
|---|---|---|---|---|
| ***Non-academic and adequate*** | 45.5 ± 3.3 | 51.0 ± 2.9 | 32.7 ± 2.2 | 41.3 ± 2.4 |
| ***Non-academic and excellent*** | 12.5 ± 1.0 | 21.6 ± 1.3 | 8.2 ± 0.6 | 15.3 ± 1.0 |
| ***Academic and adequate*** | 36.8 ±1.9 | 32.3 ± 1.5 | 25.3 ± 1.2 | 24.6 ± 1.3 |
| ***Academic and excellent*** | 0.4 ± 1.9 | 61.1 ± 13.4 | 8.5 ± 0.9 | 16.0 ± 1.9 |
| ***Total Skilled*** | 95.2 ± 4.4 | 166.0 ± 13.9 | 74.7 ±2.7 | 97.2 ± 3.5 |

Figure 5.3 depicts the number of skilled agents in four different categories, namely those:

- educated with excellent skills (**academic and excellent**);
- educated with adequate skills (**academic and adequate**);

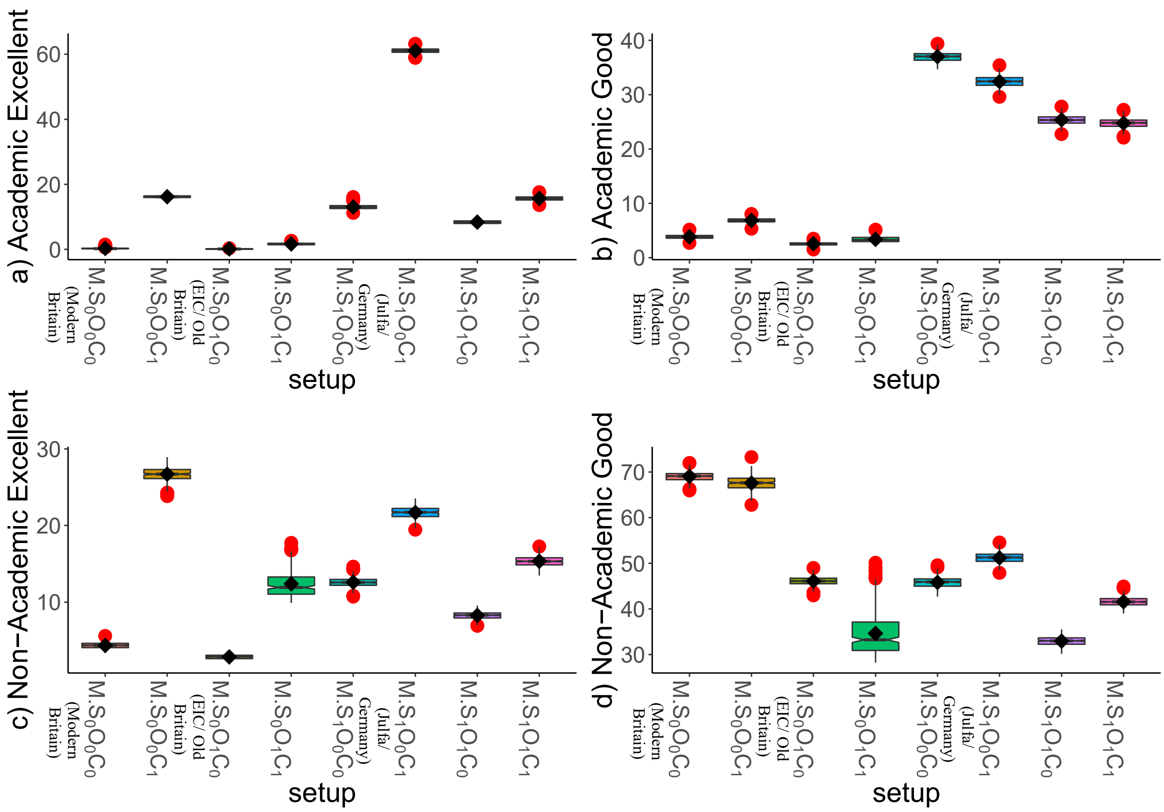

Figure 5.3: Boxplot of the number of skilled agents considering various skill types for apprenticeship programmes under different set-ups; the red dots represent outliers and a diamond indicates the mean.

- without academic skills who acquired excellent work-based skills (**non-academic and excellent**);
- without academic skills who acquired adequate work-based skills (**non-academic and adequate**).

The vertical axis indicates the number of holders of a particular skill, and the horizontal axis represents the set-up type. As can be seen, society $M.S_1O_0C_1$ (i.e. Julfa) has a significant advantage over other societies in terms of the number of agents with academic skills and significant work-based skills. As expected, the number of educated agents will increase if attending school is compulsory as a part of apprenticeship programmes (see two top charts of Figure 5.3 which indicate the number of educated agents — societies $M.S_1O_0C_0$, $M.S_1O_0C_1$, $M.S_1O_1C_0$, and $M.S_1O_1C_1$, which are societies with compulsory schooling and are identified by $S_1$, versus $M.S_0O_0C_0$, $M.S_0O_0C_1$, $M.S_0O_1C_0$, and $M.S_0O_1C_1$ societies, wherein attending school is not a compulsory part of apprenticeship programmes and they are identified by $S_0$).

On the other hand, a decrease in the degree of skill (e.g. see agents without academic skills that have adequate work-based skills versus educated agents with excellent skills) changes the pattern in favour of societies $M.S_0O_0C_0$ and $M.S_0O_0C_1$. This is intuitive, i.e. when systems are more efficient in training agents, the number of low-skilled agents reduces, because they attain skills faster than their counterparts in lower ranked societies. Therefore given a fixed number of members, when the number of members of one subset increases, the other subsets have a lower number of members.

We also conducted a Spearman correlation statistical test to assess the impact of the number of skilled agents on the GDI. This test indicates a strong and positive correlation (i.e. 0.96) between the number of skilled agents and the GDI ($p < 0.01$). Moreover, it is good to point out that in $M.S_0O_0C_1$, $M.S_0O_1C_1$, $M.S_1O_0C_1$, and $M.S_1O_1C_1$, small companies may choose to participate in programmes if they face costs in hiring already skilled agents.

Furthermore, systems with a higher quality of training have more skilled agents who have already finished their programme or are attending apprenticeship programmes. In $M.S_1O_0C_1$ the presence of an excessive number of skilled agents (i.e. more than 100 which is the total number of companies; see Table 5.5 for the number of companies and apprentices, and Table 5.9 for the total number of skilled agents) is caused by three factors:

- some agents who attend apprenticeship programmes have gained some skill levels in earlier years because of the high quality of training (note that although they may or may not search for jobs, they already have skills);
- the accumulation of already skilled agents who are not hired;
- some small companies started training agents because they found it profitable to train agents who have lower skills to maximise their utility function. This causes the system to meet the maximum capacity of training (note that participating in training is limited to some certified companies, but highly skilled agents will not compensate their wage increment by working in small companies; see Table 5.3 and Equation 5.3 for the utility function of small companies).

These factors increase the number of skilled agents and the deviations associated with this number; see Table 5.9, $M.S_1O_0C_1$.

Finally, we answer one question raised by Ryan and Unwin (2001) about the incentives for companies in Britain that first insist on having apprenticeship programmes and then not participating in training agents or only small companies participating in apprenticeship programmes to train candidates. The answer is threefold:

- Neglecting schools in apprenticeship programmes causes a significant drop in profits (especially for large companies), so they prefer to train academically educated agents, as can be seen in Table 5.6 — society $M.S_0O_0C_1$ (the replica of society $M.S_1O_0C_1$ without compulsory school) faces a 30% drop in the GDI in comparison with $M.S_1O_1C_0$ (i.e. $888/1264 \approx 70\%$).
- Companies may assume that even a malfunctioning training system has an impact on regulating wages (i.e. from the labour market point of view, contractors supply some skilled agents and help the system to balance the wages), despite the fact that under this scenario it does not have such an influence (see Table 5.10).
- A lack of skilled agents provides justifications to convince the government to grant them permission to hire from other societies (this phenomenon is studied under Scenario C). As can be seen in Table 5.10, the educated agents' wages are slightly different (i.e. between $1\%$ and $4\%$ less) when the system is closed ($O_0$) and schools are compulsory ($S_1$) in apprenticeship programmes (Societies $M.S_1O_0C_0$ and $M.S_1O_0C_1$).

Table 5.10: Statistics for wages considering different set-ups (mean ± standard deviation)

**Part 1 (Societies $\mathbf{M.S_0O_0C_0}$–$\mathbf{M.S_0O_1C_1}$)**

| **Set-up** | $\mathbf{M.S_0O_0C_0}$ (modern Britain) | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_0O_1C_0}$ (EIC/ old Britain) | $\mathbf{M.S_0O_1C_1}$ |
|---|---|---|---|---|
| ***Wage non-academic and adequate*** | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 |
| ***Wage non-academic and excellent*** | 8.9 ± 0.4 | 8.8 ± 0.6 | 8.9 ± 0.4 | 8.9 ± 0.4 |
| ***Wage academic and adequate*** | 11.0 ± 0.2 | 11.0 ± 0.2 | 11.0 ± 0.2 | 11.0 ± 0.2 |
| ***Wage academic and excellent*** | 13.0 ± 0.2 | 13.0 ± 0.2 | 13.0 ± 0.2 | 13.0 ± 0.2 |

**Part 2 (Societies $\mathbf{M.S_1O_0C_0}$–$\mathbf{M.S_1O_1C_1}$)**

| **Set-up** | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ (Julfa/ Germany) | $\mathbf{M.S_1O_1C_0}$ | $\mathbf{M.S_1O_1C_1}$ |
|---|---|---|---|---|
| ***Wage non-academic and adequate*** | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 |
| ***Wage non-academic and excellent*** | 8.9 ± 0.4 | 8.9 ± 0.4 | 8.9 ± 0.4 | 8.9 ± 0.4 |
| ***Wage academic and adequate*** | 10.6 ± 0.3 | 10.9 ± 0.3 | 11.0 ± 0.2 | 11.0 ± 0.2 |
| ***Wage academic and excellent*** | 13.0 ± 0.2 | 12.9 ± 0.3 | 13.0 ± 0.2 | 13.0 ± 0.2 |

After studying the base model, we systematically change the model's assumptions. In the next scenario, we liberalise the training market by letting all trainers participate in training apprentices. This exploration of more training liberalisation helps us to test the influence of market-oriented liberalisation ideas on apprenticeship programmes performance.

### 5.4.2 Scenario B for manufacturers: Training with maximum capacity, and no unions

The difference between *Scenario B* and *Scenario A* is about relaxing regulations, considering the restrictions on the number of trainers that controls the number of apprentices attending the programme (i.e. unions). Hence this number can be significantly more than the provisioned demand. In this scheme of the apprenticeship programme, societies invest in training so that the amount of unsatisfied demand is minimised. This scheme addresses two issues raised by the skills shortage in a society, namely: a) high wages and b) costs incurred to the system due to the lack of skilled agents needed by companies.

Therefore we assume that each contractor can train 20 apprentices per year, and when companies train, all small companies can choose to participate in training, and the system starts by training 180 apprentices (see Table 5.11 for more detail). These numbers (i.e. 180 and 200) represent no tendency to control the capacity of training for companies by limiting participants to certified companies and the tendency of trainers to increase their capacity to make the most profits. Note that in *Scenario A*, most cases faced skill shortages and relaxing the maximum capacity can help the society to tackle that issue. Table 5.12 presents the *percentage of agents who finished the programme* and the contribution of apprenticeship programmes in improving *Gross Domestic Income (GDI)* for each society (henceforth, we simply use GDI). Note that we only report the numbers for the same stickiness threshold as before (i.e. 30).

Table 5.11: The additional simulation parameters for Scenario B

| Name | Comment | Distribution | Values |
|---|---|---|---|
| Number of contractors | | Constant | 10 |
| Number of companies | Large:Small | Constant | 20:80 |
| Capacity | Large companies | Constant | 5 |
| | Small companies | | 1 |
| | Contractors | | 20 |
| Maximum number of apprentices | Companies | Capacity $\times$ maximum number of participants* | 180 |
| | Contractors | | 200 |
| Probability of leaving the system | when system is open (per run) | Constant | 0.1 |

* For companies, it can be calculated as $(20 \times 5) + (80 \times 1) = 180$, and for contractors, it can be calculated as $(10 \times 20) = 200$

#### 5.4.2.1 Impact on programme completion

As can be seen in Table 5.12, successful systems using this metric are the same as in *Scenario A* — closed systems identified by $O_0$ (i.e. $M.S_0O_0C_1$, $M.S_1O_0C_1$, $M.S_1O_0C_0$, and $M.S_0O_0C_0$ are the top four societies). There is a significant change in the percentage of agents who finished the programme for *closed societies wherein companies train apprentices*. Other systems that are run by companies (i.e. open systems that are identified by $O_1$) are faced with a slight reduction in completion (see $M.S_0O_1C_1$ and $M.S_1O_1C_1$). On the other hand, the programme completion for systems run by contractors (i.e. systems that are identified by $C_0$) changes slightly. Some of them improved (see $M.S_1O_0C_0$ and $M.S_1O_1C_0$), and one was worse-off (see society $M.S_0O_0C_0$).

Figure 5.4 depicts the completion rates of $M.S_0O_0C_1$ and $M.S_1O_0C_1$ over time for Scenarios A and B. As can be seen, there is a significant variation in terms of the programme completion at first. However, these changes decrease over time. Some of these changes are

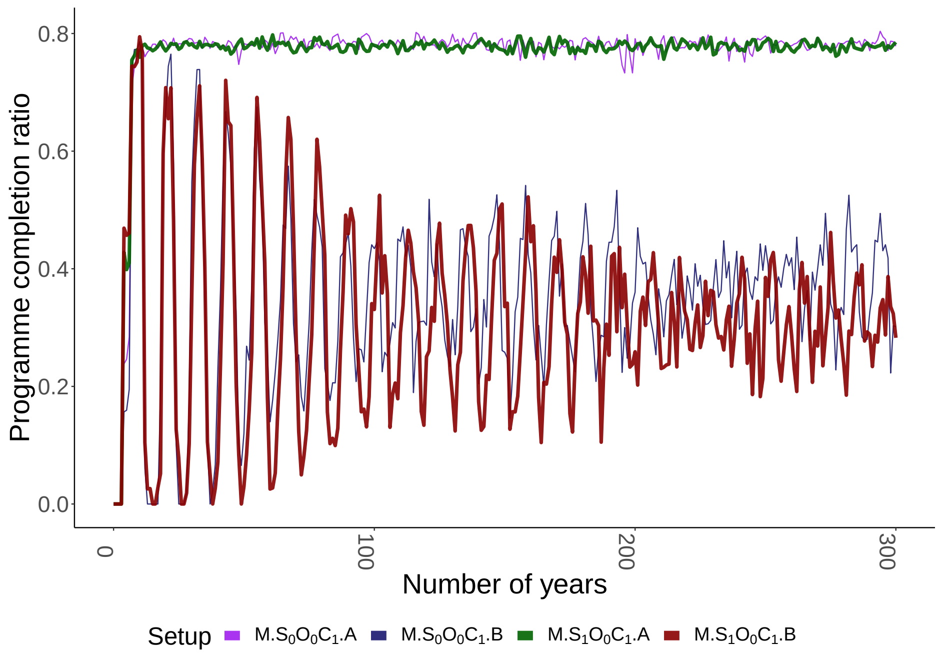


Figure 5.4: The programme completion ratio for $M.S_0O_0C_1$ and $M.S_1O_0C_1$ considering Scenarios A and B.

small, so we employed statistical tests to ensure these changes are a consequence of having more apprentices. For this, we conducted a Kruskal-Wallis test to identify the impact of more apprentices in the system, considering different set-ups. This test indicates that a location shift can be identified in the system (i.e. the medians are not equal, and they shifted positively and were enhanced, or shifted negatively and declined). To ensure this shift is not an impact of set-ups, we conducted pairwise comparisons using the Wilcoxon Rank Sum test with a Bonferroni adjustment that indicated:

- statistically significant location shifts for societies $M.S_0O_0C_1$, $M.S_1O_0C_0$, $M.S_1O_0C_1$, and $M.S_1O_1C_1$ (i.e. almost all closed societies except for $M.S_0O_0C_0$ with $p < 0.01$);
- a less significant location shift for $M.S_0O_1C_1$ ($0.01 < p < 0.05$) that indicates all companies had a negative shift in the completion rate;
- no significant shift for the rest of the socieities (i.e. $M.S_0O_0C_0$, $M.S_0O_1C_0$, and $M.S_1O_1C_0$, for all $p\text{-}value = 1$).

Table 5.12: The GDI and programme completion for different set-ups considering Scenarios A and B (mean ± standard deviation)

| **Part 1 (Societies $\mathbf{M.S_0O_0C_0}$–$\mathbf{M.S_0O_1C_1}$)** | | | | | |
|---|---|---|---|---|---|
| **Set-up** | **Scenario** | $\mathbf{M.S_0O_0C_0}$ (modern Britain) | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_0O_1C_0}$ (EIC/ old Britain) | $\mathbf{M.S_0O_1C_1}$ |
| ***Programme completion (%)*** | A | 65.7 ± 5.9 | 77.6 ± 5.4 | 39.4 ± 3.6 | 44.6± 3.5 |
| | B | 63.5 ± 5.8 | 35.4 ± 14.5 | 39.4 ± 3.4 | 44.1 ± 3.8 |
| ***GDI*** | A | 724 ± 64 | 888 ± 56 | 379 ± 35 | 361 ± 57 |
| | B | 1054 ± 93 | 498 ± 214 | 712 ± 62 | 427 ± 145 |
| **Part 2 (Societies $\mathbf{M.S_1O_0C_0}$–$\mathbf{M.S_1O_1C_1}$)** | | | | | |
| **Set-up** | **Scenario** | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ (Julfa/ Germany) | $\mathbf{M.S_1O_1C_0}$ | $\mathbf{M.S_1O_1C_1}$ |
| ***Programme completion (%)*** | A | 72.4 ± 4.7 | 77.5 ± 3.7 | 43.4 ± 2.6 | 46.3 ± 2.6 |
| | B | 72.8 ± 4.4 | 31.5 ± 15.9 | 43.5 ± 2.4 | 43.3 ± 3.0 |
| ***GDI*** | A | 1215 ± 58 | 1264 ± 45 | 740 ± 34 | 830 ± 33 |
| | B | 1502 ± 41 | 613 ± 299 | 1199 ± 50 | 1126 ± 96 |

#### 5.4.2.2 Impact on the GDI

Then we investigated the impact of *Scenario B* on the success of apprenticeship programmes considering the GDI of the society based on items manufactured by hired apprentices by comparing *Scenario B* with *Scenario A*. As can be seen in Table 5.12, the changes in the GDIs of the societies are significant. We conducted the Kruskal-Wallis test and then made pairwise comparisons using the Wilcoxon Rank Sum test to assess the impact of this scenario on the system's performance.

The test's results suggest there is a significant change in the GDIs for all societies during these runs (for all of them $p < 0.01$). While the GDIs for societies $M.S_0O_0C_1$ and $M.S_1O_0C_1$ worsened (i.e. closed societies wherein companies trained apprentices), the rest of the societies (i.e. open societies or societies wherein contractors trained apprentices) improved their GDIs. This indicates the adverse effect of the new policy for closed societies wherein companies train apprentices, who are identified by $O_0$ and $C_1$, respectively. Note that in both $M.S_0O_0C_1$ and $M.S_1O_0C_1$, the GDI decreased to less than 60% of the former scenario, and deviations increased drastically. Figure 5.5 compares the GDI of the societies based on the two scenarios.

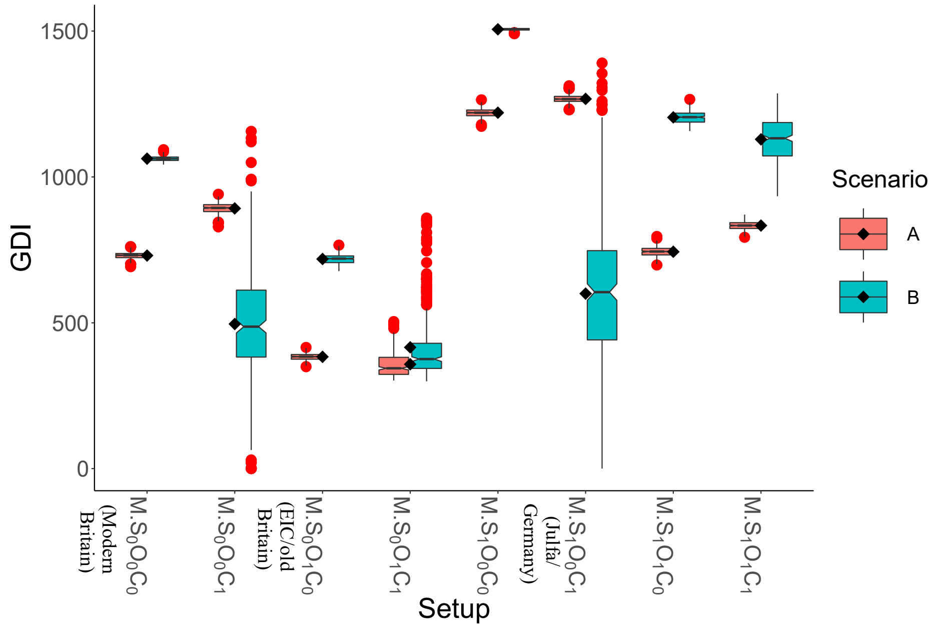


Figure 5.5: Boxplot of the GDI acquired by apprenticeship programmes under different setups for scenarios A (the boxes with a diamond on the right) and B (the boxes with a diamond on the left). Red dots present outliers, and a diamond indicates the mean.

#### 5.4.2.3 Impact on wages and the number of skilled agents

We examined the impact of *Scenario B* on the number of skilled agents and wages in the society. As can be seen in Table 5.13, the tendency to train more agents increases the number of skilled agents in all societies, except for $M.S_0O_0C_1$. However, this increase is more evident for societies where contractors train apprentices who are identified by $C_0$ (i.e. the number of total skilled agents for $M.S_0O_0C_0$, $M.S_0O_1C_0$, $M.S_1O_0C_0$, and $M.S_1O_1C_0$ is higher than societies $M.S_0O_0C_1$, $M.S_0O_1C_1$, and $M.S_1O_0C_1$). Only $M.S_0O_1C_0$ performs worse than $M.S_1O_1C_1$ in terms of increasing the number of skilled agents, which implies a lower impact of the excessive number of skilled agents on contractors' performance.

Based on the number of skilled agents and the GDI associated with societies (see Tables 5.12 and 5.13), one can conclude that hiring more highly skilled agents in a society does not necessarily mean a better GDI. This result is intuitive if we keep in mind that high-skilled agents are paid more and cannot increase small companies' profitability significantly, and part of this number of skilled agents represents overqualified agents from former iterations. This phenomenon is worsened when programmes quality is high (e.g. $M.S_1O_0C_0$ versus $M.S_1O_0C_1$) and small companies can hire some lower skilled agents. Moreover, in some societies, even training a high number of agents cannot guarantee the availability of enough skilled agents for companies (i.e. $M.S_0O_1C_1$ and $M.S_0O_1C_0$, which is the society similar to the EIC). It is an indication of the low quality of these societies and the requirement of significant investment to train apprentices, i.e. even though systems are allowed to train between 1.8 to 2 times the number of required skills, the total number of skilled agents in the systems $M.S_0O_1C_0$ and $M.S_0O_1C_1$ (including the ones who still attend the programme) is sometimes less than 100, which is the number of companies in the system.

Note that this increase in the potential number of apprentices decreased the total number of skilled agents for some societies, so that society $M.S_0O_0C_1$ faced a shortage of skilled agents that was caused by fluctuations in training apprentices due to an excessive number of skilled agents in some iterations and a shortage in others. These exhibit much higher standard deviations (23.3 versus 4.5, for Scenarios B and A, respectively). The main reason for these fluctuations is reactions of apprentices and companies to the system — at first, demand for trained apprentices by companies who are not hired by trainers decreases. Then for decreasing the chances of finding a job, some agents find it unprofitable to attend the programme, and some companies assume they can find agents, so they do not accept apprentices.

The aforementioned decisions indicate their impacts on the system in three years — the length of the apprenticeship. Based on this shortage, the probabilities will be updated. Some trainers and apprentices find the programmes profitable, and again, in some years, the first step will be reiterated (see Figure 5.4). Overall, this phenomenon is a consequence of decisions made by all parties based on local information. This *myopia* in human decisions is observed by other studies. For instance, Farmer (1997) discusses the phenomenon in supply chains and business schools. He states that in the final years of the 1960s, academics in the US believed that purchasing was not a strategic act and had a myopic attitude towards the practice. After a while, through a change in attitude triggered by the efforts of a minority of academics, purchasing was considered as a strategic activity rather than an administrative one. Without doubt, that belief shows the presence of occasional myopia in academia to avoid complexities in their decision-making.

Table 5.13: Statistics for work-based and academic skills attained under different set-ups considering Scenarios A and B (mean ± standard deviation)

**Part 1 (Societies $\mathbf{M.S_0O_0C_0}$–$\mathbf{M.S_0O_1C_1}$)**

| **Set-up** | **Scenario** | $\mathbf{M.S_0O_0C_0}$ (modern Britain) | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_0O_1C_0}$ (EIC/ old Britain) | $\mathbf{M.S_0O_1C_1}$ |
|---|---|---|---|---|---|
| ***Non-academic and adequate*** | A | 68.4 ± 6.1 | 67.2 ± 4.3 | 45.7 ± 4.0 | 34.9 ± 5.7 |
| | B | 119.4 ± 11.0 | 47.7 ± 21.1 | 76.2 ± 6.4 | 41.1 ± 14.1 |
| ***Non-academic and excellent*** | A | 4.3 ± 0.4 | 26.8 ± 1.1 | 2.8 ± 0.3 | 12.6 ± 2.1 |
| | B | 8.8 ± 0.9 | 21.9 ± 9.6 | 4.8 ± 0.4 | 14.7 ± 5.1 |
| ***Academic and adequate*** | A | 3.8 ± 0.4 | 6.9 ± 0.6 | 2.5 ± 0.3 | 3.4 ± 0.6 |
| | B | 6.4 ± 0.6 | 5.0 ± 2.2 | 4.2 ± 0.4 | 4.1 ± 1.3 |
| ***Academic and excellent*** | A | 0.4 ± 0.4 | 16.2 ± 0.5 | 0.2 ± 0.1 | 1.8 ± 0.6 |
| | B | 0.5 ± 0.3 | 22.2 ± 1.3 | 0.3 ± 0.1 | 2.1 ± 1.1 |
| ***Total Skilled*** | A | 76.9 ± 6.1 | 117.1 ± 4.5 | 51.2 ± 4.0 | 52.7 ± 6.1 |
| | B | 135.1 ± 11.1 | 96.8 ± 23.3 | 85.5 ± 6.4 | 62.0 ± 15.1 |

**Part 2 (Societies $\mathbf{M.S_1O_0C_0}$–$\mathbf{M.S_1O_1C_1}$)**

| **Set-up** | **Scenario** | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ (Julfa/ Germany) | $\mathbf{M.S_1O_1C_0}$ | $\mathbf{M.S_1O_1C_1}$ |
|---|---|---|---|---|---|
| ***Non-academic and adequate*** | A | 45.5 ± 3.3 | 51.0 ± 2.9 | 32.7 ± 2.2 | 41.3 ± 2.4 |
| | B | 79.9 ± 5.2 | 33.2 ± 17.0 | 54.7 ± 3.3 | 60.8 ± 5.2 |
| ***Non-academic and excellent*** | A | 12.5 ± 1.0 | 21.6 ± 1.3 | 8.2 ± 0.6 | 15.3 ± 1.0 |
| | B | 21.8 ± 1.2 | 16.5 ± 9.1 | 13.7 ± 0.9 | 22.3 ± 2.1 |
| ***Academic and adequate*** | A | 36.8 ±1.9 | 32.3 ± 1.5 | 25.3 ± 1.2 | 24.6 ± 1.3 |
| | B | 78.7 ± 5.0 | 24.1 ± 11.6 | 42.1 ± 1.8 | 36.6 ± 3.0 |
| ***Academic and excellent*** | A | 0.4 ± 1.9 | 61.1 ± 13.4 | 8.5 ± 0.9 | 16.0 ± 1.9 |
| | B | 25.2 ± 2.7 | 97.5 ± 8.4 | 14.2 ± 1.3 | 23.7 ± 3.5 |
| ***Total Skilled*** | A | 95.2 ± 4.4 | 166.0 ± 13.9 | 74.7 ± 2.7 | 97.2 ± 3.5 |
| | B | 205.6 ± 7.8 | 171.3 ± 24.0 | 124.7 ± 4.1 | 143.4 ± 7.3 |

As can be seen in Table 5.14, only $M.S_0O_0C_0$ and $M.S_1O_0C_0$ had a significant decrease in wages. Based on the considered stickiness threshold (i.e. 30) for wages (see Table 5.3 and Section 5.3.1 for a discussion), it is intuitive that societies $M.S_0O_0C_0$, $M.S_1O_0C_0$, $M.S_1O_0C_1$, and $M.S_1O_1C_1$ (i.e. societies with more than 130 skilled agents, which is the number of companies, 100, along with the stickiness threshold, 30) have a significant change in wages. Therefore we state intuitions to explain the lack of such a phenomenon in societies $M.S_1O_0C_1$ and $M.S_1O_1C_1$.

First, note that these numbers include apprentices attending the programme. Therefore based on the higher number of agents with **academic and excellent** skills in $M.S_1O_0C_1$, and the decrease in completion rate (see Tables 5.12 and 5.13), most agents who have low skills leave the programme at earlier stages, i.e. before they gain high skills. This phenomenon increases the excessive number of skilled agents for skills for which an excessive number of them was already present in *Scenario A*. The issue with this increase stems from the inability of these agents to increase the income of small companies unless they have a wage equal to 12 or less (the income of small companies when they produce items using these skills is 14; see Table 5.3). Thus most demand by small companies targets skilled agents without academic education for whom the system does not successfully provide.

The aforementioned phenomenon leads to a strict lower-bound for wages for ***academic and excellent*** skills (these agents expect more wages than their uneducated counterparts). This phenomenon, coupled with the fact that an increase in the number of agents causes large companies to stop accepting apprentices in the following periods, causes wages to stick near the upper limit (i.e. 13, see Table 5.3) rather than the lower bound (i.e. 12, Wage academic and adequate $+1$, as indicated in Algorithm 5.1 and Table 5.14). In society $M.S_1O_1C_1$, an increment in the number of skilled agents is more homogeneous and is due to the openness of the society and the participation of all companies in training apprentices. The unemployed agents are likewise uniformly distributed across their different degrees of skills. This uniform distribution for society $M.S_1O_1C_1$ and the behaviour of companies and apprentices in society $M.S_1O_0C_1$ prevent wages from decreaseing to lower limits. Moreover, a better distribution of more skilled agents (i.e. agents with skills better than ***non-academic and adequate***), coupled with lower wages for skilled agents, improved the GDI of society $M.S_1O_0C_0$, despite the lower number of agents with ***academic and excellent*** skills. In other words, due to the lower wages, it was rational for small companies to hire more skilled agents.

### 5.4.3 Scenario C for manufacturers: Openness for working (the impact of the influx of workers from other communities)

This interpretation of openness for Scenario C considers systems that cope with immigration rather than emigration, i.e. some skilled agents move into the community to work instead of leaving apprenticeship programmes to work in other communities. Therefore in these systems, immigrants are not aware of a wage norm (e.g. they moved due to unfortunate

Table 5.14: Statistics for wages considering different set-ups for Scenarios A and B (mean $\pm$ standard deviation)

**Part 1 (Societies $\mathbf{M.S_0O_0C_0}$–$\mathbf{M.S_0O_1C_1}$)**

| Setup | Scenario | $\mathbf{M.S_0O_0C_0}$ | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_0O_1C_0}$ | $\mathbf{M.S_0O_1C_1}$ |
|---|---|---|---|---|---|
| ***Wage non-academic*** | A | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 |
| ***and adequate*** | B | 2.0 ± 0.2 | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 |
| ***Wage non-academic*** | A | 8.9 ± 0.4 | 8.9 ± 0.4 | 8.8 ± 0.6 | 8.9 ± 0.4 |
| ***and excellent*** | B | 6.8 ± 0.4 | 8.5 ± 0.6 | 8.9 ± 0.4 | 8.9 ± 0.4 |
| ***Wage academic*** | A | 11.0 ± 0.2 | 11.0 ± 0.2 | 11.0 ± 0.2 | 11.0 ± 0.2 |
| ***and adequate*** | B | 10.8 ± 0.3 | 11.0 ± 0.2 | 11.0 ± 0.2 | 11.0 ± 0.2 |
| ***Wage academic*** | A | 13.0 ± 0.2 | 13.0 ± 0.2 | 13.0 ± 0.2 | 13.0 ± 0.2 |
| ***and excellent*** | B | 12.8 ± 0.3 | 13.0 ± 0.2 | 13.0 ± 0.2 | 13.0 ± 0.2 |

**Part 2 (Societies $\mathbf{M.S_1O_0C_0}$–$\mathbf{M.S_1O_1C_1}$)**

| Setup | Scenario | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ | $\mathbf{M.S_1O_1C_0}$ | $\mathbf{M.S_1O_1C_1}$ |
|---|---|---|---|---|---|
| ***Wage non-academic*** | A | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 |
| ***and adequate*** | B | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 | 4.0 ± 0.1 |
| ***Wage non-academic*** | A | 8.9 ± 0.4 | 8.9 ± 0.4 | 8.9 ± 0.4 | 8.9 ± 0.4 |
| ***and excellent*** | B | 6.1 ± 0.1 | 8.7 ± 0.5 | 8.9 ± 0.5 | 8.9 ± 0.4 |
| ***Wage academic*** | A | 10.6 ± 0.3 | 10.9 ± 0.3 | 11.0 ± 0.2 | 11.0 ± 0.2 |
| ***and adequate*** | B | 7.2 ± 0.2 | 10.8 ± 0.3 | 10.9 ± 0.3 | 11.0 ± 0.2 |
| ***Wage academic*** | A | 13.0 ± 0.2 | 12.9 ± 0.3 | 13.0 ± 0.2 | 13.0 ± 0.2 |
| ***and excellent*** | B | 11.3 ± 0.1 | 12.9 ± 0.3 | 13.0 ± 0.2 | 13.0 ± 0.2 |

situations in their home country). Some studies indicate that the presence of both legal and illegal immigrants in a society triggers tendencies in companies to hire them and pay them lower wages (see McCollum & Findlay, 2015; Ruhs & Anderson, 2010).

We address the impact of this tendency by considering some negotiation advantages for companies that can hire from other communities. We assume that in negotiation, **large companies** can pay average wages for all combinations of ***non-academic and excellent***, ***academic and excellent***, and ***academic and adequate*** to immigrants because they have doubts about the excellence of agents' work-based skills but are sure about their academic skills. Most parameters for this model are the same as *Scenario A* (see Table 5.15), except for the probability of leaving the society that was excluded there. Based on what has just been stated, we do not consider instances where apprentices may leave the society to work in other communities that were included in former scenarios (i.e. open societies that are identified by $O_1$, which encompass societies $M.S_0O_1C_0$, $M.S_0O_1C_1$, $M.S_1O_1C_0$, and $M.S_1O_1C_1$).

For these societies, we considered two factors, namely flexibility of immigrants and large companies' uncertainties about immigrants' work-based skills. Therefore we assume that companies suggest an average wage norm for the three types of agent skills as stated above:

$$\text{Wage} = \frac{\sum_{i=\text{non-Academic and Excellent}}^{\text{Academic and Excellent}} \text{Wage}_i}{3}$$

and have doubts about their work-based skills being adequate or excellent with the same chance (they assume that based on the agents' work experience, they at least have adequate skills, hence having inadequate skills is ruled out).

Table 5.15: The additional simulation parameters for Scenario C

| Name | Comment | Distribution | Values |
|---|---|---|---|
| Number of contractors | | Constant | 10 |
| Number of companies | Large:Small | Constant | 20:80 |
| Capacity | Large companies | Constant | 5 |
| | Small companies | | 1 |
| | Contractors | | 12 |
| Maximum number of apprentices | Companies | Capacity $\times$ maximum number of participants | 106 |
| | Contractors | | 120 |

#### 5.4.3.1 Impact on programme completion and the GDI

As can be seen in Table 5.16, the differences between the programme completion ratios for Scenarios A and C is less than 2%, and the systems in which contractors train apprentices are more sensitive to openness (i.e. societies that are identified by $C_0$). Note that only societies $M.S_0O_0C_0$ and $M.S_1O_0C_0$ faced a drop in completion where contractors train apprentices. To study the GDI, note that the presented figures indicate the GDI produced by apprenticeship programmes, i.e. the GDI of agents who are hired from other societies is not included in these figures. The only system in which the associated GDI improved is society $M.S_0O_0C_0$, which possessed too many low-skilled agents (i.e. agents with ***non-academic and adequate*** skills). The reason behind the aforementioned change is that **large companies'** demand decreases in the system for skilled agents by hiring from other societies (note that the values of items produced by agents without academic skills were 10 and 12 for small companies, versus 5 and 10 for large companies, respectively (see Table 5.3)). Overall, a significant drop in the GDI produced by apprentices in the society is evident (see Figure 5.6). **Large companies** partly cause this by hiring from other places, rather than training or hiring trained apprentices, and that leads to the following:

- large companies not preferring to participate in programmes in societies $M.S_1O_1C_0$ and $M.S_0O_1C_0$, which leads to a drop in the number of skilled agents;

- demand for agents with academic skills from the apprenticeship pool diminishes;
- the presence of unemployed agents with academic skills in the society $M.S_1O_0C_0$ (see Table 5.17).

The ratio of agents with academic skills to the total number of skilled agents increases significantly (i.e. even though small companies train, the ratio of agents with ***academic and excellent*** skills increases from around 36% to around 45% (see Table 5.17)).

Finally, it should be noted that the only system where its GDI was improved was $M.S_0O_0C_0$, which is similar to **modern Britain**, and some studies point out the openness of Britain around the same years when this scheme of apprenticeship programme was utilised (see McCollum & Findlay, 2015). The opportunity of hiring from other societies and consideration about the costs of free academic training for all apprentices by the government may be some of the reasons for not employing the German scheme in Britain.

Table 5.16: The GDI and programme completion ratio for different set-ups considering Scenarios A and C (mean ± standard deviation)

| **Set-up** | **Scenario** | $\mathbf{M.S_0O_0C_0}$ (modern Britain) | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ (Julfa/ Germany) |
|---|---|---|---|---|---|
| ***Programme completion (%)*** | A | 65.7 ± 5.9 | 77.6 ± 5.4 | 72.4 ± 4.7 | 77.5 ± 3.7 |
| | C | 64.3 ± 9.5 | 77.2 ± 12.8 | 70.9 ± 9.4 | 76.5 ± 9.8 |
| ***GDI*** | A | 724 ± 64 | 888 ± 56 | 1215 ± 58 | 1264 ± 45 |
| | C | 786 ± 115 | 513 ± 84 | 926 ± 119 | 600 ± 96 |

#### 5.4.3.2 Impact on wages and the number of skilled agents

To study the number of skilled agents we should emphasise that:

- this number indicates the total number of skilled agents, including the ones who attend the programme;
- unemployed skilled agents for one or two years stay in the skilled pool, so this increases the number of agents, and this does not essentially mean that a system works better.

The increase in the number of skilled agents may imply that some of the skilled agents are redundant; hence they cannot participate in productive jobs. Overall, the number of skilled agents decreased in all societies, except $M.S_1O_0C_0$. However, the percentage of skilled agents implies that part of this increase is caused by a lack of demand for educated agents

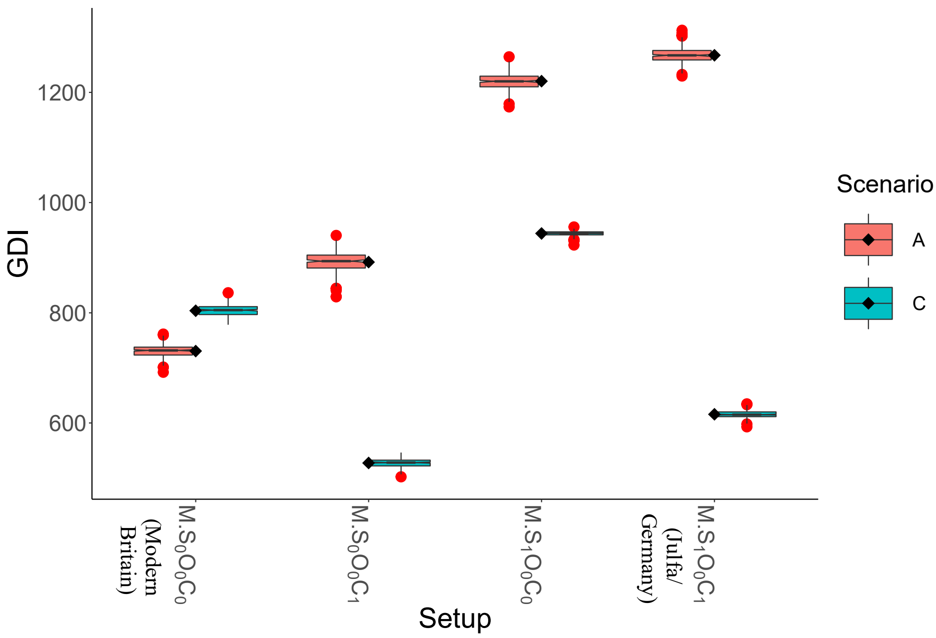


Figure 5.6: Boxplot of the GDI acquired by apprentice programmes under different set-ups for Scenarios A (the boxes with a diamond on the right) and C (the boxes with a diamond on the left). The red dots present outliers, and a diamond indicates the mean.

and part of it is caused by less demand for skilled agents in general. Less demand for skilled agents increases the proportion of agents with ***academic and excellent*** skills in $M.S_0O_0C_1$ and $M.S_1O_0C_1$ (societies in which companies train agents). Therefore the indicators, measured by the ratio $AcademicAndExcellent/TotalSkilled$, show an increase from 14% and 36% to 16% and 45% for societies $M.S_0O_0C_1$ and $M.S_1O_0C_1$, respectively.

However, this increase in the share of academic and skilled agents is coupled with a lower number of total skilled agents. This overall decrease in the number of skilled agents indicates a decrease in the number of trained apprentices in the society, which implies a lower tendency for large companies to accept apprentices. Moreover, less demand for skilled agents leads to more fluctuations in programme completion (it almost doubles the standard deviation; see Table 5.16). Based on the results, this increase mostly impacts agents with more attainability because they are the ones who are prone to the least demand in the labour market (i.e. only the number of agents with ***Academic and excellent*** skills increased).

As can be seen in Table 5.18, only $M.S_0O_0C_0$and $M.S_1O_0C_0$ had a significant decrease in wages. Based on the considered stickiness threshold (i.e. 30) for wages that was stated in Section 5.3.1, it is intuitive that societies $M.S_0O_0C_0$, $M.S_1O_0C_1$, and $M.S_1O_0C_0$ would

Table 5.17: Statistics for work-based and academic skills attained under different set-ups considering Scenarios A and C, for societies $M.S_0O_0C_0$, $M.S_0O_0C_1$, $M.S_1O_0C_0$, and $M.S_1O_0C_1$ (mean ± standard deviation)

| **Set-up** | **Scenario** | $\mathbf{M.S_0O_0C_0}$ (modern Britain) | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ (Julfa/ Germany) |
|---|---|---|---|---|---|
| ***Non-academic and adequate*** | A | 68.4 ± 6.1 | 67.2 ± 4.3 | 45.5 ± 3.3 | 51.0 ± 2.9 |
| | C | 67.0 ± 9.7 | 40.2 ± 6.2 | 44.7 ± 5.5 | 29.7 ± 4.2 |
| ***Non-academic and excellent*** | A | 4.3 ± 0.4 | 26.8 ± 1.1 | 12.5 ± 1.0 | 21.6 ± 1.3 |
| | C | 4.2 ± 0.6 | 15.9 ± 2.2 | 12.3 ± 1.6 | 12.6 ± 1.7 |
| ***Academic and adequate*** | A | 3.8 ± 0.4 | 6.9 ± 0.6 | 36.8 ±1.9 | 32.3 ± 1.5 |
| | C | 3.8 ± 0.6 | 4.2 ± 0.7 | 36.1 ± 4.4 | 19.2 ± 2.7 |
| ***Academic and excellent*** | A | 0.4 ± 0.4 | 16.2 ± 0.5 | 0.4 ± 1.9 | 61.1 ± 13.4 |
| | C | 0.3 ± 0.3 | 11.1 ± 1.3 | 14.8 ± 2.1 | 49.4 ± 5.4 |
| ***Total Skilled*** | A | 76.9 ± 6.1 | 117.1 ± 4.5 | 95.2 ± 4.4 | 166.0 ± 13.9 |
| | C | 75.3 ± 9.7 | 71.4 ± 6.7 | 107.9 ± 7.5 | 110.9 ± 7.5 |

have some changes in wages. This expectation is based on both the total number of skilled agents and the number of skilled agents per skill (e.g. agents with academic and adequate skills). As can be seen, in $M.S_0O_0C_0$ the wages for agents with academic skills or excellent skills decreased. This phenomenon is caused by factors such as:

- the availability of enough skilled agents;
- the participation of most small companies in the programme, so they do not put that much demand into the labour market;
- most of the large companies hired agents with academic skills from other societies (there is less demand for agents with academic skills).

For society $M.S_1O_0C_1$, the average wage for all skills is near maximum. The increase in the standard deviation of wages indicates that wages decreased more than the former case (i.e. Scenario A and note that this number cannot be more than its upper bound). Furthermore, in society $M.S_1O_0C_0$, the largest wage difference is associated with agents possessing ***academic and excellent*** skills (the difference in the average wages equals 2). This higher difference indicates the availability of demand for this skill during some iterations that persuaded some agents with more attainability for both academic and work-based skills to complete the programme.

However, results suggest that once apprentices finished the programme, the labour market had already fulfilled that demand (see the higher average number of agents with ***academic***

***and excellent*** skills in Table 5.17 for society $M.S_1O_0C_0$). Therefore overall, sometimes demand for highly skilled agents persuades agents to finish the programme, but this demand is a consequence of a shortage of low-skilled agents. Furthermore, more demand for low-skilled agents and less participation by large companies causes a lower number of agents to attend an apprenticeship and finish the programme in Scenario C in comparison to Scenario A (see Table 5.17). Finally, less demand for skilled agents and less motivation to attend the programme cause the system to have higher wages than the initial wages (see Tables 5.18 and 5.3).

Table 5.18: Statistics for wages under different set-ups considering Scenarios A and C (mean $\pm$ standard deviation)

| **Set-up** | **Scenario** | $\mathbf{M.S_0O_0C_0}$ (modern Britain) | $\mathbf{M.S_0O_0C_1}$ | $\mathbf{M.S_1O_0C_0}$ | $\mathbf{M.S_1O_0C_1}$ (Julfa/ Germany) |
|---|---|---|---|---|---|
| ***Wage non-academic and adequate*** | A | $4.0 \pm 0.1$ | $4.0 \pm 0.1$ | $4.0 \pm 0.1$ | $4.0 \pm 0.1$ |
| | C | $4.0 \pm 0.1$ | $4.0 \pm 0.1$ | $4.0 \pm 0.1$ | $4.0 \pm 0.1$ |
| ***Wage non-academic and excellent*** | A | $8.9 \pm 0.4$ | $8.8 \pm 0.6$ | $8.9 \pm 0.4$ | $8.9 \pm 0.4$ |
| | C | $6.3 \pm 0.3$ | $8.9 \pm 0.7$ | $8.8 \pm 0.7$ | $8.9 \pm 0.7$ |
| ***Wage academic and adequate*** | A | $11.0 \pm 0.2$ | $11.0 \pm 0.2$ | $10.6 \pm 0.3$ | $10.9 \pm 0.3$ |
| | C | $10.1 \pm 0.3$ | $10.9 \pm 0.4$ | $9.9 \pm 0.2$ | $10.9 \pm 0.4$ |
| ***Wage academic and excellent*** | A | $13.0 \pm 0.2$ | $13.0 \pm 0.2$ | $13.0 \pm 0.2$ | $12.9 \pm 0.3$ |
| | C | $12.1 \pm 0.3$ | $12.9 \pm 0.4$ | $11.9 \pm 0.3$ | $12.9 \pm 0.4$ |

## 5.5 Results of apprenticeships for artisans

The specific parameters for apprenticeships by artisans is presented in Table 5.19. As can be seen, artisans have limited training capacity (i.e. they accept only one new apprentice per run). Moreover, for the model to be more realistic, we assumed only some artisans accept apprentices and those who accept them will do so once in three years. The number of trainers considered for the system is for each run, and we considered a trainer as a representative for a group of *three possible trainers* (i.e. 100 artisans accept participants in each run). The agents already training decide based on the behaviour of similar training agents (i.e. if a similar agent decides not to train, they reduce the quality of training).

What have been stated earlier (i.e. participation by a limited number of artisans), impacts apprentices' decisions by assuming a 10% chance of being a trainer in the system in the near future;[24] hence, they have an income that is the same as the paid costs in the future. The agents assume they can be trainers after finishing the programme in three years (because the chance is not high, they do not consider conditional probabilities). The demand in these systems is a function of the following phenomena:

- Formerly active agents retire, pass away, or move to other communities. This indicates the requirement of skilled agents observed or provisioned in some societies. For instance, Neumark et al. (2013) warned that some states in the US will face skill shortages in the near future due to the retirement of "baby boom cohort";
- Population growth introduces new demands for the skill. This is a consequence of new demand for services introduced by a new person. In most countries, net population growth is positive; hence, all else unchanged, more skilled agents are required to work in the same sector.[25]

Note that based on the assumption that all agents would not participate in the training, and the ones who do train participate once in three years,[26] the demand can be a significant share of the number of trainers (we assumed that $R$ in Algorithm 5.1 is 60%). The impact of asking for a premium (i.e. prepayments by apprentices) is twofold: a) it imposes some initial costs that are considered by apprentices to calculate the profits of attending the programme and b) the imposed costs limit the share of the society that can afford to attend the apprenticeship to families with higher incomes (around 30% of the society).[27] Furthermore, for stickiness of wages (stated in Section 5.3.1), we modified the threshold employed for manufacturer societies, considering the new proportion of the demand (i.e. $60\%$), to decrease the considered number (i.e. we used 18 instead of 30).

For modelling apprenticeship programmes with respect to artisans, we chose three characteristics, namely:

[24]It is based on the evidence that suggests that "masters' experience of training did matter. Masters were able to charge higher premiums with each apprentice they took, with the fourth apprentice paying over 20 per cent more than the first" (Minns & Wallis, 2011, p. 12). From the importance of training experience, we can infer that a recently trained person could hardly recruit apprentices.

[25]Around 20 countries face shrinking populations (Wikipedia contributors, 2019).

[26]It is based on the apprenticeship period in modern instances, namely modern Britain and German apprenticeships.

[27]It is based on the evidence of 1700s England that indicates it took about two years of saving for a farmer to provide the required premium for an apprenticeship in low prestigious industries, such as the metal and footwear industries — £53.6 versus £10 (see Minns & Wallis, 2012, Table 2). Also, the more prestigious skills and professions that were not hired by a company asked for higher premiums that were mostly affordable by "sons of professionals and gentlemen"(Minns & Wallis, 2011, 2013). On average, these premiums were five times more than that of the metal and footwear industries (Minns & Wallis, 2011, 2013).

Table 5.19: The simulation parameters for artisans

| Name | Description | Distribution | Values |
|---|---|---|---|
| Number of trainer artisans | | Constant | 100 |
| Capacity | Small companies | Constant | 1 |
| | Large companies | | 1 |
| Probability of leaving the system | When system is open (per run) | Constant | 0.1 |

- asking for a premium;
- the degree of openness for candidates of other communities seeking to join apprenticeship programmes;
- benefiting from guilds as a mediator to hedge already skilled artisans' benefits (see Table 5.20).

Table 5.20 presents characteristics for the eight simulated societies and societies they represent. The set-ups (i.e. societies) are identified by a prefix (A.) as a representative for the trade type of *artisans*. In addition, each society can be identified by the first letter of the characteristics, namely *P, O,* and *G* that are representatives of the characteristics listed above. We used a Boolean index to indicate whether such an attribute was included (i.e. 1) or not (i.e. 0). Likewise, in this table a tick indicates the society includes that attribute, and a cross indicates the society does not include that attribute.

Table 5.21 represents an overview of the results. As can be seen, we do not consider academic skills for artisans (the activities are concerned with making or doing things by hand), and skills are divided into ***Adequate*** and ***Excellent***. To obtain the GDI, we employed the values in Table 5.3. Simulation started with wages equal to 7 and 11 for agents with adequate and excellent skills, respectively. The following paragraphs investigate the impact of the society's characteristics on the agents' behaviour.

Table 5.20: Set-ups for apprenticeship programmes in artisans' society

| Characteristics | $A.P_0O_0G_0$ (Julfa/Germany) | $A.P_0O_0G_1$ (Modern Britan) | $A.P_0O_1G_0$ | $A.P_0O_1G_1$ | $A.P_1O_0G_0$ | $A.P_1O_0G_1$ (Old Britain[1]) | $A.P_1O_1G_0$ | $A.P_1O_1G_1$ (Old Britain[1]/EIC) |
|---|---|---|---|---|---|---|---|---|
| Premium | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ |
| Open | ✗ | ✗ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Guilds | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ |

[1] Note that in old Britain both closed and open societies were presented.

Table 5.21: Results for the apprenticeship programmes of artisans' societies

**Part 1 (Societies $\mathbf{A.P_0O_0G_0}$–$\mathbf{A.P_0O_1G_1}$)**

| **Setup** | $\mathbf{A.P_0O_0G_0}$ (Julfa/ Germany) | $\mathbf{A.P_0O_0G_1}$ (modern Britain) | $\mathbf{A.P_0O_1G_0}$ | $\mathbf{A.P_0O_1G_1}$ |
|---|---|---|---|---|
| ***Wage adequate*** | 3±1.5 | 9.0±0.2 | 9.9 ± 0.3 | 9.9±0.3 |
| ***Wage excellent*** | 4.9±1.6 | 11.8±0.1 | 12.0±0.1 | 12.7±0.1 |
| ***Number of adequate*** | 65.7 ± 3.8 | 63.5 ± 2.7 | 54.8 ± 2.0 | 54.0 ± 2.3 |
| ***Number of excellent*** | 30.0 ± 1.3 | 30.2 ± 1.5 | 20.7 ± 1.3 | 23.2 ± 1.1 |
| ***Total skilled*** | 95.7 ± 4.0 | 93.7 ± 3.1 | 75.5 ± 2.4 | 77.2 ± 2.5 |
| ***Programme completion (%)*** | 70.6 ± 3.4 | 70.9 ± 2.0 | 59.3 ± 1.4 | 58.5 ± 1.2 |
| ***GDI*** | 797 ± 28 | 782 ± 18 | 767 ± 22 | 677 ± 19 |

**Part 2 (Societies $\mathbf{A.P_1O_0G_0}$–$\mathbf{A.P_1O_1G_1}$)**

| **Setup** | $\mathbf{A.P_1O_0G_0}$ | $\mathbf{A.P_1O_0G_1}$ (old Britain) | $\mathbf{A.P_1O_1G_0}$ | $\mathbf{A.P_1O_1G_1}$ (EIC) |
|---|---|---|---|---|
| ***Wage adequate*** | 4.0 ± 1.0 | 8.5 ± 0.2 | 9.9 ± 0.3 | 9.9 ± 0.4 |
| ***Wage excellent*** | 6.1 ± 1.0 | 11.6 ± 0.1 | 12.0 ± 0.1 | 12.3± 0.2 |
| ***Number of adequate*** | 62.6 ± 2.9 | 63.2 ± 1.9 | 54.6 ± 1.5 | 54.1 ± 1.5 |
| ***Number of excellent*** | 26.3 ± 2.6 | 29.3 ± 1.6 | 20.2 ± 1.5 | 21.4 ± 1.6 |
| ***Total skilled*** | 88.9 ± 3.9 | 92.5 ± 2.5 | 74.8 ± 2.1 | 75.5 ± 2.2 |
| ***Programme completion (%)*** | 71.2 ± 2.2 | 70.4 ± 2.1 | 59.1 ± 1.4 | 58.4 ± 1.3 |
| ***GDI*** | 769 ± 26 | 782 ± 16 | 765 ± 15 | 721 ± 12 |

### 5.5.1 Impact on programme completion

Figure 5.7 indicates the tendency of agents towards completing the programme with respect to different set-ups. In these graphs, each horizontal pair groups simulated societies, based on having (right) and not having (left) that characteristic (i.e. the same line appears in each pair of characteristics). Furthermore, the societies of interest are highlighted with thicker lines. As can be seen in Table 5.21, when there is no guild (indicated by $G_0$), the overall completion rate increases. The results comply with Wallis's (2008) claim about the impact of guilds on apprenticeships (see $A.P_0O_0G_0$, $A.P_0O_1G_0$, $A.P_1O_0G_0$, and $A.P_1O_1G_0$ versus $A.P_0O_0G_1$, $A.P_0O_1G_1$, $A.P_1O_0G_1$, and $A.P_1O_1G_1$). He claims that "apprenticeship[s] thrived despite, not because of the guilds, therefore we should be more aware of the distinction between the two institutions" (Wallis, 2008).

The only counter example for the negative impact of guilds is societies where apprentices do not pay any premium, and programmes take place in a closed society. This outcome is intuitive, and one can predict that in a society where the programme takes place for free,

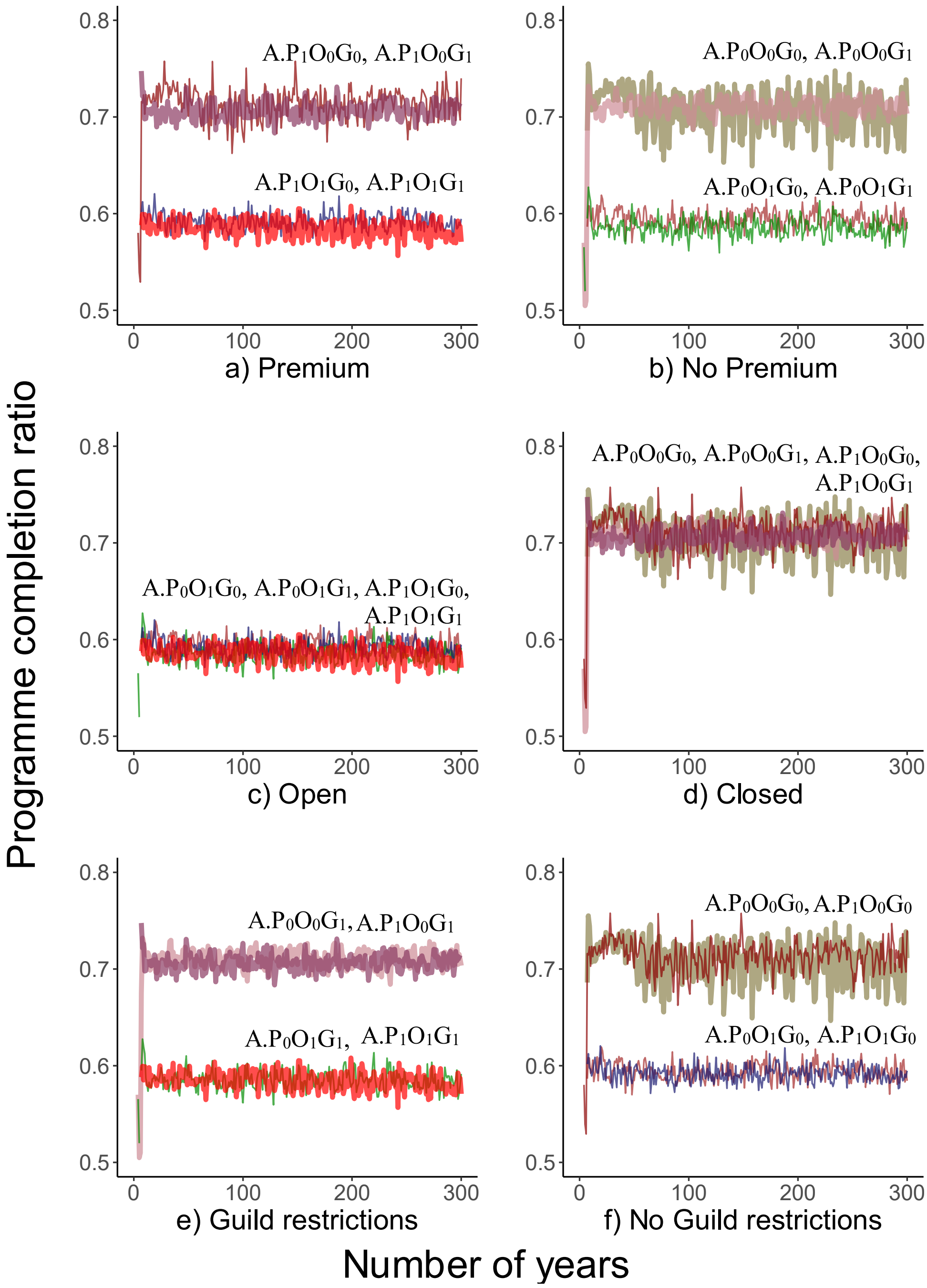


Figure 5.7: Programme completion ratio (vertical axis) in each iteration (horizontal axis), considering different system characteristics.

and no one leaves the society during or after finishing the programme, trainers will not train well to control the workforce supply, and some apprentices may leave the programme due to limited probabilities associated with finding a job.

Just as with the manufacturers' case, openness decreases the completion rate. The highest completion rate is associated with $A.P_1O_0G_0$, wherein the society is closed, agents pay a premium, and there is no guild that limits agents who join the labour market. Variations are not impacted by paying premiums, except for $A.P_0O_0G_0$ versus $A.P_1O_0G_0$ (i.e. two closed societies without guilds, with a difference in paying premiums) where we see that paying premiums had some impact on decreasing fluctuations.

Finally, the percentage of agents who finished the programme is more than the numbers suggested by Wallis (2008)[28] which can be caused by factors such as deceased agents. Note that in one instance Wallis (2008) mentioned that the reason for leaving the programme was that 14.6% of apprentices died, and 1.1 per cent wed and left the programme for paid jobs (i.e. 15.7 in total). This number justifies differences between the completion rate obtained by simulation (i.e. 58.4%) and the around 40% completion rate observed in old Britain.

### 5.5.2 Impact on the GDI

The next step is measuring the success of these programmes in increasing the GDI of society. As can be seen in Figure 5.8, paying a premium has some impact on decreasing the system's GDI by limiting the number of participants; hence, the value of items produced by them ($A.P_0O_0G_0$ and $A.P_0O_1G_0$ outperform their counterparts' GDIs, i.e. $A.P_1O_0G_0$ and $A.P_1O_1G_0$). The only case that faced an increase in the GDI once managers asked for premium is $A.P_1O_1G_1$, where the system was open and had some guilds, i.e. a representative of old Britain. This phenomenon indicates the importance of premiums in convincing artisans to train well.

Having a guild only improves society $A.P_1O_0G_1$'s GDI, where the system is closed and some premium is paid. Note that paying premiums decreases a society's performance by limiting access to the apprenticeship programme for part of the society, and the closedness of the society causes trainers to feel trained apprentices threaten their future income if no guild is available. Overall, closed societies (identified by $O_0$) produce better GDIs for training apprentices who will serve the society (see $A.P_0O_0G_0$, $A.P_0O_0G_1$, and $A.P_1O_0G_1$ versus $A.P_0O_1G_0$, $A.P_0O_1G_1$, and $A.P_1O_1G_1$, respectively).

The only instance where openness slightly improves the system performance is $A.P_1O_1G_0$, which is caused by a combination of low access to apprenticeship programmes (i.e. paying a premium) combined with a lack of guilds. Finally, for both open and closed societies, when there are free programmes and no guilds system in terms of GDI, they outperform other cases (i.e. $A.P_0O_1G_0$ outperforms $A.P_0O_1G_1$, $A.P_1O_1G_0$, and $A.P_1O_1G_1$ and $A.P_0O_0G_0$

[28]See Table 1 of Wallis (2008) for more detail.

outperform all societies).

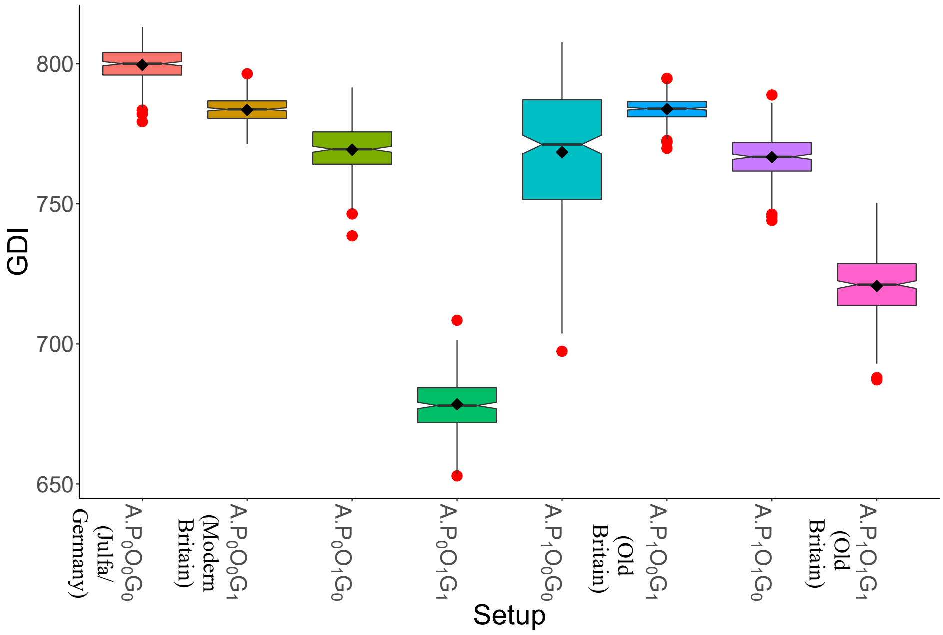


Figure 5.8: Boxplot of the GDI acquired by apprentice programmes under different set-ups in an artisan society; red dots present outliers and a diamond indicates the mean.

### 5.5.3 Impact on wages and the number of skilled agents

Figure 5.9 presents numbers of excellent (left) and adequate (right) skilled agents in the society. As can be seen in Figure 5.9 and Table 5.21, asking for premiums (indicated by $P_1$) decreases the number of skilled agents in the system by limiting the number of participants ($A.P_1O_0G_0$, $A.P_1O_0G_1$, $A.P_1O_1G_0$, and $A.P_1O_1G_1$ versus $A.P_0O_0G_0$, $A.P_0O_0G_1$, $A.P_0O_1G_0$, and $A.P_0O_1G_1$). This impact is caused by limiting the potential number of participants, and hence there is a decrease in the degree of motivation in apprentices. On the other hand, the openness of the system (indicated by $O_1$) causes a remarkable drop in the number of skilled agents in the system (see $A.P_0O_1G_0$, $A.P_0O_1G_1$, $A.P_1O_1G_0$, and $A.P_1O_1G_1$ versus $A.P_0O_0G_0$, $A.P_0O_0G_1$, $A.P_1O_0G_0$, and $A.P_1O_0G_1$). This drop is predictable, keeping in mind that some apprentices leave the system to work in other societies.

To assess the impact of the guilds (indicated by $G_1$), we compare societies $A.P_0O_0G_1$, $A.P_0O_1G_1$, $A.P_1O_0G_1$, and $A.P_1O_1G_1$ with $A.P_0O_0G_0$, $A.P_0O_1G_0$, $A.P_1O_0G_0$, and $A.P_1O_1G_0$. As depicted in Figure 5.9, the number of excellent skilled agents increases when there are some guilds in the system. This slight increase was predictable, given the fact that companies have less fear of training some potential competitors. However, the number of agents possessing adequate skill decreases in almost all societies run by guilds. The only exception is $A.P_1O_0G_1$ where agents should already pay a premium, so the presence of guilds influences the tendency to attend the programme.

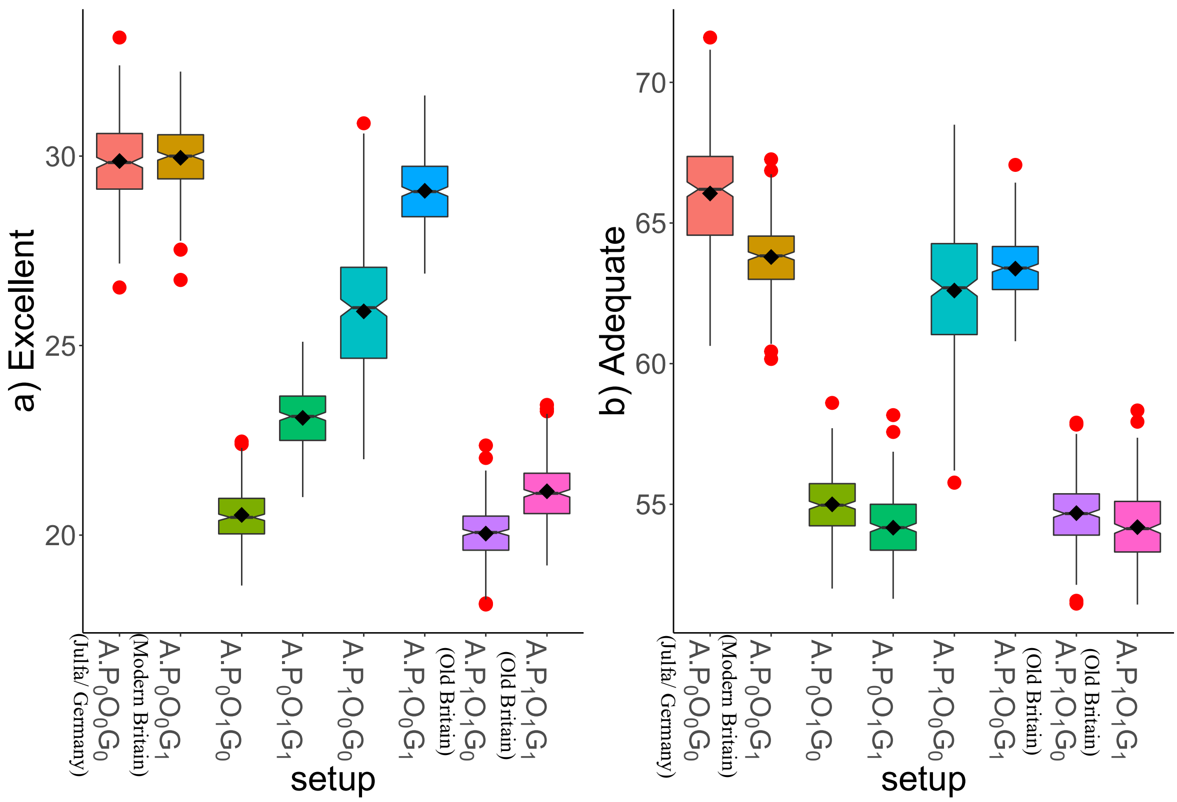


Figure 5.9: Boxplot of skill acquired by apprentice programmes under different set-ups in an artisan society; red dots present outliers and a diamond indicates the mean.

To study other influences of these characteristics, we measure wages paid in each society. Figure 5.10 presents wages associated with excellent (left) and adequate (right) skilled agents in the society. As can be seen, when there is no guild (identified by $G_0$), wages decrease to some extent (see wages in $A.P_0O_0G_1$, $A.P_0O_1G_1$, $A.P_1O_0G_1$, and $A.P_1O_1G_1$ versus $A.P_0O_0G_0$, $A.P_0O_1G_0$, $A.P_1O_0G_0$, and $A.P_1O_1G_0$). The openness of the system (identified by $O_1$) increases wages in the societies for the formerly stated reasons. Asking for a premium (identified by $P_1$) has different impacts on wages. It limits the increase in wages in some societies ($A.P_0O_0G_1$ and $A.P_0O_1G_1$ versus $A.P_1O_0G_1$ and $A.P_1O_1G_1$) but fails to do so in other societies (see $A.P_0O_0G_0$ and $A.P_0O_1G_0$ versus $A.P_1O_0G_0$ and $A.P_1O_1G_0$).

Another interesting observation regards the combination of closedness and the lack of guilds that reduces the wages dramatically. Moreover, not asking for premiums causes more drops in wages. This phenomenon was the reason for what was observed by Chardin (Chardin, 1720), i.e. masters were reluctant to train their apprentices. The masters' tendency for training will be less if they have to pay wages (as observed in Persia by Chardin). One of the essential tools of masters in such societies is the flexibility of the apprenticeship's duration. This flexibility helps masters to compensate the costs incurred to them by asking apprentices to assist them in their day-to-day tasks and reducing the speed of training to improve their future income and control the labour supply.

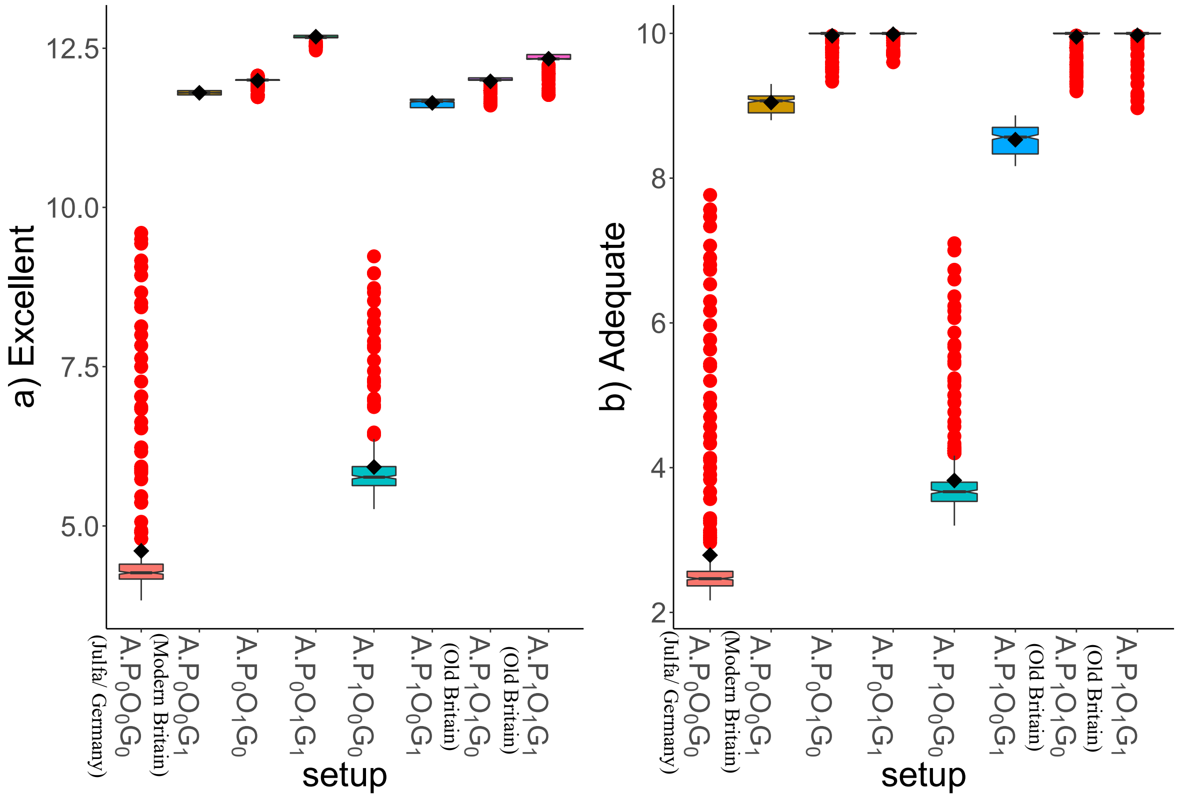


Figure 5.10: Boxplot of wages associated with different degrees of skill under different setups in an artisan society; red dots present outliers and a diamond indicates the mean.

As can be seen in Figure 5.10, societies $A.P_0O_0G_0$ and $A.P_1O_0G_0$ have a significant shift in means in comparison with medians (i.e. their means are placed outside the box). To study the reason for such shifts, Figure 5.11 presents the line plot for these two societies. Based on the figure, we can conclude that the outliers (i.e. observations outside the first and third quartiles) that caused this shift are representatives for gradual decreases in wages — over

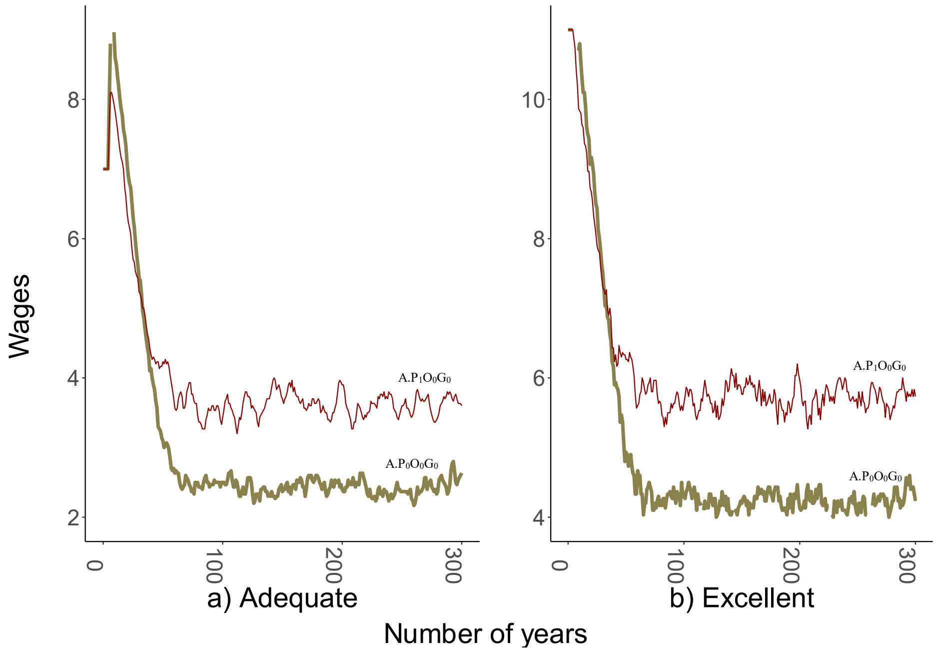


Figure 5.11: The plot of changes in wages associated with different degrees of skill for selected societies of an artisan society

time and after more than 50 iterations (i.e. years) wages reach a more stable value (i.e. the value represented by the median in Figure 5.10).

## 5.6 Summary, discussion, and outlook

This chapter has investigated the key characteristics of apprenticeship programmes by considering both historical and contemporary cases in several countries. The main aim of the simulation has been to identify the impact of institutional mechanisms and social characteristics on the success of these programmes in increasing the number of skilled agents and improving societal level profits (i.e. the GDI). To perform this modelling, we considered two trade types, namely artisans and manufacturers.

Differentiating these two trade types is essential, as their motivations for accepting apprentices were diverse. Artisans trained potential employees and may have felt threatened by their apprentices, as they were potential competitors. However, the manufacturers train future employees for themselves. For each of the aforementioned trade types, we systematically changed the key characteristics to assess their impacts on societies' performances. Furthermore, we considered different scenarios for manufacturers because of the more complicated characteristics of those societies.

For the manufacturers (as stated in Section 5.4), we considered three other characteristics, the openness of the society, the utilisation of schools in training apprentices, and the trainer type. The impact of the openness of the society is twofold and is addressed by two different scenarios:

- some agents may leave the system during training to find a job in other communities (Scenarios A and B of manufacturers);
- some agents may immigrate from other communities to work in the community under study because of issues in their communities (Scenario C of manufacturers).

We systematically mapped these characteristics into societal stereotypes which capture intrinsic separate real-world societies. These characteristics included the role of schools, one of the differences between the EIC and Julfan traders. The importance of schools is also emphasised in modern contexts by differentiating between German and British cases. The schools facilitate transferring academic skills such as mathematics and what-if scenario analysis. These skills help agents to handle more complicated tasks and also to be more able to handle changes in trade. The trainers for manufacturers have two types: contractors who are paid for training agents, and companies who train potential employees for themselves. These two factors, i.e. *employing schools* and *trainer types* were considered for all scenarios associated with manufacturers.

The other trades type that has been addressed in this chapter is artisans. In both historical and contemporary contexts, we can see some societies that use guilds as a mediator to regulate the workforce market. Such restrictions remove threats of an excessive supply of agents for artisans who already practise the profession. The openness of the society is another characteristic that impacts the workforce supply. In other words, agents may leave the system for better opportunities in other communities when the system is open; hence, less workforce supply is available for the future. Finally, in old Britain, trainers asked for some pre-payments to compensate for the costs of training. Those costs reduced the number of agents who could access the system to those from more prosperous families, and these expenses reduced the expected profit margins of apprenticeships for agents.

As the results suggest, the success of apprenticeships should not be assessed by programme completion, and the approach taken by Ryan and Unwin (2001) can be misleading. For instance, when agents are trained in a closed society that lacks academic training by manufacturers (see $M.S_0O_0C_1$ in Table 5.6), the highest percentage of finishing the apprenticeship programme was available ( $77.6\%$), but this system has a lower GDI than two other closed societies ($M.S_1O_0C_0$ and $M.S_1O_0C_1$ in Table 5.6) with 888 versus 1215 and 1264.

In the $M.S_0O_0C_1$ society, schools are not mandatory, which reduces the speed of learning and profitability. Furthermore, agents trained by a company (not by contractors) also have chances to be hired by the companies under which they are trained, and they have more motivation to complete the programme; hence, the system is expected to have a higher completion rate. Therefore the completion rate is not a good indicator for the sustainability of the apprenticeship programme in a society.

Simulation for manufacturers indicates the importance of different characteristics of the society. The Scenario A of manufacturers suggests that if the government wants to intervene in available apprenticeship programmes run by stakeholders (i.e. companies), it should be done by introducing school-based training systems, especially for skills in domains such as mechanical and electrical engineering where technical knowledge and analysing skills are essential for being flexible when a company changes its procedures. These obtained academic skills will help more prominent manufacturers improve their profits.

We assessed the impact of openness of a community (i.e. when the chances to leave the community to work in other places are available) on the GDIs for Scenarios A and B of manufacturers. The results emphasise the importance of some guarantees provided by apprentices about staying in the same society after training, since the openness of systems (i.e. leaving a system by trainees, which is indicated by $O_1$) decreases the GDI dramatically (see $M.S_0O_1C_0$, $M.S_0O_1C_1$, $M.S_1O_1C_0$, $M.S_1O_1C_1$ versus $M.S_0O_0C_0$, $M.S_0O_0C_1$, $M.S_1O_0C_0$, $M.S_1O_0C_1$ in Figures 5.2 and 5.5). This drop of the GDI is because of the substantial decrease in either collaboration by large companies to train apprentices or the failure of some companies to find the most appropriate agents to hire.

On the other hand, for manufacturing apprenticeships, a scheme that persuades agents to finish the programme instead of leaving it half way for better jobs, is another way to improve system performance. This can be achieved by requiring agents to earn their degree or diploma as undertaken in the German system. It should be emphasised that when comparing societies considering trainer type (i.e. contractors or companies), we should consider some other factors that may motivate the government to use contractors. Contractors have direct impacts on the unemployment rate by creating some jobs for contractors and trainers in the system, and utilising them is a method to instantly reduce the unemployment rate. However, the factor that demotivates the government to invest considerably in the system is the magnitude of public expenditure for training more agents as a consequence of paid subsidies to contractors.

We assessed three scenarios for apprenticeship systems in a manufacturer society to obtain more insights into the system. The scenarios were as follows:

Scenario A) training to satisfy the labour market demand (i.e. 100 to 120 apprentices per run);

Scenario B) training more than demand by relaxing unions' considerations (from 180 to 200 apprentices per run);

Scenario C) openness for skilled agents from other countries to join and work in the society.

Systems run by contractors (indicated by $C_0$) benefited more from increasing the number of apprentices to a level more than was required (see $M.S_0O_0C_0$, $M.S_0O_1C_0$, $M.S_1O_0C_0$, and $M.S_1O_1C_0$ in Figure 5.5 Scenario B). There are two reasons for this. First, the system could satisfy more demand. Second, the availability of skilled agents would not impact trainers' motivations for training. Note that manufacturers' objectives of training are to fulfil their demand, but contractors train in order to make more immediate profit.

However, an additional factor for manufacturers' apprenticeship that should be taken into account is associated with *Scenario B*. *Scenario B* has more public expenditures for the apprenticeship programme compared to *Scenario A*. Finally, the results of *Scenario C* shed some light on the potential reasons large companies in Britain asked for an apprenticeship programme but would not participate in it (Ryan & Unwin, 2001). If we assume that some skilled agents with lower expectations from outside the country are available (as suggested by McCollum and Findlay (2015)), the main intention of large companies is to stabilise the wages so they do not have to pay so much to hire skilled agents.

Assessing the apprenticeship for artisans reveals that a lack of guilds and prepayments for the programme increases the system's GDI significantly (see $A.P_0O_0G_0$ and $A.P_0O_1G_0$ in Figure 5.8). The negative impact of prepayments is through limiting the number of potential participants and dissuading them from participation by decreasing the profit of apprenticeship. Guilds, as a means of controlling workforce supply, make the system biased for trainers' benefits and fail the self-regulatory behaviour of the system by unilaterally increasing the risks associated with newly trained apprentices finding a job. Therefore on the one hand, trainers will train without considering the number of unemployed skilled agents, and on the other hand, this increase cannot reduce wages to modify demands for highly skilled agents.

Finally, there are some other important characteristics of systems that are observed in historical and contemporary cases. These phenomena are studied by considering artisan societies. The results suggest that if some premium is asked from the participants, by limiting the number of potential attendees, the degree of skill will decrease. This phenomenon was evident in old Britain where agents had to pay some premium.[29]

[29] In the EIC, agents should have asked two guarantors to sign a bond, which it was not collected uppon the

Moreover, even though guilds may improve the number of skilled agents, they also reduce the system's GDI in all cases, except one. That case is a closed society where agents were asked to pay a premium. These results suggest the efficacy of the Julfan and the German apprenticeship systems in comparison to the British system for both artisans ($A.P_0O_0G_0$) and manufacturers ($M.S_1O_0C_1$) under certain conditions.

We wish to acknowledge some of the limitations of this chapter. These include not exploring parameters in a continuous range, but only considering a systematic set of discrete values (e.g. for motivation, and bad training), especially in cases where it is predictable that a further decrease in parameter values reduces system performance (e.g. when considering outputs such as the GDI and the number of skilled agents). Furthermore, while more complex functions for the impact of these parameters and letting agents decide about the optimum numbers would have made the system more thorough, it would have increased the complexity of the system and made it more case dependent (thereby limiting the generalisation of results). This work also did not address the effect of the export and import of items produced. Considering these possibilities can increase or decrease the demand for items and encourage apprentices, as well as trainers, to change their behaviours based on other markets or prices of rival products.

Another issue that should be considered in the future is addressing wage differences among highly skilled agents, low-skilled agents, and labourers, in particular societies that decrease tendencies to attend the apprenticeship programme. This phenomenon is not considered in this chapter because certain parameter values may lead to immediate failure (no participation, which means the apprenticeship programme is failing) of the simulation. However, we should emphasise that policy-makers should consider the aforementioned factors before making any attempt to design an apprenticeship programme. Other parameters not considered are modelling more than one skill and the limited populations that indicate the agent's preferences to attend more profitable programmes, companies' bankruptcy because of a lack of skilled agents, consideration of the mortality of apprentices, and economic depression, to name a few. While we believe we have considered the essential aspects of the system, these nuances can be explored in the future, especially if exploring specific cases.

Moreover, considering obligations for companies to accept apprentices or studying the best ways for reforming an already working system is another potential extension of this model that can help developing societies (see Allais's (2012) study on South Africa and Palmer's (2009) study on Ghana). Nevertheless, based on this chapter, we know that for manufacturers, based on their needs, we can consider two situations:

fault (Hejeebu, 2005, see footnote 43).

1. When companies themselves need the skilled agents in the future. If that is the case, system characteristics are similar to one of four manufacturing societies ($M.S_0O_0C_1$, $M.S_0O_1C_1$, $M.S_1O_0C_1$, and $M.S_1O_1C_1$);
2. If companies do not need the apprentices they had trained, the system performance would be worse than that of manufacturing societies $M.S_0O_0C_0$, $M.S_0O_1C_0$, $M.S_1O_0C_0$, and $M.S_1O_1C_0$, since companies only want to reduce their costs and hence decrease the programme's quality as much as possible.

Given this, the government interventions should focus on providing academic training required by manufacturers in schools and finding some ways to persuade participants to finish the programme. For instance, Brockmann and Laurie (2016) recently conducted a comparative case study between two British apprenticeship systems, engineering and motor vehicle maintenance (MVM), which support the results of this simulation. Their results suggested that the engineering apprenticeship programme, known internationally for its quality, benefited from more motivated trainees with better education backgrounds. Finally, they suggested that even for MVM apprentices who want to be skilled workers, the programme should provide a comprehensive educational opportunity.

In the next chapter, we provide a mental architecture model by taking account of the impact of agents' roles on their decisions. We also consider the impact of the apprenticeship programme on recruits' skills and decision-making procedures.

*"Mind, in its use, is not static, but constantly developing."*

Gödel

# 6

# Dynamics in the agent's cognition

## 6.1 Introduction

This chapter presents a cognitive architecture for agents.[1] This cognitive architecture helps us to model dynamics in institutions or changes in rules and norms over time. However, these changes take place in two ways. The first one concerns failed institutional norms, as opposed to the working rules (i.e. laws that are enforced). This kind of change concerns the informal changes such as skipping formal laws. The second way of change is a formal revision of rules. For this purpose, we investigate the impact of system characteristics on agents' beliefs about the system and consequently their actions.

The chapter extends a mental architecture to model dynamics in an agent's cognition and the dynamics in institutions followed by that. To model the impact of societal meta-roles on decisions, we use and modify a folk-sociological meta-role model for a *rule-making* and *rule-following* context. Note that by rule-making we mean establishment of institutions by certain members of the society and by rule-following we mean following those institutions by a whole society. Then we state studies regarding the impact of personality on humans'

[1]We consider the agent as a male because of the gender of agents in the two historical long-distance societies addressed in this study.

decisions. Finally, we briefly state some reasons for which an agent modifies its cognition.

In developing the BDI cognitive architecture, like Gödel, we believe that minds are not equivalent to machines and "mind, in its use, is not static, but constantly developing" (Gödel in Wang 1974, p. 325, as cited in Copeland & Shagrirand, 2015, p. 2). One of the realisations of the development of mind is that having an exact simulation of it is impossible. The other aspect of such a development is dynamics of the mind which we prefer to use, because first, this development of ideas does not always mean a progress (e.g. lenient beliefs towards deceptions), and second, other aspects of human cognition also change over time (e.g. personality). In other words, a goal of this chapter is to refine the belief-desire-intention (BDI) cognitive architecture (Bratman et al., 1988) — see Section 3.2.2 for an overview — to address this aspect of agents.

After presenting the concepts required for this extension, we also briefly investigate the two long-distance trading societies (i.e. the EIC and Julfa), and we state how this model can be utilised for those societies using evidence from empirical studies. Also, we provide information on how the model can be operationalised. This chapter develops a conceptual model and we use it in the next chapter to simulate the two historical long-distance trading societies.

The rest of the chapter is organised as follows. Section 6.2 investigates the relevant concepts to our extension of the BDI cognitive architecture. Section 6.3 states the proposed architecture for agents' decision-making. Section 6.4 uses the two historical long distance trading societies to indicate how this architecture can be fitted to real-world scenarios. Section 6.5 provides detailed information of modules and their interaction. Section 6.6 states how we use the model to operationalise the agent's decision-making processes for the historical long-distance trading societies. Finally, Section 6.7 provides a summary of the chapter along with some discussions on how the presented architecture can be modified and extended to include other examples.

## 6.2 Cognitive architecture concepts

This section covers an agent's cognitive aspects to modify the BDI cognitive architecture (Bratman et al., 1988). A simplified version of this architecture is presented in Figure 6.1. **Beliefs** are an agent's information about the world. **Desires** are what an agent would like to do. **Intentions** indicate an agent's decisions that it commits to do. **Plans** coordinate the intentions of an agent. Note that as indicated in Figure 6.1, the environment impacts an agent's beliefs-desires-intentions through its perception of external events. Also, an agent's plans impact and are impacted by its beliefs-desires-intentions. An agent acts based on its beliefs-desires-intentions and also updates its plans. An agent's actions produce new events in the environment.

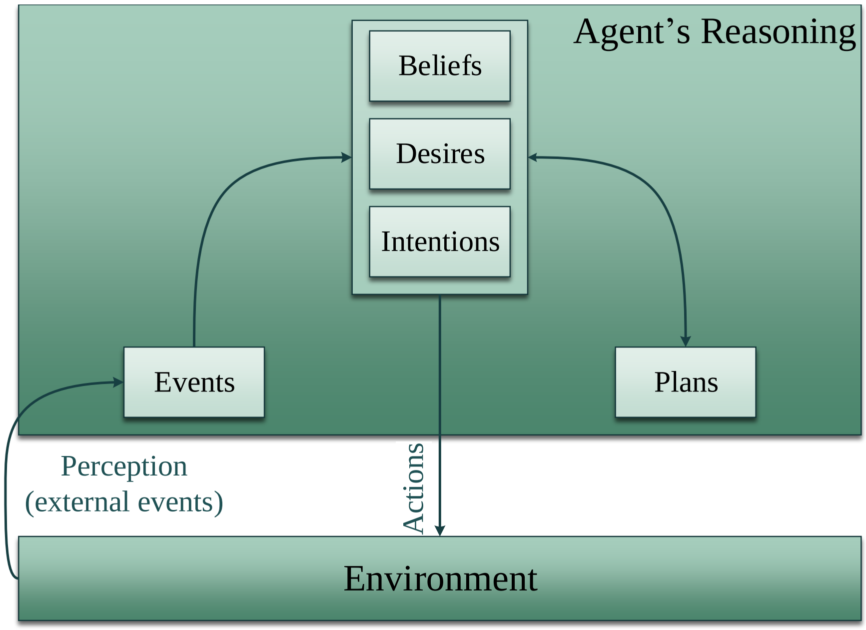


Figure 6.1: The BDI cognitive architecture (it is also presented in Section 3.2.2).

In what follows, we provide the necessary background for our extension of the BDI cognitive architecture. This extension considers the impact of psychological circumstances and the agent's meta-role on its actions. In Section 6.2.1, we describe how another cognitive model considers the influence of the different components of an agent's beliefs (e.g. internal beliefs and beliefs regarding social norms) on its decisions (Fishbein & Ajzen, 1975). In Section 6.2.2, we describe another method for identifying agents in a society, that is, categorising them regarding their meta-roles in that society (Purvis et al., 2014). Next, in Section 6.2.3 we state how agents are distinguished regarding their personality differences (Jung, 1976; Myers et al., 1998). Finally, in Section 6.2.4, we provide an overview of how an agent changes its beliefs for different reasons. These concepts will be used in Section 6.3 to modify the BDI cognitive architecture.

### 6.2.1 Theory of planned behaviour

The theory of planned behaviour was initially developed as the *Theory of Reasoned Action* (TRA) (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975). Ajzen (1985, 1991) introduced the *Theory of Planned Behaviour* (TPB) by refining the TRA. Similar to the BDI cognitive architecture, the TPB assumes that an agent's behaviour is impacted by its beliefs and information (Fishbein & Ajzen, 2011). Note that experiments indicate that the correlation between the expressed intentions and actual behaviour is about 0.6 (i.e. the actions mostly but not necessarily conform with the intentions, Ajzen, 2011; Hale et al., 2002). The reasons for not having a perfect correlation include changes in beliefs between two experiences, past behaviours (i.e. habits), moral obligations, and changes in beliefs after responding to questions (Hale et al., 2002).

A difference between the TPB and the BDI cognitive architecture is that the TPB categorises an agent's beliefs into three subcategories, namely '*behavioural beliefs*', '*normative beliefs*', and '*control beliefs*', along with a determinant factor called '*actual control*' that blocks the execution of intention.

We describe these three beliefs using two examples. As the first example, assume that we want to buy a four-wheel drive (4WD) vehicle. For making such a decision, we consider 4WD vehicle benefits, such as its ability to drive on rocky roads (behavioural beliefs). We also consider our friends' beliefs such as their approval of buying a 4WD vehicle (normative belief). If we intend to purchase a 4WD vehicle, we also consider external factors such as our budget (control beliefs). In this model, we consider the same procedure for following the organisational rules. The next example states how an agent decides about crossing an intersection in violation of a red traffic light, considering his beliefs about the rule, the reaction of others to his violation of the rule, and external punishments imposed by the system. The agent (we call him Alex) faces three distinctive components of beliefs as follows:

- The agent has his own belief about the action, regardless of other people's judgements and punishments. This belief works even if no one is around (*behavioural beliefs*). Instances of such beliefs of Alex include B.1, all rules must be followed and B.2, this rule is because of the new mayor's non-sensical policies.
- Alex also considers other people's expectations about not crossing the red light (*normative beliefs*). These expectations impose costs on him if he breaks the rule. These costs include instances, such as rebukes, scolds, and reprimands (we call them sanctions). Alex has different decisions under different situations, such as N.1, when no one is around, and N.2, when there are some of his neighbours all waiting for the light to turn green.
- Alex also considers the written rule that prohibits crossing the red traffic light under any circumstances (*control beliefs*). This indicates strict restrictions imposed on him. Note that the rule needs some official monitoring and reporting procedures to work. Instances of relevant situations to this include C.1, there are no police and C.2, there

is a traffic control camera that recently took a photo of Alex's father's vehicle when he tried to run the red light, and he was subsequently fined.

Now let us assume that Alex is driving his vehicle and is in a hurry to catch a flight. There is no vehicle in the intersection (i.e. running the red light does not cause an accident). The chances of Alex crossing the red traffic light under combinations of the circumstances mentioned above are different. For instance, the combination of B.2, N.1, and C.1 leads to crossing the red traffic light, while the combination of B.1, N.2, and C.2 provides all the reasons for not crossing the red traffic light. Finally, Fishbein and Ajzen (2011) introduce an additional control called the '*actual control*'. To have a better understanding of an actual control, consider the situation where Alex is not the driver and deals with the combination of B.2, N.1, and C.1. Although Alex decides to break the rule, he cannot.

After stating the impact of beliefs on decisions, we investigate some aspects that lead to changes in those beliefs for an agent. The next subsection provides a brief description of this aspect of the interaction between the agent and the system.

### 6.2.2 Agent meta-roles

To model agents' roles and their interactions, we use CKSW meta-roles presented by Purvis et al. (2014). However, since this chapter concerns the rule-making and rule-following context, we reinterpret those roles for the rule-following context (see Section 3.2.5 for original CKSW specifications). Our interpretations are as follows:

- *Commander* (**C**): They are agents with ultimate power over an organisation. In this context, they are the agents who are permitted to *make or revise rules*.
- *Knowledge* (**K**): They are agents who gather, keep, and transmit information. In this context, these are agents who *monitor and report* the *suspicious activities* of others (i.e. they know-what).
- *Skills* (**S**): they are agents who have the ability to turn knowledge into action (they know *how to do* things). In this context, they may interpret the rules and judge agents' activities.
- *Worker* (**W**): They are agents who perform basic jobs that do not need specialist skills.

Figure 6.2 depicts how the aforementioned meta-roles interact in an organisation. Commander agents (e.g. a board of directors) decide about the rules regarding issues such as trades. They declare those rules to all other agents. An agent's behaviour is monitored by Knowledge agents (e.g. managers) to inform Skill agents (e.g. judges) about suspicious

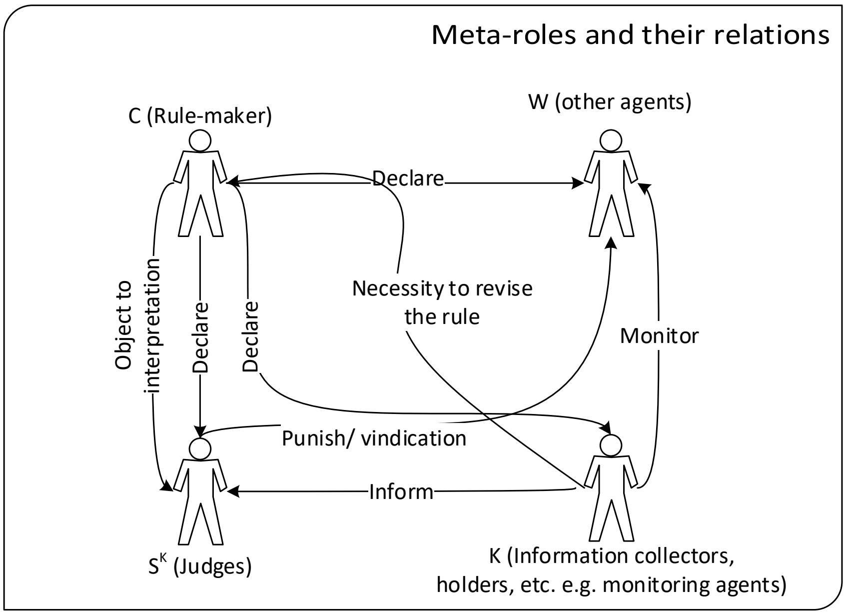


Figure 6.2: Agents' meta-roles and their relations adapted for rule-following context.

actions. Furthermore, based on agents' behaviour, Knowledge agents may suggest some revisions of rules to the Commander agents. Skill agents who also need some elements of Knowledge (i.e. they need some knowledge besides skills and are labelled $\mathrm{S}^{\mathrm{K}}$), interpret the rules and available evidence to punish the violators. Commander agents may express objections to some of those interpretations with respect to their powers.

Figure 6.3 depicts how an agent gets promoted and its meta-role changes. In this figure, the blue roles might not be a part of the organisation (e.g. judges versus human resource managers). A clerk of an organisation may get promoted to higher ranks after some years having demonstrated competence for such a promotion (Worker gets promoted to Knowledge). In certain organisations, if the manager has the relevant education and skills, he can be promoted to a higher position. In these positions, they are responsible for interpreting the situation and deciding about who to fire or hire (i.e. Knowledge gets promoted to $\mathrm{S}^{\mathrm{K}}$). Under certain conditions an agent can get promoted as a director ($\mathrm{S}^{\mathrm{K}}$ or Knowledge gets promoted to Commander).

Note that in our model, we consider two roles for an agent as follows:

- Formal role: this role is defined based on the agent's position in an organisation and was stated in earlier paragraphs (i.e. CKSW meta-roles).
- Informal (internalised) roles: these roles are unofficially and voluntarily performed by agents such as monitoring, and reporting suspicious behaviours of other agents to managers.

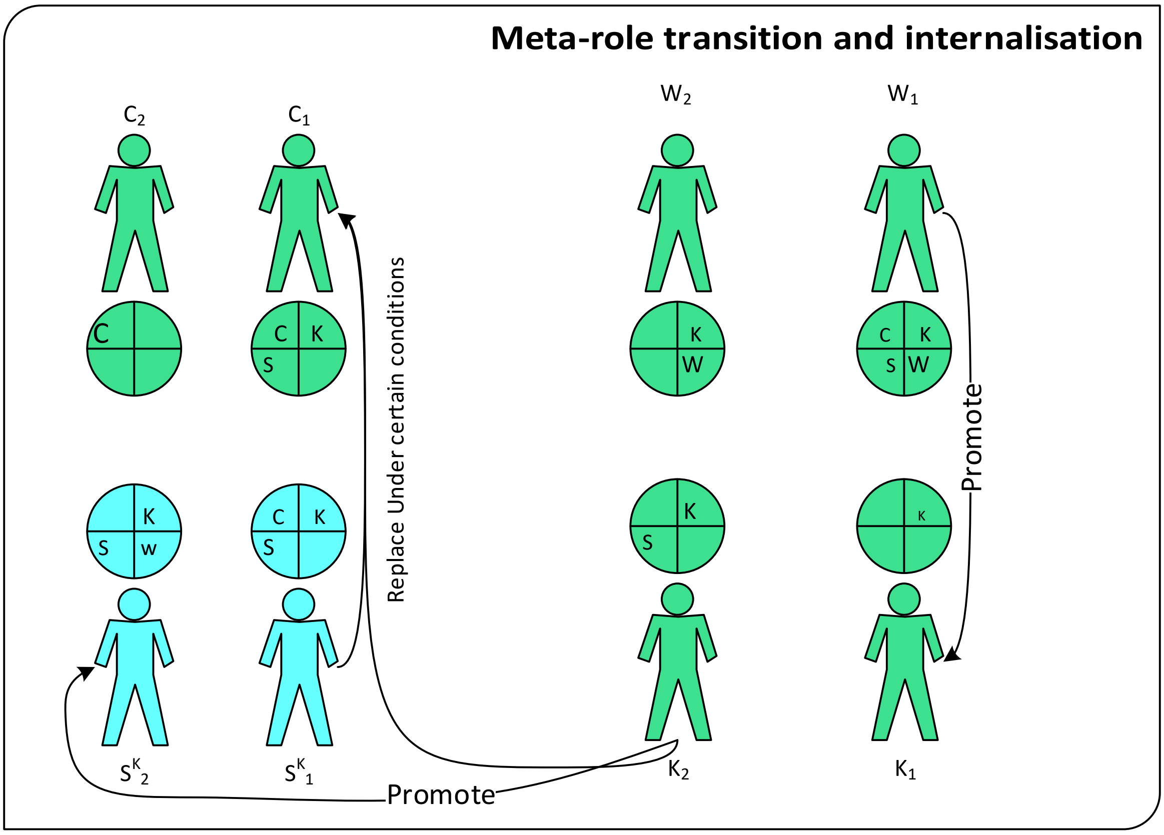


Figure 6.3: Transition of formal meta-roles and internalising informal meta-roles in an organisation (adapted for rule-following context). The circles indicate internalised roles and roles that an agent really performs, and the size of the fonts presents a combination of the importance of the roles for the agent and its ability to perform them (bigger fonts indicate more involvement in such a role). The arrows indicate the possible transitions in society.

The informal roles are voluntarily added to an agent's formal roles, as a favour to the society or organisation. Henceforth, we call the process of adding such informal roles to the formal roles as the *role internalisation*. In Figure 6.3, the combination of informal and formal roles is indicated in the circles placed near the agents. The font sizes of initials inside these circles indicate the involvement in such a role. The involvement is influenced by the ability of an agent to perform a role, as well as the importance of performing such roles by an agent.

For instance, some Worker agents may internalise more responsibilities in a company. They may monitor other agents or they have a charismatic personality and informally establish rules (i.e. norms) which are executed by the help of other agents (see internalised roles of $\mathrm{W}_1$). The other instance concerns Knowledge agents who would not find the rules sensible and are inclined to interpret them while monitoring agents (the addition of Skill to the roles for $\mathrm{K}_2$). Some Knowledge agents might avoid reporting suspicious behaviours or have less ability to monitor, because they do not have a continuous relationship with employees (small K for $\mathrm{K}_1$).

Also, $\mathrm{S}^{\mathrm{K}}$ agents might perform some tasks that are not relevant to their formal role. For instance, they may define a local rule and enforce that ($\mathrm{S}_1^{\mathrm{K}}$) or perform some clerical tasks in their spare time to help the society ($\mathrm{S}_2^{\mathrm{K}}$). Another instance is commanders who establish the rules, but they do not feel they have any obligation to follow them. This instance is available in some countries as parliamentary immunity. In an organisation, this can be the case for a sole owner (or main shareholder) of an organisation who tends to overlook the rules (i.e. does not follow them).

This subsection stated the foundations of important elements that influence an agent's decision-making and cognition. The next subsection states the impact of personality of an agent on its behaviour.

### 6.2.3 Impact of personality

In laboratory studies, differences among behaviours of different participants are observed when they are asked to perform the same simple tasks. One of the reasons for such a difference is attributed to differences in personalities. These differences in behaviour convince us about taking account of the impact of personality on human's decision-making. We model the complexity associated with agents' decision-making with respect to their personalities to identify their behaviour under the same situation. This aspect of people should be taken into the account because of its impact on aspects, such as an agent's learning methods and the way he weights societal expectations versus its internal beliefs.

Jung (1976, first published in 1921 in German language) presented eight different personality types, including Extraverted-Sensation (ES), Introverted-Sensation (IS), Extraverted-iNtuition (EN), Introverted-iNtuition (IN), Extraverted-Thinking (ET), Introverted-Thinking (IT), Extraverted-Feeling (EF), and Introverted-Feeling (IF). In his categorisation he used the notion of *general attitudes* (i.e. *Introversion* or *Extraversion*) and dominant functions. He stated that one directs one's interests towards the inner/outer world based on one's *general attitudes* and one uses a function more frequently (*dominant function*) to process one's collected information.

Myers et al. (1998, the first instance of it was published in 1944) extended types proposed by Jung to include the auxiliary functions that help one to balance one's *general attitudes* (i.e. Introversion-Extraversion). For this purpose, they included another determinant aspect called *Judging-Perceiving*. The personality aspects presented by Myers et al. (see 1998, P. 6) and their explanations are as follows:

- Introverted versus Extraverted: This aspect of personality indicates where energy is oriented, or attitudes come from. While Extraverts mostly concentrate on the outer world (i.e. people and objects), Introverts focus on their inner world (e.g. past experiences).
- Sensing versus iNtuitive: This dichotomy differentiates agents based on their *Perceiving* methods (Jung called these functions, *irrational* functions). A Sensing person pays more attention to collected information by his/her five senses and is more concerned about the facts. An iNtuitive person pays more attention to the patterns and interrelationships to identify the possibilities. For instance, the perception of an apple by a Sensing person might be 'juicy', while an iNtuitive person might perceive it as 'how to keep the doctor away' (Myers et al., 1998, p. 24).
- Feeling versus Thinking: This aspect indicates how an agent makes decisions and *judges* (Jung called these functions, *rational* functions). Thinking agents use their logical processes and being impersonal, while Feeling agents make decisions based on personal and social values. In both Jung's and Myers et al.'s (1998) work, Feeling and Thinking do not reflect being emotional and intelligent, respectively.
- Judging versus Perceiving: This indicates how fast a person wants to reach a conclusion and 'achieve closure'. Also, "*one of the most overlooked characteristics of the J-P [(Judging-Perceiving)] dichotomy is that it describes the orientation to the outer or extraverted world for every type*" (Myers et al., 1998, p. 26). In other words, a Judging person employs his/her Judging aspect of the personality (i.e. Thinking-Feeling that are *rational* functions) to collect information from the outer world and reaches the conclusion faster. However, a Perceiving person uses his/her perception (i.e.Sensing-iNtuitive that are *irrational* functions) to observe and collect data from the outer world. Note that Myers et al. (1998) introduced this aspect, not Jung (1976).

As shown in Figure 6.4, each aspect (e.g. Introverted versus Extraverted) is an extreme point. Most people are not totally on one side, but they possess more of a certain aspect. For instance, considering the Introverted-Extraverted aspect, a person with less than a $0.5$ Extraverted aspect, is considered to be Introverted (indicated by the blue line in Figure 6.4). To model this, we assume that each person has a proportion of one side of an aspect (Extraverted in the example), and the complement shows his/her share of the other side (Introverted in the example). More precisely, when a person is $0.1$ Extraverted, it means that he/she is $0.9$ Introverted (casually regarded as introverted). For simplicity of modelling, $Extraverted$ means the decided proportion of the associated aspect and the Introverted aspect is measured by $1 - Extraverted$ (i.e. $1 - 0.1 = 0.9$ in the example).

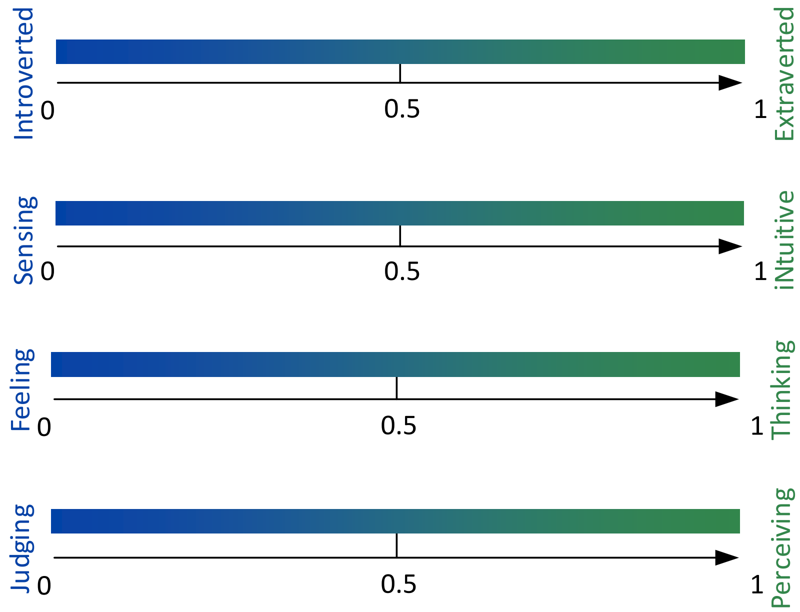


Figure 6.4: A continuous representation of personality aspects.

Another method used for the same purpose, i.e. to classify personalities, is called the *Big Five* personality factors (Goldberg, 1990). The aspects (which are called traits by the designers) are measured by the model and its revised versions are listed below (Costa & McCrae, 2008; Judge et al., 1999; McCrae & Costa, 2004):

- Agreeableness: This trait measures the tendency to be cooperative or likeable.
- Conscientiousness (or dependability): This trait indicates the extent to which an agent is achievement-oriented, dependable, and organised.
- Extraversion (or surgency): Indicates how far an agent is socially-oriented, ambitious, and active.
- Openness (or culture, intellect): Shows an agent's openness to experience and being unconventional.
- Neuroticism (or emotional instability): Refers to the inability of an agent to adjust to positive psychological states or the inability to be emotionally stable.

Note that some studies link the MBTI and the Big Five personality traits. Different studies provide the relationships presented in Table 6.1 among the factors of these metrics (Furnham, 1996; McCrae & Costa, 1989; Tobacyk et al., 2008). We disregard weak correlations among traits and types for Big Five versus MBTI in our work and only consider strong correlations in our modelling. Note that some weak correlations, even between individual Big Five traits, have been observed (van der Linden et al., 2010).

Table 6.1: Correlation among Big Five and MBTI personality traits

| Big Five ↓ MBTI→ | Thinking-Feeling | Judging-Perceiving | Introversion-Extraversion | Sensing-iNtuitive |
|---|---|---|---|---|
| Agreeableness | Feeling | | | |
| Conscientiousness* | | Judging | | |
| Extraversion | | | Extraversion | |
| Openness** | | | | iNtuitive |
| Neuroticism | Hardly correlate | | | |

* Conscientiousness might be weakly correlated with Thinking and Sensing aspects of personality (Furnham, 1996).

** Openness might be weakly correlated to Feeling and Perceiving aspects of personality (Furnham, 1996; Tobacyk et al., 2008).

In this thesis, we use the MBTI because it is easier to link it to discussions by a well-known psychologist (i.e. Carl G. Jung). Furthermore, as shown in Table 6.1, we can link the MBTI's aspects with their counterparts from traits of the Big Five anyway. Having stated personalities differences, we need to investigate the impact of other aspects of human cognition on behaviour. In the next subsection, we describe the impact of the outer world on changes in an agent's behaviour.

### 6.2.4 Cognitive dissonance and self-justification

One of the important aspects of humans is the observed dynamics (i.e. changes) in their cognitions. In our model, we address the impact of changes in internal beliefs on an agent's behaviour. For agents, these changes are formed through thinking and reasoning by themselves or based on the external factors. George Bernard Shaw expresses this idea in the following ironic terms:

> "TANNER. Yes, because to be treated as a boy was to be taken on the old footing. I had become a new person; and those who knew the old person laughed at me. The only man who behaved sensibly was my tailor: he took my measure anew every time he saw me, whilst all the rest went on with their old measurements and expected them to fit me." (Shaw, 1903, Act I, P. 37)

Aronson and Aronson (2007) stated how people are reinterpreting their internal beliefs as a means to justify their actions and to resolve *cognitive dissonance*. Overall, cognitive dissonance is defined as tensions formed by conflicts between different cognitions, such as inconsistent ideas and attitudes (for instance, one likes to smoke and loathes to get cancer).

These tensions lead to creating some justification for taking one action (quit smoking or continuing). Such justifications aim to harmonise their internal beliefs to overcome the psychological tensions of keeping contradictory ideas. For instance, dissonance of keeping two inconsistent internal beliefs like smoking kills and I like smoking, may lead to questioning the validity of the first belief. In practice, the reasons for such a phenomenon, parameters impacting it, and methods employed by agents to overcome this phenomenon are vast. Two methods of resolving cognitive dissonance are a) changing the cognition and b) adding a new cognition.

Changing the cognition is exemplified by Tagliacozzo (1979) by showing how smokers who were aware of the harms ranked their smoking habit milder than their counterparts. Also, Freedman (1965) stated how children who did not play with a desirable toy in order to avoid mild punishment had a lower tendency to play with the same toy in the future (i.e. they reduced the desirability of that toy). This aspect of cognitive dissonance is linked with studies on self-determination theory and intrinsic motivations (Deci & Ryan, 2010; Vansteenkiste et al., 2012). Changing the cognition concerns an agent's behaviour when it is contingent on some situations. For instance, in the Iraq war, President Bush accepted altered documents about Saddam Hussein possessing weapons of mass destruction, the non-existence of which was proved later. To overcome the dissonance, they altered the US mission from fighting against mass destruction weapons to liberating the country (Aronson & Aronson, 2007, pp. 214–216).

This idea is employed by several researchers in different fields (Antoniou et al., 2012; Chabrak & Craig, 2013; Hinojosa et al., 2016; Perlovsky, 2013). In our study, we consider fairness as a source of cognitive dissonance. This idea was first used by J. S. Adams and Rosenbaum (1962) who attributed workers' productivity to cognitive dissonance.

In the case of a long-distance trading society, the utilisation of this idea is two-fold. Before further descriptions, note that one of agents' intentions is to maximise their revenue; however, cheating is in contrast with being a decent person. In this situation, agents face cognitive dissonance when they want to increase their revenue through cheating. What follows describes how we implemented the aforementioned ideas in our model:

- Agents change their internal beliefs about the rule to *control* the costs incurred to them by *organisational decisions*.
- Agents change their *internal beliefs* about the rule to resolve the cognitive dissonance in the *aftermath of an action*.

The latter part has another side as well (i.e. an agent may feel guilty). As stated in Section 3.4.2 in Festinger and Carlsmith's (1959) experiment, some participants felt guilty.

In Section 7.3.2, we consider such impacts on the change of internal beliefs. Keeping all these cases in mind, the next section provides our cognitive architecture for an agent.

## 6.3 Cognitive architecture

This section states how we model the aforementioned influences on an agent's behaviour. Our extended version of the BDI cognitive architecture is depicted in Figure 6.5 (it includes a decision-making module). What follows describes different modules and their connections with one another. As can be seen, there are two separate blocks, namely a left block called '*Events*' and a right block called '*Cognitive architecture*'. The Events block represents the events from an outside environment. The *Cognitive architecture* block represents an agent's cognitive decision-making components. Note that when an action is performed by an agent, it will be an event for agents in the next iteration. For instance, an agent cheating in time $t$ will be an action learnt by associated agents for the next period ($t + 1$). What follows describes the modules of cognitive architecture.

- **Roles:** An agent has a set of roles in society that indicates how a given rule impacts it (e.g. it should be monitored or enforced by the agent). Those roles impact the beliefs of an agent, based on the social circles and its involvement in implementing them. Note that roles include both internalised and associated roles with respect to its position.
- **Beliefs:** To model beliefs, we are inspired by Fishbein and Ajzen's (2011) idea of different belief components. We consider three different punitive components, based on the agent's internal acceptance of the rule (internal belief), its perception of societal support for the rule (perceived norms), and its belief about the purpose of the rule (rule-understanding). Furthermore, an agent has other beliefs (e.g. its cognition of parameters). What follows describes the three components of an agent's beliefs, as stated in Section 6.2.1. These three components comprise:
  - **Internal beliefs:** This component indicates an agent's belief about what the rule must be. Breaking this imposes mental costs on an agent, whether or not others observe the action (it is inspired by *behavioural beliefs* described in Section 6.2.1).
  - **The perceived norms:** This component indicates an agent's perception of societal support for the rule — for instance, an agent's perception of possible sanctions for not following organisational rules. Breaking these perceived norms imposes costs on an agent when other agents identify the violation (it is inspired from *normative beliefs* stated in Section 6.2.1).

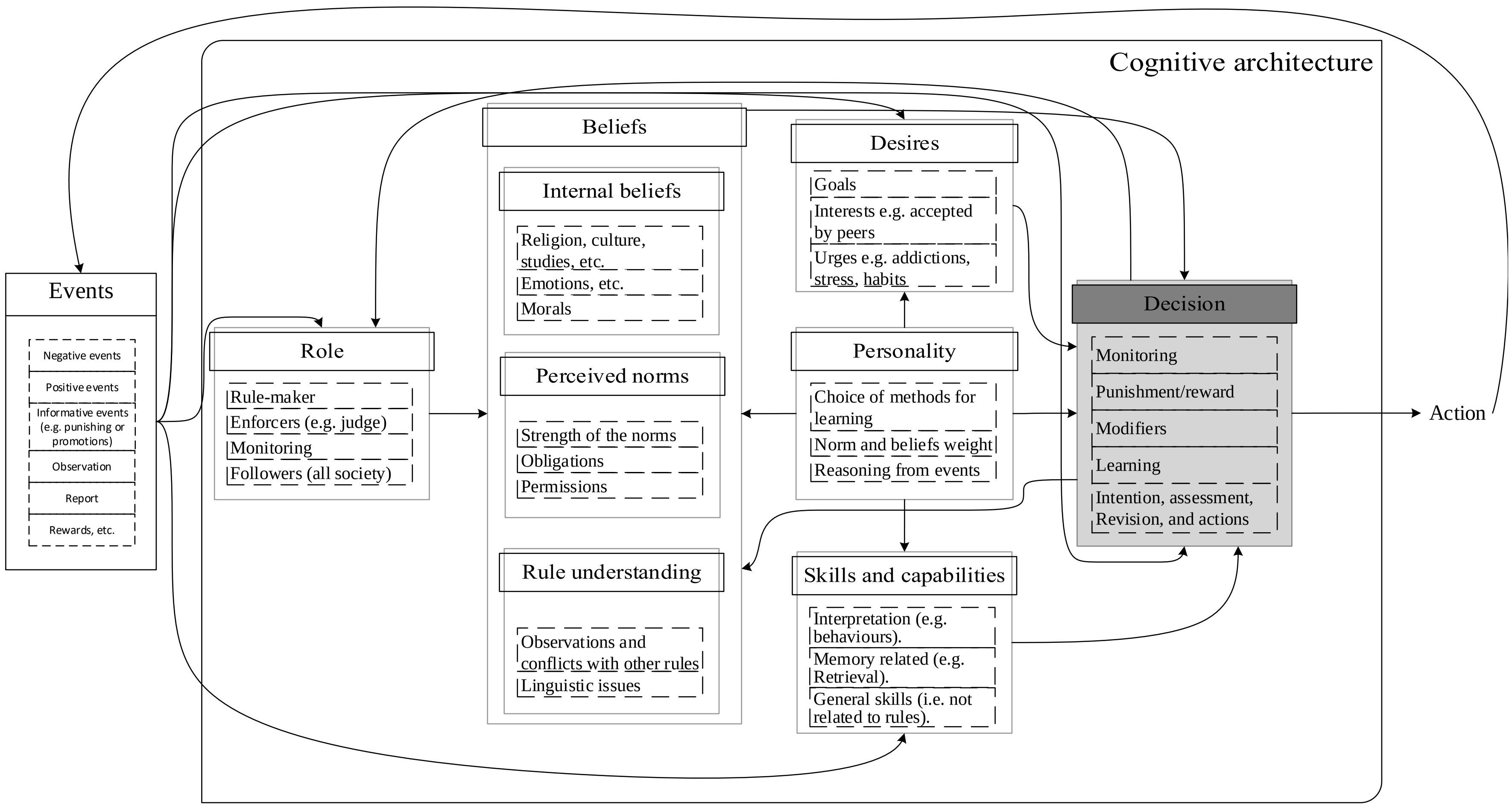


Figure 6.5: Proposed cognitive architecture for this model.

- **Rule-understanding:** This component represents the rule as an agent understands it. This may differ from the real intention of the rule-maker. This is enforced by agents who have the duty of monitoring, reporting, and punishing the violators. This component has the most rigid punishments, such as dismissal, repaying the costs, and jailing. For executing this component, the system needs some official reports about the agents' behaviour (it is inspired from *control beliefs* stated in Section 6.2.1).

- **Desires:** Agents have different desires with respect to the environment, their personalities, and the context. For instance, while most people are concerned with their reputation, sociopaths do not have such concerns. Other desires are stated by Ajzen and Fishbein (2005) as *actual control* — strong desires that control an agent's intentions, such as addictions and habitual activities — that moderate an agent's intentions.

- **Personality:** We use the MBTI's classification to distinguish agents' personalities. As indicated in the cognitive architecture, personality impacts different aspects of an agent, such as its learning method and the way it weights its beliefs. We state the impacts of this aspect on decisions and learning in Section 6.5.2.

- **Skills and capabilities:** Some determinants of an agent's behaviour and the impacts of such behaviours are its skills and capabilities. In each context (here rule-following), certain skills are required for acceptable performance. However, there are other skills that help the company to have extra performance enhancement — we refer to such skills as capabilities.

- **Decision:** An agent's decision about the final action is formed in this module (coloured in grey). The decision process includes normalising all former inputs based on the items, such as learnt parameters, personality, and roles, which results in an action. This action can be a modification of beliefs and roles or only performing a task. We expand this module in Section 6.3.1.

The next subsection goes through the decision module in more detail, along with an expansion of the module.

### 6.3.1 Decision module

Figure 6.6 presents the decision process (grey module in Figure 6.5) for an agent in more detail. The left blocks in Figure 6.6 indicate all the former modules that are external to the decision module. We wish to remind the readers that the three components of beliefs have different enforcement means. Consequently, an agent's decision is influenced by the social punishments and organisational *punishments*, along with the *monitoring* strength associated with them. What follows states the impact of the modules depicted in Figure 6.6 on an agent's decisions.

- **Monitoring:** This block indicates an agent's belief about the chances of being punished by each component for a given violation. Note that the internal belief component does not need external monitoring mechanisms to work.
- **Punishments/rewards:** As stated earlier, the punishments/rewards associated with internal beliefs and perceived norms depend on the agent's beliefs. However, the rules have more clear consequences than social norms in terms of punishment and rewards.
- **Modifiers:** As stated earlier, an agent may decide about modifying its internal beliefs, role, and beliefs about the system for reasons such as cognitive dissonance and new information. The Modifier block indicates such decisions.
- **Learning:** This block indicates an agent's interpretation of its observations, suggestions, and past information. Furthermore, the agent can increase its skills (including general skills) by observation or by practising over time.
- **Intentions and actions decisions:** This block coordinates the decisions with cognitive or organisational consequences in terms of performing modifications or turning an intention into an action. Note that as stated earlier, since agents intend to improve their revenue, they consider cheating as a potential decision. Using the Learning block, the agent decides whether or not to cheat.

To have a better understanding of the way these modules work, we briefly describe them. First, an agent takes account of the consequences of an action with respect to *monitoring* and *punishment/rewards*. It also learns and updates its *learning* of the system's characteristics with respect to its observations, collected data, and experience. Then given the agent's *intention*, *it assesses and revises its cognition to take an action*. If the agent decides to modify the beliefs and roles, it uses the *modifier* for doing so. The agent also improves its cognition about system characteristics by employing a *learning* procedure to improve and modify its understanding.

After presenting a model of an agent's cognition and decision-making, we are ready to exemplify this model with the two historical long-distance trading societies. The next section provides a brief description of these cases of interest.

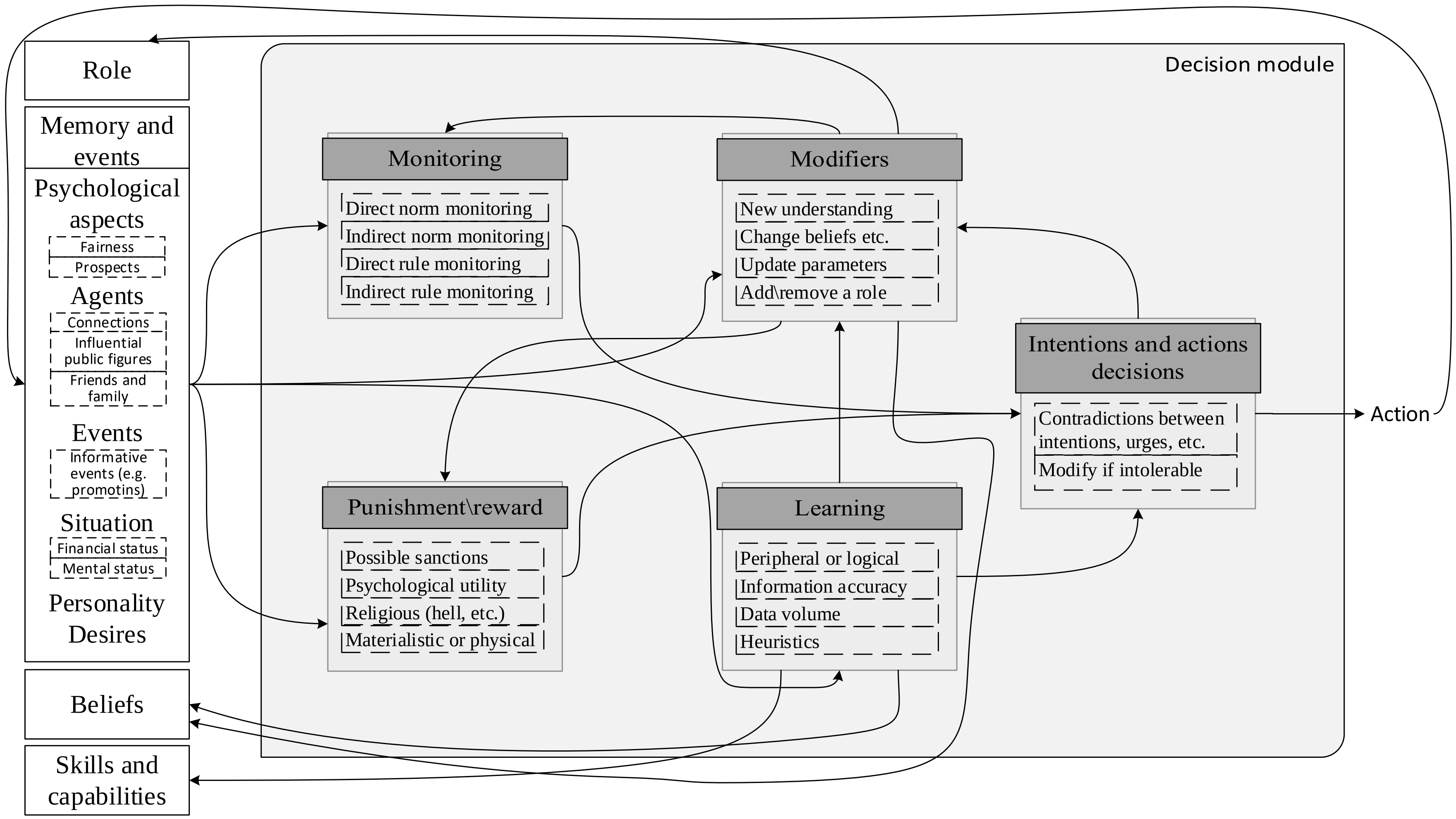


Figure 6.6: Detailed decision module of cognitive architecture presented in Figure 6.5.

## 6.4 Study of the two cases regarding the proposed method

To provide a detailed description of operationalising our model, we use the example of the two historical long-distance trading societies. Here we present an overview of those cases, namely the British *East India Company* (EIC) and *Armenian merchants of New-Julfa* (Julfa). In this overview, we provide the relevant historical information of the two societies. Section 6.4.1 provides the relevant background that helps our modelling of the two historical societies. Section 6.4.2 states the organisational structure and meta-roles of both societies. Finally, Section 6.4.3 states fairness as a factor that afflicts mercantile agents with cognitive dissonance.

### 6.4.1 Overview of cases

Julfans and the EIC were both merchants engaged in long-distance trading. However, they had different payment schemes, responsibility delegations, apprenticeship models, and different environmental circumstances (see Sections 2.2.2 and 2.3.2). Furthermore, we know that agents' behaviours in these two societies, in terms of following or breaking the rule was significantly distinct. Despite these differences, they had the same expectations and rules regarding agents' behaviours. For instance, in both societies, organisations expected employees to trade for the company not others (including the employee himself). Furthermore, expectations regarding social/friendship bonds are social norms that all agents face, regardless of the company they work in. In this section, we state the societal characteristics we choose to model, and the way we intend to operationalise our model.

**Environment:** We know that a place that both societies traded in was India; however, they had different mortality rates. This difference in the impact of environmental circumstances increased the mortality rate for the EIC agents in a way that, on average, an agent died before he was 35 years old (see Hejeebu, 1998, p. 101). On the other hand, Aslanian (2007) provides no evidence of such a situation in Julfa.[2] Such differences convince us to consider the impact of environmental circumstances in this model.

**Institutional characteristics:** Another difference between the two societies was their payment schemes and the way the system was managed. In Julfa mercantile agents had a share of profits, while the EIC paid their employees fixed wages. Furthermore, in Julfa,

[2]Some reasons include the following: they were immune to some diseases for historical relations among Indians, Persians (Iranians), Arabs, and Armenians through trading routes. Also, Iran, Armenia, and India were ruled by the same people, such as Sassanid (224–651 AD), Chengiz Khan (1206–1227 AD), and Timurid (1370–1501 AD).

agents had the chance to establish their own business when they had enough capital (Aslanian, 2007). In contrast to Julfa, the EIC agents could not establish a new company as a consequence of the monopoly of trade granted to the EIC by the Crown. Furthermore, both societies had two kinds of rules for controlling the mercantile agent's behaviours. One rule concerned following the orders of boards and managers and not using company resources for self-interests. Another rule prohibited employees from trades, except for the company (such trades were called private trade in the EIC and were eventually permitted after a while).

Finally, another difference in the institutional characteristics of these societies concerns whether they employed courts. In Julfa they had two kinds of courts for resolving disputes, while in the EIC the courts were not efficient, and mostly the agents were fired based on their bad performance, not for breaking rules.

**Apprenticeship:** As stated in Chapter 5, Julfa had organised apprenticeship programmes. However, in the EIC, for reasons such as the high mortality rate, we see a gradual shift from hiring skilled agents to hiring inexperienced agents who learned to trade in India with the help of more experienced agents. Such a difference impacts agents' skill levels.

**Agent's mobility:** Another important difference between the two societies concerns whether or not agents resided in a place for a long time. In the EIC, after some years, the company established settlements called factories (i.e. warehouses) where agents stayed in order to perform the trade. On the other hand, Julfans had some nodes where agents stayed temporarily. A long stay in a place introduces concerns, such as creating a closer *friendship circle* inside the organisation and establishing stronger relationships with local traders. Friendship among agents causes them to be more tolerant towards one another's actions. For instance, Argyle and Henderson (1984)[3] identified several '*rules of friendship*' that indicate expectations, such as keeping secrets and defending each other. In the next subsection, we describe the society's structure and the social dynamics of both societies.

### 6.4.2 Society's structure and social dynamics

This subsection presents an overview of the changes in roles (e.g. an agent gets promoted) and rules (e.g. commanders permit the agents to do what was prohibited) over time in the EIC and Julfa (with more focus on the EIC). Figure 6.7 presents how different sectors were correlated in the EIC and Julfa. The impact of the roles highlighted in red (i.e. governors and judges) are not addressed in our model. The agents highlighted in dark-blue (i.e. mercantile agents and managers) are the main concern of our model. We also consider limited impacts

[3]The participants were from Britain, Italy, Japan, and Hong Kong.

for agents highlighted in light-blue (directors) and pink (potential employees).

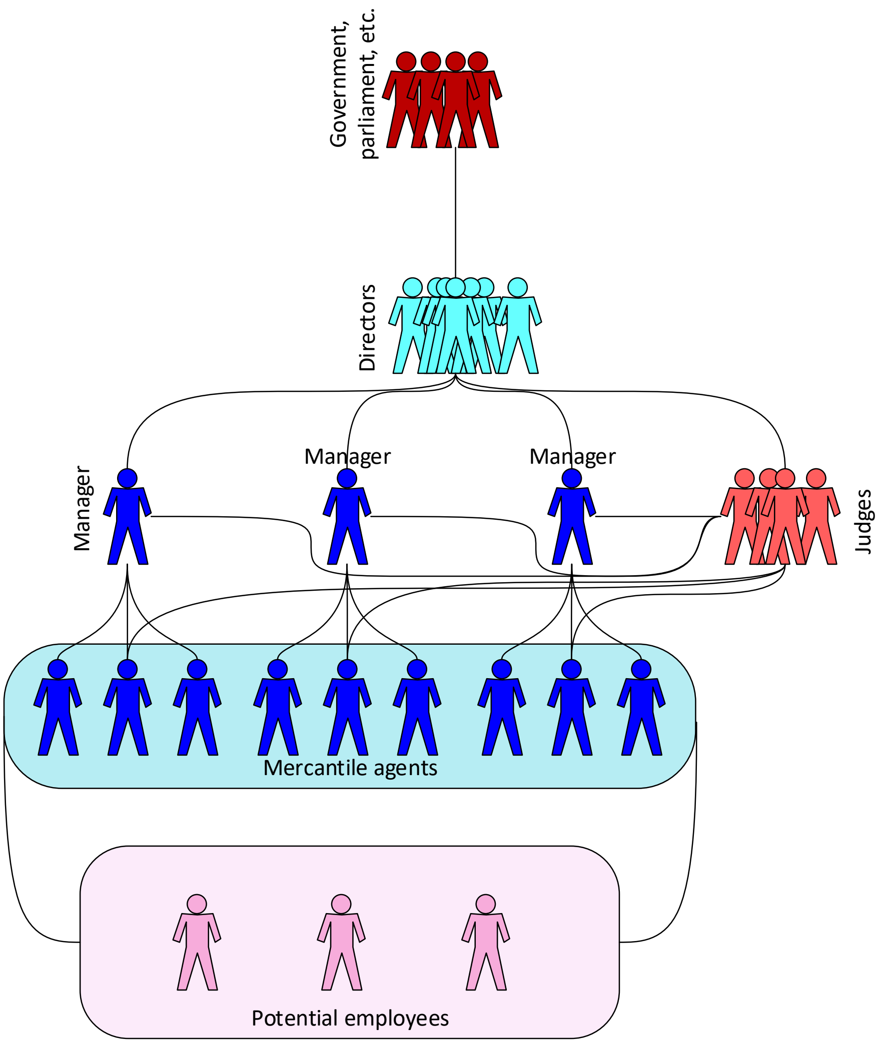


Figure 6.7: A scheme of a system for the EIC and Julfa.

Now we describe each level and their impacts in more detail. The top level shows how governors' policies impacted both societies. For instance, the main reason for the decline of Julfa was because of the threats and chaos introduced into the system by Nadir Shah Afshar (a Persian king, see Herzig, 1991, pp. 106–108). Also, the British governors dissolved the EIC (see Hejeebu, 2016, pp. 44–46).

The next level indicates company directors and their roles. In the EIC, directors did not work as agents; hence, they were remote from their employees' perception of the rules, the norms formed in India, and their internal beliefs. Also, we know that after the English Civil War (1642–1651), some managers were promoted to directors (see Erikson, 2014, p. 63). In our model, we consider the impact of directors on the system by modelling this phenomenon (i.e. some managers get promoted as directors). However, in Julfa, the directors were family members who had already worked as agents and managers in the company (i.e. they were mercantile agents in their youth). Such a characteristic makes Julfa more agile for revising ill-advised rules.

The third level concerns both managers and judges. In both societies, managers (i.e. the ones who monitor and report) were chosen from the senior agents. A task of managers concerns monitoring mercantile agents to make sure they follow the director's orders. Also, judges' verdicts are based on the provided reports and evidence. Note that judges are agents who are formally allowed to interpret the rules. However, all members of society might informally interpret the rules when they monitor (stated in Section 6.6.2).

The next level concerns mercantile agents. In both societies, directors expected these agents to collaborate in monitoring each other's behaviour. Note that this collaboration was a voluntary task and was an informal role rather than a formal one (see Section 6.4.3).

The lower box indicates new agents who can potentially work in the company. If the company has an apprenticeship programme, they train the agents at a cost. Otherwise, the box represents unskilled agents waiting for employment. In the next subsection, we state the fairness of the institutions and why we believe Julfa was much fairer than the EIC.

### 6.4.3 Fairness of the institutions and cognitive dissonance

Concerns related to fairness are sources of cognitive dissonance and such an idea initiated J. S. Adams and Rosenbaum's (1962) study on fairness. For this reason, this subsection presents different aspects of fairness in more detail. Overall, there are three well-known aspects for fairness of institutions, namely distributive, procedural, and interactional justice (see Greenberg, 1990; Tankebe, 2009, for more infromation). What follows concisely discusses each aspect.

**Distributive justice** states that rewards should be fairly shared. In other words, profits should be proportional to the investment of individuals (e.g. skills and education, J. S. Adams, 1965; J. S. Adams & Freedman, 1976). J. S. Adams's (1965) theory included a concept besides *distributive justice* called *relative deprivation/gratification* that is a consequence of breaching the fairness. Stouffer et al. (1949, see p. 1270) introduced *relative deprivation* to explain phenomena such as the existence of *more complaints* in a department with *more promotions* of others. Also, Akerlof (1982) utilised *relative gratification* to model a situation where people put forth more effort in situations that promotions are not a factor, because they were rewarded more than the norm.

The two other aspects are **procedural** and **interactional** justice. We describe them together because of their tight correlations (Bies, 2005; Cropanzano et al., 2002). *Procedural* justice concerns a *fair method for resolving disputes* (Thibaut et al., 1974; Tyler, 1989). *Interactional* justice concerns how the procedures are *framed* through some explanations. For instance, Bies and Shapiro (1987) indicated that justifications of *improper actions* or providing *clarifications* for the procedures increase societal approval of a procedure.

The impact of different aspects of fairness has already been studied by various researchers (Colquitt et al., 2005; Colquitt & Zipay, 2015; Donner et al., 2015; Dukhanin et al., 2018; Virtanen & Elovainio, 2018). Sunshine and Tyler (2003) showed that procedural justice increases public law obedience and cooperation with the police. Also, J. S. Adams (1965) stated that underpaid or overpaid persons alter their input (e.g. efforts) to make the system fairer for themselves.

In this thesis, we address the impact of two factors on the agent's decisions. This has been studied vastly by different scholars. For instance, Schweitzer and Gibson (2008) discusses that an agent's judgment about the fairness of the system leads to decisions that are not economically rational (e.g. punishing others with some costs). They also note that if some explanations persuade people about the unfairness of the societies, the agents tend to perform more unethical behaviours. Other studies also point to such behaviours (uneconomic or unethical) as a reaction to the unfairness of the system. For example, Pillutla and Murnighan (1996) report rejection of unfair offers in the ultimatum game. In another study, Greenberg (1993) designed a game in which participants had access to company resources from which they could take their wages. The game was designed such that subjects believed the experimenter did not know how much they really took. The results suggest that underpaid subjects took more than they were allowed to (i.e. they stole). Furthermore, the amount of stolen money was decreased when some evidence convinced the subjects about the experimenter having more accurate information. We model two impacts of fairness on an agent's decisions that are listed below:

- Changing the internal belief of an agent towards the violation. In other words, when an agent thinks the organisation is unfair, it softens its beliefs towards violations. On the other hand, when an agent feels the system is fair (or extremely fair), it strengthens its beliefs about the same action. This aspect is observed in studies such as Skarlicki et al. (1999) and Akerlof (1982).
- Internalising monitoring roles (i.e. monitoring and reporting violations voluntarily). As stated earlier, an agent has an official role (e.g. mercantile agent) that it is asked to perform by the organisation. However, it may add more voluntary roles internally, such as monitoring and reporting (i.e. by self-determination). Studies such as Sunshine and Tyler (2003) observe this aspect.

Table 6.2 indicates what happened in the two historical trading societies and why we believe that Julfa was much fairer than the EIC.

Table 6.2: A comparison of three different types of fairness for the EIC and Julfa.

| Type of fairness | EIC | Julfa | Comment |
|---|---|---|---|
| Distributive | ✗ | ✓ | The payment scheme in Julfa consists of sharing profits with agents, while in the EIC they had fixed payments. |
| Procedural | ✗ | ✓ | In Julfa, the agents' relationships had a negligible impact on the courts' decisions. However, in the EIC, the agents with a certain status, such as connections with headquarters, had some opportunity to break the law. Furthermore, performance-based punishments in the EIC which were not based on any rule violation evidence, lowered the trust of the agents in the fairness of the law enforcement. |
| Interactional | ✓ | ✓ | Some letters* in the EIC point to some attempts by directors to *justify* their decisions. |

*For instance, they justified firing Hugh Barker with 25 years of experience arguing: "[w]e may let our servants see that we can distinguish betwixt [sic] them *who serve us faithfully and well and those who only pretend to do so* [emphasis added]." (E/3/106 letter to Bengal 23 Jan 1735, para. 138, as cited in Hejeebu, 2005, p. 514).

After describing the fairness of these societies, in the next section, we describe the model for investigating the two long-distance trading societies, along with some explanations regarding the model's modules and their interactions.

## 6.5 Interaction and specifications of model modules

In this section, we describe the specifications of certain modules of the proposed architecture in Figure 6.5, with respect to the context of the two historical long-distance trading societies. To be more precise, Section 6.5.1 describes modelling the different rule enforcement components. Section 6.5.2 assesses the impact of personality, as one of the main determinants on different aspects of cognition.

### 6.5.1 Different components of rule enforcement

In our model, we assume that a rule can be violated with different seriousness levels by which an agent faces a specific punishment. To be more precise, we consider three levels of violations that are defined, based on the cost that the action incurs to the company's revenue. These three levels include *minor*, *mild*, and *serious* violations.

The expected punishment also varies based on the violation of different components of belief (i.e. rule-understanding, perceived norm, and internal belief). Now we state the expected punishment associated with rule-understanding. The rule has clear punishments, except for minor violations. Overall, the label for punishments and organisational administrations are as follows:

- **Serious violations**: The company incurs high costs for these actions, such as stealing, embezzlement, or bribery, that involve a significant amount of money. These violations can be easily proved when they are identified. However, there is a probability of not identifying such actions. In the two historical societies, these violations were punished variously. In Julfa, the violator was fired and was asked to repay the costs (e.g. unpaid loan along with interest). In the EIC, we know in 1613, some cheaters were fired, and their belongings were seized.
- **Mild violations**: These correspond to not fulfilling the organisation's requirements for a task an agent should or should not perform. For example, an agent should not steal an employer's items. However, stealing inexpensive items from a company is considered to be a mild violation. As a punishment, agents lost the chance for future work in the company. Aslanian (see 2007, p. 249, footnote 66) suggests that *a real list* in Julfa kept the names of "blotted out" agents as dishonest. Also, examples of these violations in the EIC include behaviours indicating not "having interests of the company at heart;" however, the alleged actions were not punishable by courts (see Table 6.2's footnote).
- **Minor violations**: These include abusing company's permissions, such as using a luxury place to stay during travel for work, using the organisation's properties for self-interest (e.g. using company's vehicle for long-distance travels), and spending working time for hobbies like watching sports. These actions are difficult to identify and punish. Even when these are punished, the punishment is mild. In other words, identifying such violation may lead only to warnings and deterrents. In Julfa, there were correspondences indicating queries about explicit information regarding costs of travels (Aslanian, 2007). The agents in the EIC were rebuked for spending too much money "to secure the company's concession". However, the manager's tolerance for such actions may vary, given the situation (i.e. the manager may decide to fire the agents under certain circumstances).

To model the rule and its associated violations, we use fuzzy numbers as presented in Figure 6.8. Zadeh (1999) suggested the notion of *Computing with Words* (CW) for using linguistic variables, such as big or small in the form of fuzzy variables in computing. In such a computing method, an agent uses words for computing/reasoning and assigns labels to group all relevant points (e.g. “serious violation”). An application of CW is modelling different understandings caused by labelling data using words. In our case, an agent attempts to associate violations based on their costs for the company.

As stated earlier, each agent has three different beliefs about the rule (we call them belief components). The rule-understanding indicates how an agent may face issues in understanding the stated rule. The perceived norm indicates an agent’s perception of social expectation about following the rule (i.e. agents believe what violations are considered to be minor, mild, or serious by society). Finally, the internal belief shows how an agent assesses the seriousness of the violation itself. The agent uses these components to predict possible punishments from different perspectives (e.g. director versus its morals).

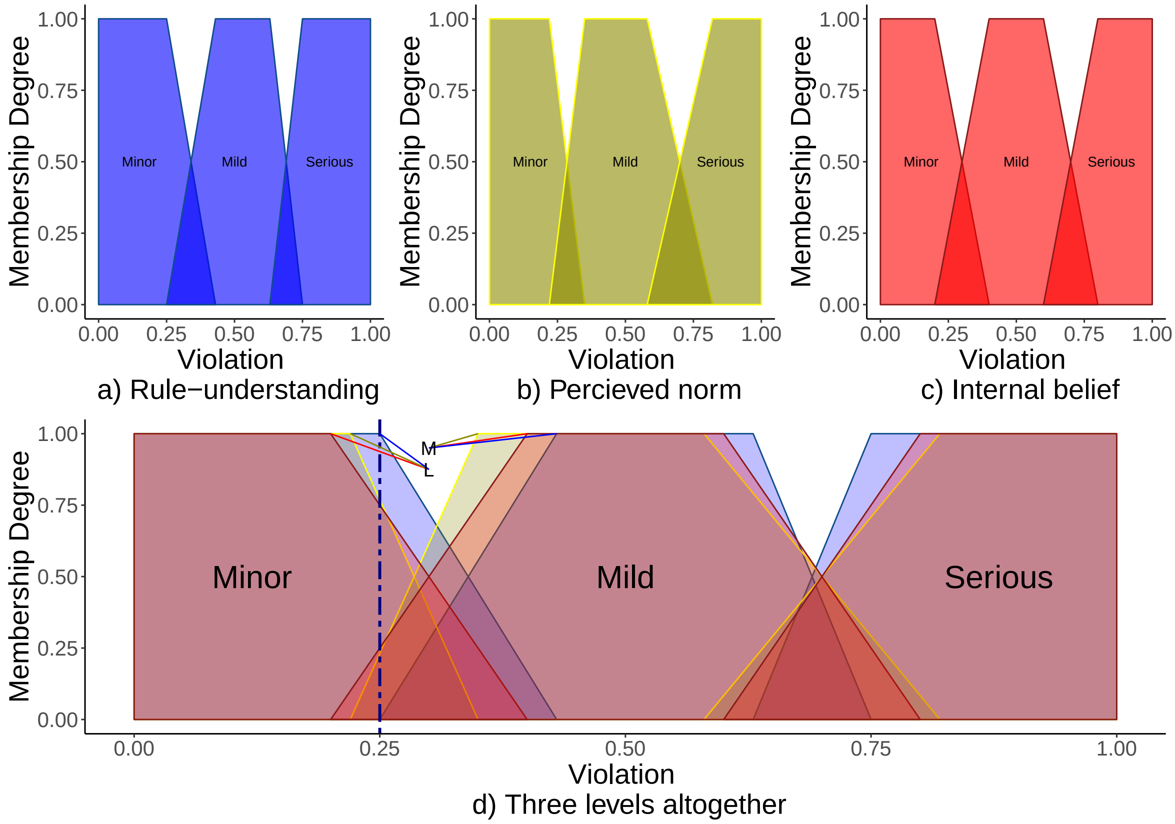


Figure 6.8: A scheme of fuzzy numbers associated with beliefs about rule violations.

First, we describe Figure 6.8a; this figure indicates how an agent understands the rule and the associated organisational punishments. Before providing more explanations, we describe what the x-axis and y-axis represent in Figure 6.8. The x-axis presents the extent to which the agent violates the rule. The y-axis indicates the agent’s belief about the possibility of assigning a certain label to this violation. We call this possibility the membership degree of such a violation to that label. As an example, assume that the agent violates the rule by 50%, and it believes the violation is mild. In Figure 6.8a the only label assigned to such a violation is Mild with a membership degree of 1.

However, some violations may have two possible labels. These are the violations where the agent is doubtful about the correct label (e.g. whether this violation is minor or mild). The same issue is held for perceived norms and internal beliefs (e.g. one may have several interpretations of a situation and cannot decide which is the correct one). Figures 6.8b and 6.8c show the perceptions associated with norms (i.e. perceived norm) and internal beliefs, respectively. Figure 6.8d indicates the combination of all these three perceptions in one graph to indicate that an agent can assign different labels to the same action considering its rule-understanding, the perceived norm, and its internal belief. In other words, an agent does not need to assume that the action would be interpreted the same by the organisation, society, and itself. For instance, in a rule violation that potentially costs 25% of the organisation's *profit* (e.g. spending too much time chatting with colleagues, Figure 6.8d, dashed-line), the agent has three distinct beliefs. It believes that the organisation considers this violation *Minor*. At the same time, it doubts if this violation is *Minor* or *Mild*, given its internal beliefs and its understanding of social norms (L in Figure 6.8d indicates up to what violation the agent is sure the violation is *Minor* for each component of belief).

Before presenting our model, note that the impact of wealth is presented by prospect theory (Kahneman & Tversky, 1979). Kahneman and Tversky (1979) stated that the current wealth influences how an agent values the outcome of a decision. We know that when the payment scheme is not proportional to the agent's performance, the wealth of the agent in comparison to its access to the company resources decreases over time. Equation 6.1 indicates how an agent calculates the costs of violation.

$$RulePunishment\big(Act^t_A\big) = \begin{cases} \dfrac{P_R \times \alpha^t_A}{access^t_A}, & \text{if } Act^t_A = Minor \\ \dfrac{\alpha^t_A}{access^t_A}, & \text{if } Act^t_A = Mild \\ \dfrac{\alpha^t_A}{access^t_A} + Act^t_A, & \text{if } Act^t_A = Serious \end{cases} \tag{6.1}$$

In our model, agent $A$ employs Equation 6.1 to calculate punishment costs imposed by an organisation for violating a rule at time $t$ by taking action $Act$. The right-hand side of this equation indicates different punishments with respect to the violation. The first (upper-right-hand) condition of this equation concerns minor violations. It indicates that the agent assumes it may get fired with a maximum probability of 1 ($P_R$). The costs of getting fired consists of two parts, namely a factor that discounts future revenue ($\alpha_A$), and another factor ($access^t_A$) that indicates the impact of welfare and wealth on the value of the function. When proportional wealth to access decreases (i.e. $\frac{1}{access_A^t}$ increases), the value of future revenue in comparison to the current violation decreases (i.e. cheating becomes more tempting).

The second condition of Equation 6.1 concerns mild violations. This indicates the agent is sure that if the organisation identifies the violations, it gets fired. The third condition indicates that the agent also takes account of paying back the cheat revenue ($Act_A^t$) along with paying back a fine proportional to the action. In the modelling, we assume that discounted fine equals the current revenue of cheating.

Figure 6.9 presents a scheme of how these functions are calculated using the concept of computing with words. For this drawing, we used 1, 0.9, and 0.5 for $access_A^t$, $\alpha_A^t$, and $P_R$, respectively. In addition, we used the same intervals as Figure 6.8a for the labels of rule violation.

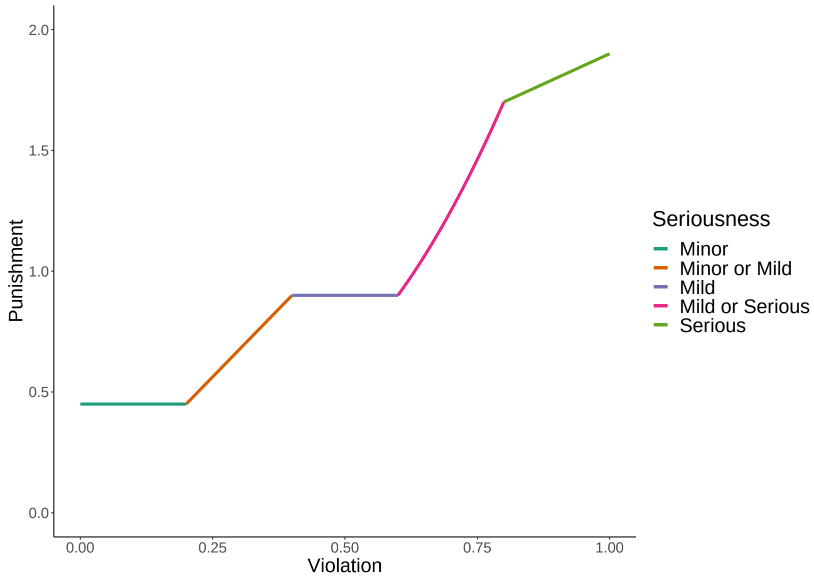


Figure 6.9: A scheme of costs associated with the organisational punishments for rule violation.

Note that when an agent has doubts about the seriousness of rule-breaking labels, it uses a linear approximation of costs associated with each label. Equation 6.2 represents the cost of action $x$ when the agent is not sure whether it is a minor violation or a mild violation ($Cost(x \in (Minor|Mild))$). Therefore the agent uses the costs associated with a minor violation ($Cost_{Minor}(x)$) and a mild violation ($Cost_{Mild}(x)$), multiplied by the degree of membership associated with these labels for such an action. To calculate this degree of membership, an agent uses a linear function. In Equation 6.2 , $L$ represents the point where the agent begins to doubt whether the violation is minor or mild. $M$ indicates the point after which the agent is sure about the mildness of the violation (see Figure 6.8d).

$$Cost(x \in (Minor|Mild)) = Cost_{Minor}(x) \times \frac{M-x}{M-L} + Cost_{Mild}(x) \times \frac{x-L}{M-L} \quad (6.2)$$

Equations 6.3 and 6.4 indicate how the mental costs associated with violating internal beliefs and perceived norms are calculated, respectively. These punishments are more flexible than that of rules — they depend on the label, as well as the seriousness of the violation. As can be seen in Equation 6.3, the costs imposed by internal beliefs ($IBeliefPunishment_A$) for agent $A$'s violation at time $t$ ($Act_A^t$) depends on the label (e.g. if the violation is minor $C_{Belief,Minor}$) and the seriousness of violation. Note that $C_{Belief,Minor} < C_{Belief,Mild} < C_{Serious,Mild}$, and these costs are different from one agent to another.

$$IBeliefPunishment_A(Act_A^t) = \begin{cases} C_{Belief,Minor} \times Act_A^t, & \text{if } Act_A^t = Minor \\ C_{Belief,Mild} \times Act_A^t, & \text{if } Act_A^t = Mild \\ C_{Belief,Serious} \times Act_A^t, & \text{if } Act_A^t = Serious \end{cases} \quad (6.3)$$

We obtain Equation 6.4 similar to Equation 6.3. We use a different equation to emphasise there is a difference between the cost associated with the perception of societal punishments (Equation 6.4) and the mental punishment for violating the internal beliefs (Equation 6.3). Figure 6.10 represents an example of such punishments.

$$NormPunishment_A(Act_A^t) = \begin{cases} C_{Norm,Minor} \times Act_A^t, & \text{if } Act_A^t = Minor \\ C_{Norm,Mild} \times Act_A^t, & \text{if } Act_A^t = Mild \\ C_{Norm,Serious} \times Act_A^t, & \text{if } Act_A^t = Serious \end{cases} \quad (6.4)$$

Figure 6.10 depicts costs associated with the agent's perception of societal punishments for a violation of expectations (and punishment for violating an internal belief) presented in Figure 6.8-b. For this figure, we used 0.2, 0.4, and 0.8 for $C_{Norm,Minor}$ $(C_{Belief,Minor})$, $C_{Norm,Mild}$ $(C_{Belief,Mild})$, and $C_{Norm,Serious}$ $(C_{Belief,Serious})$, respectively. We used a similar method to Equation 6.2 to calculate costs when the agent is not sure about the appropriate label. Note that the violation costs for such labels (i.e. the ones that the agent is unsure about) is non-linear.

In the next subsection, we state how we model the interaction between different blocks and the personality of an agent. As shown in Figure 6.5, the personality of an agent interacts with its other aspects. As a consequence, we should describe modelling an agent's cognition and decision-making given its personality.

### 6.5.2 Personality

As depicted in Figure 6.5, personality and decision modules influence each other (i.e. personality impacts decision and it is adapted to the agent's role). Furthermore, the decision

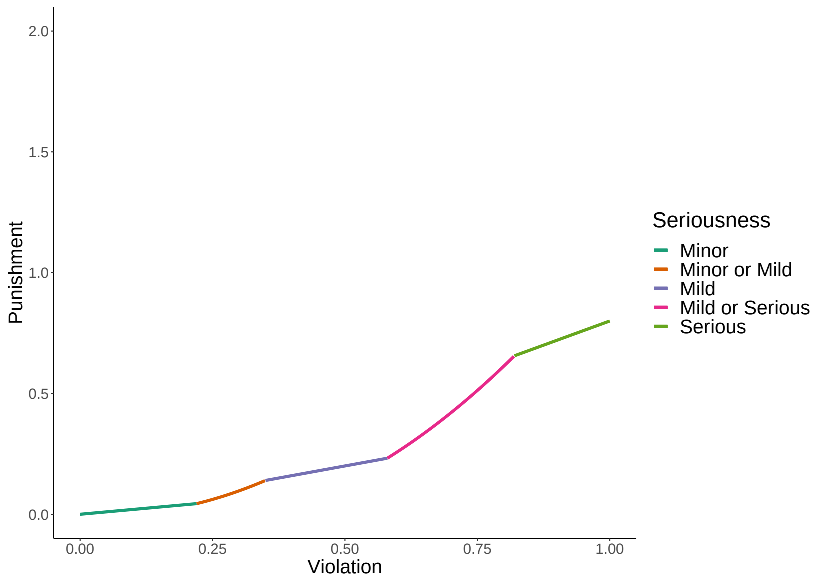


Figure 6.10: An example of costs associated with the perceived norm and internal belief punishment.

module is a mediator for modifying different cognitive aspects. First, we state the way that the Decision module impacts the agent's personality.

**The impact of the role on personality development:** Note that in our simulation (Chapter 7), we use the personality types of entrepreneurs to decide about the extent to which agents on average possess each aspect of the personality type. However, we use findings that show that agents develop their personalities to adapt to their environment (Bleidorn, 2012; Caspi & Herbener, 1990; Roberts et al., 2006). Damian et al. (2019) conducted a study on personality dynamics of around 1800 participants over fifty years. Their findings suggest a reliable shift in personality for around 40% of people with *unique patterns* (i.e. personality of 40% of agents changed, irrespective of their personality type). In our model, the agent's personality is adapted to its current role and when it is promoted to another position, its personality gradually adapts to the new role. Note that in both societies, recruits were teenagers, and their personalities change more easily over time.

**Socialising:** The main difference between Introverted and Extraverted personalities concerns their number of friends and connections. Therefore we consider a maximum possible number of friends for extremely Extraverted agents (i.e. 100% Extraverted), and this number is modified for agents based on the extent to which they are Extraverted.

**Weighting perceived norms and internal beliefs:** To model the impacts of personality on norm conformance, we use the result of correlations between behavioural tendencies as measured by the *California Psychological Inventory* (CPI). This test was developed by

Gough (2000) in 1951 to assess a person's psychological aspects that are relevant to sociology and political science (Megargee, 2009). The measured aspect of interest for us classifies agents into the norm following/questioning groups.

Fleenor (1997) examined correlations between the CPI scales and the MBTI scores for around 13,000 participants. The study indicated that Sensing and Judging in the MBTI personality types were correlated to norm-favouring personalities. Therefore the iNtuitive-Perceiving agents are the ones who question norms the most (i.e. weights their internal beliefs more than the perceived norms). Furthermore, Sensing-Judging agents are the ones who favour the norms more than any other agents. This finding is intuitive, based on the definitions presented by Myers et al. (1998) (see personality descriptions in Section 6.2.3). They argue that Perceiving agents employ their perception to contact the outer world, and iNtuitive agents are remote from immediate facts and focus on patterns and meanings.

**Dynamics of roles and internal beliefs:** As stated earlier, perceived fairness of the system have disparate impacts on the agents' behaviour in terms of rule-following and collaboration in monitoring. This phenomenon is addressed by Buboltz Jr et al. (2003) and Skarlicki et al. (1999), where they studied the impact of the MBTI personality types and the Big Five personality traits on agents' reactions to the fairness of the system. Their findings indicated that the Thinking-Feeling (agreeableness for Big Five) aspect significantly influences agents' behaviour. Buboltz Jr et al. (2003) indicated that Thinking agents had higher "*psychological reactance*" to the fairness of the system. They also indicated that the iNtuitive-Sensing aspect had an effect only on *Thinking* agents' reactions (iNtuitive-Thinking (NT) persons reacted more than Sensing-Thinking persons (ST)). Note that we do not consider the impact of the iNtuitive-Sensing aspect on an agent's behaviour directly. The reason for such an approach is the results of the aforementioned study. In other words, a change in the behaviour is not generally impacted by the iNtuitive aspect, and this difference was likely impacted by a better identification of the unfair situation by iNtuitive persons. Therefore it is their learning methods that indirectly have an impact on their reactions. Note that Feeling persons make decisions based on items, such as affiliation and keeping harmony (i.e. they weight their relationships more than fairness).

Skarlicki et al. (1999) measured the impact of perceived fairness on "*organizational retaliatory behaviour*". Skarlicki et al. (1999) and other researchers (J. S. Adams & Freedman, 1976; Buboltz Jr et al., 2003), indicate that an agent *deliberately* changes its behaviour as a reaction to an unjust situation. Different scholars study the impact of personality on such decisions. Schmitt et al. (2005) and Schmitt et al. (2010) studied this effect using a detailed questionnaire. These studies showed that the Feeling aspect of agents (i.e. $1 - Thinking$)

impacts an their decision when they are the ones who should perform an unfair action. Furthermore, they identified that the iNtuitive agents perceive the justice of the system better, which is in accordance with Buboltz Jr et al.'s (2003) findings. The way we employed these impacts and their correlations with personality is shown when we state an agent's decision-making in Section 6.6.

**Environment:** The environment influences agents' behaviour through the *discount factor*. Overall, an agent's decision about an action is affected by mental costs, perceived social punishment, and organisational punishments. The organisational punishments concern losing future revenue, paying some costs, or both. These future-oriented punishments are discounted by an agent when it computes the utility of an action using its *utility function* (i.e. the function that indicates the preference of the action, given its internal, social, and organisational costs and rewards). An unpleasant environment has a negative effect on this factor. On the other hand, as suggested by Myers et al. (1998, p. 24), Sensing personalities develop characteristics associated with immediate experiences such as enjoying and experiencing the present moment. Furthermore, Jung (1976) stated the following:

> "As sensation is chiefly conditioned by the object, those objects that excite the strongest sensations will be decisive for the individual's psychology. The result is a strong sensuous tie to the object. Sensation is therefore a vital function equipped with the strongest vital instinct. Objects are valued in so far as they excite sensations, and, so far as lies within the power of sensation, they are fully accepted into consciousness whether they are compatible with rational judgments or not. The sole criterion of their value is the intensity of the sensation produced by their objective qualities." (Jung, 1976, p. 362)

Therefore the perception of environment influences Sensing types the most by providing opportunities for them to fulfil their sensation desires, such as enjoyment, and excitement (i.e. the discount factor of Sensing types is more impacted by environmental circumstances).

**Mobility versus residency:** Residency in a place and being considerate for one another have certain impacts on the agent's behaviour. As stated earlier, the Feeling types, weight keeping harmony in the society more. In our model, this effort can be modelled, based on the weights of the connections.

**Learning:** An agent learns, based on its cognition of meaning and patterns (e.g. my payment is unfair compared to the others), collected facts by its Sensation (e.g. the wage is low or high), other agents' recommendations and its trust in their understandings and beliefs. Also, an agent weights its collected information based on its personality. To model how agent

$A$ learns a system's characteristics, we use a method inspired by Farhangian, Purvis, Purvis, and Savarimuthu's (2015b) work. For this purpose, we consider the following:

- The agents learn about system characteristics based on their intuition (i.e. extent to which they are iNtuitive) and recommendations from friends.
- The more Extraverted an agent is, the more it weights the outer world's information.
- The more iNtuitive an agent is, the more it can learn about the system's characteristics by itself.
- The stronger the friendship's bond is (i.e. link weights), the more an agent weights the trustworthiness of the recommendations.
- The more Sensing an agent is, the more it weights the current situations and information.

Table 6.3 summarises the impact of personality on different aspects of cognition. In the next section, we model how an agent's beliefs and personality impact its decisions. Also, we state how an agent decides to revise its beliefs, given its intentions and actions. Furthermore, we provide some formulae to incorporate the impact of personality on an agent's different aspects, such as the decision-making process and learning, as stated here.

## 6.6 Operationalising the decision module

As stated earlier, personality impacts an agent's behaviour through the decision module. Now we state how our model is inspired by the aforementioned statements to operationalise the decision module.

### 6.6.1 Utility function

Agent $A$ takes an action ($Act$) that maximises its utility function presented in Equation 6.5 ($Utility_A(Act)$). The utility function has four parts. The first part indicates the revenue that agent $A$ earns for such an action ($Revenue(Act)$). The second part shows how the agent is mentally punished for such an action. This part includes the punishment that stems from the internal beliefs towards the action ($IBeliefPunishment_A(Act)$) and the weight associated with this cost, based on its personality $\Big(\big(iNtuitive_A + Perceiving_A\big)/2\Big)$.

Table 6.3: Impact of personality on different aspects of cognition

| Aspect of cognition | personality aspect | | | | Comment | Reference |
|---|---|---|---|---|---|---|
| | Introversion/ Extraversion | Sensing/ iNtuition | Feeling/ Thinking | Judging/ Perception | | |
| Socialising | Extraversion | | | | | Myers et al. (1998) |
| Valuing norms | | Sensing | | Judging | | Gough (2000) and Fleenor (1997) |
| Impact of fairness on rule-breaking | | | Thinking | | | Skarlicki et al. (1999), Buboltz Jr et al. (2003), and Schmitt et al. (2010, 2005) |
| Impact of fairness on rule enforcement | | | Feeling | | | |
| Environmental characteristics | | Sensing | | | | Jung (1976) and Myers et al. (1998) |
| Keeping harmony at workplace | | | Feeling | | Residency | Myers et al. (1998) |
| Valuing recommendations | Extraversion | | | | | Farhangian et al. (2015b) and Myers et al. (1998) |
| Learning patterns | | iNtuition | | | Possibilities induced from current events | Farhangian et al. (2015b) and Myers et al. (1998) |

$$
\begin{aligned}
&Utility_A(Act)= \\
&\qquad Revenue(Act)- \\
&\qquad \left(IBeliefPunishment_A(Act)\times\frac{iNtuitive_A+Perceiving_A}{2}\right)- \\
&\qquad \Bigg(\big(NormPunishment_A(Act)\times NormMonitoring_A\big)\times \\
&\qquad\qquad \left(1-\frac{iNtuitive_A+Perceiving_A}{2}\right)\Bigg)- \\
&\qquad \big(RulePunishment(Act)\times \quad RuleMonitoring_A(Act)\big)
\end{aligned}
\tag{6.5}
$$

The third term shows the agent's perception of the punishment by its connections in the form of sanctions. Agent $A$ estimates this, based on its perception of punishment for such an action $(NormPunishment_A(Act))$. Unlike the internal beliefs, this punishment is moderated, based on agent $A$'s estimation of the connections' monitoring strength $(Norm\ Monitoring_A)$ and its personality $\Big(1-\big(iNtuitive_A+Perceiving_A\big)/2\Big)$. Finally, agent $A$ takes account of organisational punishment regarding violation $(RulePunishment(Act))$. Agent $A$ moderates the impact of organisational punishment, based on its estimation of organisational monitoring $(RuleMonitoring_A(Act))$. The next subsection states how agent $A$ estimates monitoring strength associated with rules and norms.

### 6.6.2 Perception of norms and monitoring strengths

The perception of norms differs from that of the rule by the vagueness of punishments associated with norms. To model an agent's perception of norms, we should note that a person expresses his/her beliefs, based on the weight he/she allocates to people's expectations. To consider this effect, we consider the impact of personality on an agent's norm conformance (i.e. expectations with undefined consequences). The following shows how an agent updates its perception of others' expectations (i.e. perceived norm) by exchanging ideas.

$$
\begin{aligned}
&PerceivedExpectation_A^t= \\
&\qquad Weight\times \quad \Bigg(\left(\textstyle\sum_{i\in\{C_{A,N}\}}\dfrac{ExpressedNorm_i^t}{K_A}\right)+ \\
&\qquad\qquad \left(\frac{(K_A-K_{A,N})\times PerceivedExpectation_i^{t-1}}{K_A}\right)\Bigg)+ \\
&\qquad (1-Weight)\times PerceivedExpectation_A^{t-1}
\end{aligned}
\tag{6.6}
$$

Equation 6.6 shows how agent $A$ collects its associated agents' expressions, and updates the society's expectations from itself at time $t$ $\left(PerceivedExpectation_A^t\right)$. The agent associates some weights with the recent information (i.e. $Weight$). Furthermore, the agent averages the recommended scores by its connections with whom it has strong relationships (i.e. the associated $w_{iA} \geq 0.5$). From those connections, it takes account of the ones who have at least the same experience as itself; we call the subset of such members from $C_A$ (i.e. the whole connections of $A$) as $C_{A,N}$. Also, $K_A$ and $K_{A,N}$ indicate the number of members of $C_A$ and $C_{A,N}$, respectively. This procedure states that an agent would not ask for less experienced agents' recommendations because of the feeling that it knows better. Furthermore, an agent does not criticise people's expectations unless it knows the audience well (i.e. the ones who have a higher $w_{iA}$). In addition, agent $A$ assumes that the rest of the connections (i.e. $K_A - K_{A,N}$) expect the same of it as it has already realised $\left(PerceivedExpectation_i^{t-1}\right)$. Then the agent associates the rest of the weights (i.e. $1 - Weight$) with its past perception about expectations (i.e. $PerceivedExpectation_A^{t-1}$).

Now we state how other agents express their beliefs to agent $A$. Agent $i$ does it through a weighting of its perception of social expectations ($PerceivedExpectation_i$) and its beliefs ($InternalExpectation_i$). Equation 6.7 shows how weighting the outer world impacts an agent's expression of beliefs. As stated earlier, the personality of agent $i$ (a friend of agent $A$) impacts its expression of its beliefs about the outer world's expectations. $ExpressedNorm_i^t$ indicates agent $i$'s expression of what people do and what they should do at time $t$. As stated earlier, the iNtuitive and Perceiving aspect of an agent decreases weights given to other people's expectations; hence, agent $i$ straightforwardly expresses its own beliefs and expectations at that time (i.e. $InternalExpectation_i^t$, second line of Equation 6.7). The third line shows the opposite — i.e. how personality of agent $i$ impacts its expression of ideas, based on the value it associates with other agent's expectations (i.e. $PerceivedExpectation_i^t$).

$$
\begin{aligned}
&ExpressedNorm_i^t = \\
&\quad \left(InternalExpectation_i^t \times \frac{iNtuitive_i + Perceiving_i}{2}\right) + \\
&\quad \left(PerceivedExpectation_i^t \times \left(1 - \frac{iNtuitive_i + Perceiving_i}{2}\right)\right)
\end{aligned}
\tag{6.7}
$$

#### 6.6.2.1 Learning the monitoring strength

The agent learns how the system works, based on observation. Agent $A$ learns the strength of the organisational monitoring of the system at time $t$, based on its observation using Equation 6.9. Before describing Equation 6.9, let us explain what the agent learns. Agent $A$ assumes the probability of getting fired for cheating follows a continuous uniform probability distribution in an unknown interval, given the severity of a violation ($Act$). Equation 6.8 shows the cumulative density function of rule monitoring ($RuleMonitoring_A$). $RuleMonitoring_A$ has a continuous uniform distribution[4] in $(a^t_A, b^t_A)$:

$$RuleMonitoring_A(Act) = \begin{cases} 0, & \text{if } Act \leq a^t_A \\ \dfrac{Act - a^t_A}{b^t_A - a^t_A}, & \text{if } a^t_A \leq Act \leq b^t_A \\ 1, & \text{if } Act \geq b^t_A \end{cases} \tag{6.8}$$

As can be seen in Equation 6.8, the agent assumes the action is tolerated to some extent ($Act \leq a^t_A$, the first condition). Furthermore, while the action is somewhat tolerable (i.e. $a^t_A \leq Act \leq b^t_A$, the second condition), the probability of getting fired increases linearly, based on the severity of such an action. Finally, violations are not tolerated beyond a certain threshold, and will be punished unequivocally (i.e. $Act \geq b^t_A$, the third condition).

Equation 6.9 shows how agent $A$ updates its overall estimation of these intervals at time $t$ (i.e. $a^t_A$ and $b^t_A$) to calculate probabilities of getting fired regarding the violation (i.e. $RuleMonitoring_A(Act)$). For this purpose, the agent weights its recent estimation and past calculations for each interval (e.g. $La^t_A$ and $a^{t-1}_A$, respectively).

$$\begin{aligned} a^t_A &= Weight \times La^t_A + (1 - Weight) \times a^{t-1}_A, \\ b^t_A &= Weight \times Lb^t_A + (1 - Weight) \times b^{t-1}_A \end{aligned} \tag{6.9}$$

Now we state how agent $A$ estimates the beginning and end of the interval (i.e. $La^t_A$ and $Lb^t_A$, respectively), using Equations 6.10 and 6.11, respectively. Before explaining formulae, we state the reason for considering different conditions. In the learning process, an agent may face one of the situations depicted in Figure 6.11, when it observes a violation. Figure 6.11A indicates a case that there is an obvious boundary between punished and not punished violators. In this case, the agent can easily guess the tolerance. However, in Figure 6.11B the agent faces a mixed situation. In other words, some violations are tolerated that are more severe than the punished ones (indicated by a circle in figure). In Figure 6.11C and 6.11D all the violators are either not punished or punished, respectively. Now we state an intuitive estimation for parameters based on these phenomena, in addition to observing no violation.

First, we describe the right-hand side of Equation 6.10. The first condition indicates that when agent $A$ is not aware of any violations of the rule at time $t$ (i.e. $V^t_A = 0$), it randomly decreases the society's tolerance intervals (the random number is generated in $(0, R)$). We use $\#Rnd(R)$ to indicate the random number generator (in Chapter 7, we state the initial values).

[4]Note that this distribution models homogeneous events (i.e. all events in the interval have the same chance of occurrence).

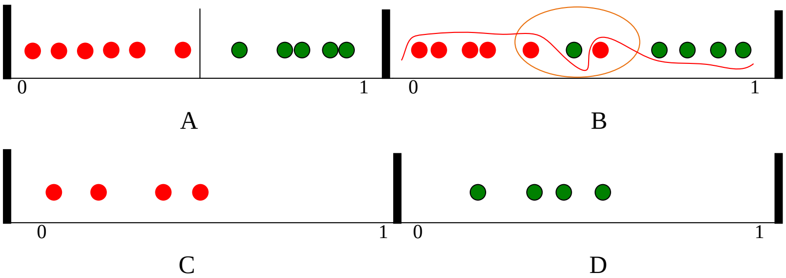


Figure 6.11: An example of different observed punishment regarding violations. The dots are violations — the green dots are punished violators and the red dots are unpunished violators. The thick vertical lines distinguish new cases. The horizontal line indicates the severity of the violation.

$$La^t_A =$$
$$\begin{cases} a^{t-1}_A \times (1 - \#Rnd(R)), & \text{if } V^t_A = 0 \\ \min\{MinPV^t_A \times (1 - \#Rnd(R)), a^{t-1}_A\}, & \text{if } V^t_A > 0 \; and \; V^t_A = PV^t_A \\ \min \left\{ \begin{array}{l} \max \left\{ \begin{array}{l} MinPV^t_A \times (1 - \#Rnd(R)), \\ MaxNP^t_A \times (1 + \#Rnd(R)) \end{array} \right\}, \\ MinPV^t_A \end{array} \right\}, & \text{if } \left\{ \begin{array}{l} NP^t_A > 0 \text{ and} \\ PV^t_A > 0 \text{ and} \\ MaxNP^t_A < MinPV^t_A \end{array} \right. \\ MinPV^t_A, & \text{if } \left\{ \begin{array}{l} NP^t_A > 0 \text{ and} \\ PV^t_A > 0 \text{ and} \\ MaxNP^t_A \geq MinPV^t_A \end{array} \right. \\ \max \left\{ \begin{array}{l} a^{t-1}_A \times (1 + \#Rnd(R)), \\ MaxNP^t_A \end{array} \right\}, & \text{if } V^t_A > PV^t_A \; and \; PV^t_A = 0 \end{cases} \tag{6.10}$$

The rest of the conditions in Equation 6.10 represent when the agent is aware of some rule violations. The second condition indicates when all the violators who agent $A$ is aware of, are punished ($V^t_A = PV^t_A$). Here the agent assumes that either the minimum tolerance of the society ($a^t_A$ ) does not change, or it is slightly lower than the minimum of punished violations ($MinPV^t_A$) .

The third condition concerns when agent $A$ is aware of some unpunished violations (i.e. $NP^t_A = (V^t_A - PV^t_A)$ and is more than 0). In this case, it also takes account of the additional information about unpunished violators. Now we state when the maximum value of unpunished violations ($MaxNP^t_A$) is less than the minimum value of punished violations ($MinPV^t_A$). First, agent $A$ assumes that societal tolerance is more than the maximum value of unpunished violations ($MaxNP_A^t$) and less than the minimum value of punished violations ($MinPV_A^t$), and it takes account of the maximum value of these two. However, this value is acceptable if it does not exceed the minimum value of punished violations ($MinPV_A^t$).

The fourth condition represents when agent $A$ faces a complicated phenomenon (see Figure 6.11B). It is aware of unpunished violators with a worse behaviour than punished agents ($MaxNP_A^t \geq MinPV_A^t$). Therefore the agent simply believes that the punished violators are determinants for the minimum value of tolerance (i.e. some of the unpunished agents were luckier).

The last condition represents when none of the violators are punished. Agent $A$ assumes that it underestimated society's tolerance and increases its former estimation, taking account of unpunished violators ($MaxNP_A^t$).

Equation 6.11 indicates how agent $A$ identifies the interval in which violations are definitely punished. Agent $A$ assumes that some violations are not tolerated, if it is not aware of any violations. For this moderation, the agent uses $\#Rnd(R)$ to reduce the maximum.

$$Lb_A^t = \begin{cases} b_A^{t-1} \times (1 - \#Rnd(R)), & \text{if } V_A^t = 0 \\ 1, & \text{Otherwise} \end{cases} \tag{6.11}$$

#### 6.6.2.2 Social monitoring

Agent $A$ assumes its connections consider *rules of friendship* when they monitor or impose sanctions on him. Equation 6.12 indicates how agent $A$ computes the strength of sanctions imposed ($NormMonitoring_A$). We only address the impact of the connections who identify an agent's violation of a norm. The right-hand side of this equation indicates agent $A$ assumes the strength of friendship with agent $i$ ($W_{iA}$) impacts agent $i$'s enforcement of *organisational* norms (i.e. friendship norms are more important than organisational norms).

$$NormMonitoring_A = 1 - \frac{\sum_{i \in \{C_A\}} W_{iA}}{k} \tag{6.12}$$

### 6.6.3 Learning societal characteristics and environmental circumstances

Equation 6.13 indicates how parameter $P$ (the score of fairness and environment) is learnt by agent $A$. In this Equation, $P_A^t$ indicates the score that agent $A$ associates with parameter $P$ at time $t$. The rest of the equation contains *two terms* (given in lines 2 and 3-5, respectively). The first term indicates how the agent weights its collected information from the outer word. Agent $A$ gathers scores of parameter $P$ from its set of friends $\{C_A\}$. A recommendation from friend $i$ about parameter $p$ ($p_i$) would be normalised, based on the values associated with that friend ($W_{iA}$), and then it is averaged, based on the number of friends $(k)$. However, agent $A$ weights beliefs of the outer word differently, based on its extraversion ($Extraversion_A$). On the other hand, the degree of being iNtuitive causes agent $A$ to weight current information less, in accordance with the degree to which it is $iNtuitive_A$, knowing that iNtuitive agents are more remote from the current situation.

$$
\begin{aligned}
P_A^t = & \\
& \Big( \textstyle\sum_{i \in \{C_A\}} (\frac{W_{iA} \times P_i}{k}) \times Extraversion_A \times (1 - iNtuitive_A) \Big) + \\
& \Big( 1 - \Big( Extraversion_A \times \big( \textstyle\sum_{i \in \{C_A\}} \frac{W_{iA}}{k} \big) \times (1 - iNtuitive_A) \Big) \Big) \times \\
& \qquad \Big( f(iNtuitive_A, P)(RandNormal(P_S, a \times (1 - iNtuitive_A)) + \\
& \qquad (1 - f(iNtuitive_A, P)) \times P_A^{t-1} \Big)
\end{aligned} \tag{6.13}
$$

The second term of Equation 6.13 (lines 3 to 5) indicates how agent $A$ is impacted by its inner world, weakness of friendship $\big(\sum_{i \in \{C_A\}} W_{iA}\big)$), and being remote from the current situations $(iNtuitive_A)$. To model this part, we consider the complement of impacts of the outer world ($Extraversion_A$), friendship $\big(\sum_{i \in \{C_A\}} W_{iA}\big)$, and the Sensing aspect of agent $(1 - iNtuitive_A)$ at once, by using $\Big(1 - \Big(Extraversion_A \times \big(\sum_{i \in \{C_A\}} W_{iA}\big) \times (1 - iNtuitive_A)\Big)\Big)$. This kind of modelling shows how an agent relies on its own abilities. However, a Sensing agent has fewer chances to identify the patterns, and it has already used its chances for collecting data by sensing the outer world. To model such a phenomenon, we assume that agent $A$ learns the patterns and possibilities with some errors. To model this error, we used a normal probability distribution with a mean of the real value of the system's parameter ($\mu = P_S$). The standard deviation of this learning ($\sigma = a \times (1 - N_A)$) is impacted by two factors, namely a maximum standard deviation ($a$), and the agent's attention to the pattern $(1 - iNtuitive_A)$. We use $(1 - iNtuitive_A)$ to indicate that iNtuitive agents pay more attention to such patterns and possibilities (i.e. they have less deviation in learning).

Furthermore, the agents have different concerns about the environment and fairness. In Equation 6.13, $f(iNtuitive_A, P)$ models this concern. Sensing agents tend to live in the current moment; hence, they weight their understanding of the environment ($P = Env$) more (i.e. $f(iNtuitive_A, Env) = 1 - iNtuitive_A$) and weight older information about the environment ($P_A^{t-1}$) less. On the other hand, as indicated by Buboltz Jr et al. (2003), iNtuitive-Thinking agents were more sensitive to the fairness ($P = fair$) of the system than their Sensing-Thinking counterparts. The availability of such difference among the

Thinking personality convinces us that iNtuitive agents pay more attention to such patterns (i.e. $f(iNtuitive_A, fair) = iNtuitive_A$). Note that besides Buboltz Jr et al.'s (2003) study, we know that iNtuitive agents are more future-oriented than sensing agents. Also, the fairness of the system influences the future of an agent more than its current status.

### 6.6.4 Decision-making factors

As stated earlier, the combination of the system's characteristics and an agent's personality impacts its beliefs about the system and its rules. We also stated that the reason why agents modify their internal beliefs is to resolve the dissonance. Those statements, along with the evidence of the impacts of the fairness of the system on an agent's behaviour, and the fact that in a trading context agents intend to maximise their profit, convince us to argue that any hurdle for an agent to cheat introduces **cognitive dissonance** on the part of an agent and should be resolved. What follows states how agents measure this dissonance.

#### 6.6.4.1 Cognitive dissonance

In our model, cognitive dissonance is measured as the cost for tensions occurring in the mind of an agent when the system possesses certain characteristics (e.g. unfair institutions). These characteristics influence an agent's behaviour through its perception and its personality. We use Equation 6.14 to measure dissonance regarding fairness of the system for agents based on their personalities. This dissonance is used to moderate the internal beliefs towards actions of an agent in the system. The dissonance felt by agent $A$ due to the fairness of the system at time $t$ is indicated by $Dissonance(Fairness)^t_A$. Costs/rewards for perceived fairness of the system ($Fairness^t_A$) are weighted, based on the Thinking aspect of the agent ($Thinking_A$). Costs/rewards regarding harmonising the society are weighted, based on the Feeling aspect of personality $\big(1 - Thinking_A\big)$. On the one hand, an agent considers some rewards (e.g. feeling good about being loyal) regarding the relative strength of the connection to its master (i.e. $W_{im}$) that is calculated as $\frac{W_{im}}{W_{im} + \sum_{i\in\{C_A\}} W_{iA}}$). On the other hand, an agent considers the relative strength of its connections $\left(\frac{\sum_{i\in\{C_A\}} W_{iA}}{W_{im} + \sum_{i\in\{C_A\}} W_{iA}}\right)$ and the impact of the perceived fairness of the system on them.

$$
\begin{aligned}
&Dissonance(Fairness)^t_A = \\
&\qquad Thinking_A \times fair\ ness^t_A + \\
&\qquad (1 - Thinking_A) \times \left( \frac{W_{im}}{W_{im} + \sum_{i \in \{C_A\}} W_{iA}} + \right. \\
&\qquad\qquad \left. \left( \frac{\sum_{i \in \{C_A\}} W_{iA}}{W_{im} + \sum_{i \in \{C_A\}} W_{iA}} \right) \times fairness^t_A \right)
\end{aligned} \tag{6.14}
$$

As suggested by J. S. Adams (1965), Tyler (1989), and Greenberg (1990, 1993), this dissonance influences agents' internal beliefs about the actions and their cooperation in monitoring others' behaviours. Some of these effects have been stated earlier, and changes in internal beliefs will be stated further in Chapter 7.

#### 6.6.4.2 Conformity

Another behaviour of agents stated by Aronson and Aronson (2007, p. 185) is enhancing values associated with an action based on the behaviour of others. This has been studied by Tyran and Feld (2002); they identified that a reason for following a law with mild punishments after a referendum is the expectation of support for it by the society and the idea that the majority will follow that law. Therefore we implement such an idea for agents' observations. We consider a threshold for an agent whereby the agent decides to modify its behaviour. When the agent observes that a greater proportion of agents than its threshold are performing a particular forbidden action, it decreases its mental costs for doing it.

#### 6.6.4.3 Perception of the future

Another factor that impacts agents' behaviour is the perception of the environment. We know this factor arises from the Sensing aspect of agent $A$ the most; hence, we modify the thresholds of agent $A$ based on its Sensing aspect $(1 - iNtuitive_A)$. An agent discounts its future revenue/punishment based on its tolerance towards the environment. Agent $A$ modifies its discount factor over time (i.e. it is not a fixed number). This modification occurs based on its sensitivity towards the environment ($TolerableEnvironment_A$) that is calculated as follows:

$$TolerableEnvironment_A = Random\ Uniform(0, 1) \times (1 - iNtuitive_A) \tag{6.15}$$

#### 6.6.4.4 Impact on monitoring (role)

Collaboration in the monitoring of norms and rules incurs some costs to an agent. Consequently, friendship and an organisation's characteristics influence the incentives for informal (e.g. boycotting) or formal (e.g. reporting) collaboration in rule enforcement. As stated earlier, fairness and relationships convince some agents to internalise some other roles. This internalisation forms in two stages as follows:

1. Internalising the monitoring role (i.e. Knowledge agents or K): An agent may decide to return company favours by improving the procedural justice by collaborating in identifying suspicious acts (see Section 6.4.3).

2. Interpretation (internalised role of skill agents S): An agent who officially or unofficially (as stated earlier) collaborates in monitoring has its own perception of the fairness of rules and situations; hence, it may overlook some actions.

We use a combination of the above in the model. Equation 6.16 shows the tolerance for unofficial monitoring agents. Note that the agent reports the violations to its direct manager. The agent tolerates rule-breakers' violations concerning its relationships with them and also the system characteristics. As stated earlier, the Thinking aspect of the agent's personality increases its reactions to the unfair treatment of itself. However, the Feeling aspect of the agent decreases its inclination to treat others unfairly. Furthermore, the Feeling aspect of personality takes account of the weight of friends in the group who the agent is associated with and the weight of the connection (i.e. relationship) with the manager.

$$\begin{aligned} &Tolerance_{A=MercantileAgent} = \\ &\qquad (((1 - iNtuitive_A) \times Environment_A) + (Thinking_A \times fairness_A) + \\ &\qquad ((1 - Thinking_A) \times \textstyle\sum_{i \in \{C_A\}} (\frac{W_{iA}}{k_A}) \times fairness_A)) \end{aligned} \tag{6.16}$$

First, we state the aspects of tolerance that are impacted by the agent's beliefs. As stated earlier, the Sensing aspect of personality $(1 - iNtuitive)$ is impacted the most by immediate joys perceived from the environment $(Environment_A)$ that is reflected in the first term of the model. The second term shows how an agent directly includes the costs or benefits of the system's fairness in its calculations. As stated earlier, the Thinking aspect is directly impacted by the perceived justice and fairness $(fairness_A)$ in the system. Furthermore, Feeling agents consider fairness when their actions impact others. The fairness of the system is a good way of measuring this impact as stated by Sunshine and Tyler (2003). To reflect the impact of the Feeling aspect of agent $A$ $(1 - Thinking_A)$, we should also consider the associated weight with this group of people $\big($i.e. $\sum_{i \in \{C_A\}} \frac{W_{iA}}{k_A}\big)$. In this way, we reflect the impact of the importance of group members on the associated weight with the perceived fairness by agent $A$ (i.e. $fairness_A$).

$$
\begin{aligned}
&Tolerance_{A=Manager} = \\
&\qquad ((1 - iNtuitive_A) \times Environment_A) + \\
&\qquad ((1 - Thinking_A) \times fairness_A))
\end{aligned} \tag{6.17}
$$

Equation 6.17 shows the tolerance of agent $A$ who officially monitors others (i.e. it is a manager). These agents only consider the impact of the environment and their actions on others. As before, the Sensing aspect $(1 - iNtuitive_A)$ is impacted by the perceived environment $(Environment_A)$. However, note that a manager is not from the same group of mercantile agents, and they do not monitor managers. As noted by Schmitt et al. (2005), the Feeling aspect of personality $(1-Thinking_A)$ causes an agent to consider the consequences of its actions on others. Note that the manager's responsibilities include constant monitoring of the mercantile agents. Furthermore, the directors are remote (i.e. they do not impact workplace harmony). Consequently, it considers only the impact of the fairness of the system on mercantile agents (i.e. he considers $fairness_A$).

### 6.6.5 The impact of the private trade on negotiation

The combination of an agent's behaviour and skill impacts organisational profitability; more skilled agents can increase the organisational profitability. Breaking organisational rules has two potential impacts on organisational profitability. One of these influences is the direct cost for the organisation based on the agents' behaviour. Another important cost is the indirect expenses incurred due to the formed "*social exchange relationships*". Cropanzano and Mitchell (2005) divide exchange into two subcategories, namely transactions and relationships. In this context, relationships refer to interpersonal-attachments, not transactions between two groups. Note that it is dangerous when relationships and transactions are mixed.

A rule established to control this phenomenon in the EIC and Julfa was the prohibition of private trade. Private trade raises concerns regarding becoming friends with local traders that leads to sacrificing company profits. This happens through either only trading with friends (i.e. not searching for the best offers) or not negotiating well. In our model, we assume that agents will break this rule (prohibition of private trade), if they face intolerable dissonance costs for unfair organisational institutions. The intuition for this includes a) lack of moral concerns (i.e. internal costs) for breaking the rule and b) challenges for monitoring such a violation. To summarise, the private trade can impact the agent's behaviour (consciously or unconsciously) in two steps. First, the agent either consciously uses its trade for the company as a way of gift exchange and making friends with local traders, or this ongoing relationship strengthens the agent's social relationships with them. Then it uses this social relationship in its private trade (economic exchanges). This has been observed in bell boys' behaviour ("in order to maximize their tips, bell boys can compromise the interests of their employer", Seth, 2018, p. 171).

To model the impact of the steps mentioned above on an agent's behaviour, we also consider the impact of two characteristics of the system. An agent who has the right to perform private trade negotiates less for the master. However, in a payment scheme that shares the profit, the agent compromises less, because it would also lose its share of the profit. Furthermore, if an agent resides in a place, some friendships and expectations of local traders gradually form — the agent's response to such an expectation is based on its personality. Finally, we know that when the board of directors permitted the agents to perform private trade in the EIC, they also decided to significantly decrease the agents' wages. This decision of the board of directors was because private trade creates enough incentives for agents to apply for the job. This kind of issue impacts both friendships with locals and negotiations for its master. Equations 6.20 and 6.18 indicate how we model the impact of the stated concerns for agent $A$.

Equation 6.18 shows the impact of connections with local traders on agent $A$'s negotiation. This impact is moderated in two steps, as shown by the two terms in the equation. The first part indicates how agent $A$ compromises its negotiation for its social bonds with local traders. Using $f(Fairness, Private, W_{A,locals})$, the agent takes account of its profits (i.e. its share of profit $Fairness$), the margin of profits (this decreases after legalising private trade ($Private$)), and the strength of its relationship with local traders ($W_{A,locals}$). These concerns are modified, based on the agent's personality and the weight it places on the expectations of others. The second term indicates how the agent's personality motivates it to ignore all social concerns and negotiate well ($Negotiation_A$). The sum of the two terms determines how the agent negotiates with local traders (i.e. $ImpactedNegotiation_A$).

$$ImpactedNegotiation_A = \left(\left(f(Fairness, Private, W_{A,locals}) \times \left(1 - \frac{iNtuitive_A + Perceiving_A}{2}\right)\right) + \frac{iNtuitive_A + Perceiving_A}{2}\right) \times Negotiation_A \tag{6.18}$$

Equation 6.19 indicates how agent $A$ decides about its negotiation ($Negotiation_A$). If it performs private trade, it negotiates for $PNegotiation_A$ amount. However, if it does not perform private trade, it negotiates with its full strength (second term of Equation 6.19).

$$Negotiation_A = \begin{cases} PNegotiation_A, & \text{if he is engaged in private trade;} \\ 1, & \text{otherwise,} \end{cases} \quad (6.19)$$

$PNegotiation_A$ indicates agent $A$'s negotiation strength when it performs private trade. The first term of Equation 6.20 indicates that the agent negotiates to some extent. The extent to which the agent negotiates is determined by the payment scheme (determined by system $Fairness$) and whether or not the private trade is legal. Note that profit-sharing increases the agent's incentives to negotiate — i.e. $ConstantNegotiation(Fairness, Private)$ is higher in a fair organisation. Furthermore, granting permissions for private trade and decreasing wages changes the main source of agents' revenue for local trades. The second part shows how an agent changes its negotiation power based on its vested interests in trade.

$$\begin{aligned} PNegotiation_A = \\ & ConstantNegotiation(Fairness, Private) + \\ & RandomUniform(0, 1 - ConstantNegotiation(Fairness, Private)) \end{aligned} \quad (6.20)$$

In the next section, we provide a summary of what has been stated in this chapter. We also provide an overview on other aspects of the model that have not been stated in the previous sections.

## 6.7 Conclusion and discussion

This chapter has proposed a modification of the BDI cognitive architecture, coupled with the CKSW meta-roles. Also, the model considers contradictions between beliefs and intentions as a source of cognitive dissonance. To model human interpretations of seriousness of violation, we have employed fuzzy sets to map violations of a rule, along with their punishments in the modelling. Then we have utilised the architecture to model the interactions between different modules using the two main historical long-distance trading societies of this thesis.

The presented agent cognitive architecture can be used or be extended to model other societies. Also, more social impacts can be addressed by considering other sociopsychological studies or other methods of learning (e.g. reinforcement learning). Some instances of potential extensions of this model include, considering the impact of mass communication and social networks on a human's decision-making and behaviours (Kissas, 2019; W. Zhang et al., 2009). An instance of these impacts concerns media playing the role of a catalyst for copycat crimes and suicides (Ji et al., 2014; Surette, 2012; Yang et al., 2012). Another instance of such impacts concerns employing social media to collect information in order to use it to impact an agents' decisions (Berghel, 2018; Schneble et al., 2018, e.g. Cambridge

Analytica). This impact can be modelled by taking account of changes in beliefs with exposure to new information (e.g. discussions on the validity of a behaviour). Another impact concerns context-based comparisons (Kenrick & Gutierres, 1980). For instance, the context can impact an agent's understanding of fairness (e.g. an agent who is used to high wages considers lower wages unfair, Herz & Taubinsky, 2017). Note that this *understanding of fairness* and impacts of that on an agent's behaviour can be used to model stickiness of wages used in Chapter 5 (i.e. market resistance to reach an equilibrium).

Another important method for changing beliefs concerns persuasive arguments (Hunter, 2018). The influential elements regarding this concern include, but are not limited to, the modes of persuasion, weighting vivid examples more than general statistical evidence, the self-esteem of the audience, and self-biases. Aristotle suggested that argument (logos), character (êthos), and emotions (pathê) are influential components for persuasion (i.e. in models different weights are associated with different arguments and debaters, Rapp, 2010). The generalisation because of a vivid example is another issue that impacts the model. Note that such an issue is observable, even though participants were told that the observed instance was an atypical case (i.e. agents weight their own experience more than collected information, Hamill et al., 1980; Zebregs et al., 2014). Also, the impact of self-esteem on persuasion is another influential parameter that impacts the model (Zellner, 1970). Finally, self-bias simply suggests that one is biased when interpreting events regarding oneself (e.g. he attributes his achievements to his capabilities and his failures to the situation, Cunningham & Turk, 2017).

The impact of such elements on changes in beliefs, along with influences such as the impact of prejudice on a person's behaviour, are other issues that can be modelled utilising and extending the provided cognitive architecture. However, there exists a need to identify these modules' and related modules' impacts on each other (e.g. the impact of personality on self-biased information processing). Furthermore, this chapter has considered fairness in a trading society as a source of cognitive dissonance; however, an extension of this work could consider the conflicts between internal beliefs, perceived norms, and rules (e.g. moral dilemmas). Finally, as stated at the beginning of the chapter, like Gödel, we believe that the mind is not static; hence, an exact *mechanical* replica of humans' cognition and mind is not achievable.

The next chapter provides implementations of the two historical long-distance trading societies using the cognitive model provided in this chapter.

# 7

# Simulation using the refined BDI mental architecture

## 7.1 Introduction

This chapter employs our extension of the BDI mental architecture presented in Chapter 6 to explain the behaviour of agents in the two long-distance trading societies studied in this thesis. The chapter concerns the dynamics and efficacy of institutions in the studied historical cases.

Using this simulation, we examine the same system studied in Chapter 4, from another point of view. This chapter aims to find out whether it is possible to gain insight into what happened in Julfa without the need for a closed hiring scheme. This chapter also explores an example of conflicts between norms (friendship expectations) and organisational rule. Furthermore, based on what has been stated in Chapter 6, we model the monitoring conducted unofficially by other members. This kind of modelling helps us to explore a pivotal concern stated by Sproule-Jones (1993) that led him to classify rules in terms of *rules-in-use* versus *rules-in-forms*. What makes this exploration interesting, lies in keeping the rules of interest the same and changing other characteristics and institutions of the system.

The rest of the chapter is organised as follows: Section 7.2 reviews the two historical long-distance trading societies. Section 7.3 presents the simulation model for these cases that is developed based on the architecture and descriptions presented in Chapter 6. Section 7.4 provides simulation results of this simulation. Finally, Section 7.5 provides a summary of the chapter, along with some discussions about the results and limitations of this study.

## 7.2 Review of systems

In this section, we provide an overview of the two historical long-distance trading societies. Also, we compare them with respect to the four characteristics of interest. The characteristics are listed below:

1. **Environmental circumstances:** The favourable/unfavourable environment and low/high mortality rates impact agents' behaviour and system costs. Such impacts were discussed earlier; however, we provide an overview of them here.
2. **Fairness of institutions:** As stated in Chapter 6, an agent's perception of fairness concerns several characteristics that include distributive justice (e.g. paying based on personal performance), procedural justice (fair dispute resolution), and a convincing presentation of the procedures. We state such aspects for both societies.
3. **Apprenticeship programme:** The influence of apprenticeship programmes on increasing a trader's performance has been stated in Chapter 5. Here we use the characteristics of the EIC and Julfa in connection with our investigation of this matter.
4. **Mobility versus long-term residency:** A difference between the EIC and Julfa concerns their policy regarding mercantile agents. In the EIC, mercantile agents stayed in places called factories (i.e. warehouses), but in Julfa they moved among different trading places.[1]

In the next section, we provide an overview of the two long-distance trading societies.

### 7.2.1 Societies' background

In what follows, we provide descriptions of the two historical long-distance trading societies, and how these societies possess the characteristics of interest.

[1]For instance, Santiago di Barrachiel (an Armenian trader) did not return to Julfa for ten years. What makes it interesting is the fact that this round of trading travels started only one year after his marriage (Aslanian, 2007, p. 343).

**Armenian Merchants of New-Julfa (Julfa):** Armenian merchants of New-Julfa were originally from old Julfa in Armenia. They re-established a trader society in New-Julfa (near Isfahan, Iran) after their forced displacement in the early 17th century. They used commenda contracts (profit-sharing contracts) in the society and also used courts to resolve disputes. The mercantile agents were responsible for buying and selling items and moved among different nodes of the trading network. The society also had apprenticeship programmes to improve their recruits' skill levels.

**The British East India Company (EIC):** During the same time, the British contemporaneous counterpart of Julfa (i.e. the British *East India Company* (EIC, AD 1600s-1850s)) had a totally different perspective on managing the society. The EIC faced a high mortality rate for environmental circumstances in India. They hired inexperienced apprentices, asked them to provide signed bonds, and sent them off for trading to India to be trained by fellow merchants on a voluntary basis. They built settlements for their mercantile agents to stay in India. Also, they paid their employees fixed wages and fired agents based on their beliefs about their trading behaviour. Furthermore, the EIC's trading period covers the English Civil War (1642–1651), which had some impacts on the company (see Section 7.3.1). We did not consider impacts such as militarisation of the EIC after the 1750s, which was a shift from being traders to being governors, because we are only interested in studying trading aspects of these societies.

### 7.2.2 Characteristics

This section provides an overview of the aforementioned societies with respect to the characteristics stated earlier, namely environment, fairness, apprenticeship, and agents' mobility.

**Environment:** As stated earlier, these historical long-distance trading societies had different mortality rates. This difference resulted in the phenomenon that on average in the EIC an agent died before he was 35 years old (see Chapter 2 and Hejeebu, 1998, p. 101). On the other hand, Aslanian (2007) provides no evidence for such a situation in Julfa. As stated in Chapter 6, the impact of high mortality rates on agents' behaviour varies, based on the agents' personalities. Furthermore, the main impact of this characteristic concerns the agent's perception of the future. Also, the cost of this mortality rate for companies concerns some fixed costs regarding hiring and sending new agents to the settlements. In addition, companies face costs of lost opportunity, because a dead agent cannot finish the trade.

**Fairness:** Another difference between the two historical long-distance trading societies is associated with their payment schemes and adjudication processes affecting the general perception concerning the way the organisations were managed, and even issues such as granting permissions for establishing another trading organisation. As stated in earlier chapters, the EIC rarely employed an adjudication process and they paid low wages to their employees. However, Julfa used commenda contracts, and a mercantile agent was paid based on his performance. They had adjudication processes to resolve disputes considering available evidence (including contracts). However, the Julfa society had certain characteristics that questioned its complete fairness — for instance, in the Julfa society, the capital of the family was managed by the elder brother. This rule helped the families to work like a firm; however, other brothers were deprived of managing their capital (the rules somehow made it irrational to ask for capital). Such a rule can lead to a partial dissatisfaction regarding the head of a family's decisions for other members.

**Apprenticeship:** As stated in Chapter 5, Julfa had organised apprenticeship programmes. However, in the EIC, we see a gradual shift from hiring skilled agents to hiring inexperienced agents who learn to trade in India with the help of more experienced agents. This influences the skills of the agents in societies. Furthermore, apprentices learn about fairness of the system during training. Also, the relationships between masters and recruits become stronger over the training period. Section 7.3.1 states some impacts in addition to what has been stated in Chapter 6.

**Agent's mobility:** Finally, a difference in the policy of the two historical long-distance trading societies concerns whether or not the mercantile agents stayed in a certain place to perform trades. In the EIC, the company built its own factories and mercantile agents (not sailors) resided there. This introduces issues such as forming an informal community inside the company that will be run on friendship norms (see Chapter 6, Section 6.4). Another impact of residency in a node concerns friendship with local traders (i.e. sellers of the items) that impacts an agent's incentives for negotiation.

Table 7.1: System specifications based on the EIC and Julfa Societies

| ***Characteristics*** | EIC | Julfa |
|---|---|---|
| Environment | Unfavourable | Favourable |
| Fairness of institutions | Low | High |
| Apprenticeship programme | Weak | Strong |
| Mobility | Reside in company's factories | Move between trading nodes |

An overview of the stated characteristics is presented in Table 7.1. In the next section, we present an agent-based simulation to study the effects of these differences on the success of the two long-distance trading societies and some stereotypical societies formed, based on the characteristics presented in Table 7.1.

## 7.3 Simulation model

In this section, we describe how we simulate the two historical long-distance trading societies using the refined BDI mental architecture and CKSW meta-roles presented in Chapter 6. This modelling is narrowed down to the characteristics stated in Table 7.1. For this purpose, first, we state assumptions of the model. Then we explain the procedures we used to implement this model. Finally, we state the simulation parameters and the reasons for choosing specific values for them.

### 7.3.1 Model assumptions

This section states the assumptions employed for this modelling. Note that in Chapter 6, we stated how our refined version of the BDI mental architecture can be utilised for the EIC and Julfa. There we also covered the interactions between modules and their specifications. In this section, we state the pivotal assumptions utilised for this simulation. These assumptions concern the influence of several factors on agents' behaviour and organisational profitability, namely the apprenticeship programme, opportunities for revising certain rules, methods for learning the norms, and the system's characteristics. Note that some aspects of the system impose costs on the organisation. These costs are important because we study trading societies that manage to improve their profitability even by tolerating fraud. For instance, Ali (2008) stated that "flexible ethics" tolerate harm done by self-interested agents and even justify them.[2] In such a context, we should consider the costs and profits of actions, along with the agents' behaviour.

**Apprenticeship programme:** This model considers other effects besides skill improvement. The first impact concerns providing an opportunity for the agents to have a better rule-understanding. Furthermore, the agents' internal beliefs (their internal beliefs towards a rule) have fewer deviations from the stated rule. The agents also have a better understanding of the organisational characteristics such as fairness of institutions. Another impact of apprenticeship programmes concerns strengthening bonds between the trainee (mercantile agent) and the trainer (manager). Finally, one should note that the apprenticeship improves skills of the agents at a cost for the organisation. These costs include what the company loses for putting aside some capital for training. In societies such as Julfa, the company should

[2] An example of such justifications is stated by Ali and Camp (2003) when they compare the "Evangelical capitalism" to other forms of capitalism. They state that "[Evangelical capitalism] differs from other forms of capitalism in its unique emphasis on the proposition that the end justifies the means and that the individual is 'free to act on his own judgment' to achieve his/her 'ambitions for wealth and success' ".

give the trainees some capital to trade with. Note that inexperienced traders cannot make as much profit as experienced traders (i.e. they decrease the profits significantly).

**Opportunities for revising bureaucratic rules:** We know that in certain societies such as Julfa, directors (i.e. heads of families) had already been working as mercantile agents, and they were aware of employees' perceptions of rules and institutions. However, in the EIC after the English Civil War (1642-1651), some mercantile agents were promoted to directors. This led to some changes in company institutions over the years. In 1665, the agents were granted permissions for self-interested trade (private trade) inside India for non-monopolised items (private trade; see Davies, 2014, Note 3). Between 1667 and 1669, the permission was extended, such that it included more items and international trade (see Erikson, 2014, p. 76). The immediate consequence of such permissions was a reduction in imports, such that they were about 0 between 1666 and 1668 (see Figure 2.5 in Chapter 2).[3] We model the EIC's circumstances (i.e. once some managers have the opportunity to permit private trade). In 1698, the establishment of a new trading company (the New East India Company, Bohun, 2008) increased the number of traders. This increased the living costs and made private trade more competitive.[4] We call the consequence, that is a decrease in private trade profit margins, *market saturation*.

Given historical changes in the EIC, in our simulation, we distinguish three intervals with respect to the two limit points, namely a) granting permissions for private trade and b) the market saturation. These intervals and limiting points, along with their definitions, are listed below:

- Interval *A*: Before the time that managers had the opportunity to revise rules regarding private trade (before 70).[5]
- Interval *B*: Between the aforementioned time and market saturation (between 70 and

[3]This drop could be partly caused by wars between the Dutch and British companies; however, the impact of private traders was significant in a way that a company decided to start a *trade war* against them by increasing the imports and reducing the market price of such items (Chaudhuri, 1978, pp. 285–287).

[4]These issues are stated in correspondence between agents in India and the EIC directors who resided in England and are narrated by Marshal as follows:

> "In 1730 the Directors complained about an 'expensive and extravagant way of living, particularly in equipage and show'. [...] The servants [...] had 'dancing twice a week to keep up a social spirit'. [...] The expense of life for Europeans in Bengal became notorious. [...] By 1735 it was said that 'no one at present from the hightest [sic] to the lowest can live conveniently on his allowanee' [sic]." (Marshall, 1976, p. 17)

[5]Note that this number is figurative and we shifted the actual year from the EIC establishment by 4 years in this simulation (i.e. it was 66 years after establishment).

100 time units in our simulation).

- Interval $C$: After the market saturation (after 100 years in this simulation).

**Learning norms:** In our model we assume that an agent revises his perception of norms (i.e. social expectations) through discussions with other society members. However, when norms are different than stated rules, agents are considerate about questioning them; hence, only strong social bonds initiate such discussions between two agents.

**Environment and mortality rates:** An influence of the environment is on mortality rates. Replacing deceased agents imposes some costs on the organisation by introducing the requirement of dispatching new agents from the company's homeland to the destination. Furthermore, if the company has apprenticeship programmes, some expense is incurred to train new agents (the formula and effect of the environment on mortality rates is presented in Section 7.3.3). Note that the costs stated above and other similar costs impact the decisions of managers of an organisation to choose certain policies, given their intention to increase their profits (we do not address this aspect here).

**Personality dynamics:** In our simulation model, the personalities of mercantile agents are modified gradually as time goes by such that they fit their roles (see Section 6.5.2). This is inspired by the notion of "attraction-selection-attrition" (Schneider, 1987). This suggests that individuals are chosen for and stay in positions such that their colleagues possess similar personalities.

In the next subsection, we state our employed procedures to simulate these two historical long-distance trading societies, as well as other stereotype societies made by changing system characteristics.

### 7.3.2 Algorithms

In this section, we state the procedures employed to use the model described in Chapter 6 to simulate the two aforementioned societies. The simulation model is split into four distinctive procedures and one sub-procedure. The first procedure models the societal level of simulation, including creating an initial population and staffing (hiring new recruits) to create a stable population. The second level describes procedures for *mercantile agents*' decision-making and learning the system's parameters. The second level also includes a sub-procedure for defining new parameters associated with hired mercantile agents. The third level covers the decision-making and learning procedure associated with managers (i.e. monitoring agents). The last procedure is the meta-algorithm that executes the aforementioned algorithms in an appropriate sequence and updates parameters required for them.

**Algorithm 7.1:** Societal level set-up

```
/* n equals deceased and fired agents (mercantile agents and managers) in
   the former iteration.                                                  */
```

1 The most experienced mercantile agents get promoted to a managerial role to keep the number of managers constant.

2 Create $n$ new agents $status \leftarrow new$, $Experiene \leftarrow 0$, randomly initialise personality aspects and other parameters

3 $HiringCost = n \times HirePerPersonLostOpportunity$

4 **if** *There are apprenticeship progammes* **then**

5     $TrainingCost = n \times TrainPerPersonLostFortune$

6 **else**

7     $TrainingCost = 0$

8 **end**

9 $OrganisationROR \leftarrow$

$$\frac{\left(\sum_{\forall_{i \in \{MercantileAagent\}}} ROR_i \times Experience_i\right)}{\sum_{\forall_{i \in \{MercantileAagent\}}} Experience_i} - TrainingCost - HiringCost$$

**Algorithm 7.1** shows how the societal level of the system is simulated. The organisation hires and promotes agents to sustain the number of agents per role — i.e. replaces deceased agents (lines 1-2). As stated earlier, deceased agents incur some costs for the systems. We take into account such costs by calculating $HiringCosts$ (line 3). Furthermore, systems that benefit from apprenticeship programmes face the cost of training in terms of lost opportunity (stated in Section 7.3.3) per hired agents (lines 4-8). Finally, the rate of return (ROR) for the iteration will be calculated. In calculating the ROR, we assume an agent contributes to the company's ROR based on his experience (line 9).

**Algorithm 7.2** shows how the parameters of newly introduced mercantile agents are initialised. This algorithm is executed only for inexperienced agents (i.e. new recruits). If the system has apprenticeship programmes, the hired agents have a better skill level and a better perception of the system's characteristics (lines 1-4). Furthermore, trained agents have a different internal belief and rule-understanding than their untrained counterparts (lines 5-6). An untrained agent has a lower skill level and a completely random understanding of the system's characteristics (lines 7-10). Besides, untrained agents' rule-understandings and their internal beliefs about the seriousness of violations are modelled using different variances (lines 11-12). The social norms are not learnt during training, because trainees are not in contact with other traders. In other words, the variance of norm understanding for both trained and untrained agents is the same (line 14). Finally, the agent updates his status to experienced so that the system can identify him (line 15).

**Algorithm 7.2:** Initialising the mercantile agent's algorithm

1 **if** *There are apprenticeship progammes* **then**

2 $\quad Skill \leftarrow 0.7 + RandomUniform(0, 0.3)$

$\quad$`/* Perceived environment and fairness for trained agents. */`

3 $\quad PEnvironment \leftarrow RandomNormal(\mu \leftarrow Environment, \sigma \leftarrow TrainedPerceptionDeviation)$

4 $\quad Fair \leftarrow RandomNormal(\mu \leftarrow Fairness, \sigma \leftarrow TrainedPerceptionDeviation)$

$\quad$`/* Rule-understanding and the internal belief towards rule. */`

5 $\quad Rule \leftarrow RandomNormal(\mu \leftarrow ViolationIntervals, \sigma \leftarrow SD_{TrainedRule})$

6 $\quad Belief \leftarrow RandomNormal(\mu \leftarrow ViolationIntervals, \sigma \leftarrow SD_{TrainedBelief})$

7 **else**

$\quad$`/* There are no apprenticeship programmes (e.g. training at work). */`

8 $\quad Skill \leftarrow RandomUniform(0, 0.5)$

$\quad$`/* Perceived environment and fairness for inexperienced agents. */`

9 $\quad PEnvironment \leftarrow RandomUniform(0, 1)$

10 $\quad Fair \leftarrow RandomUniform(0, 1)$

$\quad$`/* Rule-understanding and the internal belief about rules. */`

11 $\quad Rule \leftarrow RandomNormal(\mu \leftarrow ViolationIntervals, \sigma \leftarrow SD_{UntrainedRule})$

12 $\quad Belief \leftarrow RandomNormal(\mu \leftarrow ViolationIntervals, \sigma \leftarrow SD_{UntrainedBelief})$

13 **end**

14 $Norm \leftarrow RandomNormal(\mu \leftarrow ViolationIntervals, \sigma \leftarrow SD_{Norm})$

15 $Status \leftarrow Experienced$

**Algorithm 7.3** shows the procedures associated with mercantile agents' cognition and decision-making processes. Note that in this algorithm $\#Rnd(x)$ indicates a random number generated in the interval $(0, x)$. As stated earlier, if the status of the mercantile agent is new, he goes through an initialisation algorithm (i.e. Algorithm 7.2, line 1). Then the algorithm generates a random rate of profit for an iteration. This profit consists of two parts. The first part is a general profit $(GenProf)$ that is obtainable through trade, irrespective of the mercantile agent's skills. The second part is a profit that is impacted by the mercantile agent's skills, and the extent to which he negotiates that is obtained by Equation 6.18 (line 2). If the payment scheme is unfair, the mercantile agent's *relative access* to the company resources increases over time. This increase is proportional to the profit he makes for the company (line 3). Then the mercantile agent updates his computation of the company shares of profit after subtracting his wage or his share of profit (line 4). Experienced mercantile agents decide on cheating based on a set of potential violations (lines 5-10). If the mercantile agent decides to cheat, the company's ROR decreases, based on the decided violation (line 11).

Furthermore, a consequence of cheating is a cognitive dissonance. To resolve this, the

**Algorithm 7.3:** Mercantile agent's algorithm

/* Upadate parameters for new recruits. */

**if** *Status* = *New* **then** Set agent's parameter using Algorithm 7.2

/* $ImpactedNegotiation$ is obtained using Equation 6.18. */

$PotlProf \leftarrow \#Rnd(GenProf) + (ImpactedNegotiation \times skill \times \#Rnd(ExtProf))$

/* Agent's access is modified. */

**if** *Unfair* **then** $access \leftarrow access \times (1 + (0.3 \times PotlProf))$

$CompanyROR \leftarrow PotlProf \times (1 - AgentShare)$

**if** $Experience > 3$ **then**

  /* Make decision on cheating using Equation 6.5. */

  $Cheat \leftarrow 0$

  /* $\mathcal{V}iol$ is a set of random violations. */

  **foreach** $viol \in \mathcal{V}iol$ **do**

    $util \leftarrow Utility(viol)$

    **if** $Util > Utility(Cheat)$ **then** $Cheat \leftarrow viol$

  **end**

  $CompanyROR \leftarrow (1 - Cheat) \times CompanyROR$

  **if** $Cheat > 0$ **then**

    **if** $\#Rnd(1) < FeelGuilty$ **then**

      $IBeliefCost \leftarrow (1 + \#Rnd(0.1)) \times IBeliefCost$

      $FeelGuilty \leftarrow \min\{(1 + \#Rnd(0.1)) \times FeelGuilty, 1\}$

    **else**

      $FeelGuilty \leftarrow (1 - \#Rnd(0.1)) \times FeelGuilty$

      **foreach** *Violation level* $< Cheat$ **do**

        $IBeliefCost \leftarrow (1 - \#Rnd(0.1)) \times IBeliefCost$

        Change the internal belief's level by $\#Rnd(MaxSh)$

      **end**

    **end**

  **end**

**end**

/* Internal beliefs are modified based on the fairness calculated by Equation 6.14. */

**foreach** *Violation level* **do**

  **if** $\Big( (|Dissonance(Fair)| < DissonThresh)$ **and** $\big(|Dissonance(Fair)| < (|(Belief - Rule)| \times MaxShift)\big)\Big)$ **then** Change the internal belief's level by $\#Rnd(MaxSh)$

**end**

$PropCheaters \leftarrow \dfrac{FriendCheaters}{CountFriends}$

/* Agent justifies the violation based on the cheaters observed. */

**if** $PropCheaters > JustifThresh$ **then**

/* Agent modifies costs associated with his action. */

$MViolation \leftarrow \frac{\sum_{\forall FriendCheaters} Violation_i}{CountFriendCheaters}$

**foreach** *Violation level* $< MViolation$ **do**

Change the internal belief's cost of different violation levels by $\#Rnd(MaxSh \times PropCheaters)$

**end**

**end**

**if** $Experience > 3$ **then**

/* Updating role and making decisions on private trade. */

**if** $Dissonance(Fair) < -DissonThresh$ **then**

/* Agent stops collaboration in monitoring. */

$K \leftarrow No$

**if** $\Big((Fair < thresh)$ ***or*** $(\frac{No.\ PrivateTraderFriends}{No.\ Friends} < JustifThresh)\Big)$ **then**

/* Agent decides to perform private trade. */

$PrivateTrade \leftarrow OK$

**end**

**end**

/* Agent voluntarily collaborates in monitoring. */

**if** $Dissonance(Fair) > DissonThresh$ **then** $K \leftarrow Yes$

**end**

**if** $\Big($*Private trade is recently permitted* ***and*** $(\#Rnd(1) \leq LeaveThresh)\Big)$ **then** Leave the organisation

**if** *Desperate* **then**

**foreach** *Violation level* **do**

/* Punishment of internal beliefs decreases significantly */

Change the costs of internal belief violations by $\#Rnd(MaxSh \times 3)$

**end**

**end**

/* Agent ($I$) increases the weight of manager and friends. */

$W_{Ij} \leftarrow W_{Ij} \times (1 + \#Rnd(FriendIncrease))\ \forall_{j \in frinds}$

$W_{IManager} \leftarrow W_{IManager} \times (1 + \#Rnd(ManagerIncrease))$

**if** *Moving to a new place* **then**

/* Most of the former friends are replaced with new friends */

Replace Mob% of friends with new friends.

**end**

/* Parameters adjustment; */

**if** Not intuitive or Judging **then**

/* The agent's personality is gradually adjusted to better fit the position. */

56 Change the relevant aspect by $\#RndPersAdj$

57 **end**

58 **if** $|PEnvironment| > TolerableEnvironment$ ***and*** $|1-\alpha| > (|PEnvironment| - TolerableEnvironment) \times MaxShift$ **then**

59 Modify $\alpha$ for $\#Rnd(\alpha Adj)$

60 **end**

/* learning; */

61 Learn system's characteristics and norms using Equations 6.13 and 6.6, respectively. Learn monitoring strength using Equations 6.10, 6.11, and 6.9.

62 **if** $Experience > 3$ **then**

/* Reporting observed violations; */

63 **if** *K* = *Yes* **then**

/* The agent reports some of the cheaters observed. */

64 Agent reports connections who impose more costs on the organisation than his tolerance calculated by Equation 6.16.

65 **end**

66 **end**

/* Agent may die based on the Equation 7.2. */

67 $Experience \leftarrow Experience + 1$

68 **if** $Rand(1) \leq MortalityProbability(Experience + 15)$ **then** Die

mercantile agent either feels guilty, or changes his beliefs. If he feels guilty, he increases his mental punishment and more probably he feels guilty in the future. Otherwise, his mental costs for the violation are reduced. Also, his internal beliefs about the seriousness of such violations are modified, and he feels guilty with a lower probability in the future (line 12-24).

Then a mercantile agent, irrespective of his experience, faces a cognitive dissonance based on the fairness of the system. This cognitive dissonance may incur extra costs for him for following or breaking the rules (because of that, we used the absolute number of $x$, $|x|$). To resolve this, the mercantile agent changes his internal beliefs to feel better about the system and himself (lines 25-27).[6] Furthermore, as a profit-maximising entity, if his proportion of observed violations exceeds a threshold, the mental costs for violating such internal beliefs decrease. This is only applied to costs associated with violation labels that are less than the average of observed violations. Also, the coefficient for this reduction is randomly generated in an interval such that its upper bound ($MaxSh$) decreases, based on

[6]When we say it changes by $x$, we mean $1 + x$ or $1 - x$ based on the context.

the frequency of cheating ($MaxSh \times PropCheaters$, lines 28-34).

Furthermore, more experienced mercantile agents decide on their participation in monitoring by considering cognitive dissonance incurred for their perception of fairness. They also decide on performing private trade with respect to the perceived fairness and their friends who perform such trades (lines 35-43). Lines 44-49 model the consequences of permitting private trade. As stated earlier, once private trade is permitted, a drop in trade is evident for three consecutive years (see Section 2.3.3). In our model, each mercantile agent has a threshold by which he decides to leave the organisation (line 44). We also know that after some years, mercantile agents in the EIC faced financial troubles. In other words, after 100 iterations (years after the company's establishment), mercantile agents were faced with a decrease in wages and a drop in private trade's revenue such that they were desperate to pay for their living costs. As a consequence, costs associated with violating the internal beliefs decrease (lines 45-49).

**Algorithm 7.4:** Manager's algorithm

```
/* Parameters adjustment;                                                */
if Not enough thinking or sensing then
    /* Agent adjusts personality to better fit the position.             */
    Change the relevant aspect for #RndPersAdj
end
/* Manager reports (and eventually punishes) a number of employees who
   impose more costs to the organisation than his tolerance calculated by
   Equation 6.17.  We call the number TolPunish.                         */
PotPunish ← reported employees with violations more than TolPunish
if The number of members of PotPunish > MaxPunish then
    /* The manager has a limit for punishing called MaxPunish.           */
    Punish MaxPunish of PotPunish with the most violation
else
    Punish all PotPunish members.
end
/* Agent may die based on the Equation 7.2.                              */
Experience ← Experience + 1
if Rand(1) ≤ MortalityProbability(Experience + 15) then Die
```

Also, the mercantile agent increases the weight of social bonds with his associated agents (lines 50-51). The majority of a mobile mercantile agent's work friends (e.g. Julfans) are replaced (lines 52-54). His personality is also gradually adjusted to his role (lines 55-57). If the system has an environment more different than what a mercantile agent expects, he modifies his discount factor — a discount factor impacts an agent's perception of the net present value of money (i.e. $\alpha$, lines 58-60). He learns system characteristics, monitoring strength, and social norms using Equations 6.6, 6.10, 6.11, 6.9, and 6.13 (line 61). If the mercantile agent has enough experience and has already decided to collaborate in monitoring, he helps the system to identify violators, based on his interpretation of a fair action (line 62-66). Finally, the mercantile agent increases his experience and dies with a probability governed by Equation 7.2 (lines 67-68).

**Algorithm 7.4** shows the procedures associated with managers (i.e. monitoring agents). First, the personality of a manager is gradually modified, based on his role (lines 1-3). He creates a set that consists of reported violators with unacceptable violations (i.e. he tolerates violations to some extent, line 4). Note that the manager reports and punishes a certain number of violators. If the number of violators exceeds a certain number, he punishes the worst violators (lines 5-6). Otherwise, all the violators are punished (lines 7-9). Finally, his experience and age increase, and he may die (lines 10-11).

**Algorithm 7.5:** Meta algorithm

```
/* Intialise the system starting with iteration ← 0.                        */
/* Define a symmetric organisationsl fuzzy number for violation labels,
   assign random system parameters to environment based on the
   environmental characteristics.                                            */
Create 500 new agents with status ← new, random personality aspects, and random parameters
Assign appropriate roles (i.e. mercantile, managers, and directors) to created agents
Find MaxFriends × Extraverted number of friends
/* Call algorithms in an appropriate sequence.                               */
repeat
    Run Algorithm 7.1
    Run Algorithm 7.3
    Run Algorithm 7.4
    if iteration = 70 then
        Update directors with NReplace of managers
        if majority (Major) of new agents support private trade then
            Legalise private trade and reduce Wages
        end
        if Private trade is legalised and iteration = 100 then  Mercantile agents feel desperate for
          basic living costs
    end
    iteration ← iteration + 1
until iteration = 250
```

**Algorithm 7.5** shows how the simulation is initialised, the earlier procedures are executed, and the system's characteristics are modified. In iteration 0, the system is initialised by creating 500 new agents with random parameters (line 1). The roles are assigned to created agents (about 2% directors, 5% managers, and the rest mercantile agents), and they have 0 years of experience (lines 2). Finally, these agents make friends, based on the Extraverted aspect of their personality, coupled with the maximum number of friends ($MaxFriends \times Exteraverted$, line 3). The rest of the algorithm is repeated until the stop condition is met (lines 4-16).

In each iteration, the simulation begins with the societal algorithm (i.e. Algorithm 7.1, line 5). Then the algorithm associated with the mercantile agents is run (i.e. Algorithm 7.3). Note that the Algorithm 7.2 associated with the newly recruited mercantile agents is called Algorithm 7.3 (line 6). Finally, the manager's decisions are made using Algorithm 7.4 (line 7). When the simulation reaches the year that managers are promoted to directors (i.e. consequences of the English Civil War, iteration 70), a decision about permitting private trade is made (lines 8-12).

Furthermore, 30 years after granting permission for private trade (if it happens), the mercantile agents face financial issues and feel financially desperate. This phenomenon was observed in the EIC after a decrease in wages, coupled with fewer opportunities for private trade because of the establishment of the New East India Company. Note that for simplicity, when we modelled the phenomenon, we did not consider a gradual decrease (line 13). Finally, the simulation iteration increases by one, and the stop condition is checked (lines 15-16).

### 7.3.3 Simulation parameters

In this subsection, we state the important parameters employed in the simulation (see Table 7.2), along with the reasons for choosing specific values for them. Note that we used 250 iterations to reflect the longevity of the EIC (it was active with some interruptions and changes in power from 1600 to 1850). Each iteration thus models one year of activities in these systems. In Table 7.2, column 'Name' indicates the name of parameters, column 'Comment' shows additional information if required, column 'Distribution' indicates the probability distribution of these parameters, and column 'Values' indicates the values of parameters estimated for the two historical long-distance trading societies. Note that these parameters can be easily revised to reflect other societies.

Table 7.2: Parameters associated with the model

| Name | Comment | Distribution | Values |
|---|---|---|---|
| Personality aspect | Extraversion<br>iNtuitive<br>Thinking<br>Judging | $Beta(a, b)^2$ | $(1.13, 1)$<br>$(1.36, 1)$<br>$(1.13, 1)$<br>$(1.28, 1)$ |
| Modifier for personality | Based on the roles | $Uniform^3$ | $(0, 0.02)$ |
| Rule-understanding[1] $(SD_{Rule})$ | Trained<br>Untrained | $Uniform$ | $(0, 0.02)$<br>$(0, 0.05)$ |
| Perceived Norm[1] | | $Uniform$ | $(0, 0.05)$ |
| Internal belief | $Modifier \times SD_{Rule}$ | Constant | 1.02 |
| Fairness | Unfair : Fair | Constant | $-0.4 : 0.6$ |
| Environment | Favourable<br>Severe | $Uniform$ | $(0.2, 0.6)$<br>$(-0.6, -0.2)$ |
| Perception of environment and fairness of system | Trained<br>Untrained | $Normal\ (\mu, \sigma)$<br>$Uniform$ | $(x, 0.4)$<br>$(-1, 1)$ |
| Rule monitoring | The lower bound $(lb)$<br>The learnt probabilities | $Uniform$ | $(0, 1)$<br>$(lb, 1)$ |
| Norm monitoring strength | | $Uniform$ | $(0, 1)$ |
| Thresholds | Dissonance<br>Environment<br>Feeling guilty<br>Discount factor<br>Fired agents | $Uniform$ | $(0, 1)$<br>$(0, 1)$<br>$(0, 1)$<br>$(0, 1)$<br>$(0, 0.3)$ |
| Profit | General profit<br>Skill-related profit | $Uniform$ | $(0, 0.1)$<br>$(0, 0.1)$ |
| Access | Initial | Constant | 1 |
| Minor violation punishment | Probability | $Uniform$ | $(0, 1)$ |
| Costs of lost opportunity per recruit | Hiring<br>Training | Constant[2] | 0.1<br>0.3 |
| Weight of the connections | Manager trained<br>Manager untrained<br>Friends | $Uniform$<br>$Uniform$<br>$Uniform$ | $(0.5, 1)$<br>$(0, 1)$<br>$(0, 1)$ |
| Number of friends | Maximum | Constant | 20 |
| Monitoring $(K)$ | Internalised role | $Uniform$ | $\{0, 1\}^4$ |
| Discount factor for money $(\alpha)$ | All agents | $Normal\ (\mu, \sigma)$ | $(0.9, 0.03)$ |
| Skills | Good apprenticeship<br>Bad apprenticeship | $Uniform$ | $(0.7, 1)$<br>$(0, 0.5)$ |
| Modifier for internal beliefs | Cognitive dissonance | $Uniform$ | $(0, 0.05)$ |
| Modifier for mental costs | Cognitive dissonance | $Uniform$ | $(0, 0.1)$ |

Continued on next page

**Table 7.2 — continued from previous page**

| Name | Comment | Distribution | Values |
|---|---|---|---|
| Modifier for weights of connections | Friendship<br>Managers in a fair system<br>Managers in an unfair system | $Uniform$ | $(0, 0.2)$<br>$(0, 0.05)$<br>$(0, 0.01)$ |
| Permission for private trade | Per cent of joined managers who agreed to change | Constant | 70% |
| Mental costs | Minor violation $C_{minor}$<br>Mild violation $C_{mild}$<br>Serious violation $C_{serious}$ | $Uniform$ | $(0, 0.25)$<br>$(C_{minor}, 0.5)$<br>$(C_{mild}, 1)$ |

[1] We only state the standard deviation (i.e. $\sigma$).

[2] Stated in this subsection.

[3] $Uniform(a, b)$ indicates generating random real numbers with the same chance from interval $(a, b)$.

[4] $Uniform\{a, b\}$ indicates generating random integers with the same chance between a and b (including them).

**Personality**: The first parameter we investigate is the personality of agents. To model these merchandising companies, we used personalities associated with entrepreneurs. A reason for differences between personality type frequencies for various jobs is the notion of "attraction-selection-attrition" (Schneider, 1987).

That idea initiated different studies, for instance, Zhao et al. (2010) conducted a meta-review on entrepreneurs' personalities (see Table 7.3). As can be seen, an Extraverted-iNtuitive-Thinking-Judging (ENTJ) personality more probably chooses this job. However, it does not mean this personality is the only personality who chooses the job (the correlations are weak). The estimated personality frequencies provided by the Myers & Briggs Foundation emphasises the impact of personality on job preference (this frequency belongs to a general context; see 'General population' in Table 7.4).[7]

We use a Beta probability distribution to model this. The parameters used for Beta distribution (presented in Table 7.2)[8] produce a relatively similar proportion of personality for mercantile agents. To estimate the required parameters to generate a ratio $(x)$ of a certain aspect, we used the following:

$$I_{0.5}(a, 1) = x \implies a = 1 + log(x)/log(0.5), \tag{7.1}$$

where $I_y(a, b)$ is the cumulative probability distribution function of $Beta(a, b)$ at point $y$.

**Modifier for personality:** To model the gradual change in the relevant aspects of agents' personalities, we considered a random change by a maximum of $2\%$. As stated in Chapter

[7]Retrieved from `https://www.myersbriggs.org/my-mbti-personality-type/my-mbti-results/how-frequent-is-my-type.htm`.

[8]See Chapter 4, footnote 8, for more explanation.

Table 7.3: Tendency of personalities to be entrepreneurs and the impact of them on an organisation's performance

| **Big Five**[1] | **MBTI**[2] | **Intention**[3] | **Performance**[4] |
|---|---|---|---|
| *E* | *E* | 0.11 | 0.05 |
| *O* | *N* | 0.22 | 0.21 |
| *A* | *F* | -0.09 | -0.06 |
| *C* | *J* | 0.18 | 0.19 |

[1]**E:** extraversion, **O:** openness to experience, **A:** agreeableness, **C:** conscientiousness.

[2]**E-I:** Extravert-Introvert dimensions, **S-N:** Sensing-iNtuitive dimensions, **T-F:** Thinking-Feeling dimensions, **J-P:** Judging-Perceiving dimensions. Note that initials show the aspect used — for instance, E is the degree to which the person has the Extravert aspect (see Figure 6.4). Note that as with their earlier study, we assume that results of different tests are interchangeable (see Zhao & Seibert, 2006, Appendix).

[3]It shows the correlation between personality and the *intention* of the person to be an entrepreneur.

[3]It shows the correlation between personality and the *performance* of the person as an entrepreneur.

Table 7.4: Frequency of personalities

| ***Aspect*** | | Extraverted | iNtuitive | Thinking | Judging |
|---|---|---|---|---|---|
| ***Estimated Frequency (%)*** | General population[1] | 49.3 | 26.7 | 40.2 | 54.1 |
| | Entrepreneur[2] | 55.5 | 61 | 54.5 | 59 |
| | Managers[3] | 54.7 | 43 | 79.7 | 65.8 |

[1]Presented by Myers & Briggs Foundation.

[2]Estimated based on the entrepreneurs' tendencies.

[3]Estimated based on Gentry et al. (2007).

6, an agent's personality is modified over time. Here we consider a gradual change such that it becomes more similar to the average personality of the agent's colleagues. To do so, we use two parameters, namely the extent to which the personality should be adjusted and the maximum change based on the agent's roles. A mercantile agent's personality changes to iNtuitive and Judging if he is Sensing or Perceiving (i.e. it changes towards $50\%$; see Figure 6.4).

Furthermore, a manager's personality changes to be more Thinking and Sensing (see Table 7.4). Here we consider a change in the personality of agents possessing iNtuitive aspects of more than 55% (see Figure 6.4). However, Feeling agents' personalities with a score more than 60% (i.e. less than 40% Thinking, see Figure 6.4) change because of the strong correlation.

**Rule-understanding, perceived norms, and internal beliefs:** We used fuzzy numbers to model rule-understanding, perceived norms, and the internal beliefs for violations. This way, we model the uncertainty about attributing labels to violations. As shown in Figure 7.1, to define such a set of beliefs, we need 4 limiting points in addition to 0 and 1 (i.e. $a, b, c$ and $d$ in Figure 7.1). We used a normal distribution to generate these points for each agent (see Figure 7.2). As depicted in Figure 7.1, the averages used for normal number generators for limiting points are $0.2, 0.4, 0.6$, and $0.8$, respectively. In what follows, we investigate the *standard deviation* ($SD$ or $\sigma$) used for the normal distributions. Also, Figure 7.2 represents different perceptions of an agent under different circumstances. For instance, a pink plot indicates a trained agent's internal beliefs and an green plot indicates that of an untrained agent.

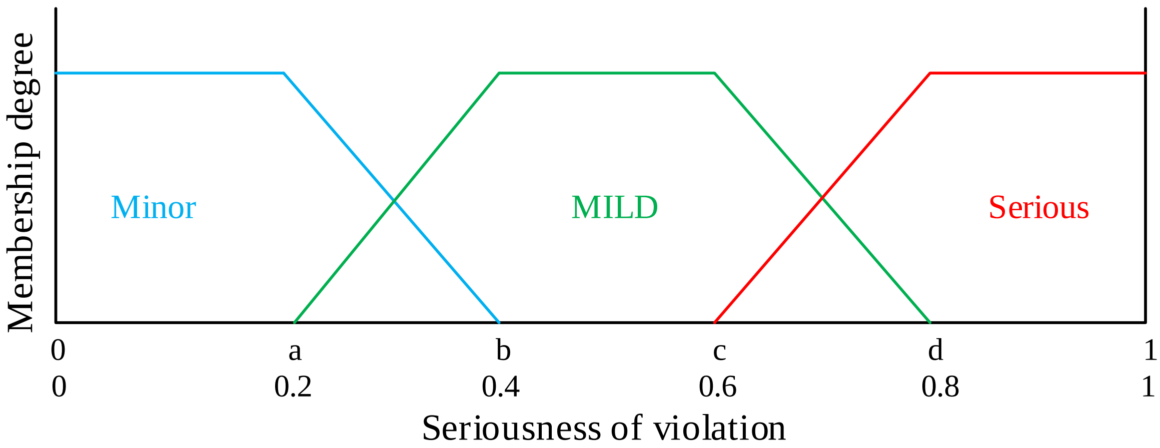


Figure 7.1: An example of rule violation labels

First, we describe a trained agent's **rule-understanding**. Trained agents have a better understanding than their untrained counterparts (i.e. less standard deviation), because trainers have an opportunity to clarify the rules during training. In our simulation, this difference is modelled by using a narrower $SD$ (see 'Rule-understanding' row in Table 7.2). This difference is shown in Figure 7.2 where the blue plot shows a trained agent's rule-understanding, while the red plot indicates that of an untrained agent. Note that this distribution is the same as a trained agent's norm perception (see Table 7.2, rows 'Perceived norm' and 'Rule-understanding').

For the **perceived norms**, each person thinks the society expects him to follow the rule, albeit this perception has the same $SD$ as the one associated with untrained agents (red plot in Figure 7.2). In other words, because the agent is mostly in contact with his trainer during training, his perception of norm is not corrected.

Finally, the agent's **internal beliefs** form with slightly more $SD$ than that of the rule-understanding (2% more). This is caused by differences between the extent to which an

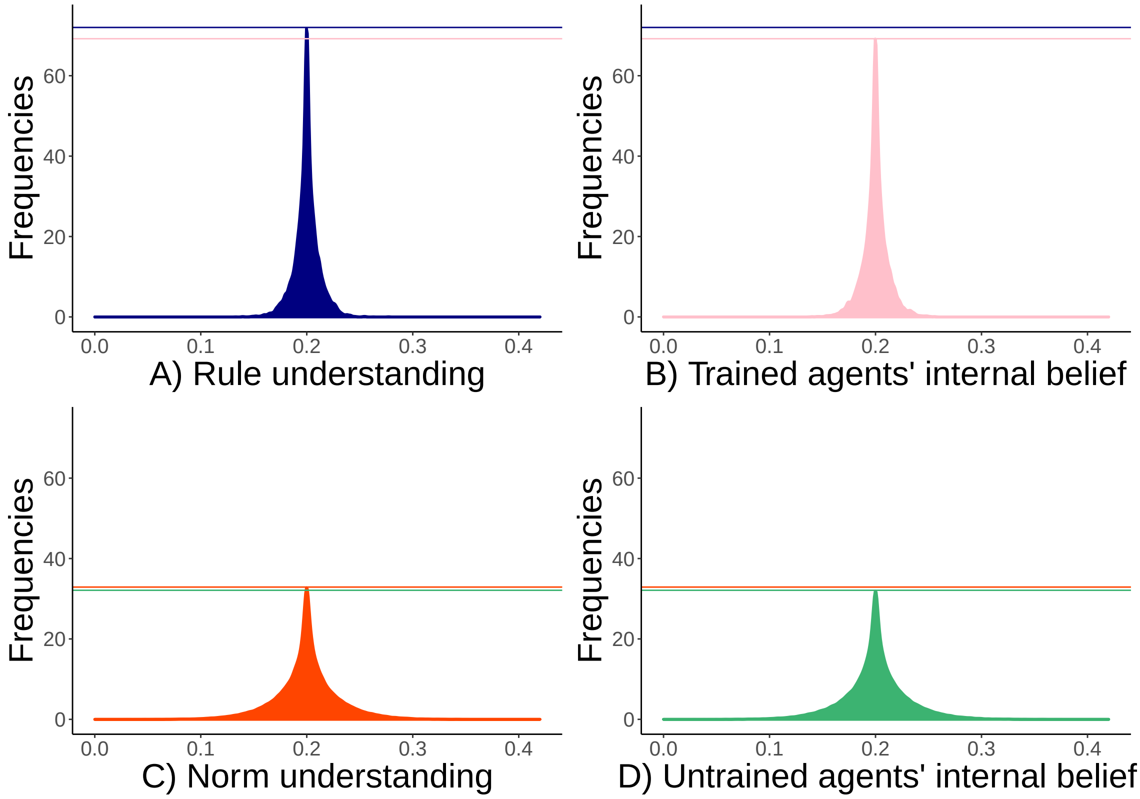


Figure 7.2: Probability density function for different perceptions, when the limiting point for seriousness equals 0.2. Coloured horizontal lines show peaks of each distribution given their associated colours.

agent is convinced about the rule (i.e. his internal belief) versus his understanding of the rule. Figure 7.2 indicates such a difference. As can be seen in this figure, the internal beliefs and rule-understandings of trained agents are almost distributed the same (pink plot versus the blue plot). The same applies for those of untrained agents (green plot versus red plot).

**Fairness:** Note that as stated in Chapter 6 (see Table 6.2) and Section 7.3.1, Julfa had fairer institutions than the EIC. We set system fairness for fair and unfair societies as 0.6 and -0.4, respectively. Because of the following, we believe that neither of these two societies was completely fair/unfair:

- Some evidence from the EIC, such as the availability of letters sent to the nodes for declaring the reasons for firing agents (i.e. justifying the action), indicates some efforts towards interactional fairness.
- Although the EIC asked for signed bonds from recruits, there is no evidence of asking for paying those bonds upon fault (i.e. they did not ask the guarantor to pay money for the agent's wrongdoings).

- In Julfa, inheritance rules (controlling power of elder family member) and power of prominent families are reasons we did not consider the society as completely fair.

**Environment and mortality rate**: To model the influence of environmental circumstances on mortality rates, we extended Equation 4.2. This helps us to test the impact of different environmental circumstances and mortality rates on agents' behaviour (in modelling favourable and unfavourable environments).

To obtain a generalised function for varying the environmental circumstances, we used an additional parameter called $SystemEnvironment$. Also, we normalised the numbers of Table 7.2 to fall between 0 and 1.[9] We also used the following assumptions to model the impact of the new parameter:

- The environment of Julfa has a $SystemEnvironment$ equal to 0.7 (average of favourable environments modelled).
- The environment of the EIC has a $SystemEnvironment$ equal to 0.3 (average of severe environments modelled).
- In a completely unfavourable environment, most people die after they are born (i.e. $92\%$).
- For a completely favourable environment, in the early years, the survival rate is very high ($\approx 1$), but it decreases after the age of 40.

Note that the last two assumptions indicate hypothetical situations we use to define extreme points. However, in our modelling, we do not generate numbers near these extreme points. Equation 7.2 is the function obtained using the aforementioned assumptions. Also, to clarify the impact of the environment and age on life expectancy and the mortality rate, we present some of these numbers in Table 7.5. Note that this equation obtains almost the same equations as Equation 4.2 for 0.7 and 0.3 (low/high mortality rates in Chapter 4).

$$\begin{aligned}&MortalityRate(Age, SystemEnvironment) = \\ &\quad \left(0.001 + 0.00015^{(SystemEnvironment+0.01)}\right)\times \\ &\quad \exp\left(Age \times \left(0.067 - \frac{0.00858}{(0.136 + SystemEnvironment^{3.38})}\right)\right)\end{aligned} \tag{7.2}$$

As can be seen in Table 7.5, for a given age (e.g. 20), the survival rate increases in more favourable environments. However, the mortality rate of elders may be higher (see mortality rates associated with 100 years). Finally, note that the function is an attempt to generalise mortality rates associated with Julfans and EIC members and is pessimistic for the modern world, because of substantial improvements in public health.

[9] To normalise $x \in (-1, 1)$ we use $((x+1)/2)$. For instance, $0.4$ and $-0.4$ obtains $0.7$ and $0.3$, respectively.

Table 7.5: Some instances of the percentage of mortality rates and the survival rate (*Mortality rate*$||$*survival rate*).

| | | ***Environment*** | | | | |
|---|---|---|---|---|---|---|
| | | **0** | **0.25** | **0.5** | **0.75** | **1** |
| ***Age*** | **0** | $92\|\|8$ | $10\|\|90$ | $1\|\|99$ | $\approx 0\|\|100$ | $\approx 0\|\|100$ |
| | **20** | $97\|\|0$ | $12\|\|9$ | $2\|\|70$ | $1\|\|92$ | $\approx 0\|\|95$ |
| | **40** | $100\|\|0$ | $14\|\|1$ | $4\|\|37$ | $2\|\|74$ | $1\|\|82$ |
| | **60** | $100\|\|0$ | $16\|\|0$ | $7\|\|12$ | $5\|\|40$ | $4\|\|50$ |
| | **80** | $100\|\|0$ | $18\|\|0$ | $13\|\|1$ | $13\|\|7$ | $13\|\|9$ |
| | **100** | $100\|\|0$ | $21\|\|0$ | $24\|\|0$ | $35\|\|0$ | $44\|\|0$ |

**Perceived characteristics:** Trained recruits have a better understanding of the system's characteristics (i.e. the system's fairness and environment), for their experience. However, this experience helps the agents to learn the parameters with significant deviations. Note that during the apprenticeship, agents work in a controlled situation, where a master accepts to train them (i.e. the environment is favourable). Also, during the apprenticeship the income is not an issue — i.e. trainees and inexperienced agents do not expect significant wages, so they do not have a good understanding of the system's distributive fairness. We consider standard deviations about 0.4 for learning the parameters. Note that an inexperienced agent has a completely random understanding of system characteristics.

**Rule and norm monitoring:** As stated in Chapter 6, the agents believe the more serious violations are more likely to be punished. Furthermore, since the agents use a linear function to model this phenomenon, they use a Uniform probability distribution that is identified by its lower and upper bounds. For the upper bound, they use 1 (i.e. completely violating the rule such as stealing all the money). However, for the lower bound they are unsure about the tolerance of peers and managers; hence, each agent uses a number between 0 and 1 (i.e. the lower bound has a continuous Uniform probability distribution in (0,1)). For the strength of the norm monitoring (i.e. how often agents punish each other), agents have a random understanding. However, these parameters will be updated by learning them over time.

**Thresholds:** These are the numbers that reflect an agent's tolerance of different aspects and characteristics of the system. All these thresholds are generated in a completely random manner except for firing. For the proportion of fired agents, we assume that a manager would not fire all the cheaters, and at most, they would fire 30% of their employees. This 30% was inspired by checking the model and the observation that initially around 30% of agents cheated (these numbers are presented in the next section).

**Profit:** In our modelling, we consider two kinds of potential profits. The first kind is general profit that is independent of the agent's skills and negotiation. Another aspect of profit is the skill-related profit that is impacted by agents' negotiation and skills. For both of these profits, we assume that a society can make up to 10% profit from the initial capital (i.e. maximum of 20% in total).

**Punishment moderators (i.e. access and minor violation punishment):** As stated earlier, the relative access to a company's resources (the access of the agent to the allocated company's capital in comparison with his own capital) has an impact on the temptation of the agent to cheat. In the model, we assume this access does not impact the temptation of the agent (i.e. it is 1). Note that in an unfair system, no profits are shared, and this access increases over time. On the other hand, sharing profits in a fair system moderates this access by increasing agents' capital as a ratio of profits made for the company. We have assumed that sharing substantial profits (e.g. Julfa) controls this access. In the EIC, access to the company's resources increases gradually, because the agent's profits using company capital are much more than what he earns, based on his limited capital. We have assumed that in an unfair society, the agent's access increases as 30% of profit is made by him.

**Minor violation punishment**: In the model, we assume the agents have doubts about being fired for minor violations. This doubt is modelled by using uniform random numbers.

**Costs of lost opportunity:** To calculate these costs, we employed the values presented in Table 7.2. Note that we moderate these numbers with respect to the budget associated with the training. Overall, costs of training are assumed to be in the form of losing some profits that could be made by providing the same capital to a trained agent. However, the associated capital is limited (i.e. 5% of a recruit capital), because the training aims to emulate a trading situation. We also assume that the capital used to budget recruits could alternatively be used for trading by *fully skilled* agents. This way (i.e. considering a strict alternative), we also model the failure of some trainees in attaining skill. Furthermore, we considered 30% lost profit (i.e. we assumed some profits would be attained) to reflect the following:

- As stated in Chapter 5, the apprentices have some abilities that can be used by masters at the beginning of the programme.
- The apprentices also attain some valuable skills after some training.

Costs of replacing agents also include:

- Lost profit incurred because of deceased agents (it is considered in the model by calculating the ROR associated with agents who are alive).
- The cost of transporting new recruits (assumed to be 10% of the initial capital allocated to them).

The latter also includes the cost of mortality. Note that in societies with a lower mortality rate, this cost is lower.

**Weight of the connections:** To model all the possibilities for new links, such as knowing one another in advance, we used a random number (0,1) for new friendship links. For links between mercantile agents and middle managers, we considered two different cases. If the recruits are untrained, then the situation is the same as new friendship links. However, the trained agents have stronger connections with their managers because:

- Trained agents would have closely worked with the managers for quite some time.
- The relationship should have been good enough to persuade the manager to hire the apprentice.

**The number of friends:** This number is inspired by Dunbar's number. Zhou et al. (2005) stated that humans have preferred group sizes for different functions, such as personal advice and sympathy groups (the persons with whom one has a stronger connection). We used the maximum of preferred size associated with a sympathy group that is reported to vary between 12-20 (i.e. 20).

**Monitoring:** In the model, a recruit may voluntarily decide to participate in monitoring — we use a random Boolean generator to represent this. However, as stated earlier, these agents may change their decisions based on the situation.

**Discount factor:** Discount factor is obtained, based on the Julfan's customary interest rates (Herzig, 1991). The norm for the interest rate in Julfa was about 10% per annum. This number shows how Julfans mentally calculated the net present value of money.

**Skills:** In Chapter 5, we stated the importance of apprenticeship programmes and their impact on traders' skills. In this model, we consider the system possessing apprenticeship programme benefits from enough high-skilled agents — i.e. they can perform relatively complicated calculations in negotiations, and are skilled in identifying high-quality items. However, in an organisation lacking such a programme, agents are mostly low-skilled.

**Modifier for internal beliefs:** We parametrise agents' modification of internal beliefs in a gradual manner. The agent randomly changes his internal beliefs by a maximum of $5\%$ of its initial point to resolve cognitive dissonance for fairness.

**Modifier for mental costs:** When an agent violates a rule, he randomly discounts the costs associated with such an action by a maximum of $10\%$ of its initial point — on average the initial costs decreases by $5\%$ of its initial point.

**Modifier for weights of connections**: For changes in weights of connections, we increase the connection's weight as a proportion of the current weight (i.e. $weight \times x$). Now we state the proportion of changes (i.e. $x$) case by case. For friendship, due to the ongoing interactions, the weight increases faster. We used a continuous uniform probability function in (0, 0.2) for this purpose. To increase the weight of the connection between managers and mercantile agents, we used a continuous uniform probability function in (0, 0.05). The weight of connections between managers and directors increases the same in a fair system. However, in an unfair system, because of blaming directors for using such institutions, managers do not have an emotional attachment to them. We used a continuous uniform probability function in (0, 0.01) to parametrise such an idea.

**Permission for private trade:** In this simulation, we assume that permission is granted if more than 70% of the most experienced managers agree to such a decision — more than or equal to 8 out of 11 of them. We used this relatively high proportion to model the impact of their negotiation power with other directors (i.e. a strong attitude towards such a practice should be introduced to the board of directors).

**Mental costs:** These costs are punishments associated with perceived norms and internal beliefs. Overall, the agent uses an increasing function with different slopes for each seriousness label (i.e. costs of serious violations increases faster than mild violations). These slopes are randomly generated from intervals defined with respect to the seriousness of the violation. In this model, we considered different intervals for these costs to indicate how an agent differentiates between violations, such as stealing and being lazy at work. The intervals are as follows:

$$\begin{cases} C_{Minor} & Uniform(0, 0.25) \\ C_{Mild} & Uniform(C_{Minor}, 0.5) \\ C_{Serious} & Uniform(C_{Mild}, 1) \end{cases} \tag{7.3}$$

Furthermore, we parametrise the agents' learning as follows. Agents discount past information using a weight of 30% for the past, and a weight of 70% for recent information. This reflects the importance of recent information for agents, because they are not sure about the stability of the system's behaviour in the long run.

Having presented the simulation's assumptions and parameters, in the next section, we present and describe the simulation results.

## 7.4 Simulation results

In this section, we describe the simulation results considering 16 different combinations of four characteristics, namely:

- Mobility of agents;

- Environmental characteristics of the system;
- Apprenticeship programme;
- Fairness of the system.

We utilised *NetLogo* to perform our simulation (Wilensky, 1999). We also used 30 different runs for each set-up and then averaged their results. Table 7.6 indicates the characteristics for the 16 simulated societies and societies they represent. The set-ups (i.e. societies) are identified by the first letter of the characteristics, namely *M, E, A,* and *F* that are representatives of the **m**obility of agents across trading nodes (M), favourable **e**nvironmental circumstances (E), providing an **a**pprenticeship programme (A), and **f**airness of the institutions (F), respectively. We used a Boolean index to indicate whether such an attribute is included (i.e. 1) or not (i.e. 0). Likewise, in the table, a tick indicates that the society possesses such an attribute, and a cross indicates the society does not possess such an attribute. In this table, we gradually change characteristics of the EIC ($M_0E_0A_0F_0$) to get closer to Julfa ($M_1E_1A_1F_1$), to examine their effects on the success of these societies.

Table 7.6: System specification based on different characteristics

| Characteristics | $M_0E_0A_0F_0$ (EIC) | $M_0E_0A_0F_1$ | $M_0E_0A_1F_0$ | $M_0E_0A_1F_1$ | $M_0E_1A_0F_0$ | $M_0E_1A_0F_1$ | $M_0E_1A_1F_0$ | $M_0E_1A_1F_1$ | $M_1E_0A_0F_0$ | $M_1E_0A_0F_1$ | $M_1E_0A_1F_0$ | $M_1E_0A_1F_1$ | $M_1E_1A_0F_0$ | $M_1E_1A_0F_1$ | $M_1E_1A_1F_0$ | $M_1E_1A_1F_1$ (Julfa) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mobility | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Environment[1] | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ |
| Apprenticeship | ✗ | ✗ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Fairness | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ | ✗ | ✓ |

[1]For brevity, we used environment instead of favourable environmental circumstances.

First, we state the results associated with all 16 societies; then we investigate detailed results for the EIC and Julfa, and their relevance to historical information available about them.

### 7.4.1 General simulation results

#### 7.4.1.1 Bureaucratic rules (private trade)

As mentioned earlier, societies are classified based on characteristics possessed. As a result, in each row of the figures (which indicates a characteristic), we have complementary clusters divided, based on the lacking/having a characteristic; hence, each has half of the line plots (i.e. 8). Note that the representatives for the EIC ($M_0E_0A_0F_0$) and Julfa ($M_1E_1A_1F_1$) are always placed in the left column and the right column, respectively. Also, we distinguish these two societies (i.e. Julfa and the EIC) with thicker lines in the following plots. The considered intervals in the model and their limiting points are depicted in Figure 7.3. These points represent the iteration that permissions for private trade might be granted (70), and the iteration that market saturation might happen for the formation of the New East India Company and its aggregation with the EIC (100).

Erikson (2014) suggests that a reason for the longevity of the EIC in comparison to rival companies such as the Dutch East India Company (VOC) was permitting private trade. She suggests that private trade was a motive for the agents to collect information about trade opportunities and that was a part of invaluable information conveyed to the directors.[10] However, we should note that fair institutions such as bilateral commenda (i.e. sharing profit along with the opportunity of investment, see Chapter 2) provide motivation, not only for collecting information, but also for sharing information deliberately and more accurately.

(e.g., Hejeebu, 1998)

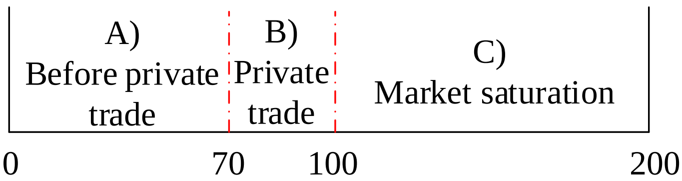


Figure 7.3: The three intervals and limiting points associated with changes to bureaucratic rules

Now we state the impact of the same characteristics on the tendency to perform private trade during different intervals (A, B, and C). Figures 7.4a-7.4d and 7.5a-7.5d present how different characteristics change the inclination towards performing private trade.

Note that after granting permission for private trade, these plots indicate the popularity of violating prohibitions that seems harmless for the company (bureaucratic rules). In these plots, the y-axis is the percentage of agents who performed private trade. As can be seen in Figure 7.5, the most influential characteristics are fair institutions (Figure 7.5c versus 7.5d) and having apprenticeship programmes (Figure 7.5a versus 7.5b). These two, especially the combination of them (i.e. $A_1F_1$ societies), significantly reduce the number of private traders.

Now we statistically compare results presented in Figures 7.4 and 7.5. We employed the Kendall's test[11] to identify the correlation among the characteristics and inclination to

[10] Erikson's (2014) arguments are based on some correspondents and ship routes.

[11] We used non-parametric tests, because the non-homogeneity of variances was identified by the Fligner-Killeen test. We used this test because of the presence of ties.

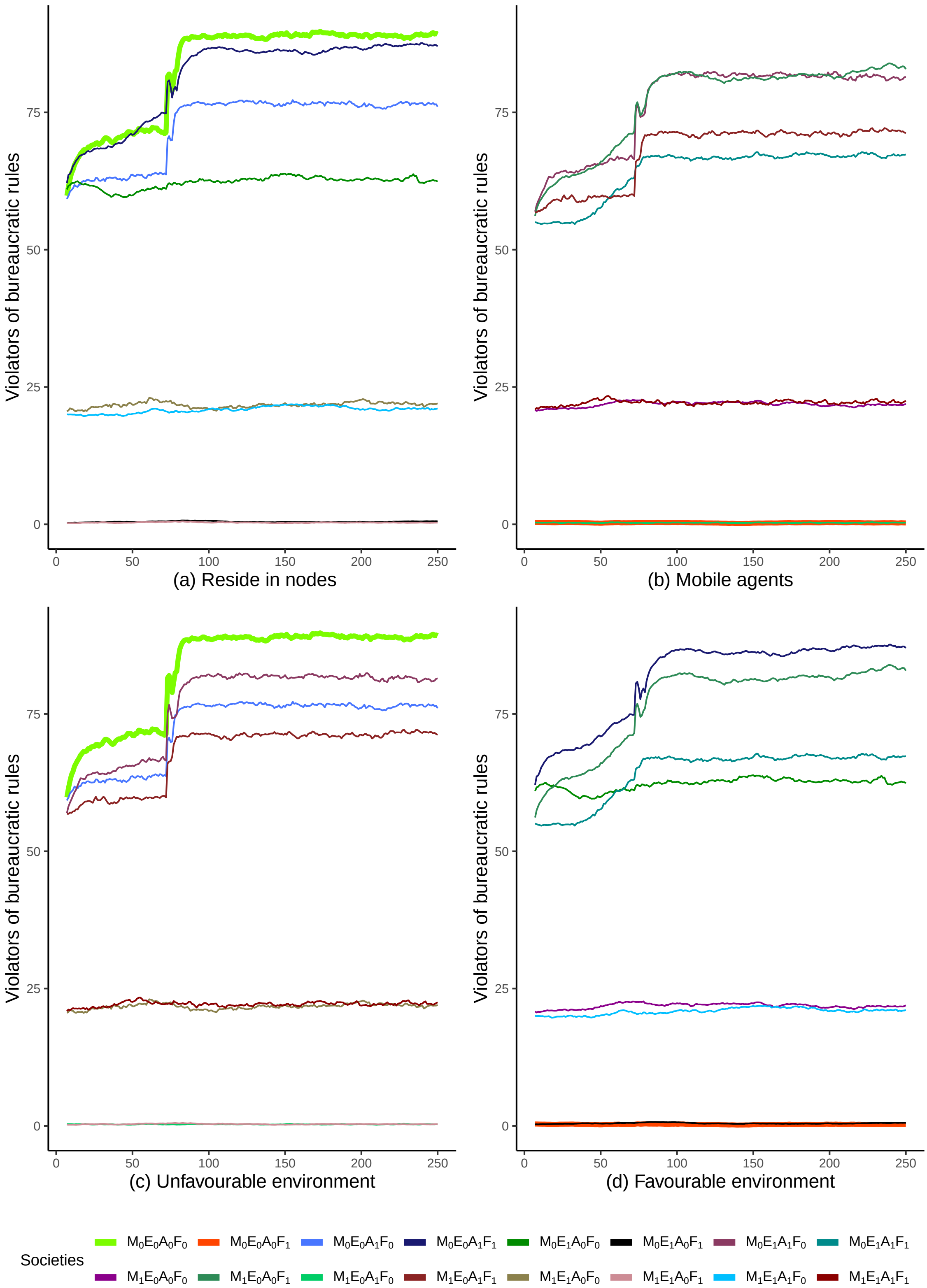


Figure 7.4: Frequency of breaking bureaucratic rules for 16 societies, considering mobility and environment.

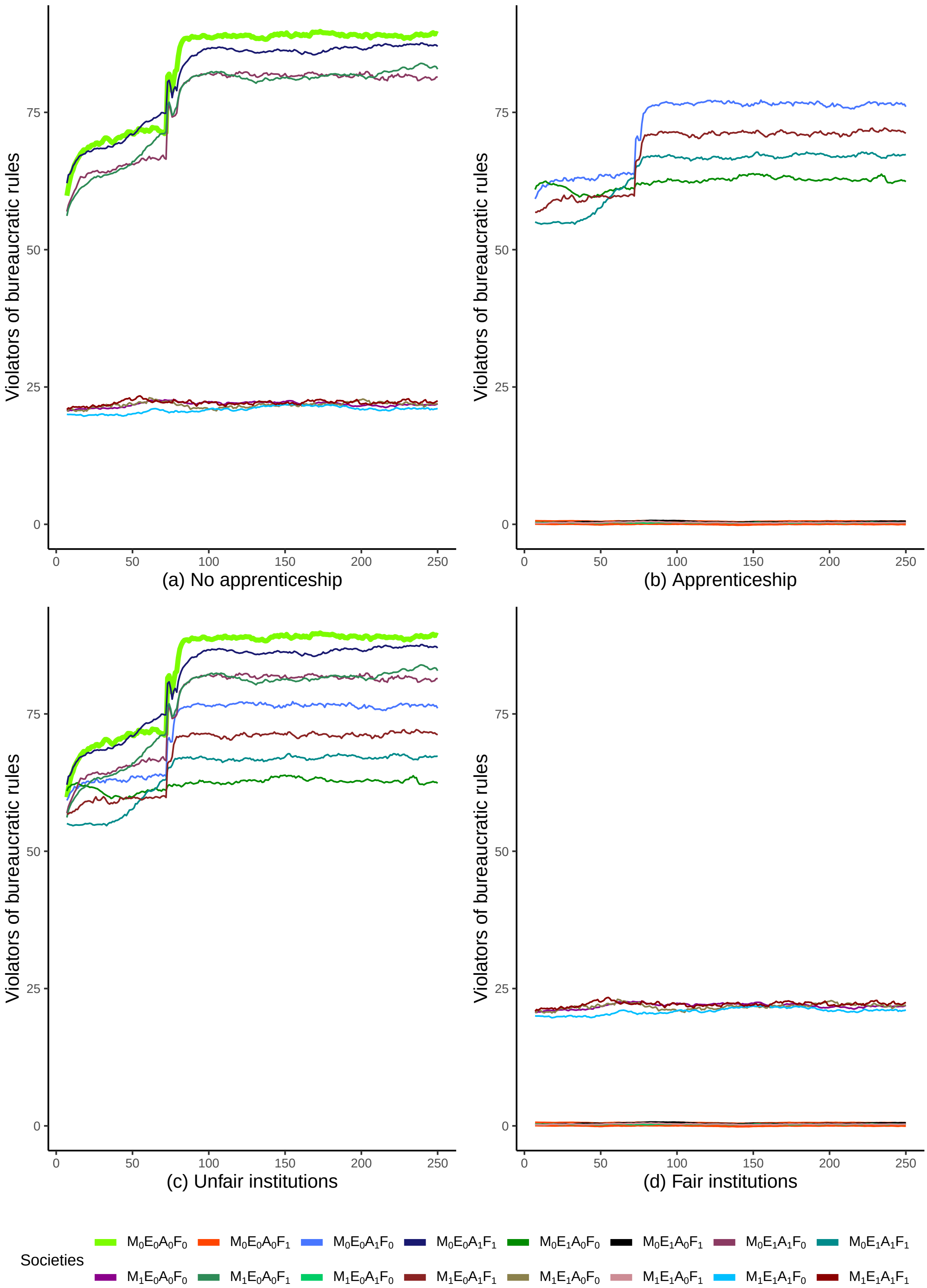


Figure 7.5: Frequency of breaking bureaucratic rules for 16 societies, considering apprenticeship and fairness.

perform the private trade. The results of these tests are as follows:[12]

- The **mobility** of the agents had a negative impact on the inclination towards private trade, with values of $\tau$ varying between $-0.08$ and $-0.05$, that all are weak. The values of $\tau$ associated with intervals *A*, *B*, and *C* are $-0.08$, $-0.04$, and $-0.05$. The $p\text{-}values$ for the aforementioned values of $\tau$ are $\approx 0.001$, $> 0.25$ and $\approx 0.006$, respectively. Note that given these $p\text{-}values$, the obtained correlation for interval *B* is statistically insignificant. Given this, whether or not agents reside in a node does not impact their inclination towards private trade (regardless of other factors).
- The **favourable environment** has a weak negative impact on inclinations towards performing private trade. The values of $\tau$ for intervals *A* and *B* are $-0.04$ with $p\text{-}value > 0.2$ that is insignificant. However, for interval *C* the value of $\tau$ decreases to $-0.06$ with $p\text{-}value \approx 0.0002$. This indicates the environment has a weak influence on the inclination towards performing private trade (i.e. its combination with other characteristic might be important).
- The presence of **apprenticeship** programmes in the system has a weak impact on disinclination towards private trade. The values of $\tau$ associated with intervals *A*, *B*, and *C* are $-0.32$, $-0.34$, and $-0.35$, respectively, and all of them are significant ($p\text{-}value < 0.0001$). The numbers suggest that the disinclination towards private trade is weakly correlated with this characteristic.
- The correlation between **fairness** of the system and the inclination towards performing private trade is strongly negative ($p\text{-}value < 0.0001$). The values of $\tau$ for all intervals are around $-0.71$. Historically, no evidence of a complete lift of prohibition of private trade in Julfa is reported (i.e. there was not a high appetite for private trade in Julfa).

To sum up, the above statistical tests on the values depicted in Figures 7.4a-7.4d and 7.5a-7.5d point out that the most influential characteristics for disinclination towards private trade include the fairness of the system and possessing apprenticeship programmes.

#### 7.4.1.2 Permissions for private trade

Now we state an observation of an increase in the numbers of private traders after year 70 (see Figures 7.4 and 7.5). This is evident among societies with unfair institutions (see Figure

[12]For the strength of coefficients, we have used Dancey and Reidy's (2017, p. 182, Figure 6.7); also see Akoglu (2018, Table 1, for other metrics) interpretations. For absolute values of correlation, zero and one are none and perfect correlations, respectively. Also, the limiting points to identify weak, moderate, and strong correlations are $0.4$ and $0.7$.

7.5c). Note that environmental circumstances in each simulation run are randomly generated and consequently, slightly change agents' behaviour. The proportion of simulation runs under which private trade was permitted is presented in Table 7.7. As can be seen, fair institutions never lead to private trade permission (see Table 7.8).

Table 7.7: Percentage of runs where private trade was permitted (out of 30 runs).

| **Societies** | **Permission granted for private trade** | **EIC** | **Julfa** |
|---|---|---|---|
| $M_0E_0A_0F_0$ | 93% | ✓ | |
| $M_0E_0A_0F_1$ | 0% | | |
| $M_0E_0A_1F_0$ | 57% | | |
| $M_0E_0A_1F_1$ | 0% | | |
| $M_0E_1A_0F_0$ | 57% | | |
| $M_0E_1A_0F_1$ | 0% | | |
| $M_0E_1A_1F_0$ | 3% | | |
| $M_0E_1A_1F_1$ | 0% | | |
| $M_1E_0A_0F_0$ | 80% | | |
| $M_1E_0A_0F_1$ | 0% | | |
| $M_1E_0A_1F_0$ | 47% | | |
| $M_1E_0A_1F_1$ | 0% | | |
| $M_1E_1A_0F_0$ | 57% | | |
| $M_1E_1A_0F_1$ | 0% | | |
| $M_1E_1A_1F_0$ | 20% | | |
| $M_1E_1A_1F_1$ | 0% | | ✓ |

Table 7.8: Average of percentage of runs where private trade was permitted for different characteristics (out of 30 runs).

| | Characteristics | | | |
|---|---|---|---|---|
| | Mobility ($M$) | Favourable environment ($E$) | Apprenticeship ($A$) | Fairness ($F$) |
| Having (1) | 0.25 | 0.17 | 0.16 | 0 |
| Not having (0) | 0.26 | 0.35 | 0.36 | 0.52 |

As can be seen in Table 7.7, the societies with unfair institutions had different percentages for permitting private trade. The unfair societies with the highest and the lowest chance of granting such permissions are $M_0E_0A_0F_0$, that is the simulated EIC ($93\%$), and $M_0E_1A_1F_0$ ($3\%$), respectively (see Table 7.8). On average, more than $50\%$ of times private trade was permitted in societies possessing unfair institutions. Of those societies, agents' mobility had the least impact (i.e. residing in nodes is not important). Besides, the second impact is associated with the presence of apprenticeships; their presence decreases this probability by $20\%$ (i.e. $36\%$ versus $16\%$, see Table 7.8). The chance of a society permitting private trade for mobile agents is around $1.5\%$ less than immobile agents ($52.5\%$ versus around $51\%$, see Table 7.8). The impact of the environment is also significant; overall, a favourable environment decreases the chance of permitting private trade by $18\%$ (i.e. $35\%$ versus $17\%$, see Table 7.8).

This simulation result matches the evidence from Julfa. In Julfa, managers were the ones who eventually ran the family business. Also, mercantile agents and managers made decisions regarding violations as juries in certain courts.[13] The aforementioned situation, combined with keeping private trade illegal,[14] indicate that this rule was socially accepted.

Now we state the relevance between these findings and the implication for the prohibition of private trade. These results indicate that fair institutions and apprenticeship programmes deter agents from private trading. Furthermore, as shown in 7.5c, in all the societies, more than 50% of agents were engaged in private trade, even before official permission for doing so.

However, granting permission for private trade in unfair societies is different. Keeping in mind that this permission is granted if more than 70% managers agree (see permissions for private trade in Section 7.3.3), additional characteristics are also important. For instance, societies with a favourable environment and apprenticeship programmes are less likely to grant such permissions. Overall, fair institutions and having apprenticeship programmes deters agents from performing private trade.

#### 7.4.1.3 Rule violation

Certain characteristics of societies impact agents' tendencies to violate trade rules. Figures 7.6a-7.6d and 7.7a-7.7d present the percentage of mercantile agents who violated the rules in a year. In these plots, the y-axis represents the percentage of cheaters. As can be seen in Figure 7.7, the most influential characteristic is fair institutions (7.7c versus 7.7d) that reduces the number of cheaters significantly.

We also use the Kendall's test to inspect the impact of characteristics of the system on the percentage of rule violators (irrespective of its seriousness), and the results of the test are stated below:

[13] Here, we refer to the portable courts which have been already stated in Chapter 2.

[14] In the Armenian rules, it is mentioned that trade for self-interest is illegal, unless otherwise agreed (Herzig, 1991).

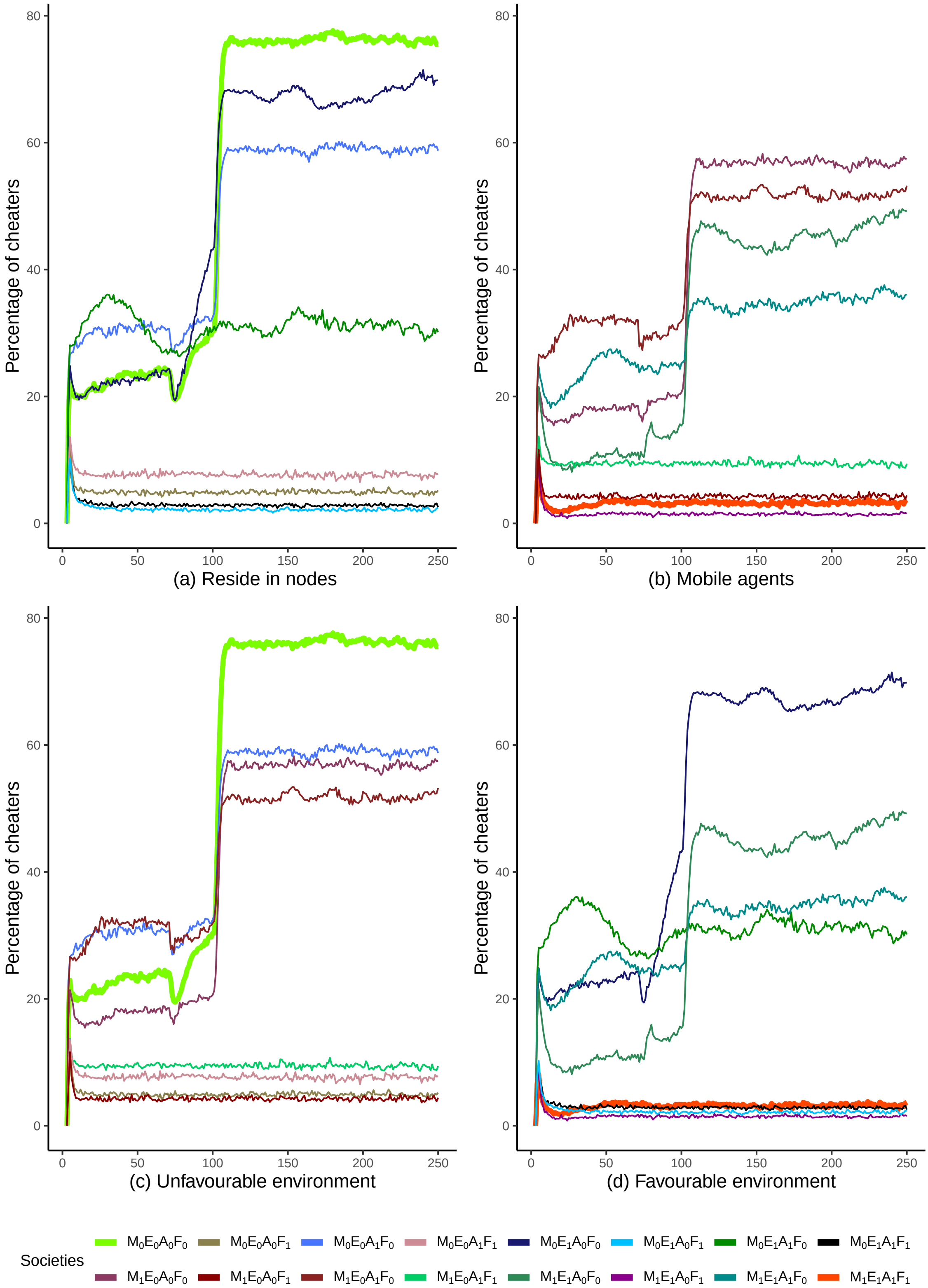


Figure 7.6: Cheating frequency associated with 16 societies, considering mobility and environment.

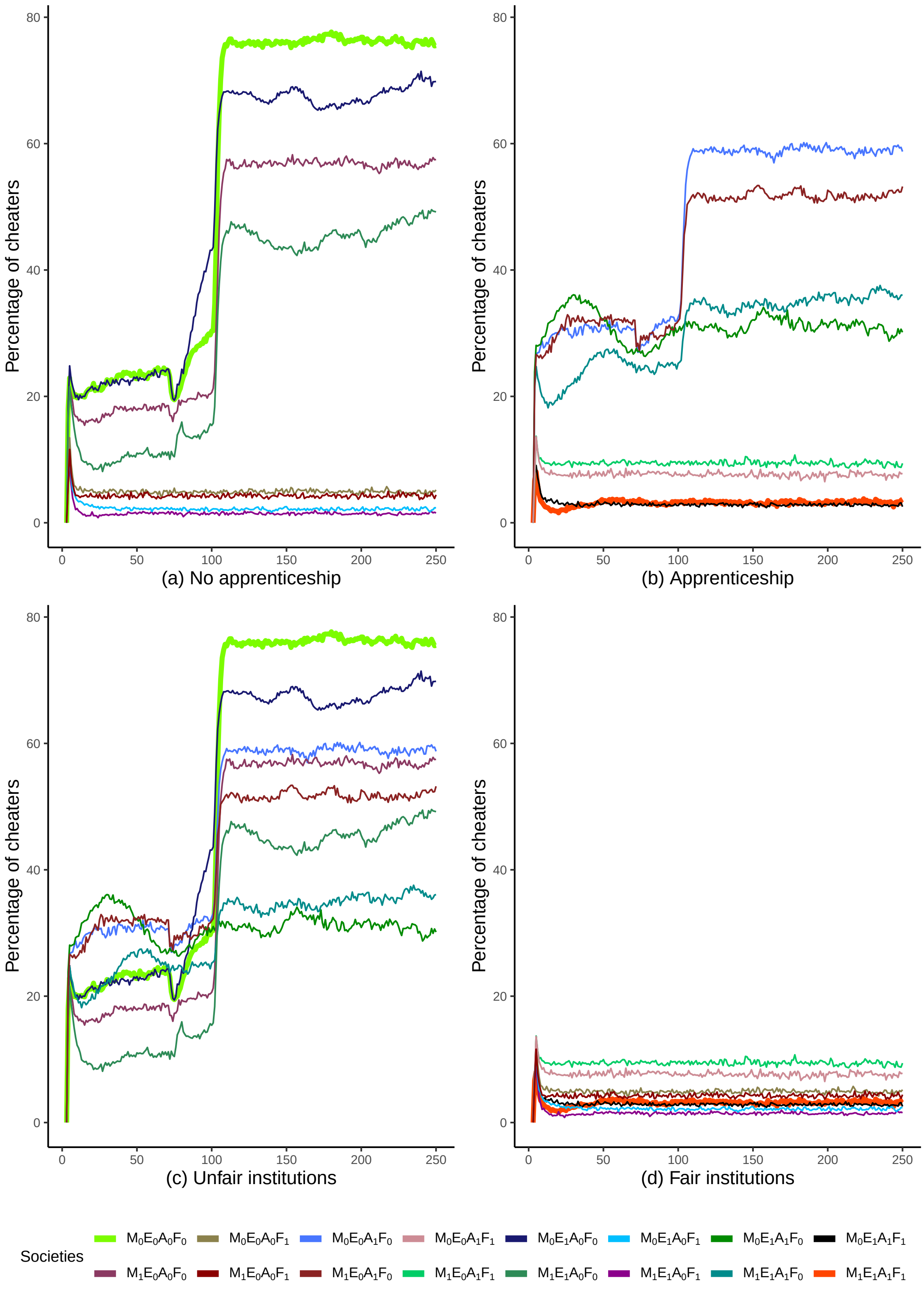


Figure 7.7: Cheating frequency associated with 16 societies, considering apprenticeship and fairness.

- The agent's **mobility** weakly impacts their inclination towards violating rules. The values of $\tau$ associated with intervals *A*, *B*, and *C* are $-0.1, -0.1$, and $-0.08$, with $p\text{-}values$, $\approx 0.0001$, $\approx 0.01$, and $< 0.0001$, respectively. Overall, these results indicate that the mobility of agents is not an important characteristic of the system to control violations.
- The **favourable environment** is statistically significant ($p\text{-}value < 0.0001$) and weakly impacts on decreasing the tendency towards violating trade rules. The values of $\tau$ for intervals *A*, *B*, and *C* are $-0.21, -0.22$, and $-0.28$. The weak correlation indicates this characteristic has a limited impact on controlling cheating.
- The presence of **apprenticeship** programmes in the system *increases* inclination towards cheating for intervals *A* and *B*. The values of $\tau$ associated with intervals *A*, *B*, and *C* are $0.24, 0.2$, and $-0.02$, respectively. The values of $\tau$ associated with intervals *A* and *B* are statistically significant ($p < 0.0001$), but the one associated with interval *C* is statistically insignificant ($p > 0.25$).[15]
- The societies with **fair** institutions have a lower percentage of cheaters ($p\text{-}value < 0.0001$). The values of $\tau$ for all intervals are about $-0.7$. Note that the simulation result is supported by empirical studies about the influence of fair institutions on "counterproductive behaviour," and "organisational citizenship behaviour" even in closely monitored systems (see Spector & Fox, 2010). Furthermore, our simulation results match historical reports of Julfa (i.e. Julfans did not have a great appetite for cheating).

The negative correlation between an apprenticeship and cheating seems counter-intuitive. However, one should note that we expect that an apprenticeship improves the agent's rule compliance through ways such as:

- Agents who are trustworthy during training are selected for future employment.
- Any deviations of agents are corrected by deterrence during training; hence, they increase their mental costs.

[15] We have checked the results by changing the variances for learning system characteristics to 0.1 and used a Uniform distribution to test the impact of these parameters. For lower variance (i.e. 0.1) the pattern was relatively the same ($0.27, 0.21$, and $-0.04$), but all correlations were statistically significant (the $p\text{-}value$ of the last correlation decreases to $\approx 0.02$). Using continuous Uniform distribution for learning system parameters attains $0.24, 0.17$, and $-0.07$, all statistically significant with $p < 0.0001$. Furthermore, we have also checked the impact of the deviations in rule-understanding and internal beliefs, once when the characteristics are learnt uniformly and once when they are learnt as defined in the model. In connection with the correlations obtained for the first instance (i.e. uniform distribution), the results were relatively the same ($0.25, 0.18$, and $-0.06$) and all were significant for $p \approx 0.0001$.

- Costs associated with violating rules increase due to the time spent learning the skills during an apprenticeship.

Putting aside such ideas, being skilled means making more profits; hence, there is an increase in income for the same violation of the rule. Also, the negative impact of increases in experience and skills on cheating has been reported in the EIC (Hejeebu, 2005). Finally, note that in both systems, the costs associated with the perceived norms and internal beliefs are the same (i.e. skill increases utility function associated with the cheating).

Now we wish to state the relevance of some of the findings of this simulation to previous studies. Some lab experiments regarding common pools indicate that some people always break the law, and some others do the right thing, even without a law. For instance, Tyran and Feld (2002) find that for strict laws (i.e. severe sanctions and punishments) around $7\%$ of participants break the law and in the case of no law, around $30\%$ do not free-ride (i.e. they contribute to the public goods). In another study, Ledyard (1994) provides a review and some discussion on early studies of public goods. He reports the findings that contradict the self-interest behaviour of the whole society (e.g. contributions to the public project). Our simulation results indicate a similar pattern. In other words, even in the worst cases, the whole society of agents do not cheat, and in the best scenarios, some cheaters are punished.

Another important issue regarding cheating is the seriousness of violation. Figures 7.8 and 7.9 present results for this phenomenon. In these plots the y-axis indicates the average of the seriousness of violations of cheaters. As can be seen, societies with fair institutions and the mobility of the agents had less serious violations in the long-run. In other words, Figures 7.8a-7.8d and 7.9a-7.9d indicate relatively the same patterns with respect to the percentage of cheaters. The correlation test also indicates the similarity of the patterns. The results of the Kendall's test are as follows:

- The correlation of the **mobility** of the agents with the seriousness of violation is weak. The correlations associated with intervals *A*, *B*, and *C* are $-0.14$, $-0.12$, and $-0.08$, respectively (all significant $p < 0.01$). Overall, these results indicate that the mobility of the agents does not considerably control the extent of violations.

- The **favourable environment** has a statistically significant ($p\text{-}value < 0.001$) and weak impact on decreasing the seriousness of the rule violation. The values of $\tau$ for intervals *A*, *B*, and *C* are $-0.13$, $-0.14$, and $-0.19$, respectively.

- Societies possessing **apprenticeship** programmes faced more serious violations for intervals *A* and *B* (the correlations are weak with values of $\tau$ equal $0.13$ and $0.11$). However, for interval *C* the correlation is negative ($\tau$ is $-0.05$). All the correlations are significant with $p < 0.01$.

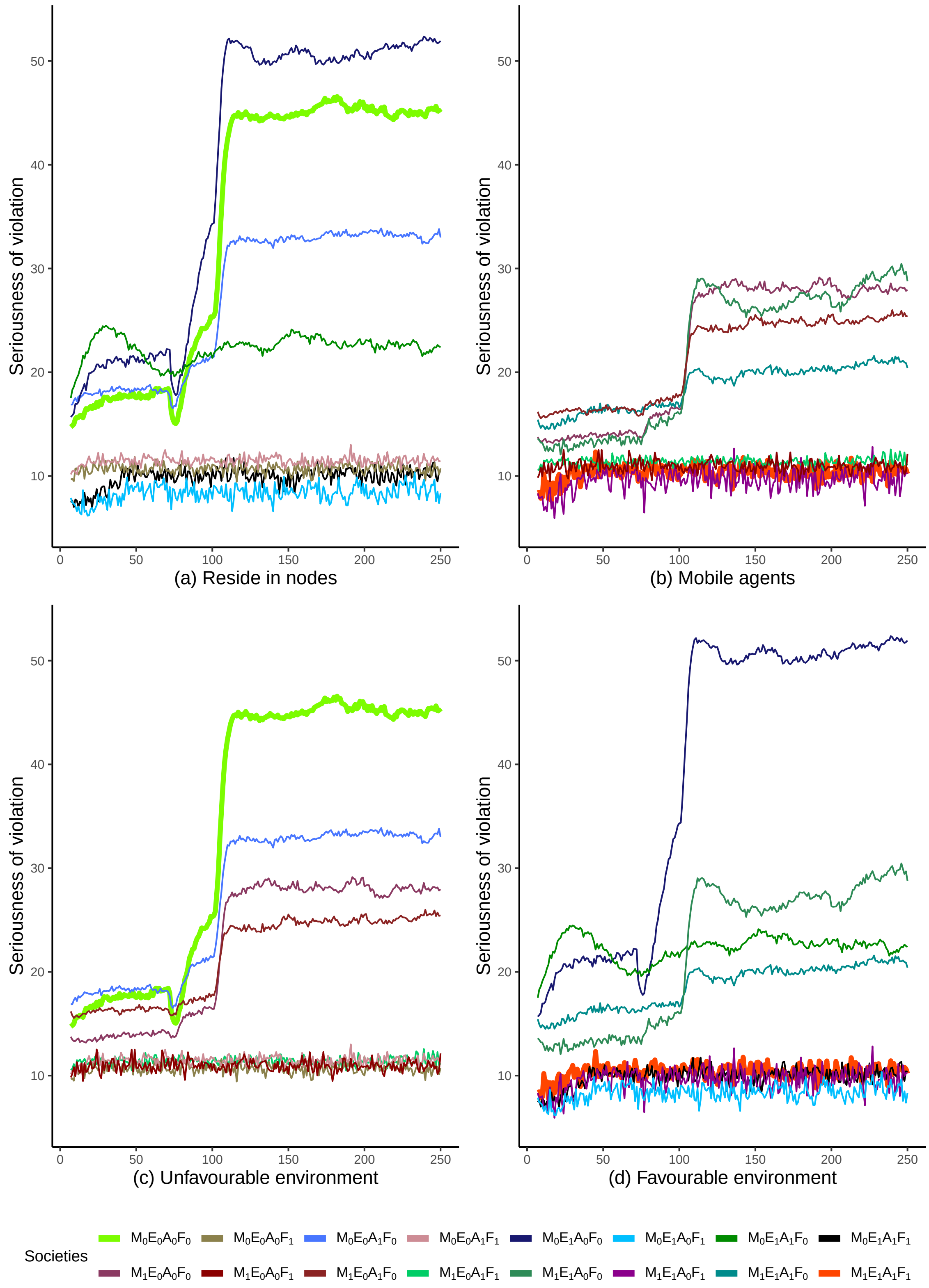


Figure 7.8: The seriousness of violations for 16 societies, considering mobility and environment.

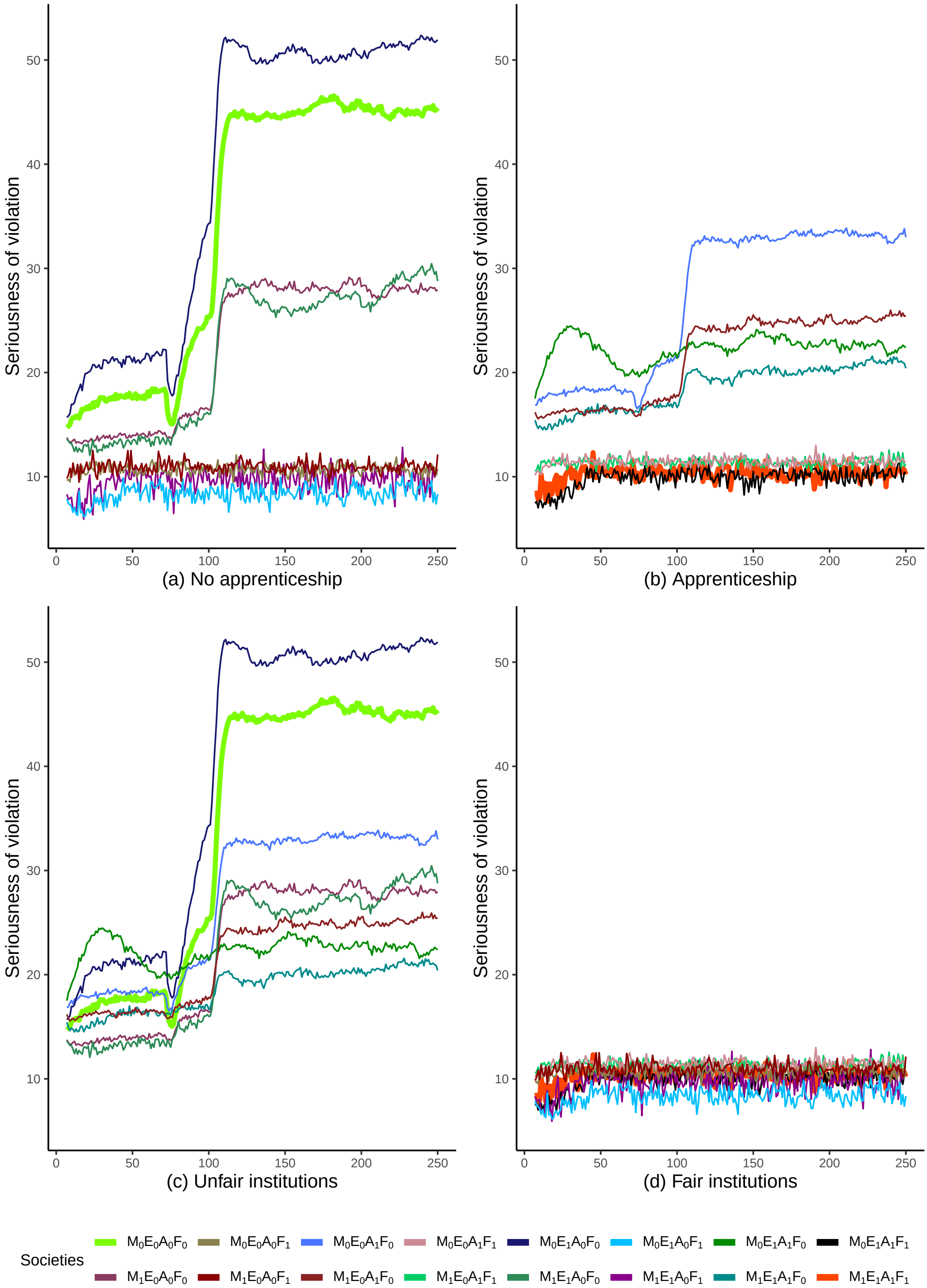


Figure 7.9: The seriousness of violations for 16 societies, considering apprenticeship and fairness.

- **Fair** institutions have a negative correlation with the seriousness of a violation in a society with values of about $-0.7$ ($p\text{-}value < 0.0001$). Note that this simulation result mirrors the empirical studies, pointing to the importance of fair institutions to control cheats and vice versa.

In what follows, we state the impact of system parameters on monitoring agents' behaviour and punishing violators.

#### 7.4.1.4 Fired violators

Figures 7.10a-7.10d and 7.11a-7.11d present the percentage of the mercantile agents fired. In these figures, the y-axis indicates the percentage of fired cheaters. As can be seen, the most fired agents belong to society $M_0E_1A_0F_1$. However, finding a pattern that applies to all societies with shared characteristics is difficult. In connection with the statistical test, note that we are not interested in comparing the percentage of agents fired irrespective of the impact of the percentage of cheaters. In other words, we are interested in the percentage of cheaters who are fired, as opposed to the percentage of those fired compared to the percentage of agents. Note that the latter percentages are misleading when we compare societies with a high number of cheaters versus societies with a low number of cheaters. In other words, although most of the historical information concentrates on the percentage fired, comparing agents fired in the two societies with totally different percentages of cheaters seems to be misleading. Because of that, we have used a partial correlation of the Kendall's test to remove the effect of the percentage of cheaters.[16] The results of this test are listed below:

- The **mobility** of the agents has a weak positive correlation with firing cheaters. The partial correlation test indicates correlations for intervals *A*, *B*, and *C*, with values $0.13, 0.15$, and $0.22$, respectively ($p < 0.0001$). The positive sign indicates that not forming clusters and friendship groups might help the system to better identify violators.
- The **favourable environment**'s impact on firing cheaters is weak ($0.03, 0.06$, and $-0.03$) for intervals *A*, *B*, and *C*, respectively). The partial correlation for interval **A** is not significant ($p > 0.1$) and two others have a 0.05 significance level. This indicates the environment is not an influential factor.
- **Apprenticeship** programmes have a statistically significant and positive impact on firing cheaters for all intervals ($P < 0.0001$). The partial correlations for intervals

[16] "A partial correlation coefficient describes the strength of a linear relationship between two variables, holding constant a number of other variables." (Freund et al., 2010).

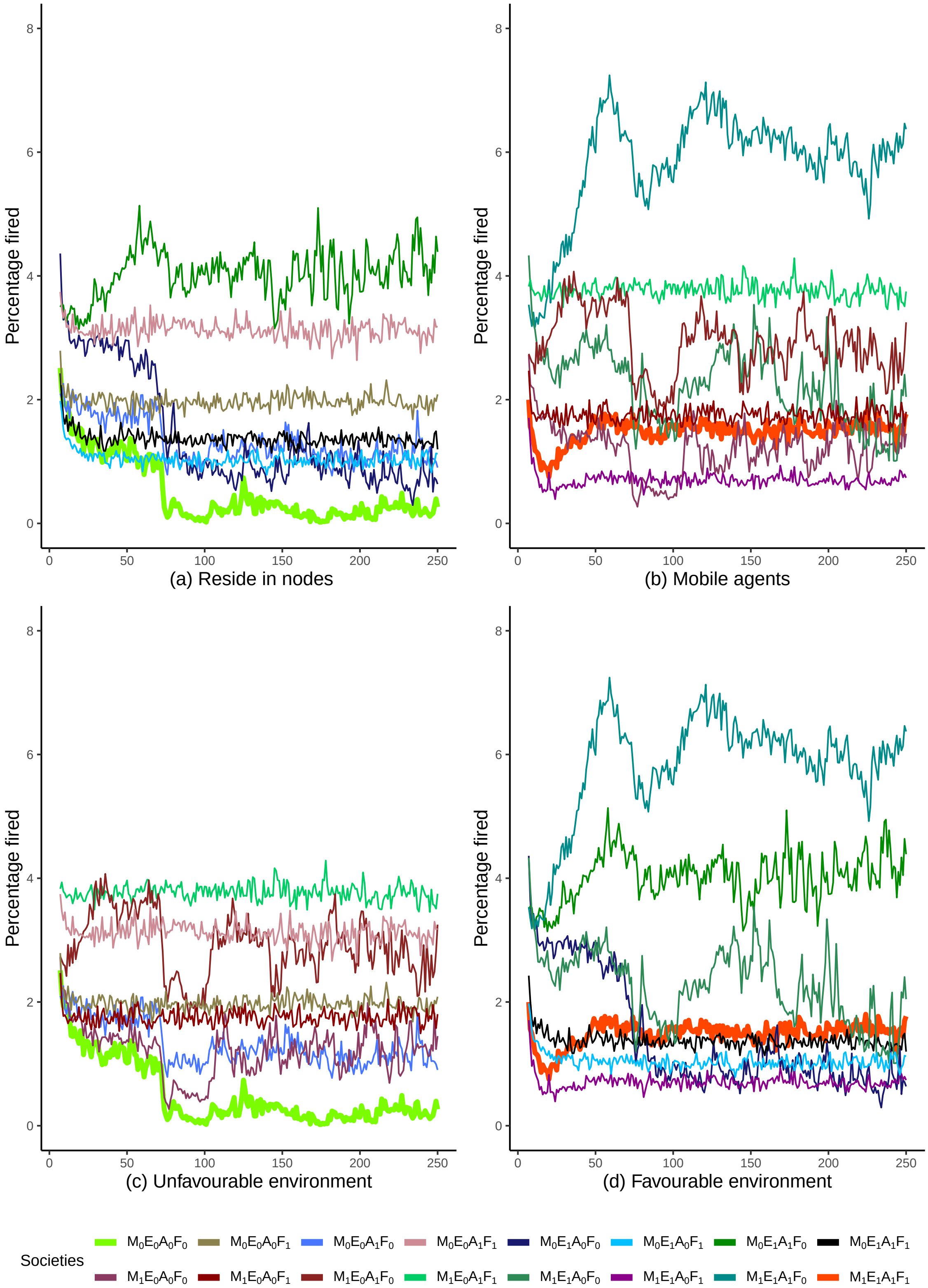


Figure 7.10: The percentage of fired agents who violated the rule for 16 societies, considering mobility and environment.

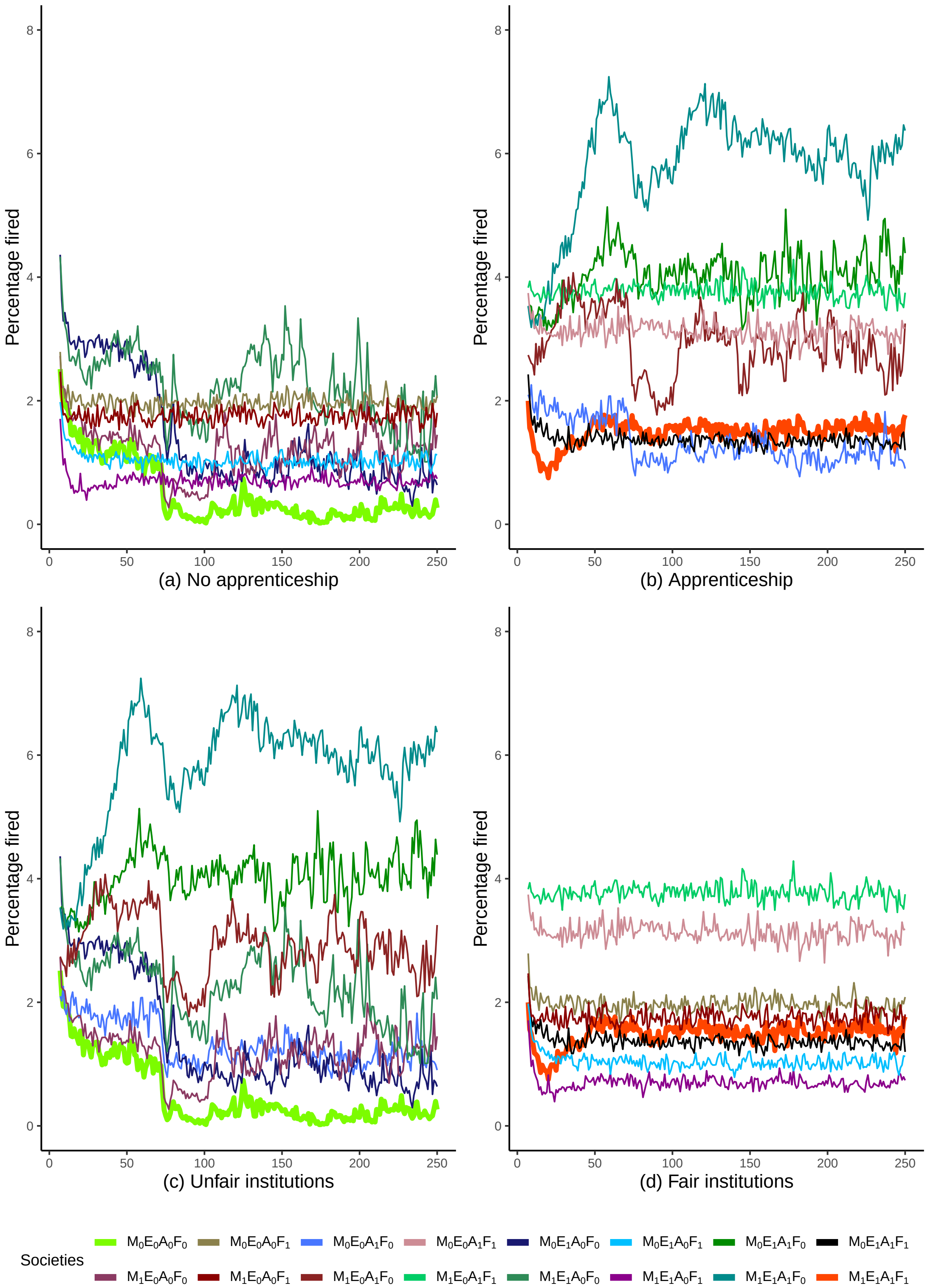


Figure 7.11: The percentage of fired agents who violated the rule for 16 societies, considering apprenticeship and fairness.

*A*, *B*, and *C* are $0.3, 0.44$, and $0.49$, respectively. This indicates that having a better understanding of system rules and characteristics, along with a better relationship with managers moderately improves the collaboration of the society (those who do not cheat) in monitoring and firing the violators.

- The correlation between the **fair** institutions, after removing the influence of the percentage of cheaters, indicates that fairness is *positively* correlated with the firing of cheaters. The partial Kendall's test shows weak correlations ($0.11, 0.27$, and $0.07$, for intervals *A*, *B*, and *C*, respectively, $p < 0.0001$).

#### 7.4.1.5 System profitability

Here we investigate the profitability of these societies with respect to their characteristics. To measure profitability, we used the *rate of return* (ROR) (same as in Chapter 4). This indicator normalises the profitability of the system by removing the impact of the initial capital. Figures 7.12 and 7.13 categorise the ROR associated with the 16 societies regarding different system characteristics.

In Figures 7.12 and 7.13, the x-axis indicates the time line in years and the y-axis indicates the ROR. The fall in the ROR, if available, is caused by granting permissions for private trade that leads to promoting self-interest at a cost to the company (see Section 2.3.3). We conducted the Kendall test to assess the impact of the system characteristics on the ROR. The correlations associated with the characteristics and the aforementioned intervals are as follows:

- The correlation between **mobility** of the agents and the ROR is significantly positive ($p\text{-}value < 0.0001$). We obtained $0.3, 0.45$, and $0.59$ for values of $\tau$ associated with intervals *A*, *B*, and *C*, respectively. As can be seen, the agents' mobility improves a system performance in different phases because of weaker friendship bonds with local traders.

- The sign of a correlation between a **favourable environment** and the ROR changes over different periods. The values of $\tau$ for intervals *A*, *B*, and *C* are $-0.09$, $0.06$, and $0.11$ with $p\text{-}values$ of $0.0006, 0.09525$, and less than $0.0001$, respectively. However, this correlation is weak for all of these intervals and for interval B, it is not even statistically significant.

- As predicted, the presence of **apprenticeship** programmes in the system significantly improves profitability ($p\text{-}value < 0.0001$). We obtained $0.38, 0.42$, and $0.46$ for the

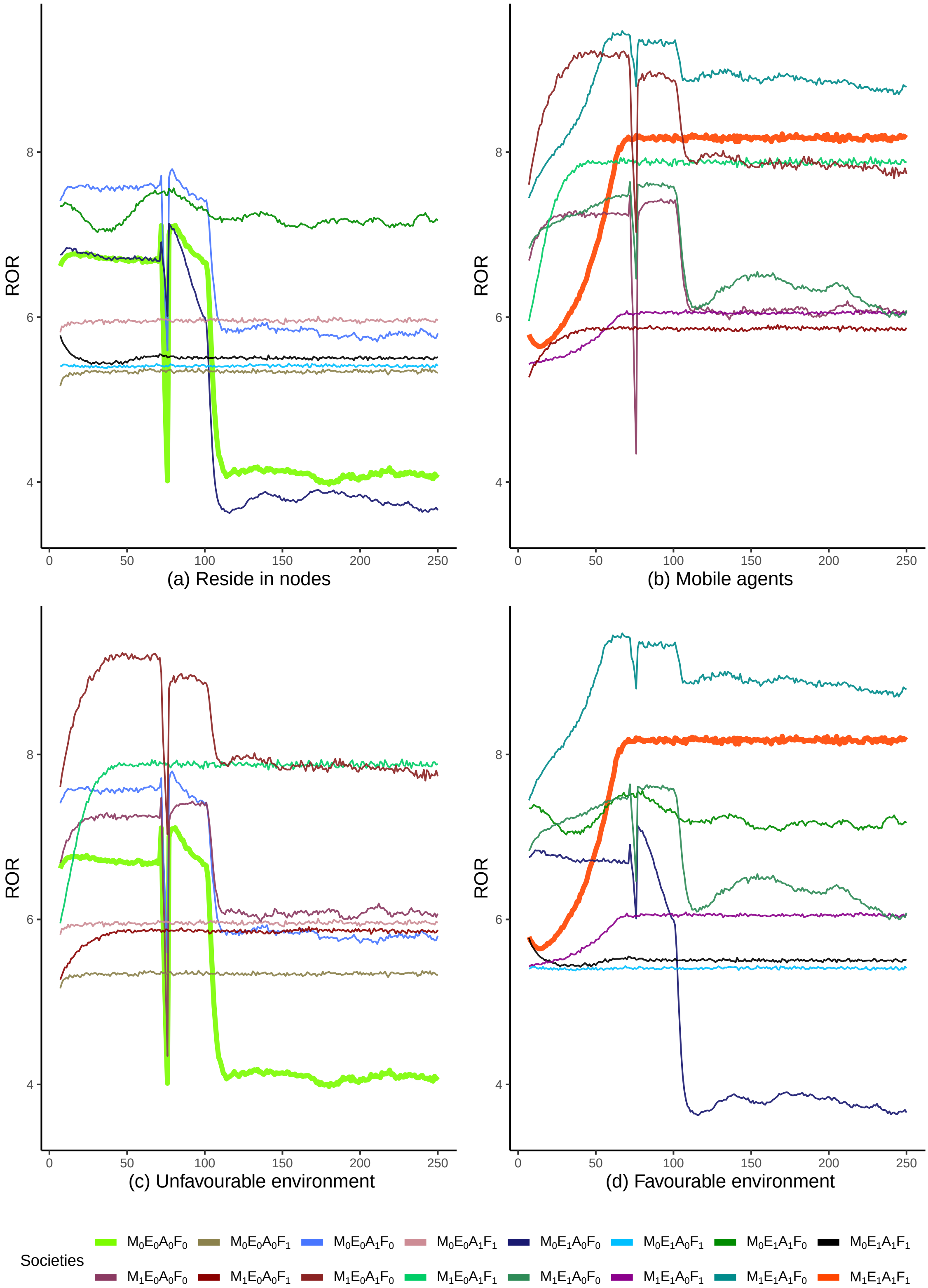


Figure 7.12: The ROR associated with 16 societies, considering mobility and environment.

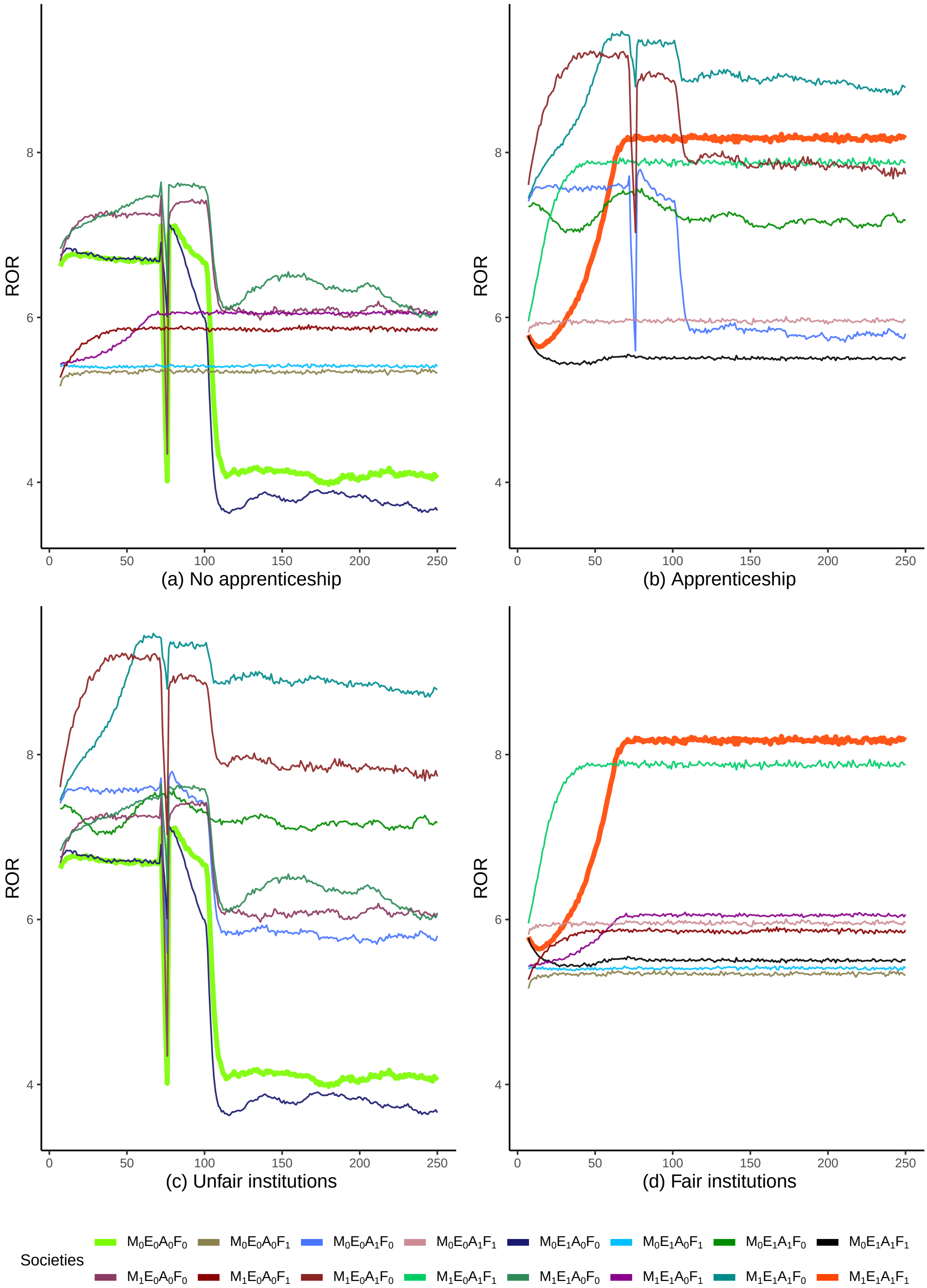


Figure 7.13: The ROR associated with 16 societies, considering apprenticeship and fairness.

values of $\tau$ associated with intervals *A*, *B*, and *C*, respectively. In comparison with results for mobility, the value of this correlation is relatively the same.

- The correlation between the **fairness** of the system and the ROR is negative ($p$-$value$ $< 0.0001$). The values of $\tau$ (i.e. correlation) for intervals *A*, *B*, and *C* were $-0.57$, $-0.41$, and $-0.08$. As can be seen, the market saturation weakens the $\tau$ drastically (i.e. the savings through low payment cannot compensate the cheats' loss). Overall, given these simulation assumptions (significant profit-sharing), fairness alone would not improve the profitability of a system.

To sum up, the mobility of agents and apprenticeship programmes have a positive and weak/moderate impact on the ROR. Furthermore, as shown by Figures 7.12a-7.12d and 7.13a-7.13d, approximately all societies with unfair institutions granted permission for private trade once they had the chance. The consequence of this decision is an immediate drop in the ROR, because agents leave the company to pursue their own self-interests, and the company loses revenue (i.e. its ROR drops).

We wish to point out that the same phenomenon was observed in the history of the EIC after the English Civil War. When some managers were promoted to directors as a consequence of the English Civil War, they convinced other members to grant permission for private trade.

We state the general results in the next subsection, and we focus our investigation on the direct comparison of the societies for which we have empirical evidence, namely Julfa and EIC.

### 7.4.2 Comparing the simulated EIC and Julfa

Here we focus on the results associated with the two societies of interest to this thesis, namely the EIC and Julfa. We also state some evidence from other societies (e.g. VOC) that had relatively the same institutions and the reasons we believe the model helps to identify the important institutions for a long-distance trading society.[17]

#### 7.4.2.1 Bureaucratic rules (private trade)

Figure 7.14 presents the overall inclination towards private trade — or other rules without a moral concern — in the EIC and Julfa (also shown in Figures 7.4 and 7.5). As can be seen, there is a significant difference between these two simulated societies, such that in the model

[17]We believe these institutions are also helpful to manage other traders' societies, especially the ones facing the principal-agent problem.

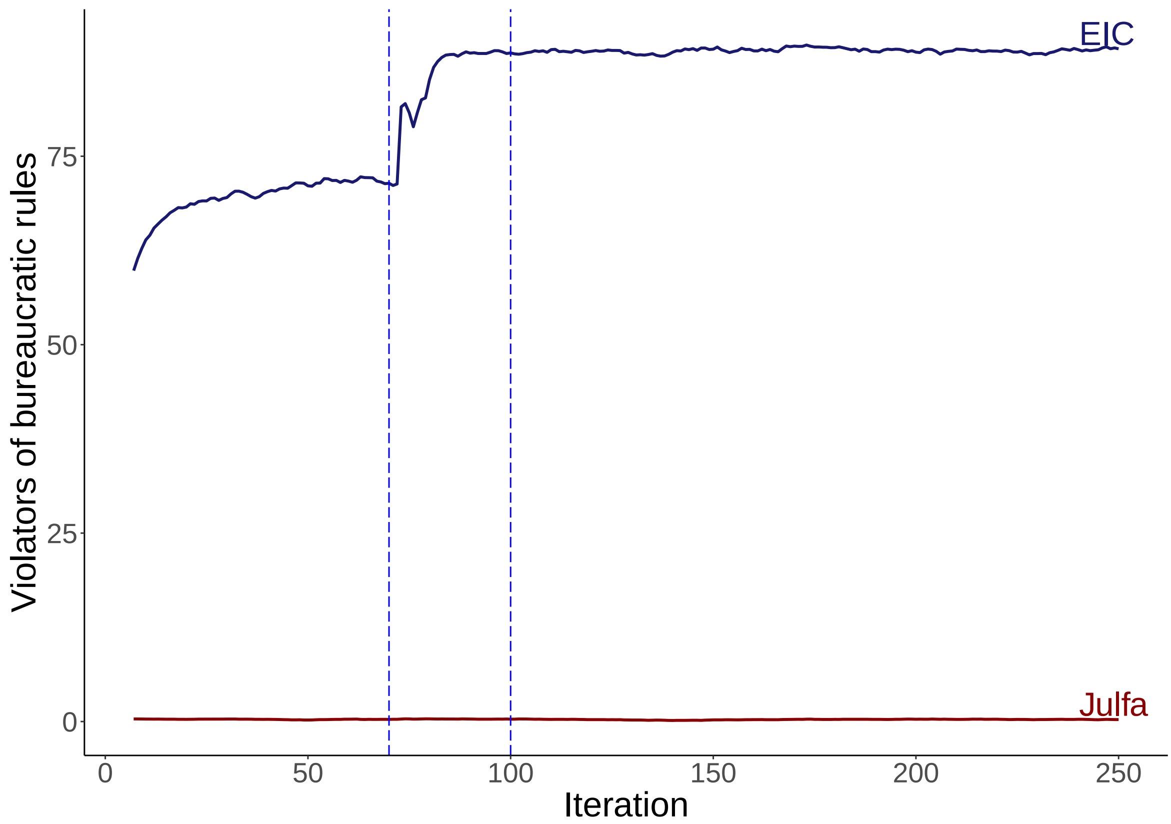


Figure 7.14: The percentage of agents who break bureaucratic rules in the EIC and Julfa

representative of Julfa, less than $1\%$ of agents broke bureaucratic rules. Note that for the period after permissions for private trade (i.e. first blue line), the line shows agents' tendency to break rules that seem harmless to the company. The simulated difference shown in our results in practising private trade in the EIC and Julfa is also reported in historical contexts. For instance, Erikson (2014) stated that captains used methods such as "*losing the season*" (i.e. they deliberately prolonged the process to lose the monsoons) to pursue private trade.[18] Also, some managers defended mercantile agents' private trade:

> "if some tolleration [sic] for private trade be not permitted none but desperate men will sail our ships." (Factory Records: Miscellaneous, I, 26, 18, February 1620, as cited in Chaudhuri, 1965, p. 87)

[18]For instance see the following:

> "[Captains] deliberately 'los[t] the season' for their return voyages to Europe by moving in a dilatory fashion from Bombay to other Asiatic ports, investing and reinvesting their 'privilege' ". (Furber 1948, p 280, as cited in Erikson, 2014, p. 115)

The same kind of arguments exist about the popularity of such actions in the VOC. For instance, J. Adams (1996) points out the following:

> "Gerard Demmer [...] whose salary was set at 350 fl. (guilders) a month, sent over 165,000 fl. to the Netherlands in 1652, and 57,000 in 1654. Pieter Sterthemius, director of the Bengal factory, made 200 fl. a month, but carried 52,000 fl. with him at his repatriation." (J. Adams, 1996, p. 21)

Furthermore, the VOC also granted permissions for private trade. For instance, Sgourev and van Lent (2014) stated how flexibly and frequently private trade was permitted or prohibited (see Sgourev & van Lent, 2014, Table 1). They point out the following:

> "The analysis confirms that adaptation occurred as a response to declining performance. However, even if the observed form of adaptation proved beneficial to the organization, it was insufficient to prevent long-term decline." (Sgourev & van Lent, 2014, p. 936)

Here they argue that the VOC adapted to the duopoly (i.e. sharing trade with the EIC) by converging their policies to the EIC. This convergence happened through adopting the same policies (e.g. permissions for private trade). They also point it out that this permission was not beneficial in the long-term.

However, for Julfa as Aslanian (2007) claims,[19] breaking the rules in any form was rare. He indicates a potential reason in the following letter between two brothers: "I would rather chuse [sic] to dye [sic], than for them to [blot my] name out of the List" (Santa Catharina logbook of Spanish and English translations, letter no. 147, folios 369-370, as cited in Aslanian, 2007, pp. 248–249). Note that the brother explains that being 'blotted out' was "the same as if you was [sic] a dead man."

Note that as stated in Chapter 2, in Julfa, agents could ask for permission for private trade or even invest in the same trade. These characteristics indicate they had flexible rules to control incentives for private trade.

As the simulation results suggest, and also based on the historical reports from the EIC, the VOC, and Julfa, certain characteristics, such as fairness of institutions, controlled inclinations towards private trading. In what follows, we compare the popularity of rule violations and their influence on profitability (the ROR) for these two societies.

[19]The claim is made with respect to his studies of different archives.

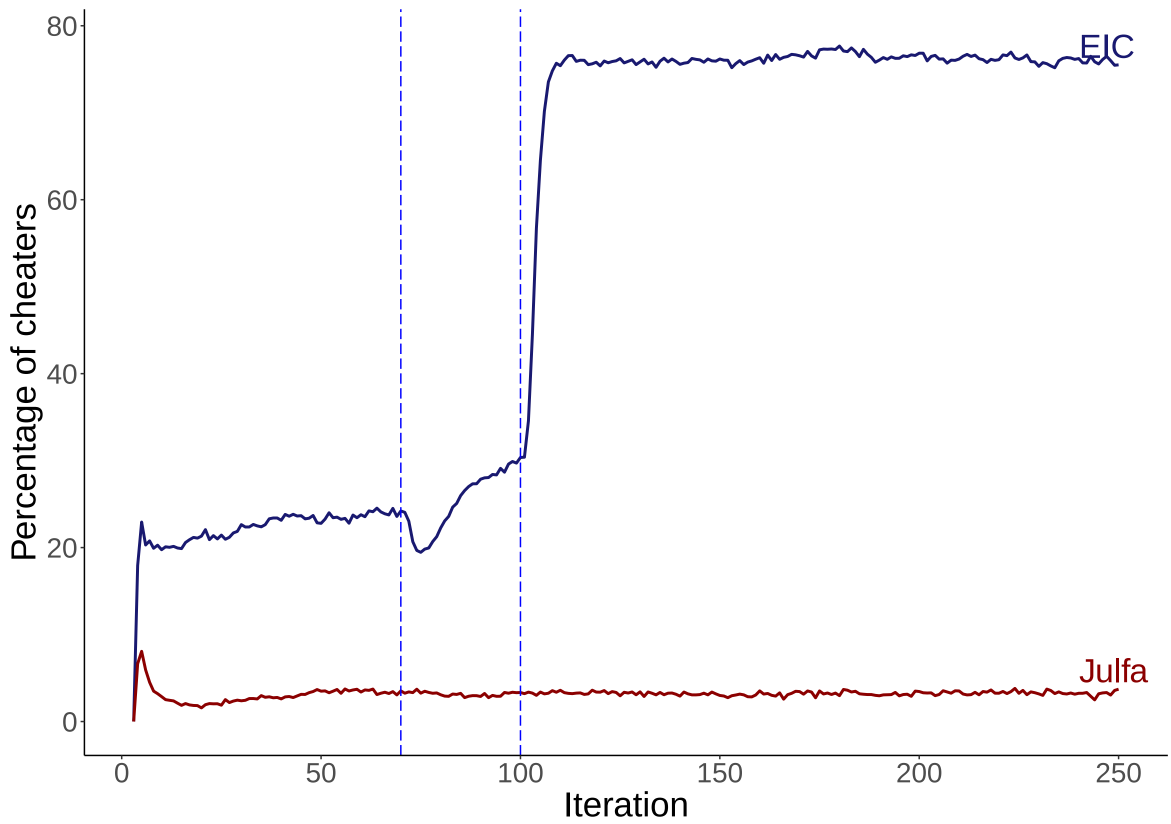


Figure 7.15: The percentage of agents who violated the merchandising rules

#### 7.4.2.2 Rule violation

First, we investigate the impact of the differences between these societies with respect to their agents' inclination towards violating the rules. As can be seen in Figure 7.15, which shows the results of our model, the EIC has more cheaters. After ten runs when the system has more experienced agents (i.e. between ten and 250), the percentage of cheaters in Julfa is less than **four**, while in the EIC it is more than **nineteen**. In the EIC, this inclination increases a few years after granting permissions for private trade (around 13 years). As stated in the former section, the reason for this shift is a combination of a reduction in wages and less opportunity for private trade due to a high level of competition, as indicated in the correspondence.[20] Note that in our simulation, the aforementioned phenomenon only decreases costs associated with internal beliefs (see Section 7.3.2).

Now we state the historical evidence from the chartered companies (e.g. EIC and VOC)

[20]Note that potential reasons for this decrease in profits of private trade include the permissions granted to other agents (e.g. sailors and other traders) and the formation of the New East India Company and its aggregation with the EIC. These increased the number of engaged traders in markets of intra-Asia and Asia to the European market (see Chapter 2 for description).

and Julfa to evaluate the patterns suggested by our simulation results. The evidence is presented in the form of quotations from historians. The passage below belongs to the EIC:

> "There were even fraudulent attempts to charge the Company [EIC] a higher price by buying it [pepper] during the cheap season and then entering in the books the later price which had been raised by the demand from private traders arriving late on the coast. In fact, the Court of Directors felt so strongly about the expenses incurred at Tellicherry [sic] under the management of Robert Adams that they were prepared to abandon the settlement altogether unless the charges were drastically reduced." (Chaudhuri, 1978, p. 325)

Chaudhuri (1978) notes that the reason for the court's decision was a downswing in the pepper market inside Europe. However, this argument not only suggests the cheating behaviour and acceptance of it, but it also points to the beliefs about some coalitions. Note that another point indicated here is the impact of private traders on price increases and reductions of marginal profits that was stated earlier.[21]

Another instance is Carlos and Nicholas's (1990) observations on chartered companies. They state the same issue for the *Hudson's Bay Company* (a chartered company for trade between England and Canada) and they note that the company was aware of such issues and reformed contracts and company structure with respect to the company's aims. Before going through more evidence, we wish to remind the reader that as Jones and Ville (1996) suggest, these contracts are evidence of the existence of the issues, and not about resolving them. The following passage is another interesting case:

> "[An investigation of fraud] in the late sixteenth century estimated that about ten per cent of the treasure that arrived in Europe never appeared in the registers. [Furthermore, Hamilton noted that] 'smuggled treasure has been estimated at from 10 to 50 per cent of the registered, but there is reason to believe that it

[21] Other instances of fraud are changing the exported or imported items (see Sainsbury, 1922, pp. 66–67), and plotted frauds — for example, Thomas Skinner plotted a fraud by using several ships to send pepper for others "at company expenses" (see Sainsbury, 1922, pp. 247–248). Furthermore, minor violations with substantial costs for the company are reported. An instance of this is as follows:

> "You have to the life expressed your own vanity, folly, and riot unto those people, and wasted so much of our estate in such a lavish manner as if we sent our ships and monies hither for you to make shows and pagents [sic] for those people to scorn at." (Letter Book, I 127, 27 October 1636, as cited in, Chaudhuri, 1965, p. 87)

Here the violation was spending about £4000 to secure company benefits.

was rather nearer the former than the latter figure.' " (Lorenzo Sanz, Comercio de España con América,pp. 142–146 and Hamilton, American Treasure and the Price Revolution in Spain Phillips, 1990, p. 88)

Finally, the letter between two Julfan brothers stated earlier, indicates that punishment was available and severe enough to control an agent's behaviour.

To sum-up, in Julfa, there was not much inclination towards violating trade rules. In the following subsection, we investigate the ability of an organisation to identify the violators.

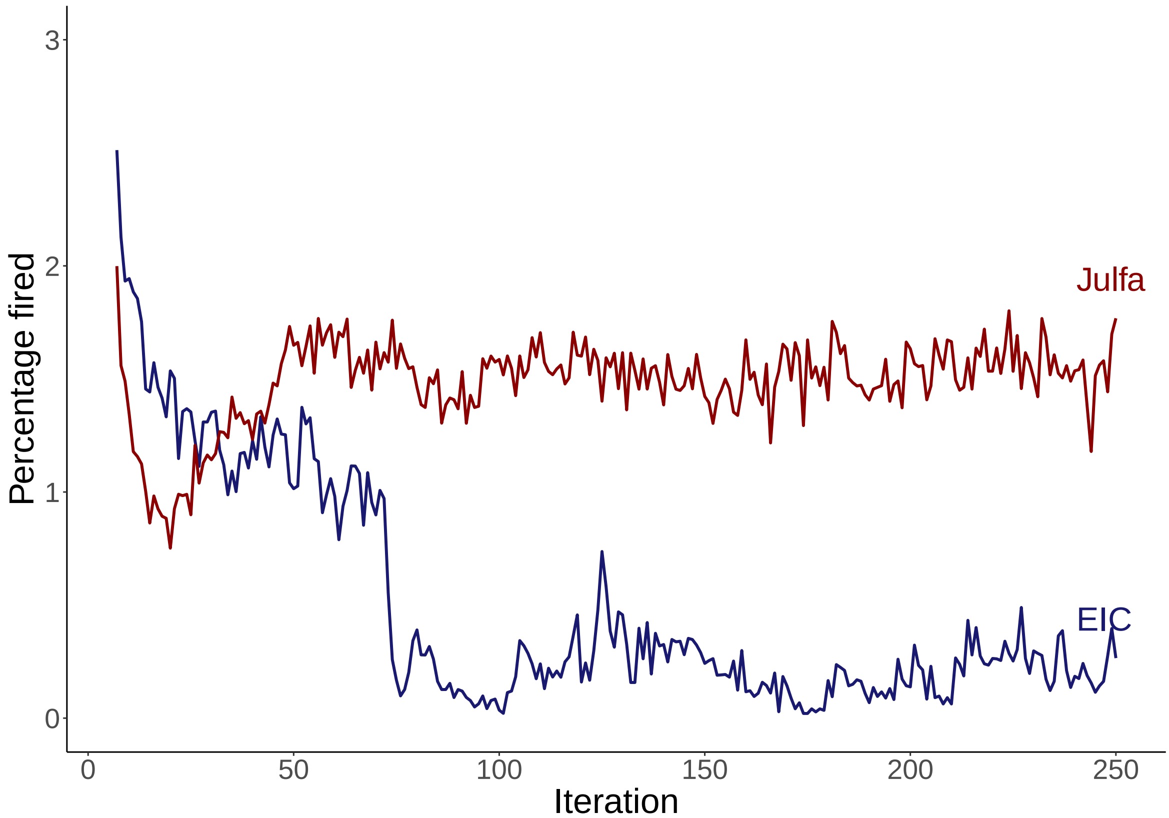


Figure 7.16: The percentage of fired agents who violated the rule for the EIC and Julfa

#### 7.4.2.3 Monitoring

Figure 7.16 shows that fewer agents were punished in the simulated EIC, despite the presence of a large number of cheaters (less than $1\%$ of society are fired). Furthermore, the proportion of fired agents in the simulated Julfa is about $2\%$, while on average, about 5% of society cheated (i.e. 40% of cheaters are fired). The simulation results for the EIC match historical evidence for the EIC and other chartered companies. Most studies on chartered companies point out the distrust about agents' honesty. For instance, Chaudhuri (1965) claims the following:

> "One of the reasons for that distrust of the factors which seems to have been habitual with the Court of Committees was the feeling that they had no means of arriving at the true state of affairs in the Indies unless other factors chose to give information against the delinquent ones. Sometimes, one factor more honest than the others would report on the behaviour Of those guilty of *too flagrant abuses* [emphasis added.]" (Chaudhuri, 1965, p. 87)

To have a better understanding of the reasons for such a weak monitoring system, let us state the attributes of its success. Jones and Ville (1996) point out three characteristics for a successful monitoring system, namely accuracy, timeliness, and comprehensiveness. They also identify some barriers such as "sabotaging" the system. The authors suggest the following:

> "Chartered companies may have been innovative in terms of organizational design, but [...] we do not believe that their control systems were particularly effective [...], information was sometimes inaccurate and often out of date, a situation that got worse as companies expanded, while data transmitted was often narrow in scope and limited in usefulness." (Jones & Ville, 1996, p. 906)

They also point out that the organisations did not efficiently use the available information. Some of the instances of companies that did not use the information include the Royal African Company, the Hudson's Bay Company, and the VOC (Jones & Ville, 1996).

However, these issues were not observed in Julfa. First, not using data was not a concern in Julfa. A reason is the decentralised management of agents by peripheral managers such as other senior family members (Aslanian, 2007). Also, information was voluntarily shared with masters and used in the system. An instance which indicates the data was meticulously assessed can be inferred from the following[22] passage:

> "[Y]our letter from Livorno dated Atam 22 [May 11] reached us on Hamira 8 [November 23], and we became acquainted with your situation. [However] your letter was without flavor or salt [Bi Namak, literally "without salt"] because it contained no news about purchases and expenditures. The salt in a merchant's letter is [the news about] purchases and expenditures. When you send us your

[22]Note that the categories of such information and their applications have already been stated in Chapter 2.

next letter, be sure to write about the state of purchases and expenditures both in Livorno and Venice, so we too can be more satisfied." (39Letter of ovdan 7, 96 (January 21, 1711) to Parons Ohannes and Petros. ASV Documenti Armeni, Busta 2s  Aslanian, 2007, p. 182)

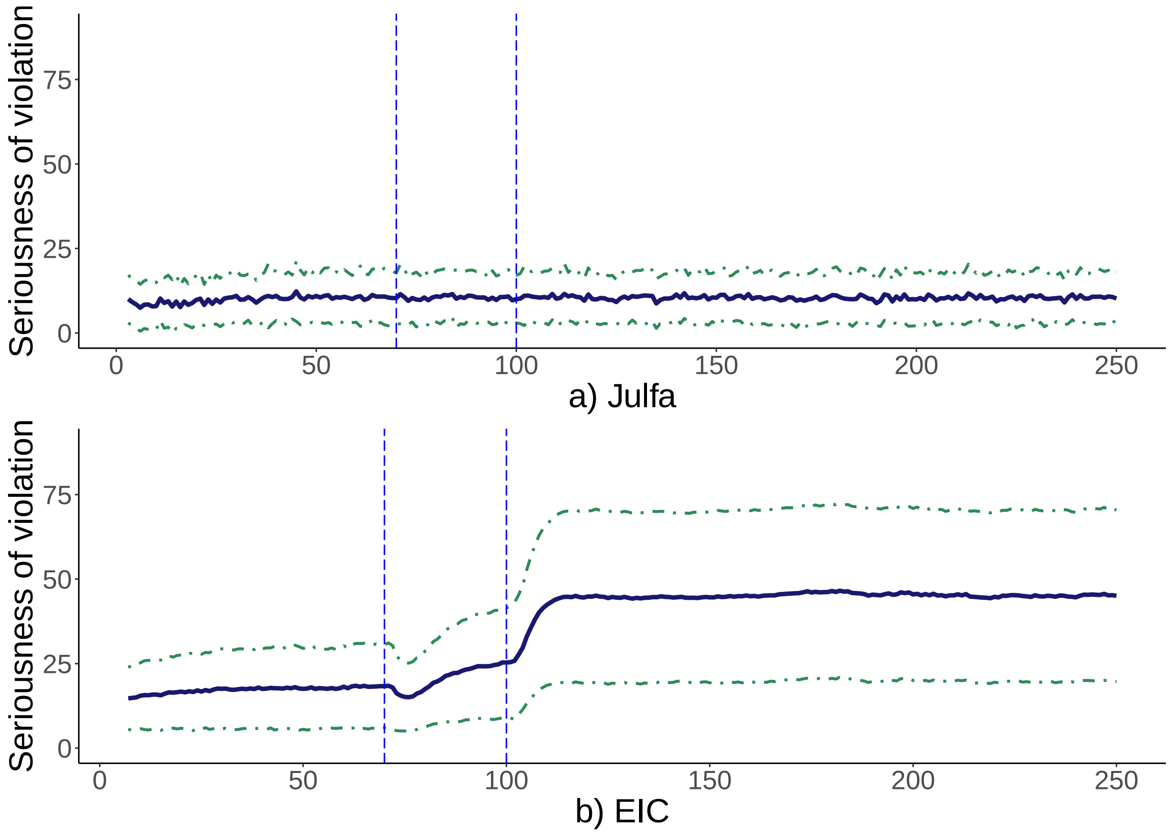


Figure 7.17: Seriousness of violation ± its standard deviation for a) Julfa and b) the EIC

We wish to mention a particular example that indicates tolerance of cheating in Julfa. One of the few instances of violations of a trading rule in Julfa involves Matos di Panos (the mercantile agent) and Vatan (the master) (see Aslanian, 2007, pp. 585–590). It is inferred from the letter that it was not the first time Matos di Panos had violated the rule.[23]

After stating the results and evidence associated with the monitoring strength, in the next subsection, we describe the results related to the extent of violation.

[23]In part of the letter Vatan says: "To this day, our merchants here who hear about what I have done [for you] become astonished [and tell me that] no idiot has done the things that you have done for that *shifty servant* [emphasis added] of yours [i.e., for Matos] Perhaps you [i.e., Matos] are not a servant of God." (see Aslanian, 2007, p. 588)

#### 7.4.2.4 The seriousness of violation

Before describing the results depicted in Figure 7.17, note that the previous simulation results suggest that Julfa had fewer violations than the EIC. Besides, the Julfans identified rare cases of violation better and this can also be inferred through the letters. Figure 7.17 concerns the seriousness of violations in a) Julfa and b) the EIC. The blue lines in this figure indicate the average of the seriousness of performed violations (i.e. violations greater than zero). Also, the green dashed-lines show an interval of one standard deviation around this average. Note that the standard deviation is calculated based on the seriousness of all violations in an iteration. The results depicted in Figure 7.17 (a and b) suggest that in our simulation of Julfa, the extent of violations was more limited with lower variations in comparison to our simulation of the EIC. This result is in agreement with historical evidence from Julfa. As Aslanian (2007, p. 249) points out, the "cases of cheating and dishonesty are rarely mentioned in Julfan correspondence". Furthermore, based on the historical evidence, he notes that blacklisting in Julfa was extended to cases such as refusing to pay the share of taxes (Aslanian, 2007, p. 249, footnote 66). This indicates the honesty of Julfan traders that made it possible to boycott society members for reasons other than violating trade rules.

However, the real EIC situation was much worse than that of our simulation results. Some of the cases of violations were stated earlier, and the following case is an example that indicates another popular cheating mechanism (i.e. embezzlement) and its extent in the system:

> "The most common practice of partial defraudment in the Indies was to enter large sums of money in the name of fictitious Asian merchants as advance payment for goods and use the money to finance the private trade of the servants." (Chaudhuri, 1978, p. 466)

#### 7.4.2.5 System profitability

Up to this point, we have stated the impacts of system characteristics on the agent's rule-following behaviour. Now we compare the profitability of the EIC and Julfa. Note that in Julfa the mercantile agent has a significant share of the profit (around 30%). This share of the profit significantly decreases the organisation's income. Figure 7.18 presents the ROR for the EIC (blue line) and Julfa (red line). The vertical blue dashed-lines indicate years 70 and 100 — i.e. granting permissions for private trade and market saturation, respectively. As can be seen, at the beginning, the EIC makes more profits, despite having lower skills. Furthermore, in our simulation, the result for Julfa are fairly stable. These (i.e. stability and less profits at the beginning) are caused by profit-sharing in the Julfa, along with the limited profits of skill (see ‘Profit’ in Table 7.2). Also, it takes time for Julfa to reach the steady-state (i.e. agents’ internal beliefs become adjusted). Note that the limited impact of skills on profitability is due to the monopoly of trade granted to the EIC that made their profit margins higher than Julfans. The next paragraph presents the simulation results for the EIC.

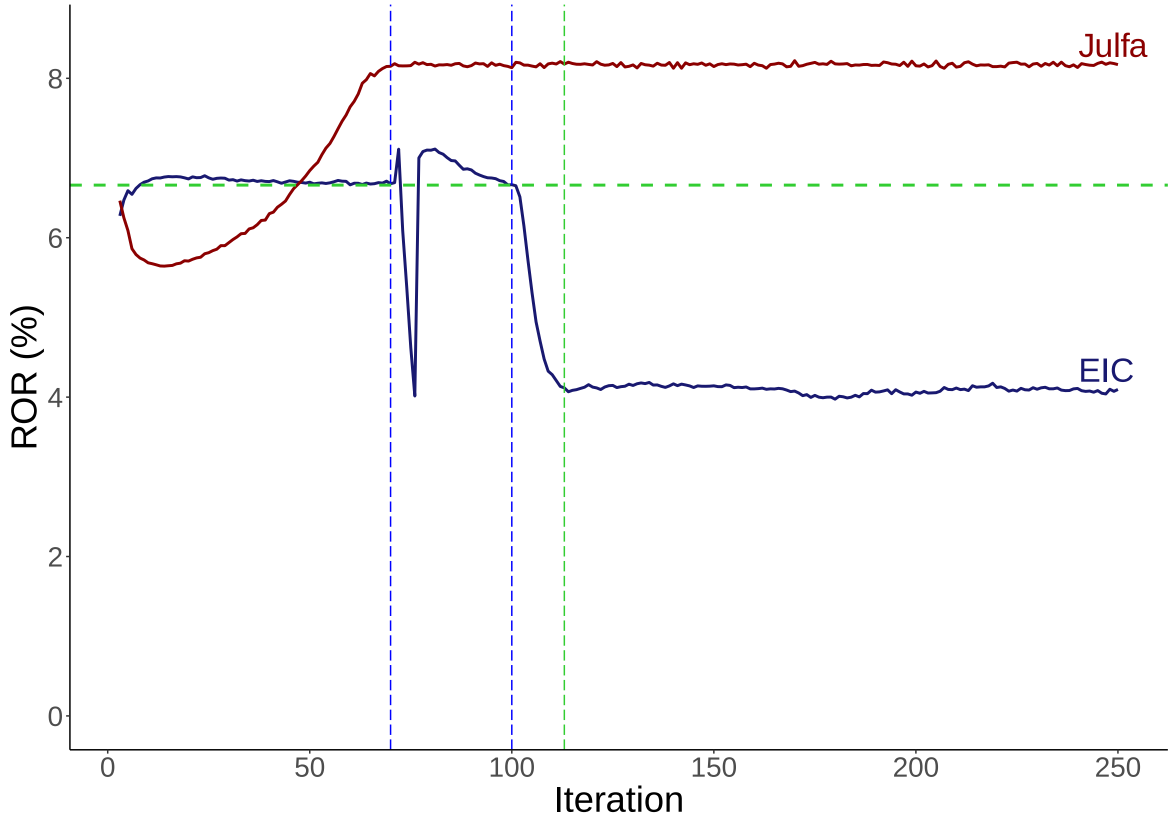


Figure 7.18: The ROR associated with the EIC and Julfa

As can be seen in Figure 7.18, granting permissions for private trade increases the profits of the simulated EIC (see the peak around 71). A decrease in company costs (due to reducing employees’ wages) leads to this increase in profits. However, mercantile agents leave the organisation to trade for themselves at this time. Finally, after market saturation, the mercantile agents reduce the violation costs associated with their internal beliefs; hence, they cheat more frequently.

The market saturation phenomenon (i.e. the second blue vertical line) is a figurative presentation that indicates the importance of costs associated with internal beliefs. As can be seen, reducing costs associated with internal beliefs by a random coefficient[24] causes a sig-

[24]The coefficient for a decrease per iteration is at most 0.85. In other words, we generate a number between 0.85 and 1 for agents to reduce their costs per run.

nificant drop in the EIC profits. The EIC profits decrease by around $2.5\%$ in $13$ years (the green dashed vertical line). The horizontal green dashed-line shows the tangent line to the EIC's ROR before iteration $70$. This highlights another instance of the importance of internal beliefs, albeit regarding the seriousness of the violation (i.e. changes in beliefs, if a degree of violation is minor, medium, or serious, and not the costs associated with the seriousness of the violations). As stated earlier, we have assumed that after reducing wages, the fairness of the system decreases (the organisation paid the mercantile agents a wage equal to unskilled labourers which they could perceive to be unfair). This decrease in wages first increases the company's profits. However, a shift in the perceived fairness changes agents' internal beliefs about the seriousness of violations. This decreases the ROR to levels about that of before granting such permissions. These phenomena indicate the importance of internal beliefs and their influence on the organisation's profits.

#### 7.4.2.6 Perceived norms and internal beliefs concerning the seriousness of the violation

What follows presents a description of the impact of the characteristics on the societal internal beliefs and the societal perception of the norms. These results indicate the influence of certain characteristics on societal internal beliefs following socio-psychological studies on cognitive dissonance. These results also mirror historical evidence of the revisions of rules through referendums and philosophical shifts.[25] In the following, we state the evidence for such changes for the EIC and Julfa. We also describe how the simulations presented the same results.

Figure 7.19a presents the simulated Julfans' societal perception of norms over time (i.e. perceived norms). In this plot minor, mild, and serious are labels an agent associates with the seriousness of violations — i.e. how unacceptable they are. In our representation of Julfa, the mobility of agents is a hindrance to deep friendships (since they do not stay in a place to develop strong bonds) and exchanging ideas about system norms, and on average, agents cannot correct their perception of the system's norms. One should note that because Julfa was a closed society, Julfans had the opportunity to learn those norms inside the society in advance. However, we did not include such an idea to keep our model more generic. Furthermore, based on the societal internal beliefs in Julfa, corrections of perceived norms

[25]An instance of an attempt to control such shifts is a warning by B. Russell (1948, Book 3, Chapter 30, p 828). He warns philosophers and people about "*cosmic impiety*" as a consequence of considering '*truth*' controllable by humans. Russell attributes this to Fichte who he claimed removed *humility* from philosophy (which *modern men* are also inclined to do).

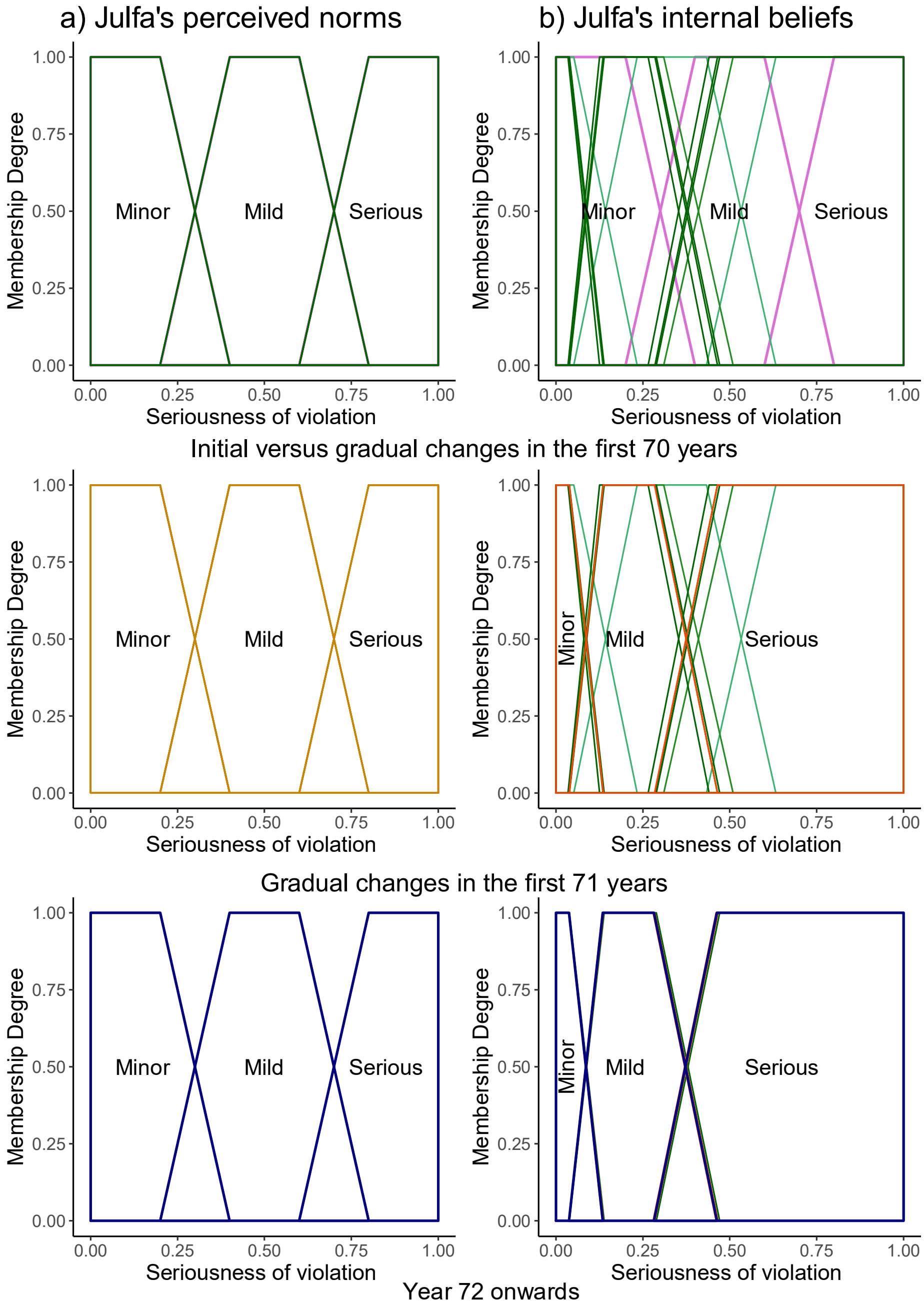


Figure 7.19: Changes in the a) Julfans' societal perceived norms and b) Julfans' societal internal beliefs, over time. For internal beliefs, the pink lines represent the average of internal beliefs at the first iteration, the dark-green lines represent those before iteration 70, the red lines show iteration 72 onwards, and the blue lines show those of the last iteration.

decrease cheating.

Figure 7.19b shows the gradual changes in the simulated Julfans' societal internal beliefs about the seriousness of violations. As can be seen, the Julfans' perceptions of minor and mild violations shift to the left (see the pink lines versus the blue lines). This shift shows, on average, an agent in Julfa considers a violation more serious than what was originally meant by the rule over time. Furthermore, as can be seen, the societal internal beliefs are relatively focused around an area after some iterations. To provide a summary of this change, Figures 7.20a and 7.20b show the initial and steady-state societal internal beliefs in Julfa, respectively.

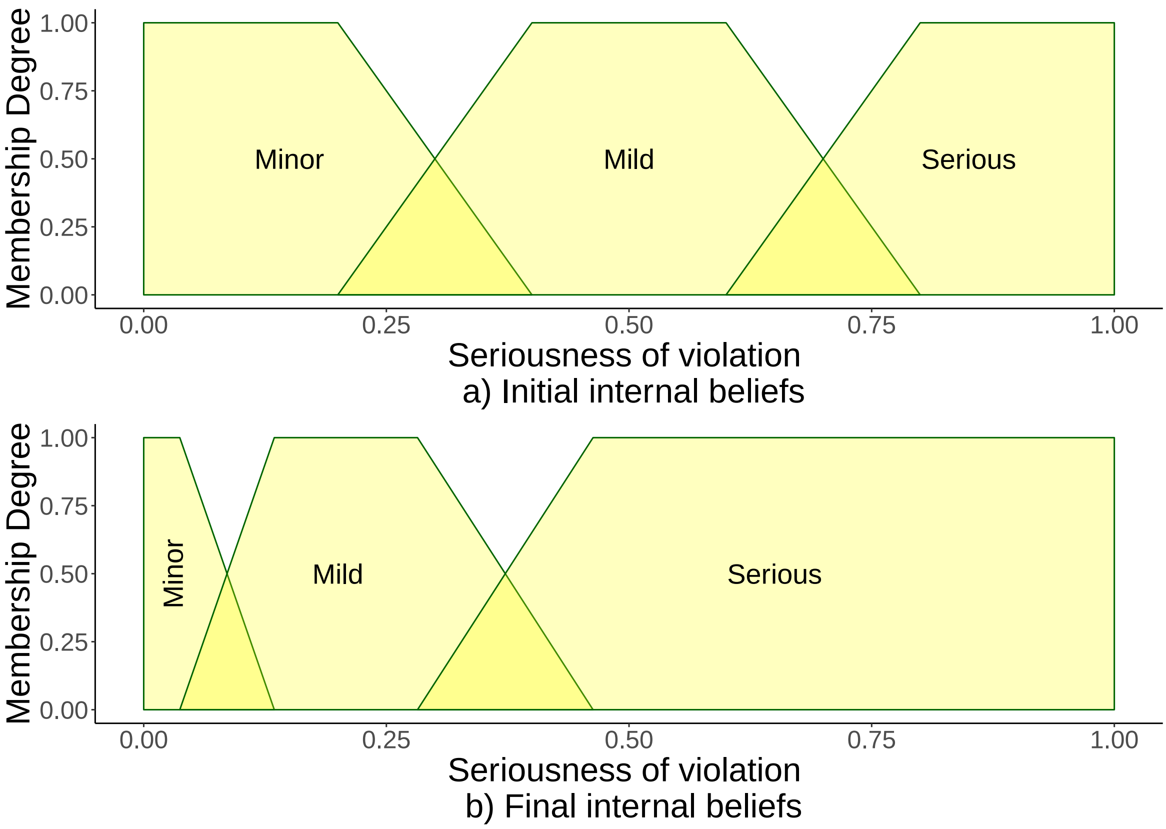


Figure 7.20: Changes in Julfans' internal beliefs in two snapshots.

One can see how agents made their beliefs stricter after a while (see Figure 7.20 b). The final state (i.e. following the rule strictly) had historically been reported for Julfans. For instance, Roques states Julfans' diligence.[26] Note that although the masters paid living costs,

[26]Roques states:

"These people [Julfans] are shrewder than the Indian sarrafs [sic], because they do not work alone, when it comes to evaluating their merchandise and money. More enterprising amongst them deal with all that is there [to trade in], and do not ignore the price of any merchandise, either from Europe or Asia, or any other place because they correspond with all others and receive rapid information on current prices wherever they are. Thus they do not get cheated in their purchases, and *are very economical, and work unbelievably hard to trade so as not to overpay on the merchandise. They spend very little towards their living. They are by nature* this thrift and prudential expenditures indicates that mercantile agents gradually adapted to the belief that their careless spending was not a minor violation of the contract. In particular, the distinction is more clear when we compare Julfans' behaviour with the EIC's employees' lavish lifestyle — the other group of merchants who were engaged in trade in the very same place and time — and note they should have covered their own living costs.[27]

Now we state the changes associated with the mercantile agents in the simulated EIC. Figures 7.21a and 7.21b indicate the gradual shift in the simulated EIC's societal internal beliefs and societal norms perceptions regarding the trade rule. As can be seen, the internal beliefs and perceived norms gradually move to the right (pink lines versus green lines). In other words, agents consider a violation less serious than what the rule originally meant. However, after iteration 70, when some agents leave the company and new agents replace them, the perceptions of beliefs and norms first move towards the left and get nearer to that of iteration 0, and after ten iterations, they move towards the right for an increase in the experience of the mercantile agents (orange lines). After iteration 100, the beliefs and perceptions are focused on about the same point (red and blue lines). A snap shot of these changes is provided in Figure 7.22.

Figure 7.22a indicates the patterns of changes in the simulated EIC societal perceived norms (i.e. perceived norms by all members of the society). After granting permissions for private trade, the cautiousness of new recruits regarding sharing their internal beliefs reverts to the average perception of norms near the initial state (see Figure 7.22 red and green lines). Note that perception of the norms also has lower changes compared to internal beliefs (further stated in Section 7.5).

Figure 7.22b presents the simulated EIC societal internal beliefs associated with the four iterations of interest, namely the first, the 70th, the 75th, and the last iterations. In this figure orange and blue trapezoids indicate the EIC societal internal beliefs at the first and last iterations, respectively. As can be seen, the internal belief of society gradually shifts to the right (red and orange lines) over the first 70 iterations. However, after granting permission for private trade, some agents leave the company to pursue their self-interests. Leaving the company and hiring new recruits whose beliefs are more consistent with the rules (i.e. their

> *accustomed to living frugally* [emphasis added]..." (Roques, translated by R. K. Husain, 1994, pp. 939–40, as cited in Moosvi, 1999, pp. 268–269)

[27] "Where the British lived in any numbers, [... s]ocial life revolved around field sports, riding or driving out in the evenings and a cold weather season of balls, assemblies and theatricals. [...] The scale of entertainments was lavish in the presidency cities, above all, in Calcutta, where cultural ambitions ran high. A string of notable painters from Zoffany [sic] to Chinnery [sic] competed for commissions there in the late eighteenth century."(Marshall, 1997, p. 101).

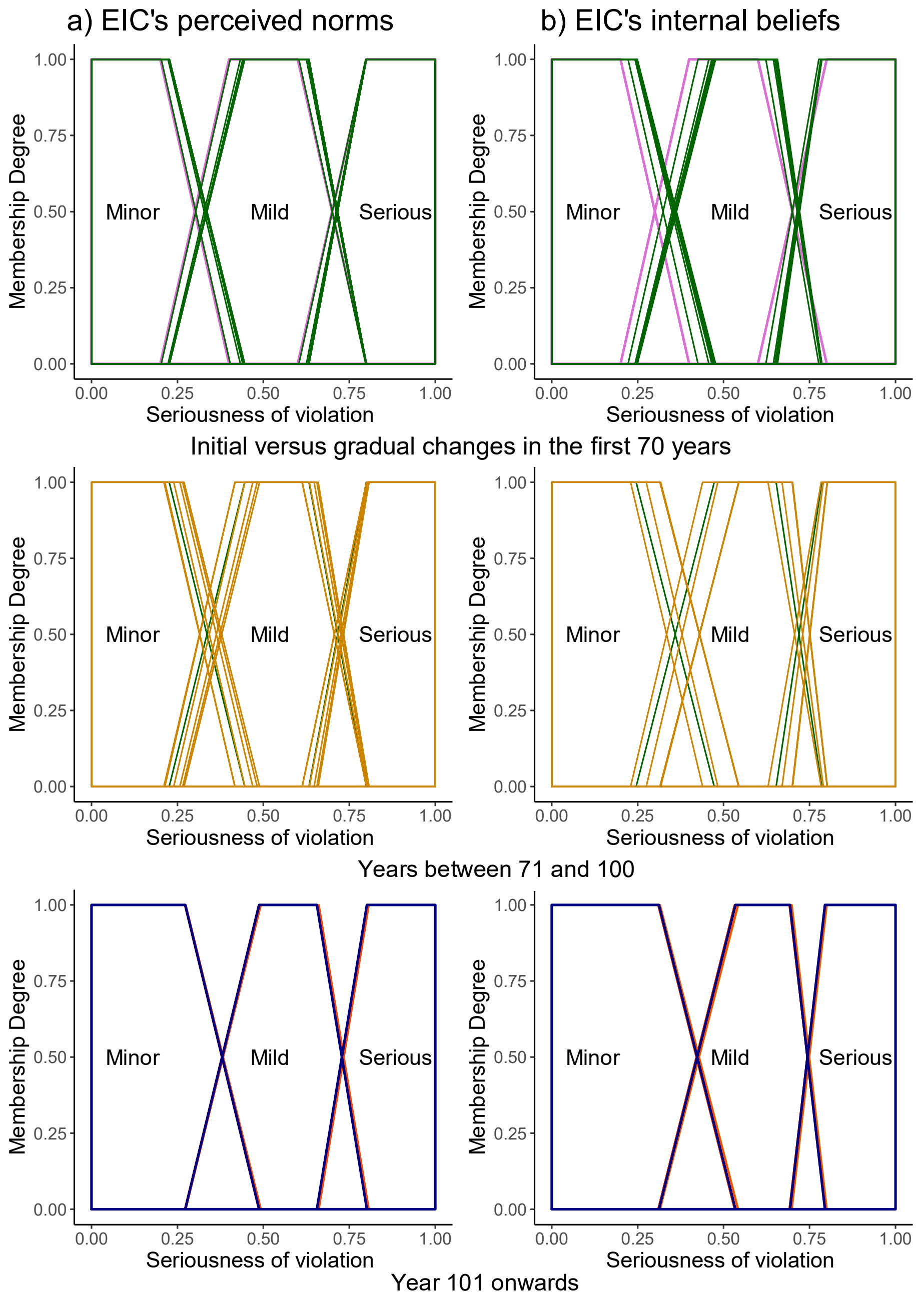


Figure 7.21: Changes in the simulated EIC's a) perceived norms and b) internal beliefs over time. The pink lines are associated with iteration 0, the green lines indicate iterations before 70, the orange lines are those of iterations 71-100, the red lines indicate iteration 101 onwards, and the blue lines indicate the last iteration. Note that historically, permission for private trade was granted in the EIC.

beliefs are not changed) moves the societal internal beliefs towards the left (green lines). Finally, a decrease in the fairness of the company as time goes by, moves the societal internal

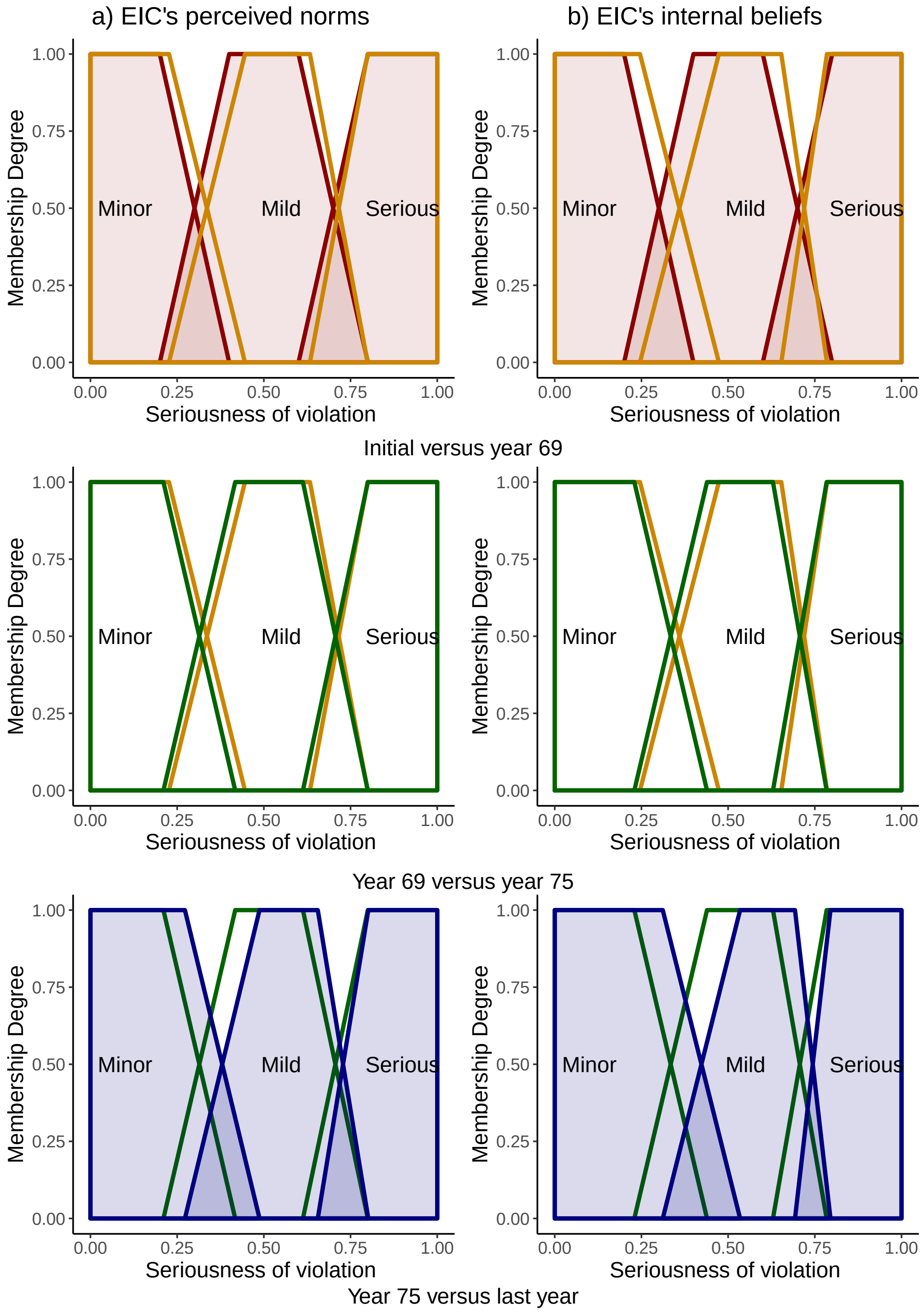


Figure 7.22: Changes in the EIC's societal perceived norms and internal beliefs concerning four points of interest. The red lines indicate that of iteration 0, the orange lines indicate iteration 70, the green lines depict iteration 75, and the blue lines indicate the last iteration.

beliefs towards the right (blue lines).

The simulation results match historical evidence. For instance, we know that mercantile agents used the company's capital for private trades. Evidence for the popularity of corrupt (immoral) behaviour in the EIC and its extensions is reported by Burke (1723–1792), by some of the EIC's directors, and by managers over time.[28] These arguments also point to a gradual change in mercantile agents' morals. Furthermore, those letters (i.e. 1618, 1711, and Burke comments), point out that this corruption had first been observed in the EIC mercantile agents' behaviour, then it had spread in the *host country* (i.e. India), and finally, it had impacted the home country (i.e. England).

Figures 7.23a and 7.23b present the last societal perceived norms and internal beliefs for the simulated EIC and Julfa. The red-edged trapezoids indicate the societal internal beliefs, and the yellow trapezoids indicate the societal perceived norms. First, we wish to compare the shifts, disregarding their direction for the simulated EIC and Julfa. As can be seen, the Julfan's societal internal beliefs shifted more than the EIC's (see red-edged trapezoid in Figures 7.23a versus 7.23b). The reason for such a difference lies in higher mortality rates in the EIC. The higher mortality rate leads to replacing more experienced individuals with inexperienced ones. Note that experience is a key element for adjusting internal beliefs regarding system institutions. This indicates the inverse effect of short-term contracts on knowing and adjusting internal beliefs. However, for systems with unfair institutions, such as the EIC, it may act for the benefit of the organisation.

Another difference concerns the average of the perceived norms of the two simulated societies (see yellow trapezoid in Figures 7.23a versus 7.23b that is caused by the mobility of

[28]The speed of the change in the internal belief is pointed out in the early letters such as the following:

> "At home men are famous for doing nothing; here they are infamous for their honest endeavours." (Original Correspondence, V, 595, 19 January 1618, as cited in Chaudhuri, 1965, p. 77)

Also, an EIC's director states:

> "It is a sad truth, [...] that in all parts of India where the Europeans generally come the natives soon learn to flatter, cheat, and wreck their malice whereas in the inland countries where few Europeans ever are, they are generally harmless and innocent and not inclined to mischief. The difference must be from the ill examples of those who call themselves Christians." (Despatch Book, 10 January 1711, vol. 97, para. 83, pp. 179-80, as cited in Chaudhuri, 1978, p. 113)

Burke (1723–1792) states the following:

> "all the tyranny, robbery and destruction of mankind practiced [sic] by the company in the East are popularized and pleasing to the country." (Seth, 2018, p. 179)

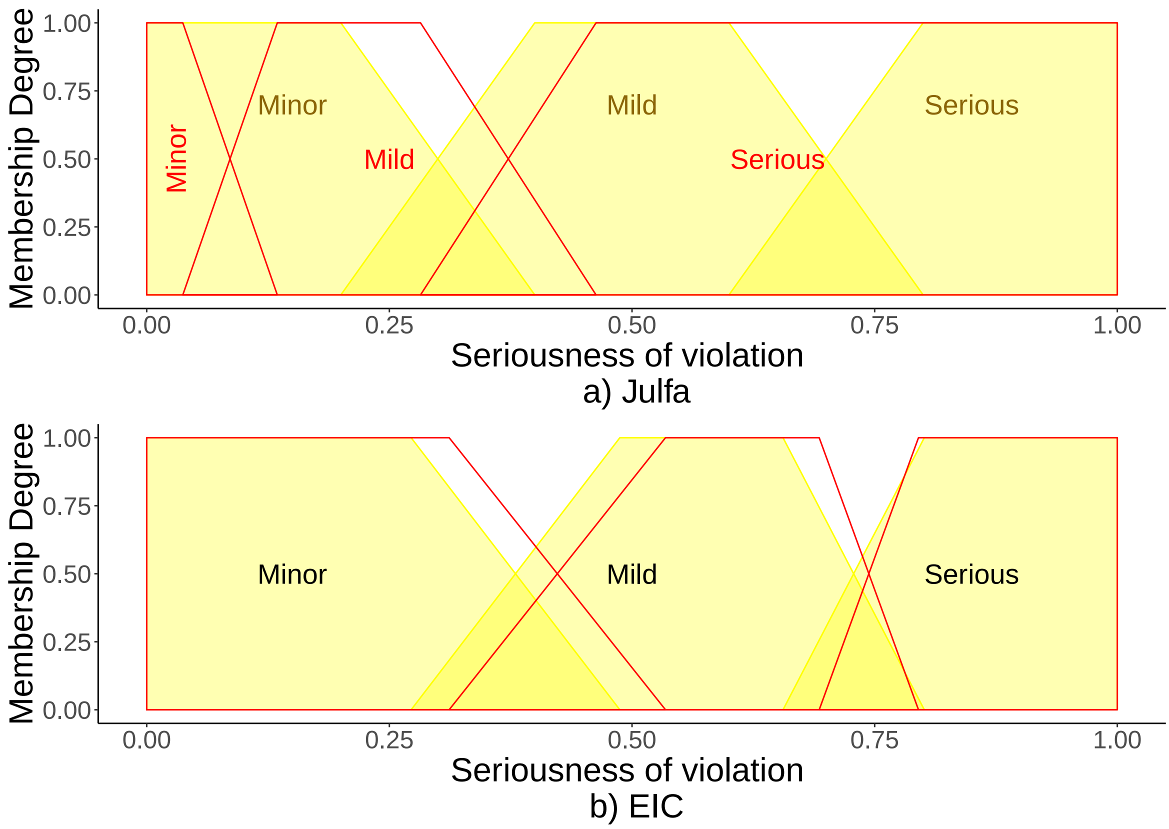


Figure 7.23: Differences between the last societal perceived norms and internal beliefs for a) Julfa and b) the EIC. Red lines are internal belief and yellow lines are perceived norms.

agents in Julfa. Note that societal internal beliefs (i.e. expectations, shown by the red-edged trapezoids) define the actual norm. However, mobile agents do not have strong friendship bonds and they do not state their internal beliefs. This gap has positive and negative effects — when societal expectations are more lenient than organisational rules, it helps the organisation's profitability. However, when society has stricter expectations (Julfa), not knowing them may decrease organisational profitability.

Now we investigate the smaller gap between societal perceived norms and internal beliefs (i.e. the EIC case; see Figure 7.23b). The misperceptions of norms have been observed in some previous studies (Blanton et al., 2008; Neighbors et al., 2006). However, for a drinking norm, the higher level of drinking behaviour on the part of students may cause them to exaggerate their peers' drinking norm (Neighbors et al., 2006). The previous study may apply here as listed below:

- Students in the study overestimated the drinking norm because of the exaggeration of older friends (i.e. they thought their own drinking behaviour was less than average). In conformance with that norm the younger students tended to exaggerate their own drinking behaviour. This would have had the same impact observed in our simulation. Note that in our model, we assumed that agents believe the society expects them to follow the rule.

- The students in the study were biased about collecting information related to their behaviour to justify their action and reduce their cognitive dissonance. In our model, we did not consider such a biased information collection; however, the model can be extended to include such a phenomenon.

The solution to overcome the misperceptions is to correct agents' understanding of the norm. Note that in the EIC, the directors did not have any incentives to let the agents learn the real norm (i.e. more tolerance towards cheating). However, in Julfa, some evidence, such as the correspondence of cousins and two brothers,[29] indicates attempts at such corrections.

## 7.5 Conclusion and discussion

This chapter has presented a simulation model for investigating the rules of long-distance traders and has examined the key characteristics impacting rule-following behaviour of agents in historical cases. The main aim of the simulation has been in identifying the impacts of institutional mechanisms and social characteristics on rule-following and monitoring strength. In addition to the two historical long-distance trading societies, we have considered other hypothetical societies, and we measured several indices to identify different aspects that potentially improve our simulation model.

To perform this modelling, we addressed four characteristics of the system, namely the mobility of agents, the impact of environmental circumstances, apprenticeship programmes, and the fairness of institutions. In our simulation, we systematically mapped the characteristics mentioned above into general societies, these societies also capture basic real-world scenarios. We also considered three time intervals, namely before the opportunity of permitting private trade (iteration 70, A), after that opportunity and before market saturation (between iterations 71 and 99, B), and during market saturation (iteration 100 onwards, C). Note that differences between the two historical long-distance trading societies have inspired these characteristics.

In Julfa, mercantile agents were **mobile** and they did not reside in a certain trading spot for a long period. However, in the EIC, mercantile agents mostly resided in their settlements,

[29]The first one is the letter that stated the flavour of a letter (Aslanian, 2007, p. 182), and the second, stated the consequences of being blacklisted (Aslanian, 2007, pp. 248–249).

leading to forming friendship groups and possessing information rents (i.e. trade-related information of mercantile agents not provided to the principal). Furthermore, although mercantile agents of Julfa and the EIC worked in India and Europe, they faced different **environmental** circumstances. The evidence indicates that the Indian subcontinent climate was not conducive to Europeans. The unfavourable environment reduced agents' life expectancy and impacted their ability to make future-oriented decisions.

The **apprenticeship** programme is a future-oriented policy that has already been separately addressed as a model for its importance (see Chapter 5). In this chapter, we have investigated the impact of apprenticeship programmes on controlling cheating. However, we have limited its impact to the enhancing agents' skill, and improving their perception of the system's characteristics and system's rules. The last characteristic of the system is the **fairness** of the institutions; in our model, we have considered substantial costs for possessing fair institutions as a consequence of sharing significant profits. Finally, in our model, cheating is limited to manipulating profits (i.e. the cheats would not cause a negative balance). What follows is a summary of the main findings accompanied by a discussion.

An overview of the simulation results is presented in Table 7.9. In this table, columns indicate the aforementioned intervals (A, B, C) for each characteristic. The rows indicate the measured output variable in our simulation. Also, a cell of this table indicates the values of the correlation between the output variable and the characteristics for an interval.

The **mobility** of agents has a positive impact on all aspects of the system; however, this impact for most cases is weak. More precisely, looking at the three columns associated with the title 'Mobility', we see private trade, rule violation, seriousness of violation, and monitoring strength are weakly impacted by this characteristic. However, not residing in a node for long periods prevents mercantile agents from creating strong friendship bonds with other employees, as well as local traders. This causes a moderate correlation between mobility and **system profitability**.

Benefiting from a **favourable environment** has positive influences on the agent's behaviour; however, the correlation is weak. The only exception for this is the firing of violators after market saturation (the correlation is $-0.03$ and the $p\text{-}value = 0.05$). This indicates an increase in societal tolerance of violators in a favourable environment. Finally, it is worth noting that a favourable environment has a weak and negative correlation with rule violation (it weakly deters employees from cheating). This can be caused by the impact of an unfavourable environment on decreasing agents' discount factor, which mirrors empirical studies that indicate the deterrent impact of high discount factors on committing crimes (Lee & McCrary, 2005).

Table 7.9: A summary of correlations

| Output | Characteristics | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mobility | | | Favourable environment | | | Apprenticeship | | | Fairness | | |
| | A | B | C | A | B | C | A | B | C | A | B | C |
| Bureaucratic rules | −0.08 | −0.04• | −0.05 | −0.04• | −0.04• | −0.06 | −0.32 | −0.34 | −0.35 | −0.71 | −0.71 | −0.71 |
| Rule violation | −0.1 | −0.1 | −0.08 | −0.21 | −0.22 | −0.28 | 0.24 | 0.2 | −0.02• | −0.7 | −0.7 | −0.7 |
| Seriousness of violation | −0.14 | −0.12 | −0.08 | −0.13 | −0.14 | −0.19 | 0.13 | 0.11 | −0.05 | −0.7 | −0.7 | −0.7 |
| Fired violators | 0.13 | 0.15 | 0.22 | 0.03• | 0.06 | −0.03 | 0.3 | 0.44 | 0.49 | 0.11 | 0.27 | 0.07 |
| System profitability | 0.3 | 0.45 | 0.59 | −0.09 | 0.06 | 0.11 | 0.38 | 0.42 | 0.46 | −0.57 | −0.41 | −0.08 |

• means statistically insignificant

A is the period before the opportunity of granting permissions for private trade (years 0–70).

B is the period after A and before market saturation (years 71-99).

C includes the year 100 onwards.

The **apprenticeship programme** has a weak correlation with violating rules. Based on these correlations, changes in signs, and the significance of correlations over time, it is obvious that an apprenticeship is not successful in deterring agents from cheating. A reason for this is an improvement in the degree of skills increases the profits made; hence, there is more temptation to cheat. Especially, in this model, apprenticeship programmes would not increase moral costs associated with violating the rules; however, through increasing the skills, it increases the agents' access to the company resources and the income obtained from a given violation — the observation was made in the EIC firing patterns (see Section 2.3.1). Furthermore, the absolute value of correlation between apprentice programme and performing private trade (i.e. breaking bureaucratic rules), firing violators, and system profitability is more than $0.3$. The signs and strengths of these correlations indicate that apprenticeship programmes were almost successful in these aspects.

The **fairness** of the system has negative and strong correlation with all of the rule-following aspects of the system (i.e. private trade, rule violation, and seriousness of violations). In other words, the fairness of the institutions successfully deterred agents from violating the rules. The fairness also has a positive and weak correlations with firing the violators. This indicates that a fair institution is more successful in preventing crime. However, the correlation between income and fairness of the system was strong and negative for most periods (i.e. the costs exceeded savings over time). This result is in accordance with the intuitions of the chartered companies' directors — they believed that the costs of being fair are more than the profits.

A result of this simulation is shown by the visualisation of the EIC and Julfa fuzzy beliefs. The simulation results and historical evidence suggest that the fairness of the system influences agents' internal beliefs. This change in internal beliefs can be extended to the outside of the organisation through "making bad examples" or conveying the justifications to others (i.e. the society that agents work in or come from). Note that this kind of change in attitude is more of a moral concern than an economic issue. For instance, Ruggiero (2013) says Adam Smith's promotion of the idea that in an economy our actions are governed by our self-interests is used by criminal entrepreneurs to justify their wrongdoings.

Now we state the results related to other historical trading societies that indicate the importance of apprenticeship programmes for long-distance trading. When we compare Genoese and Venetian societies, we see both of them have used commenda contracts to manage their trades. However, a difference between the two societies concerns using apprenticeship programmes. In other words, while Genoese did not have apprenticeship programmes, Venetians invested in that (see Colavizza et al., 2019). The war of Chioggia exemplifies the importance of investments made by Venetians. After this war, the Venetians' trade rapidly recovered while Genoese trade declined. Another possible reason for Genoa's decline could be getting involved in factional rivalries; however, recovery of Venice after the war emphasises the importance of such investments especially in critical times.

Now we wish to discuss some limitations of the current chapter. In our model, we were conservative about cheating behaviour. In other words, we assumed the cheaters have perfect information about the consequences of their behaviour for the organisational profits. We also have not addressed the cheating behaviour of the managers, which impose high costs on the system for their access to the resources (Ville & Jones, 1995). For this purpose, imperfect information games with asymmetric utility functions can be employed in the future. For such modelling, two distinctive cost functions regarding cheats should be utilised. One of these functions should indicate agents' perception of the costs and the other indicates the real consequences. The imperfect information game with asymmetric utilities is a realistic approach for strictly salaried agents who do not have any information about prices at the destination (e.g. EIC).

In what follows, we state some simulation results that indicate the importance of other aspects of considered societies. The simulation results indicate that, before market saturation, the number of cheaters increases when the system has apprenticeship programmes. As stated earlier, in the simulation model, an apprenticeship increases skills and improves agents' understanding of the rules. Making more profits because of higher skills, and a faster increase in the agents' access to the company resources are some reasons for these observations. Historically, in the EIC, more experienced agents tended to cheat more (see section 2.3.2.1 and Hejeebu, 2005). However, these results emphasise the importance of considering other impacts such as screening and choosing trustworthy agents (e.g. see Frantz et al. (2015)). These considerations may improve the impact of apprenticeship programmes on profitability. In our simulation, trustworthy agents have more mental costs regarding their internal beliefs and consequently cheat less. Note that Machiavelli (1998) discussed the impact of associating significant costs with internal beliefs on social order.[30] In this model, we

[30]Machiavelli stated the following that indicates how internal beliefs could help a governor to bring order into society:

> "Lucius Manlius, father of Titus Manlius, who was later called Torquatus, had been accused by Marcus Pomponius, tribune of the plebs; before the day of the judgment [sic] came, Titus ... threatening to kill him if he did not swear to drop the accusation against his father, he constrained him to take the oath; and Marcus, having sworn through fear, dropped the accusation. So those citizens whom the love of fatherland and its laws did not keep in Italy were kept there by an oath that they were forced to take; and the tribune put aside the hatred he had for the father, the injury

narrowed the apprenticeship's impact to test the adequacy of correcting rule-understanding during an apprenticeship; hence, we did not consider screening the agents (i.e. identifying agents with more costs associated with their internal beliefs).

Another finding of this study was the negative impact of the mobility of agents on learning social norms (i.e. modified beliefs and expectations of the society). This issue can be addressed by considering the impact of norm learning/enforcement (feedback) for the correction of agents' behaviour (value aggregation) using the notion of nested-ADICO (see Frantz et al. (2013, 2014)). To avoid adding complexities that would make it hard for us to identify the impact of other characteristics on the system performance, we did not use the corrections (e.g. reinforcement learning). However, the results suggest that mobile agents need additional means for a better norm understanding. The means include the closedness of society (e.g. Julfa), which provides the opportunity to learn the norms inside the families, improving agents' perceptions of norms by notifying them, and using methods such as nested-ADICO.

There are some potential extensions to this study that we wish to point out. First, more advanced studies such as Farhangian (2018) can be used to investigate the impact of personality on team formations and recruitment in organisations. As stated earlier, the impact of the apprenticeship on increasing the trustworthiness of agents can be included in the model. Also, utilising other methods for norm understanding would help make the model more realistic.

Furthermore, the refined BDI cognitive architecture can be used to interact with institutional mechanisms designed by employing the RMDL principles (Purvis & Purvis, 2014), which include human **rights**, free access to **markets**, **democracy**, and the rule of **law** to investigate the influence of them on designing system mechanisms for managing a trading society. In the following, we briefly state these four principles:

- (Human) Rights — These rights are given to all members of society and among them is freedom of speech that guarantees the opportunity of interaction and a free exchange of ideas.
- (Free access to) Markets — This points to the need to establish exchange markets to facilitate a fair exchange of goods and services across society. This provides a suitable environment for societal collective benefits.

that the son had done him, and his own honor to obey the oath he had taken. This arose from nothing other than that religion Numa [sic] had introduced in that city." (Machiavelli, 1998, Section 2, p. 34)

- Democracy — The society needs to involve all its members in decision-making (e.g. rules established by representatives of people).
- (Rule of) Law — The society needs to have a set of clearly written rules for interactions and regulating the society. These laws can be revised by actions of the democratically-elected government.

Now we present some instances of interaction between these two modelling approaches — i.e. the refined BDI for cognitive architecture and the RMDL for designing institutional mechanisms. Human ***Rights***, in terms of freedom of speech, help the individuals to state their ideas better; hence, perceived norms can be corrected (i.e. they raise social awareness about the expectations of others). Also, not identifying internal beliefs of agents — depriving agents from freedom of speech — causes issues such as feeling deep dissatisfaction through cognitive dissonance (e.g. see Kassing, 2000, for observations made of employees' dissatisfaction in the workplace). Free access to the ***Markets*** not only impacts the economic performance of society (e.g. by removing the influence of agents' position on their future and certain inclusive priorities and opportunities they may have), but it also impacts agents' cognition regarding the system. For instance, granting a monopoly, empowering guilds, and placing other kinds of obstacles in the way of agents is conceived as an unfair action. However, in the modelling, the negative impacts should be considered — e.g. this liberalisation may increase poverty (Winters, 2002, provided a checklist to assess the possibility of such an impact). ***Democracy*** is a way that provides the opportunity of reflection of agents' internal beliefs in society. Also, it helps the agents to adjust their perceptions of the majority's expectations — e.g. Tyran and Feld (2002) showed that the referendum improves agents' rule-obedience. Also, the refined BDI cognitive architecture model can be used to take account of the different aspects of democracy to test the consequences of different theories, such as 'public choice theory' (e.g. using game theory for making political decisions), and to investigate concerns about the impact of voters' preferences on predicting Senators' behaviour (Griffin & Newman, 2005). Also, the interaction with a deliberative democracy is through persuasion, given the following definition:

> "[D]eliberation involves discussion in which individuals are amenable to scrutinizing and changing their preferences in the light of persuasion (but not manipulation, deception or coercion) from other participants. Claims for and against courses of action must be justified to others in terms they can accept." Dryzek and List (2002)

However, the refined BDI cognitive architecture, similar to real-world cases, also looks at the impact of manipulative persuasion. The impact of the rule of ***Law*** on preserving order in society has two aspects. First, having clear rules reduces the possibility of subjective decisions, and decreases uncertainties regarding rule-understanding in the system. Second, the rule of law provides mechanisms for the time when the majority feel there is a need to change the rules. This need can be addressed by changing the rules or persuading the society of the rules' benefits. The latter is important to avoid frequent changes in the rules (i.e. stability). For this purpose (i.e. persuading the society instead of changing the rules), the refined BDI cognitive architecture could be extended to include the articulation of ideas and information considering the impact of influential figures or broadcasting media (see Rossler, 2000; Sears & Kosterman, 2005, for more discussion).

# 8

# Discussion and conclusion

In this chapter, we provide a summary of what has been stated in the earlier chapters, along with our contributions. We also provide some future directions as well as some limitations of this work. The structure of this chapter is as follows. Section 8.1 states the main contributions of this thesis. Section 8.2 states some limitations of the thesis and some future directions. Finally, Section 8.3 provides concluding remarks for the chapter.

## 8.1 Contributions

In this thesis, we have developed three agent-based simulation models to identify, and systematically study, the key institutions and characteristics of two historical long-distance trading societies, namely the EIC and Julfa. We have also evaluated the successes of these trading societies using different metrics. The thesis work has used agent-based social simulation as an approach to develop novel models of the long-distance trading societies. Below, we list our modelling contributions in this thesis work:

- Chapter 4 has developed a model to investigate the impact of contractual schemes and environmental circumstances on the success of the societies by considering agents who maximise their utility made in terms of money.

- Chapter 5 has developed a model to investigate the impact of apprenticeship programmes and vocational schools, along with other characteristics of the system, on the success of societies.
- Chapter 6 has refined the BDI cognitive architecture by considering the impact of personality and different belief components. It has also used type-1 fuzzy sets to model agents' understandings of the seriousness of violations.
- Chapter 7 has developed a model to investigate the impact of the characteristics of institutional mechanisms on the success of the society.

Note that in our modelling, we have also gone beyond the two historical long-distance trading societies by a) modelling other societies, and b) mapping combinations of their characteristics into some societal stereotypes. Using the societies, we confirmed our model; however, we believe this model can represent other societies too. Also, mapping characteristics can help users, after adjusting model parameters, to identify the best policies. In other words, by using societal stereotypes, one can make predictions by asking *what-if* questions. This way, the models can be used for other societies after estimating the value of parameters and by adding constraints specific to the new society (e.g. estimating the discount factor for the net present value of money or considering budget constraints). Note that, overall, these models can be used or extended for trading societies or to simulate systems in a more general context.

### 8.1.1 Impact of the contractual scheme and environmental circumstances

This subsection briefly states our first contribution — the model developed in Chapter 4. This model has addressed our first research question — i.e. "how do different *contractual schemes* and differing *environmental circumstances* impact the success of these societies?" We have developed a model to investigate the impact of contractual schemes (including contract management schemes) and environmental circumstances, in terms of mortality rates, on the success of the long-distance trading societies for agents who just consider utility function in terms of money. To implement this modelling, we have extended Greif's (1993) model by considering the impact of the limited transparency of cheating behaviour and more contract management characteristics than just the payment scheme employed. What follows briefly states the addressed contract management characteristics in the first model.

First, we have investigated the impact of the preference of long-distance trading societies for hiring recruits. The societies can have different hiring preferences; for example, a society may prefer to hire known recruits — e.g. its agents' relatives — and form a closed society or it simply hires recruits who are unknown to the company owners and forms an open society of traders. We have also considered two distinctive payment schemes, namely bilateral commenda contracts — a profit-sharing contract where a significant ratio of made profit is shared and agents have the opportunity to be a partner in trades — and fixed payment with the opportunity of private trade — i.e. conducting trades in non-monopolised items. Another important aspect of managing contracts concerns how an agent's behaviour is assessed. In our model, the company may choose not to use the courts to fire cheaters or to use a performance-based firing instead. After identifying an inappropriate behaviour (e.g. cheating), we investigated how it was penalised. The considered penalties in our model have different varieties, including the possibility of confiscating bonds and requiring the paying back of the illegal income along with the accumulated interests. We also have investigated the impact of agents' conformity to potential cheaters' policies, based on the proportion of cheaters observed. Note that this model also showcases the impact of a combination of penalties and payment schemes for more general contexts. We have used these models to study what happened in the two long-distance trading societies of interest — the EIC and Julfa. Some of the findings of our simulations are stated in the next paragraph.

First, the high mortality rate that the European chartered companies have dealt with in Asia, made it impossible to use a closed hiring scheme — i.e. they would have needed an extremely high birth rate to cope with this situation. Profit-sharing — i.e. using commenda contracts — pays back itself by deterring agents from cheating (e.g. see Section 4.4.1.1 and 4.4.1.2). Having strong monitoring mechanisms — e.g. forming a closed society to monitor agents better — when wages are low, in comparison with profits of cheating, does not deter agents from cheating (e.g. see Section 4.4.1.1). If we consider the impact of conformity on agents' behaviour (i.e. some agents consider cheating based on the number of observed cheaters), closed societies lacking profit-sharing face an increase in the number of potential offenders (see Figure 4.13). Finally, considering different consequences for contractual schemes and adjudication processes employed, indicates that the best mechanisms to deter agents from cheating in the EIC — where the company paid fixed wages — were the performance-based firing and asking for bonds (see Sections 4.4.3.1 versus 4.4.1.1 and 4.4.2.1).

### 8.1.2 Apprenticeship model and vocational schools

This subsection briefly states our second contribution — the model developed in Chapter 5. This model has addressed our second research question — i.e. "how do successful societies maintain *skill levels* over time? What are the impacts of employing different mechanisms, including *apprenticeship programmes* and *vocational schools*, on the success of skill development?" For this purpose, Chapter 5 has modelled training schemes, taking account of the impact of apprenticeship programmes and vocational schools. This has essentially modelled an aspect of the CKSW meta-modelling approach, that is, converting people with the Worker meta-role into people with the Skill meta-role. In this model, we have considered different success metrics, which include completion ratio, societal skill levels, and societal profitability. To do this modelling, we went beyond the two historical long-distance trading societies by including two contemporary cases (i.e. the German and British apprenticeship programmes) and an additional historical case (old Britain). The study aimed to identify the impact of apprenticeship programmes and societal characteristics on the success of the society. However, this model also addresses improving skill levels in a society, which is beneficial for other contexts. What follows states some other characteristics that have been used in our model.

First, we have divided the systems into two trade types, namely manufacturers and artisans. These trade types have different needs — e.g. manufacturers need a high level of analytical skills (e.g. engineers), while artisans need fine motor skills (e.g. potters). We have also considered different trainer types to address differences in trainers' incentives — e.g. a training contractor may have a different incentive to train someone than a potential employer would have. We have also addressed different recruiting schemes to cover the hiring and training restrictions — e.g. conditions imposed by guilds and unions and the closedness of the society — and the associated training costs. For manufacturers, who need analytical skills for success, we also addressed the engagement of schools (i.e. vocational schools). This concerned the impact of declarative knowledge and skills obtained in the vocational schools on system performance. We have also used certain values for our parameters to test the model for our considered cases, and the next paragraph states some of the findings of this model, based on the parameters used.

The model indicates that the effectiveness of training by firms increases, if trainers want to hire skilled apprentices (see Figures 5.2 and 5.5). Also, interventions by government should focus on moderating the number of smaller companies who train agents to balance the workforce market and providing vocational schools (see Figure 5.5). Guilds may have negative impacts on societal skill level because they deprive some skilled agents from using their skills; hence, they deter potential apprentices from participating in the programme (see Figure 5.8 and discussions of Wallis, 2008, about the impact of the guilds). Another finding concerns the importance of the closedness of societies for the success of apprenticeship programmes, especially when governors aim to attract companies' collaboration.

This closedness has two sides — immigration and emigration. Overall, skill emigration decreases the completion ratio and the contribution of apprenticeship programmes to the GDI of societies (see Figures 5.2, 5.1, 5.7, and 5.8). Also, apprenticeship programmes in open societies that host immigrants may face some issues in completion rate and the contribution of these programmes to the GDI (see Figures 5.6 and 5.6) — e.g. they may not need such programmes. Note that a potential reason that bigger companies did not train in Britain is the opportunity of finding low-wage skilled agents from other countries; for instance, McCollum and Findlay (2015) pointed to lower wages and higher flexibility of immigrants compared to those of local employees in Britain.

### 8.1.3 The impact of the characteristics of the institutional mechanisms on an agent's rule conformance

This subsection briefly states our third contribution — the models developed in Chapters 6 and 7. These models have addressed our third research question — i.e. "how do the characteristics of *institutional mechanisms* (e.g. fairness) impact the success of these societies?" For this purpose, in Chapter 6, we have extended the beliefs-desires-intentions (BDI) cognitive architecture by considering the impact of personality and different belief components, such that it can interact with institutional mechanisms and the CKSW meta-role modelling approach. We have also employed type-1 fuzzy sets to model agents' utility functions reflecting their understanding of the seriousness of a violation and its associated consequences. In Chapter 6, we have also provided an operationalisation of our BDI cognitive architecture based on empirical studies. In Chapter 6, the main characteristic of institutional mechanisms that impacted agents' decisions was fairness of institutions. Note in addition that, the proposed refinement of the BDI cognitive architecture can also be employed to investigate the interactions with institutions and meta roles from other points of view.

Chapter 7 has utilised the extended cognitive architecture of Chapter 6 to model agents' decision-making and interactions with institutions. To build this simulation model, we have drawn inspiration from the two historical long-distance trading societies. We have also used different success metrics, which include societal rule conformance, societal profitability, changes made to the rules, and system monitoring strength (firing violators). In our model, we have also addressed the impact of the mobility of agents, which restricts the formation of strong friendship bonds, as well as the apprenticeship programme, and environmental circumstances. In the next paragraph, we elaborate some findings of the simulation conducted, based on the parameters' values inspired by the two trading societies in question.

The apprenticeship programme has a moderate correlation with improving monitoring strength, as well as deterring agents from private trade (see Table 7.9) — i.e. they also improve the loyalty of some agents. The fairness of the institutions is a pivotal aspect, when the company concerns rule monitoring and rule conformance; however, it does not guarantee improvements in a system's profitability (see Table 7.9).

Using unfair institutions increases the frequency of violations. In other words, the unfair institutions facilitate the justification of illegal behaviour and increases the seriousness of violations (see Table 7.9). In other words, the agent underestimates his violations — e.g. he considers stealing the company's properties the same as reading news at work (see Figure 7.21).

What is stated above also addresses a concern that arose in Greif's (2008) argument against Edwards and Ogilvie (2011)[1] regarding utilising adjudication processes. Greif (2008) suggested that no adjudication processes were used in the reputation-based system of Maghribis. However, not using adjudication processes decreases the fairness of a society — i.e. it may have negative impacts on agents' behaviour.

## 8.2 Limitations and future directions

### 8.2.1 Limitations

Although our models explain the essential aspects of the systems, they also have some limitations. These limitations are categorised into two subcategories, namely simplifications and a lack of quantitative data.

The first subcategory (i.e. simplification) includes instances such as simplifying the apprenticeship model by considering only one type of skill and not modelling agents' preference of some skills over others. Another instance concerns learning social norms through information sharing or having an a priori understanding of social norms — i.e. we did not address learning new norms by mechanisms such as reinforcement learning in Chapters 6 and 7. In our modelling of changes in institutions (Chapter 7), we did not model the impacts of a country's governors' decisions on trading societies. This aspect is important as a future direction, because all the issues that convinced Julfans to leave Iran happened in 25 years due to changes in governments and rulers — starting with the Afghan wars in 1722 and ending with Nadir Shah's death in 1747. The same happened for the EIC. The EIC faced problems because of the parliament's interventions such as cancelling the EIC's monopoly

[1]Edwards and Ogilvie (2011) had earlier published their work as a working paper.

and reducing their influence over the military. Most of such limitations are stated in each chapter.

However, the second limitation subcategory (i.e. lack of quantitative data) should be addressed through lab studies. For instance, although we know that motivation has a positive effect on learning, we do not know the coefficient (i.e. does it increase the speed of learning by 20% or by 50%?). Another instance concerns the correlation between the fairness of the institutions and personalities. The question is how to incorporate specific personality dimensions in connection with how they change their behaviour. For instance, do all personalities change agents' behaviour if the institutions are unfair, or it is just those personalities who are near one extreme of dimensions?

### 8.2.2 Future directions

Some future directions for this thesis work are stated here, in the same sequence of chapters. The approach employed in the first model (i.e. considering limited information transparency) can be used to test mathematical models developed using game theory. Note that a strength of the agent-based modelling is providing a platform for agents who learn over time, based on local information. However, most game theory models either overlook this uncertainty or use expected values to calculate utility functions associated with all agents. These models, including our model, can also be extended by considering agents' learning biases (Mesoudi et al., 2006; Rendell et al., 2011).

A future direction for the second model (i.e. apprenticeship programmes) concerns modifying the models to address other types of trades — e.g. service sectors such as tours — by adjusting the value of parameters and choosing the influential aspects — e.g. added value by vocational schools. Also, some apprenticeship programmes may be judged, based on their trainees' performance. However, a low level outcome may be primarily influenced by a low-quality of trainees' intake.

Also, the extension of the BDI cognitive architecture can be employed to interact with institutions designed using Ostrom's (1990, p. 90, Table 3.1) principles for "governing the commons". For instance, for boundaries that are unclearly defined (breaching the first principle), we can use more variations for the fuzzy understanding of permissions granted. Also, our method for modelling a fuzzy rule-understanding can be used to model agents' understanding of graduated sanctions.[2] Also, using "conflict-resolution mechanisms" (Ostrom's sixth principle) improves agents' perception of fairness and impacts agents' collaboration

[2]The fifth Ostrom principle states: "appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense)."

in monitoring (Ostrom's fourth principle).[3] Another potential extension of the refined BDI cognitive architecture is attainable if we agree there are some objective moral standards (i.e. moral principles that are independent from social values). This helps us to consider some embedded principles for agents disregarding their societies that can be awakened with proper discussions.[4]

Now we wish to state a general extension of the earlier models, that is, considering decision-makers' characteristics and desires. For instance, it might be hard to convince managers like those of the EIC to use fair institutions, because, as stated earlier, the EIC was formed through a monopoly privilege. EIC managers disregarded their employees' welfare, and that restricted the managers from accepting the value of investing in the fairness of institutions. However, the Julfans shared the same background and sometimes were from the same family, which made it easier for them to be fair out of altruism. Taking account of such differences — e.g. altruism rewards in utility function for some agents or skipping certain policies for others reflecting their prior beliefs — would make the model more general.

## 8.3 Concluding remarks

In this thesis, we have presented three agent-based models to simulate long-distance trading societies. The theme of these models was inspired by the two historical long-distance trading societies, namely the Armenian merchants of New-Julfa (Isfahan, Iran) and the British East India Company. Comparing these two societies helped us to identify various characteristics used in our models. We have also employed evidence from additional societies, as well as contemporary experimental studies, to make the models generic.

The first model extended Greif's (1993) model by considering the impacts of limited

[3]Ostrom's fourth and sixth principles concern "monitoring" and "conflict-resolution mechanisms." The principle concerning "monitoring" states: "monitors, who actively audit CPR conditions and appropriator behavior, are accountable to the appropriators or are the appropriators." The principle concerning "conflict-resolution mechanisms" states: "appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials." Also, (Ostrom, 1990, p. 94) said that "in all of the long-enduring cases, however, active investments in monitoring and sanctioning activities are quite apparent."

[4]Note that this is a controversial matter. Some philosophers such as Shafer-Landau (2003, 2012) believe in the existence of such principles, because denying them facilitates blaming the actions on social values — e.g. "is human sacrifice acceptable because it is popular in a society?". However, other philosophers, such as Mackie (2012) and Blackburn (1999), discuss that such principles are not real, and morals equal either subjective values or a normative understanding. Because of such unsolved debates for us, it was difficult, if not impossible, to consider moral principles as an independent component in our model.

information transparency and punishments beyond firing, as well as social characteristics in terms of the closedness of society and the mortality rate.

With the second model, we looked at apprenticeship programmes with an emphasis on societal skill and income improvement. We have used different parameters (e.g. considering different trades) that impacted training schemes (e.g. employing vocational schools). For this model, we have also investigated contemporary apprenticeship programmes. Using these programmes, we found that the basically considered characteristics — not so much the exact methods — of historical societies can still be employed to model and predict the performance of contemporary apprenticeship programmes — and this emphasises the usefulness of "learning from history" suggested by Hegel (Little, 2017).

The third model has refined the BDI cognitive architecture such that it can interact with CKSW meta-roles and institutional mechanisms. We have used this model to investigate the impact of the fairness of institutions and additional institutional mechanisms on the rule-conformity of society.

These models can be used as a package to study the impacts of different institutional mechanisms on the success of a society. More precisely, the second model can be used to make decisions about how to prepare new recruits by employing apprenticeship programmes and vocational schools. The first and third models can be used to decide about organisational mechanisms and structures. More precisely, the first model addresses the impact of the societal structure (e.g. closedness versus openness) and different types of punishments (e.g. asking for bonds) for societal success. The third model investigates the interaction of agents (employees) with the institutional mechanisms and system characteristics. Note that the third model is more appropriate if the user wants to invest in the fairness of the institutional mechanisms. However, the first model is more conservative, because agents only consider the utility function in terms of money.

Overall, although this thesis has developed models for long-distance trading societies with an emphasis on the two historical societies, the proposed models can be used or extended to other trading societies. Also, some models (e.g. the refined BDI cognitive architecture) might be used in simulating agents' interactions with institutional mechanisms in a more general context.

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# A

# Impact of random seeds on simulation results

In this appendix, we present some histograms to investigate the impact of random numbers on simulation results. For this purpose, we present histograms associated with the last results of selected metrics for each chapter. In this thesis, we evaluated the simulation results by averaging different runs, because a "goal in analysing output data from running a simulation model is to make a valid statistical inference about the initial and long-term average behaviour of the system based on the sample average from N replicate simulation runs" (Garrido, 2009). Also, the law of large numbers states that the average of performing the same experiment converges to the distribution mean (von Luxburg & Schölkopf, 2011). Different scholars mathematically proved this theory (e.g. see Etemadi, 1981). Some studies suggest that 30 experiments are sufficient (Sedlmeier & Gigerenzer, 1997). In this thesis work, we use 30 simulation runs and average $n$ ($n \in \{2, 3, ..., 30\}$) runs to calculate the error associated with them as follows:

$$error = \frac{average_n - average_{n-1}}{average_n}. \tag{A.1}$$

In plots associated with errors, we have used three guiding lines; a blue line that indicates zero error, and two red lines that indicate $\pm 1\%$. As shown in the following sections, in most cases the measured error is lower than $1\%$ for the last five runs (i.e. the law of large numbers is held). As histograms and line plots indicate, different runs lead to distinctive results that may help to study the worst-case scenario. However, as stated earlier, averaging these results indicates that the impact of random numbers decreases over time.

## A.1 Sample results associated with Chapter 4

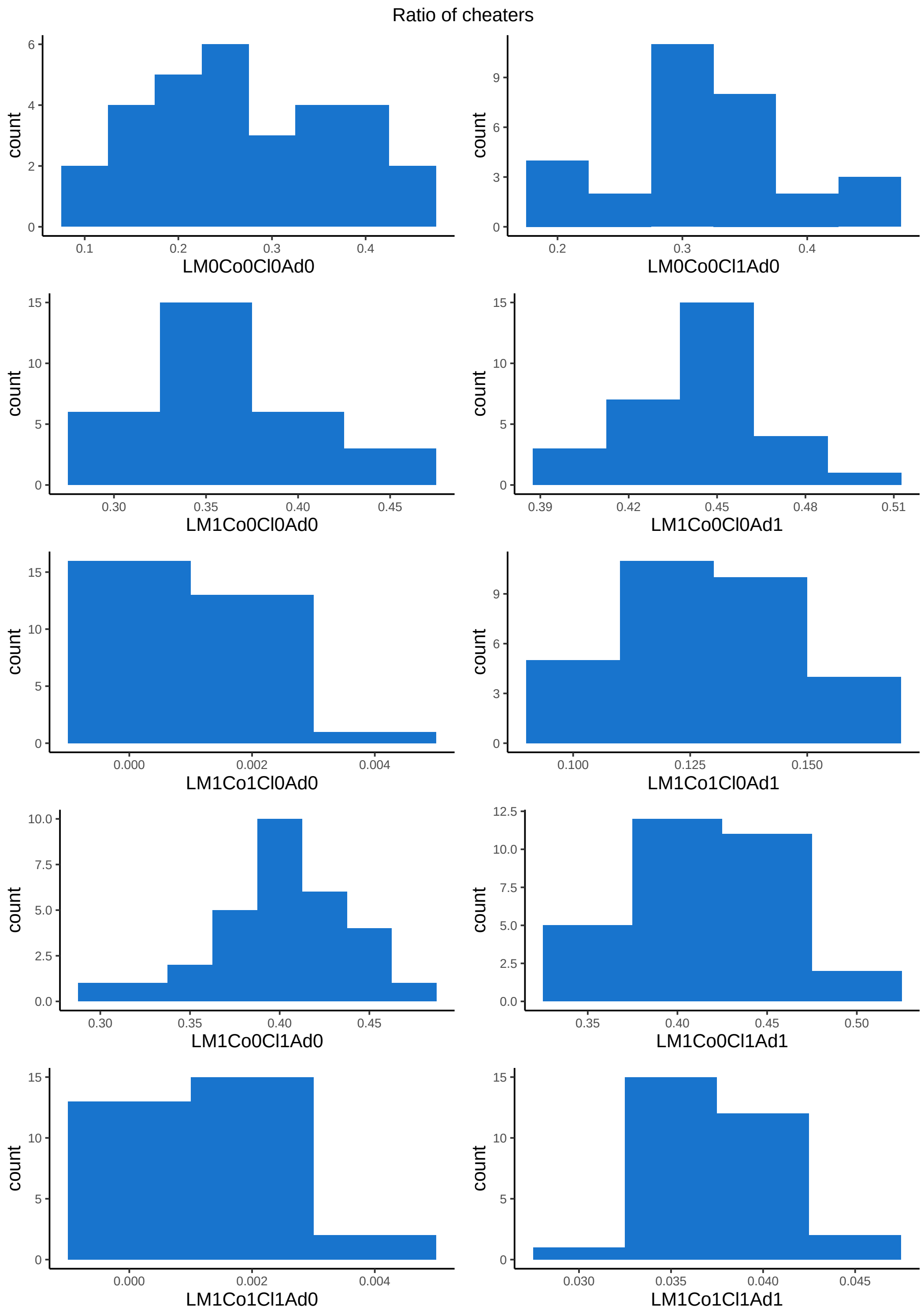


Figure A.1: Histogram associated with the impact of random numbers on the ratio of cheaters in the last iteration (see Table 4.4 for a definition of societies)

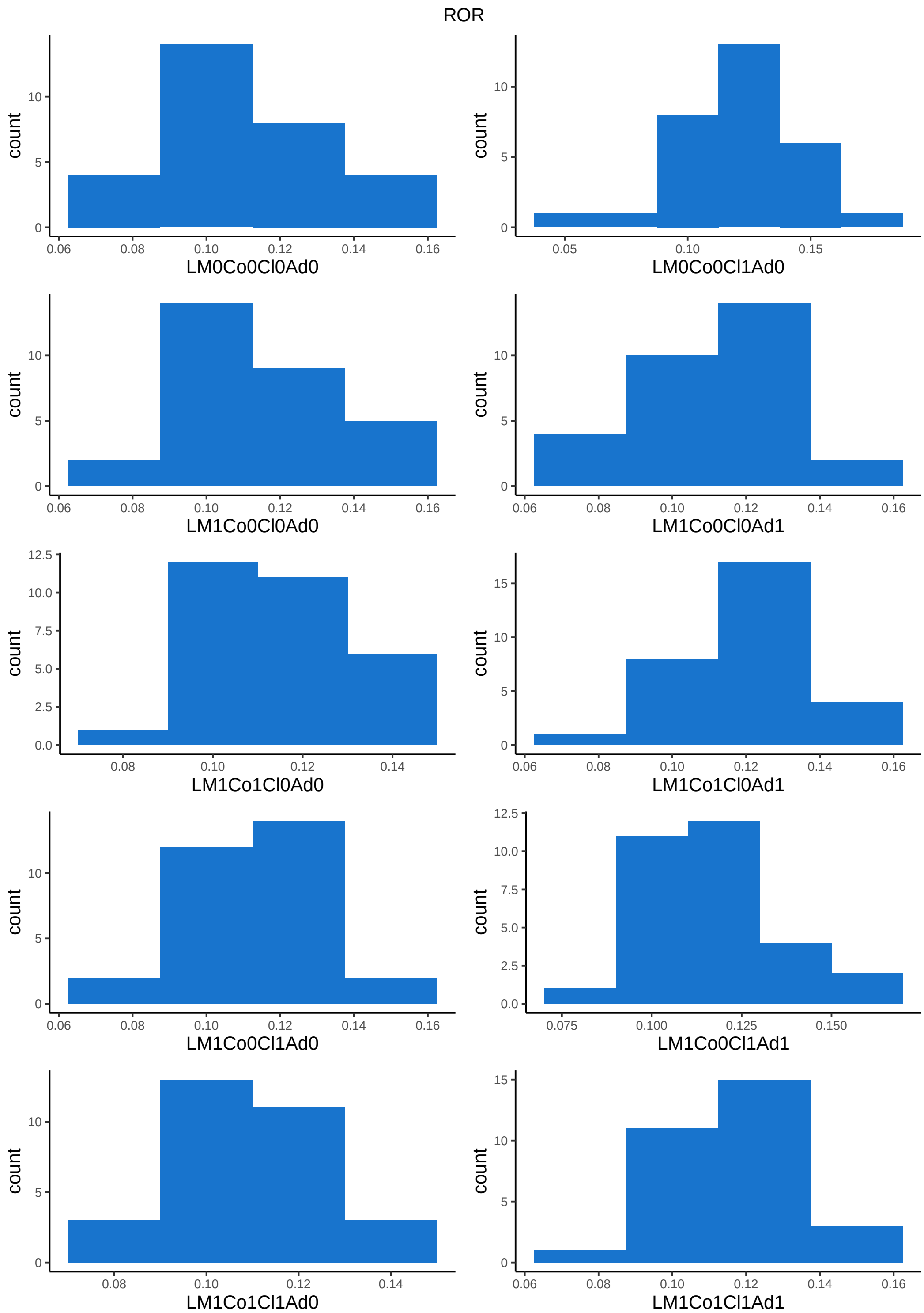


Figure A.2: Histogram associated with the impact of random numbers on the organisational ROR in the last iteration (see Table 4.4 for a definition of societies)

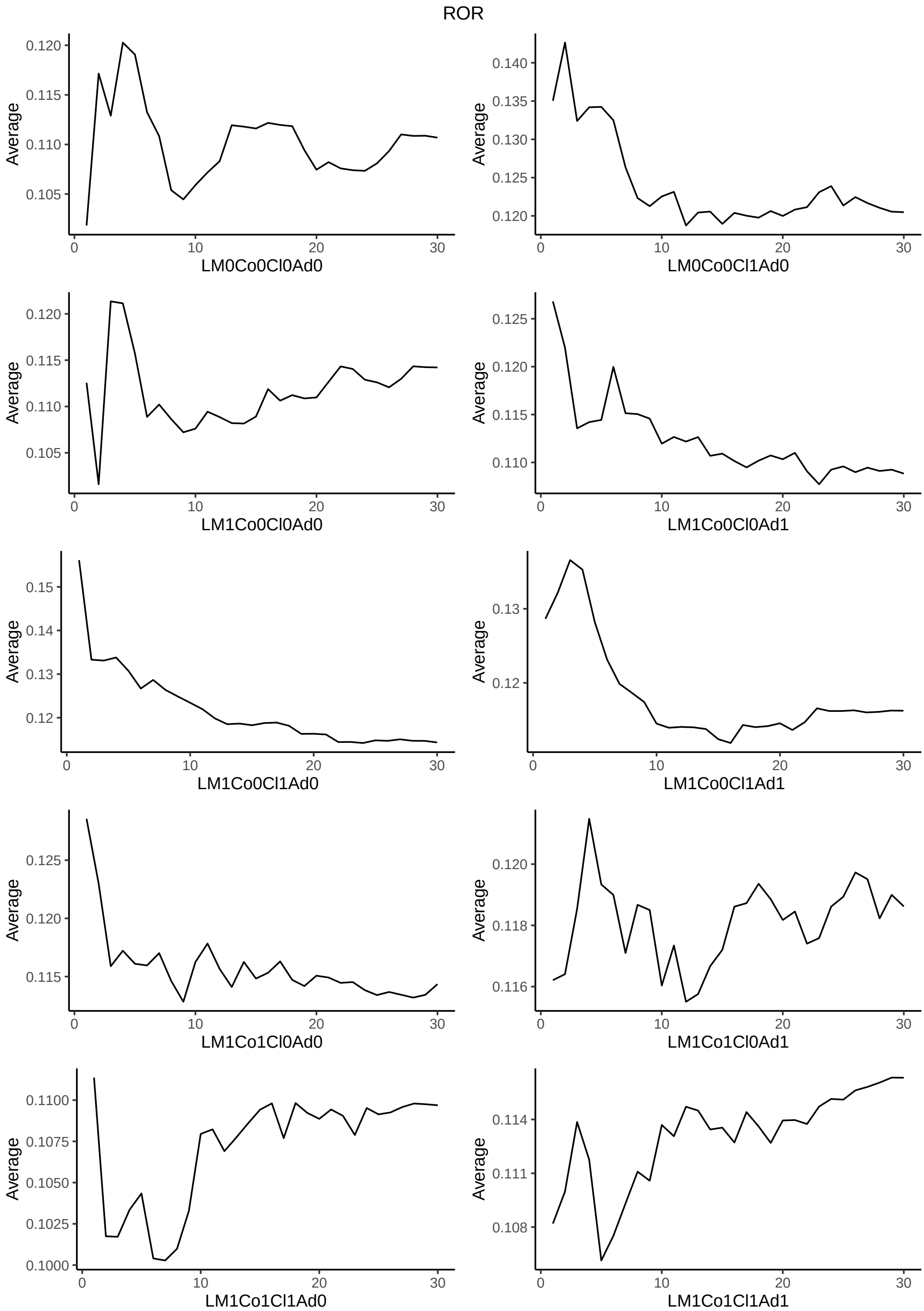


Figure A.3: Changes in the average of organisational ROR obtained from the last iteration (see Table 4.4 for a definition of societies)

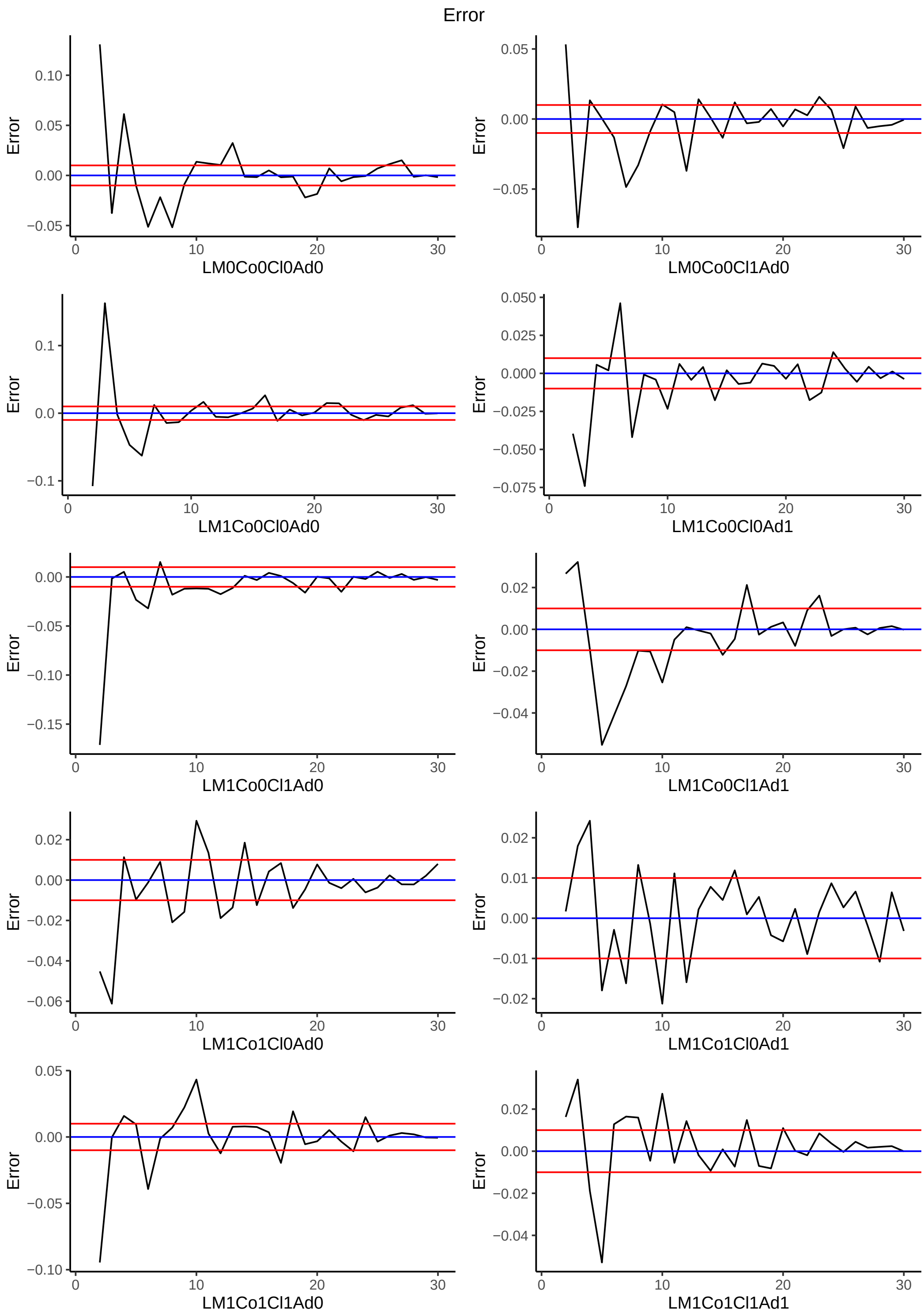


Figure A.4: Changes in the error of the average of organisational ROR obtained from the last iteration (see Table 4.4 for a definition of societies)

## A.2 Sample results associated with Chapter 5

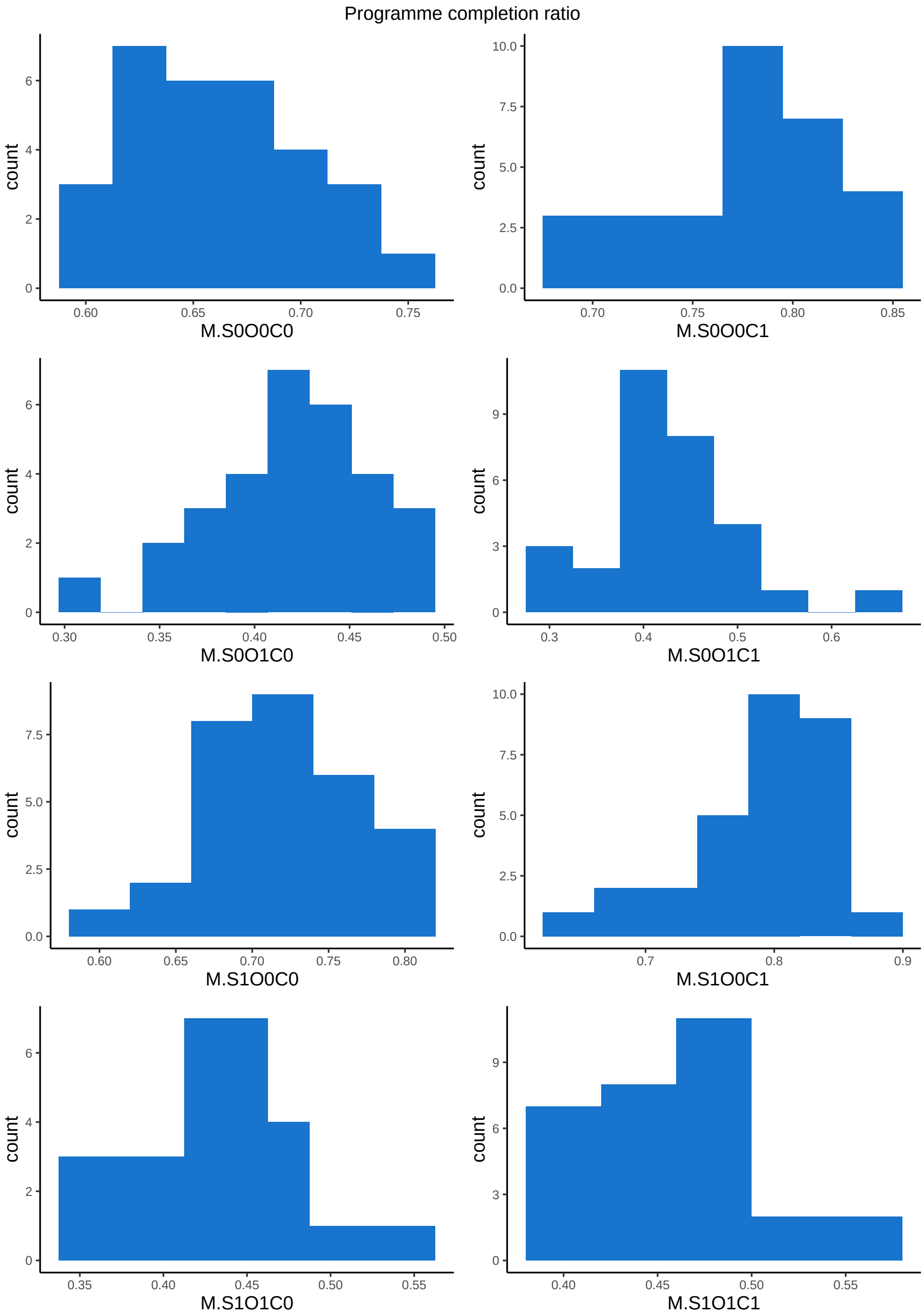


Figure A.5: Histogram associated with the impact of random numbers on the last completion ratio for apprenticeship run by manufacturers (see Table 5.4 for a definition of societies)

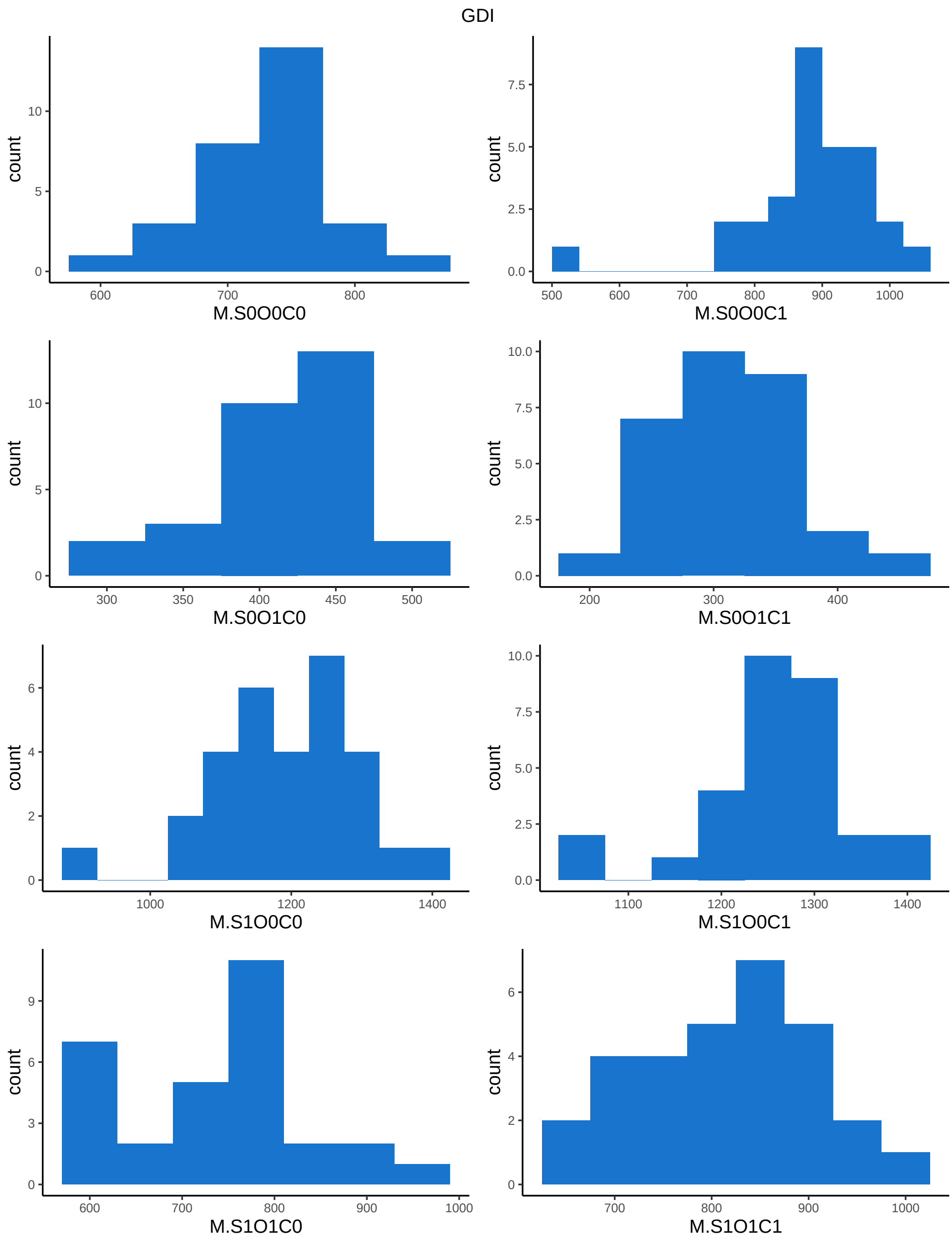


Figure A.6: Histogram associated with the impact of random numbers on the last GDI produced by apprenticeship run by manufacturers (see Table 5.4 for a definition of societies)

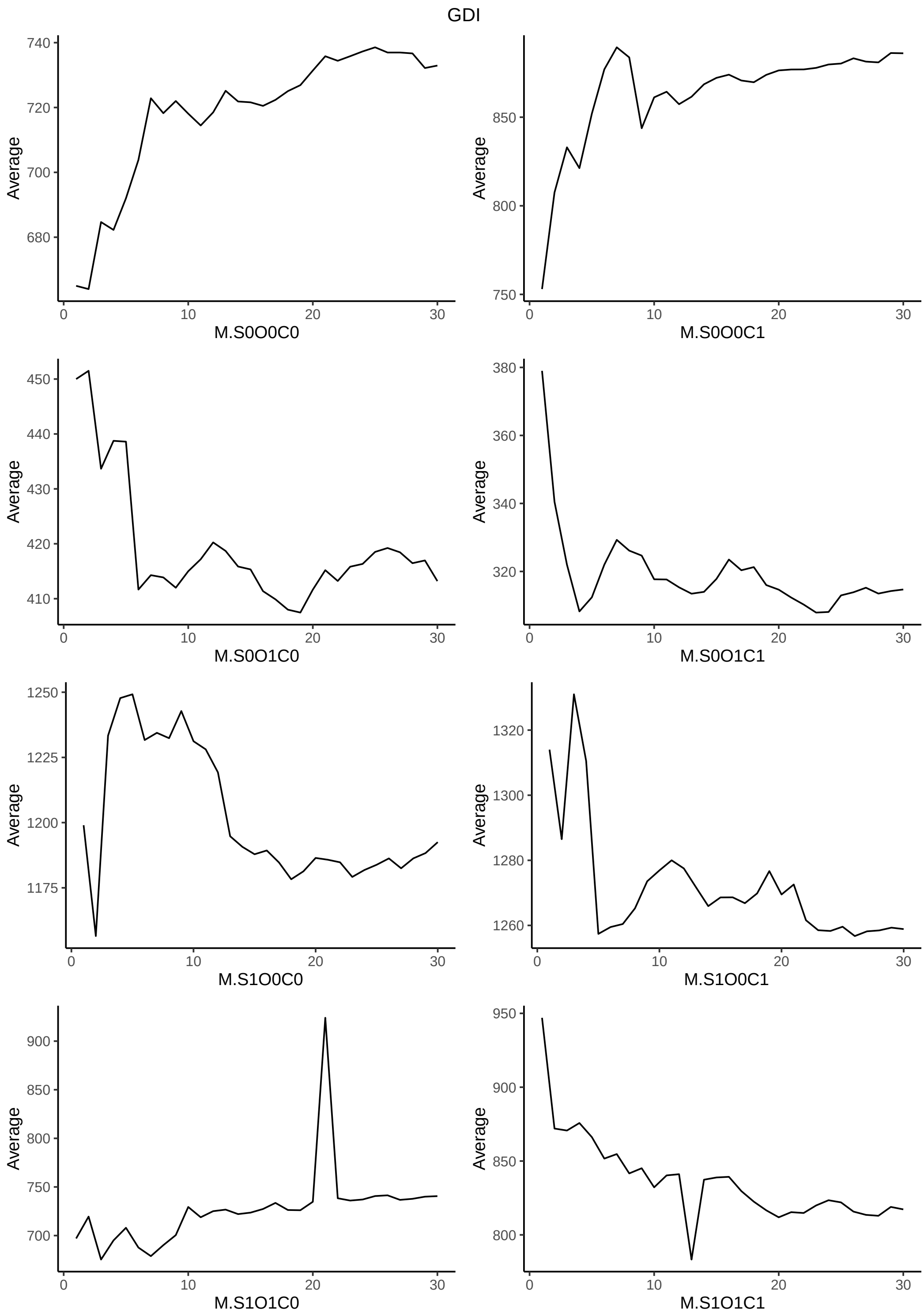


Figure A.7: Changes in the average of the last GDI produced by apprenticeship run by manufacturers (see Table 5.4 for a definition of societies)

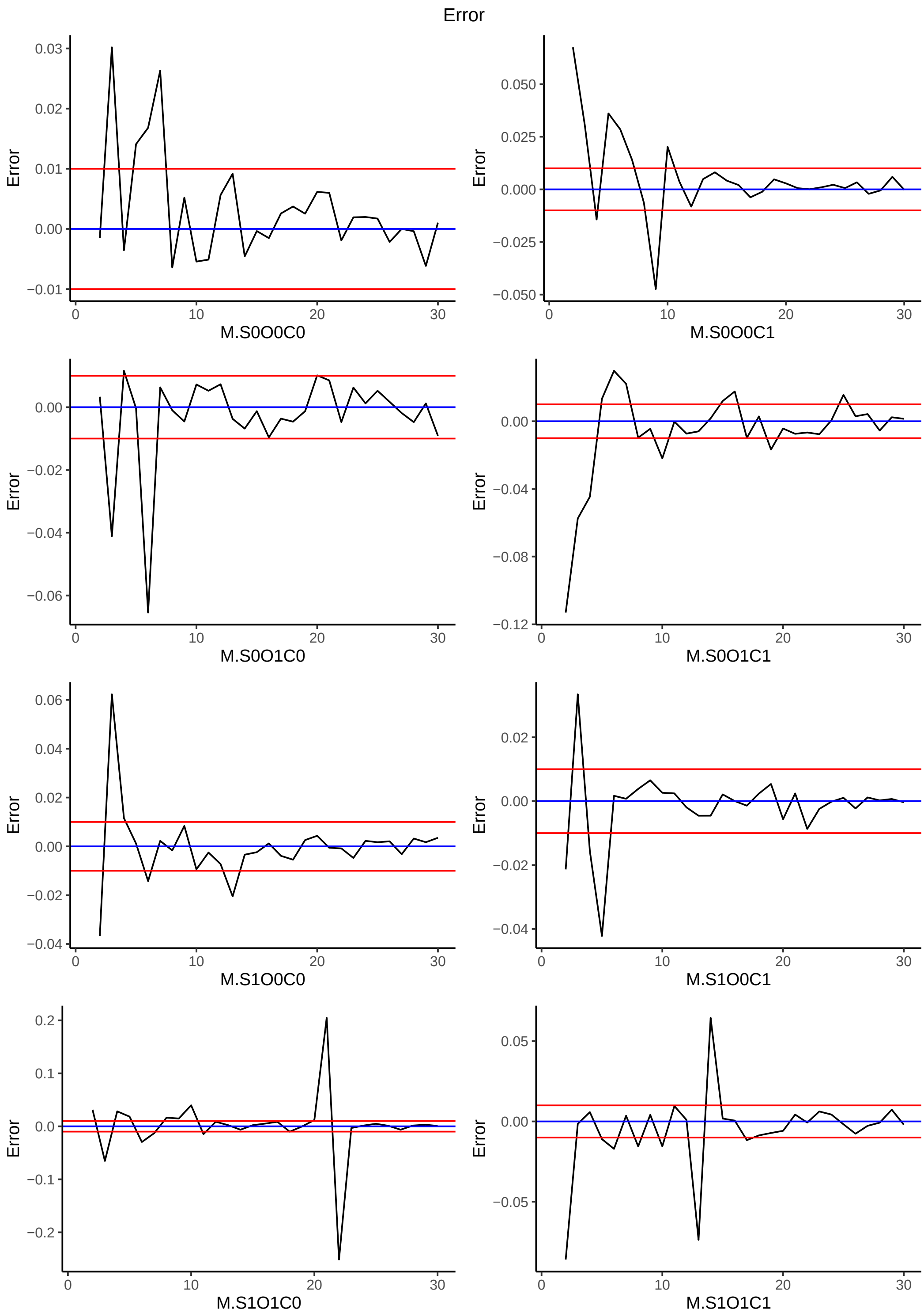


Figure A.8: Changes in the error of average of last GDI produced by apprenticeship run by manufacturers (see Table 5.4 for a definition of societies)

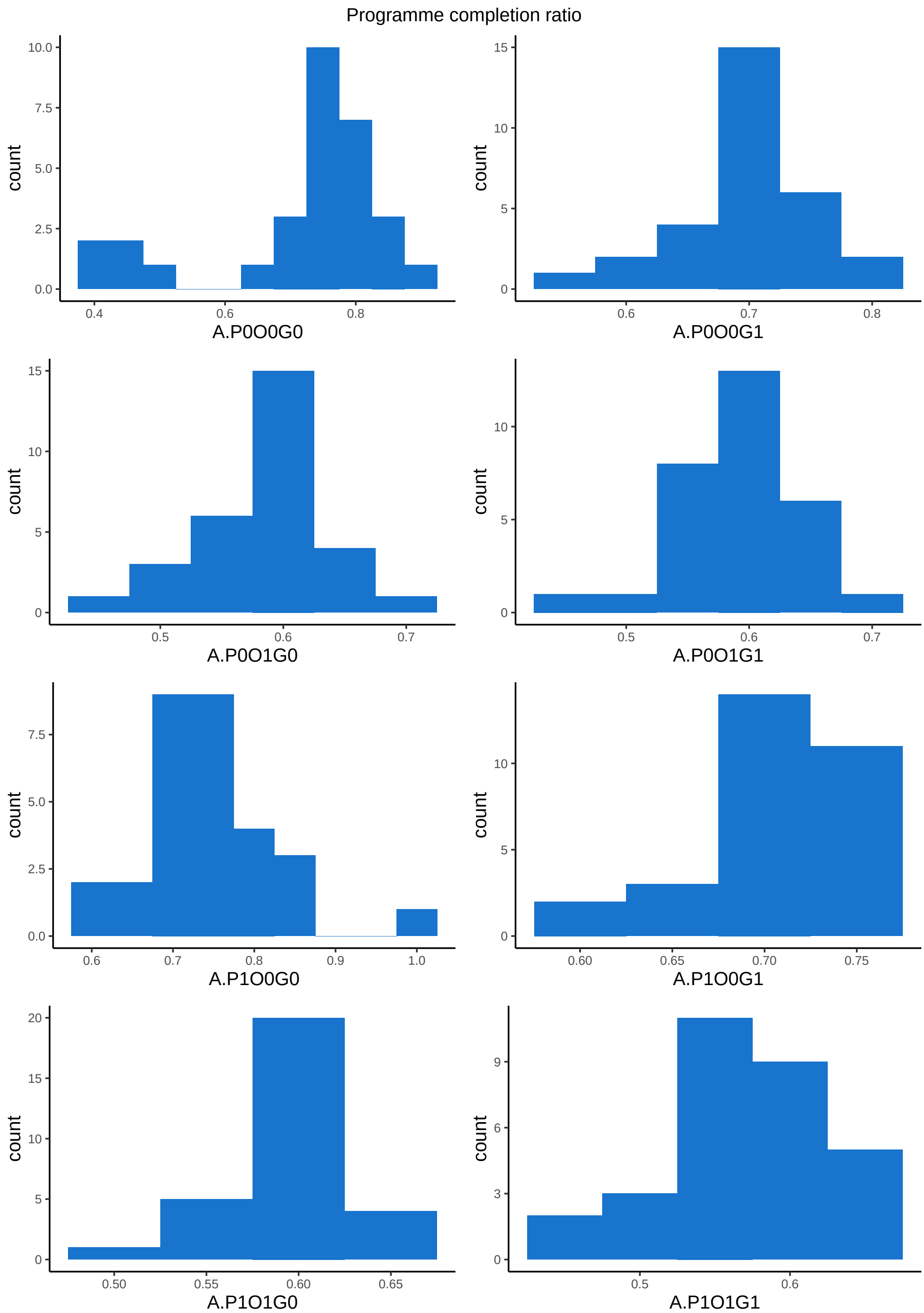


Figure A.9: Histogram associated with the impact of random numbers on the last completion ratio for apprenticeship run by artisans (see Table 5.20 for a definition of societies)

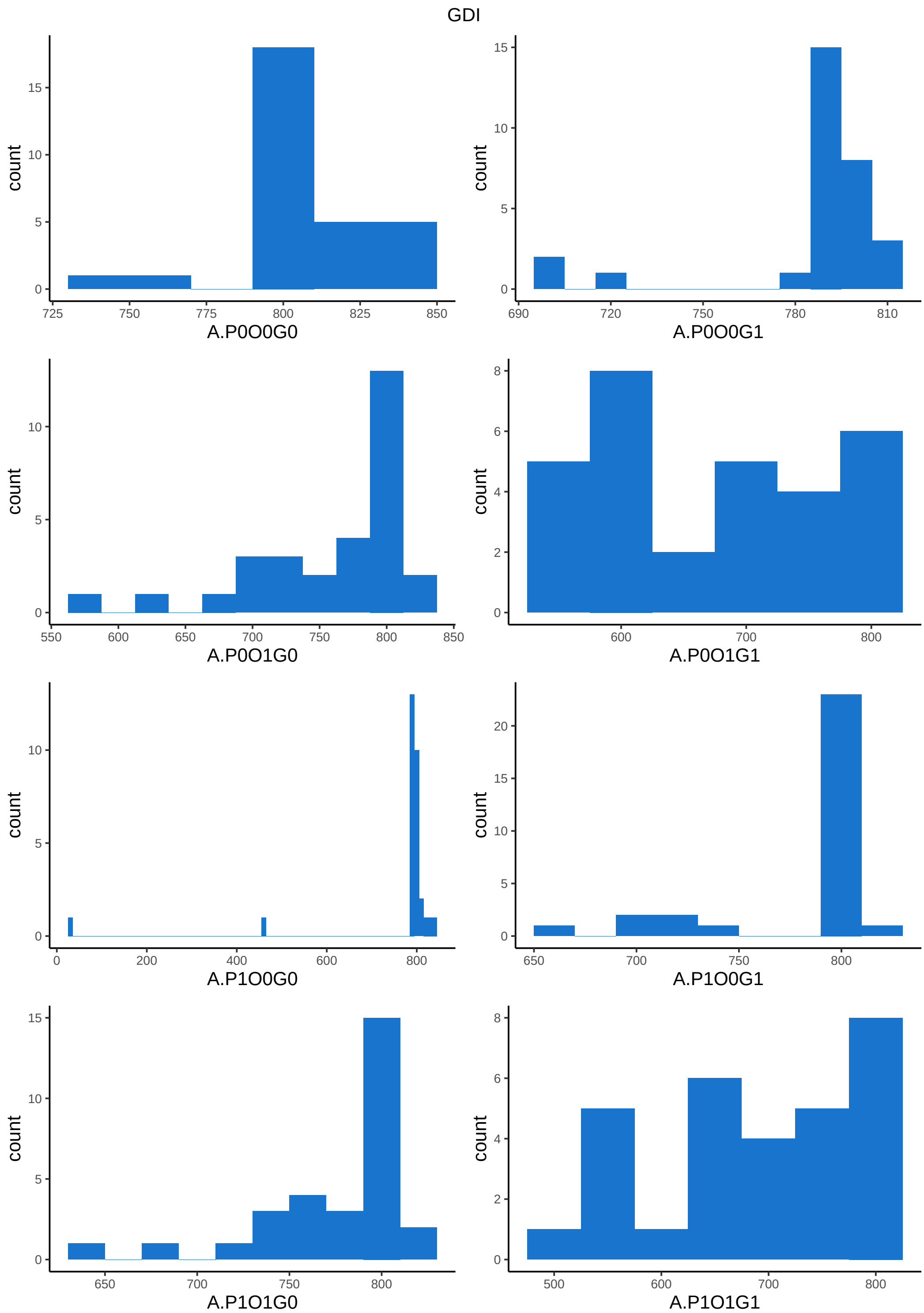


Figure A.10: Histogram associated with the impact of random numbers on the last GDI produced by apprenticeship run by artisans (see Table 5.20 for a definition of societies)

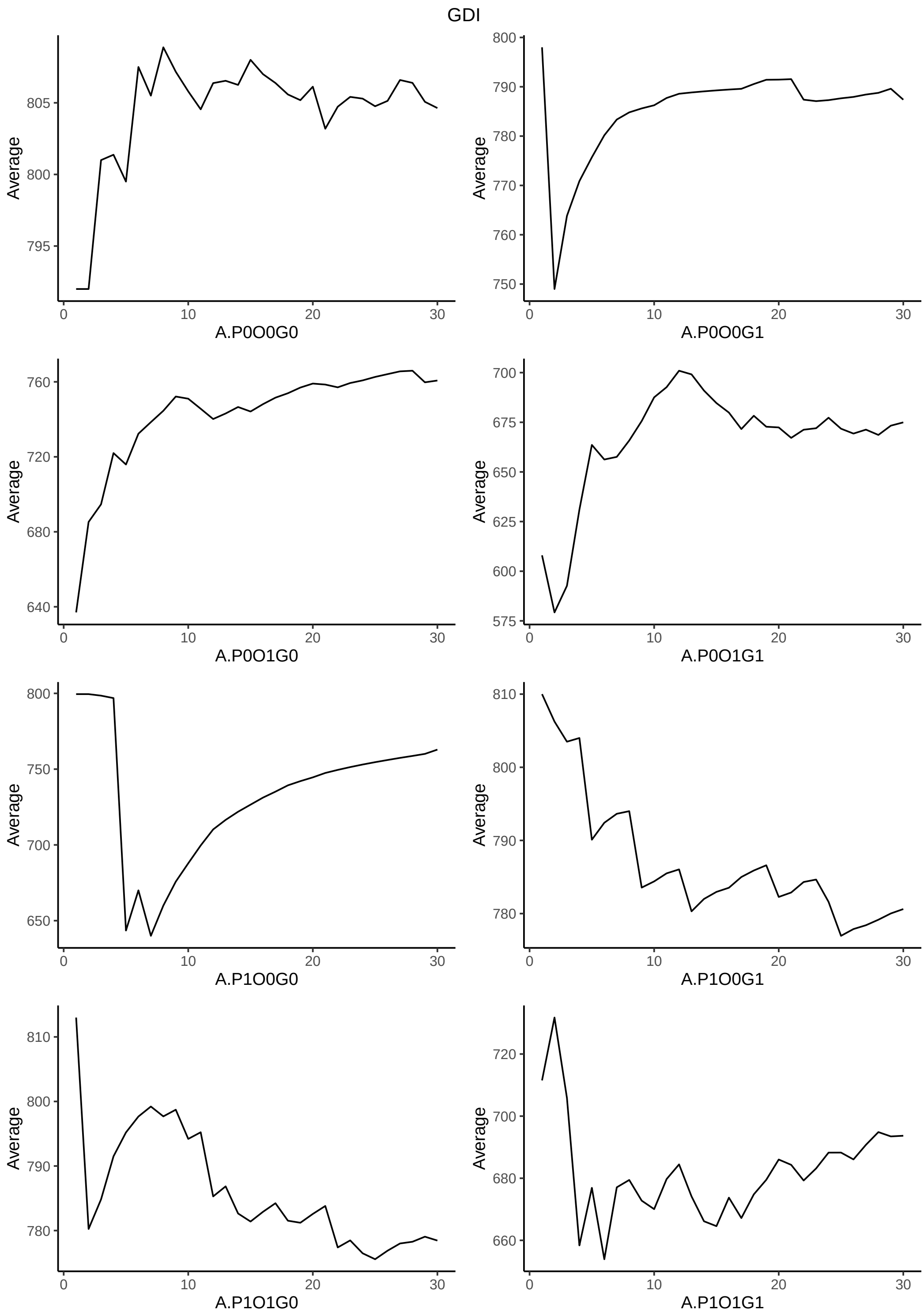


Figure A.11: Changes in the average of the last GDI produced by apprenticeship run by artisans (see Table 5.20 for a definition of societies)

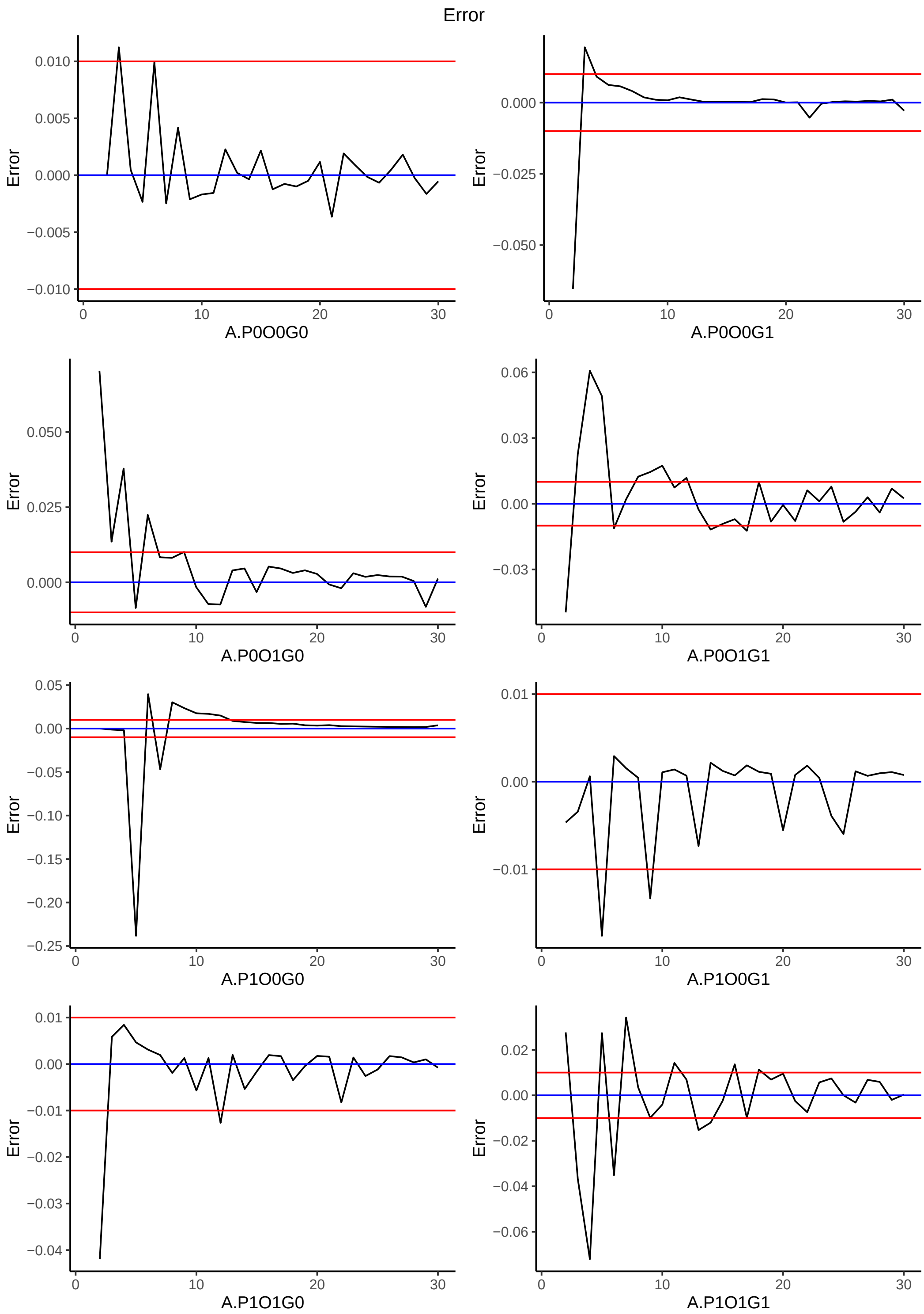


Figure A.12: Changes in the error of the average of the last GDI produced by apprenticeship run by artisans (see Table 5.20 for a definition of societies)

## A.3 Sample results associated with Chapter 7

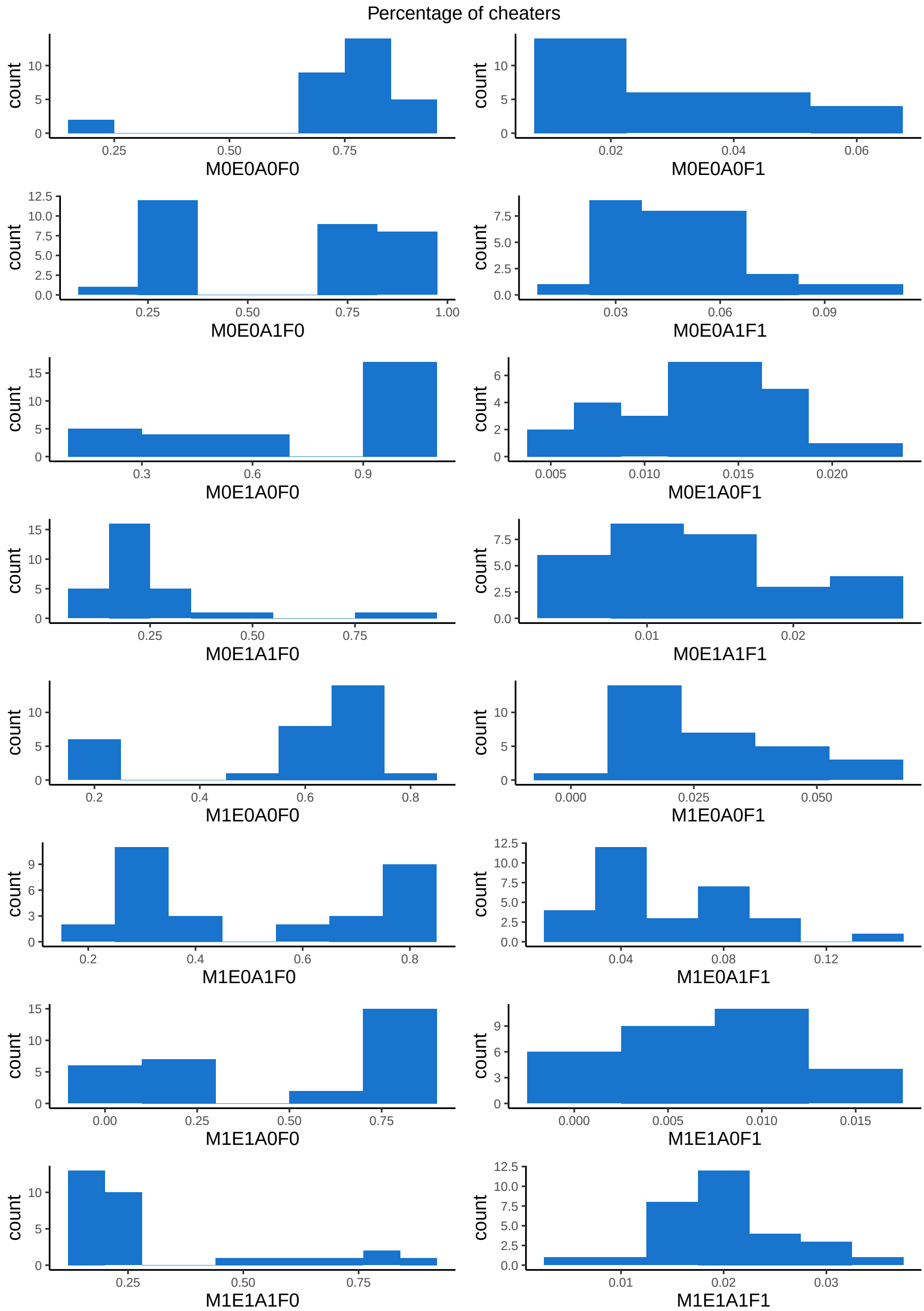


Figure A.13: Histogram associated with the impact of random numbers on the ratio of cheaters in the last iteration of cognitive model (see Table 7.6 for a definition of societies)

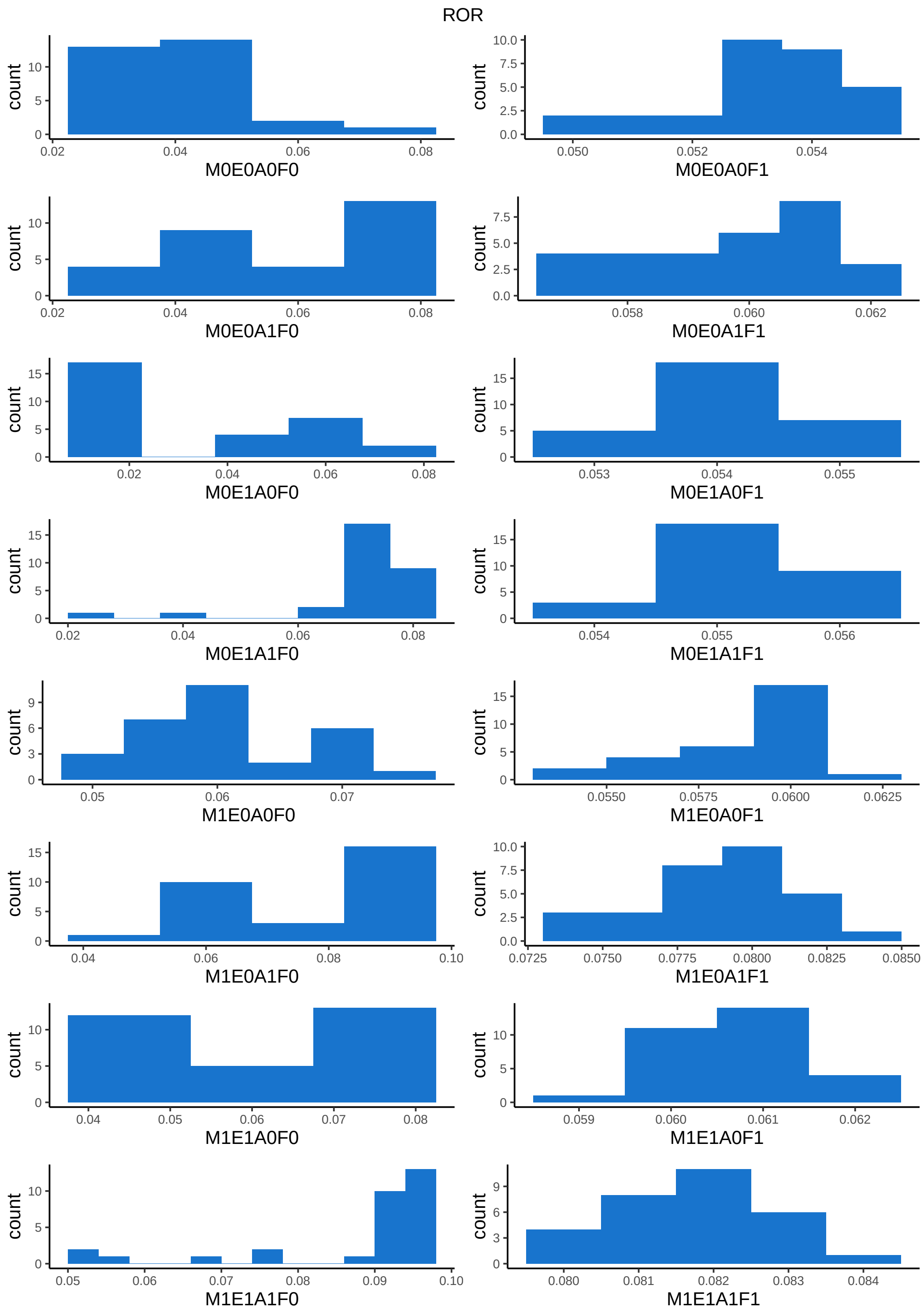


Figure A.14: Histogram associated with the impact of random numbers on the organisational ROR in the last iteration of cognitive model (see Table 7.6 for a definition of societies)

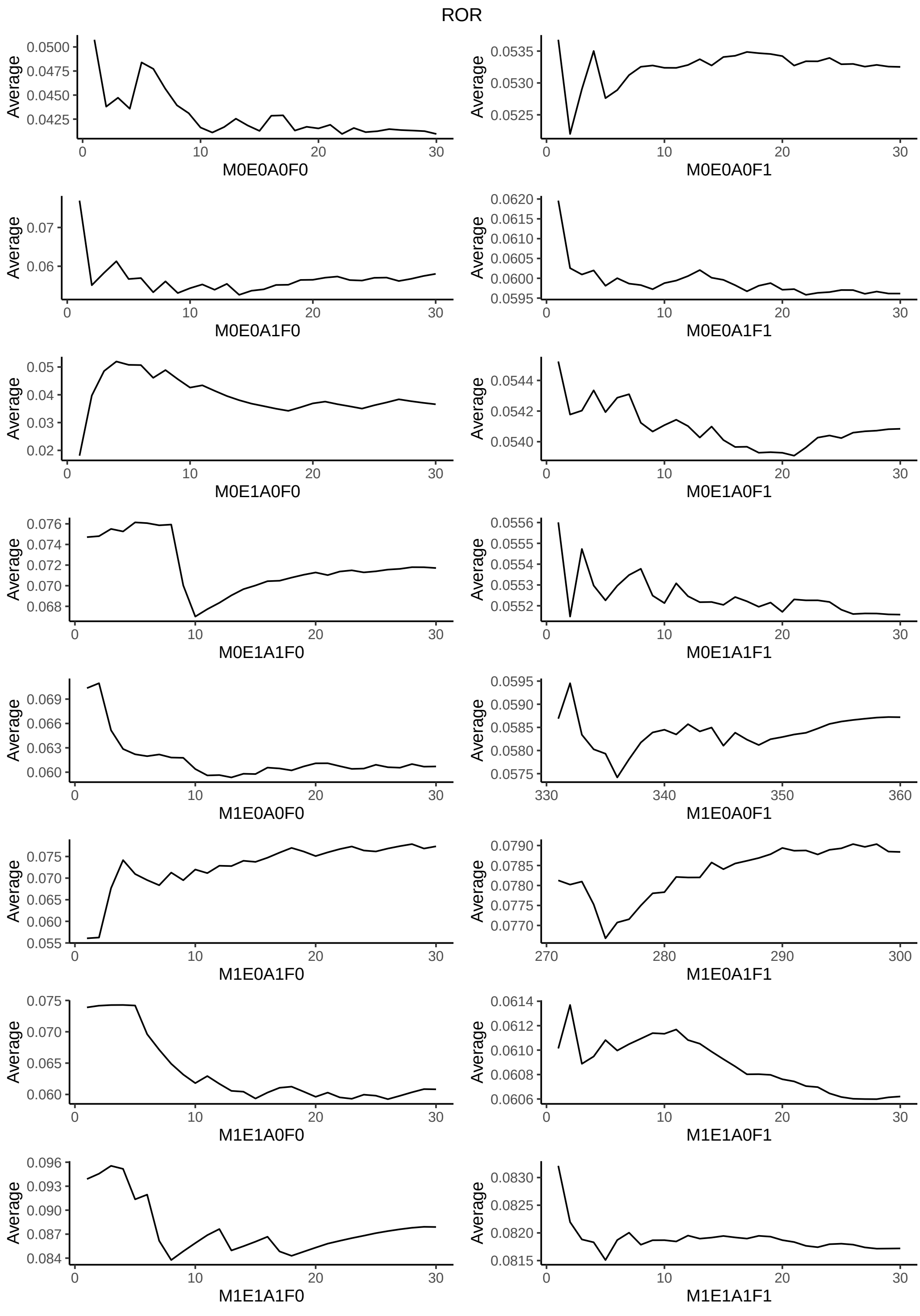


Figure A.15: Changes in the average of the organisational ROR in the last iteration of cognitive model (see Table 7.6 for a definition of societies)

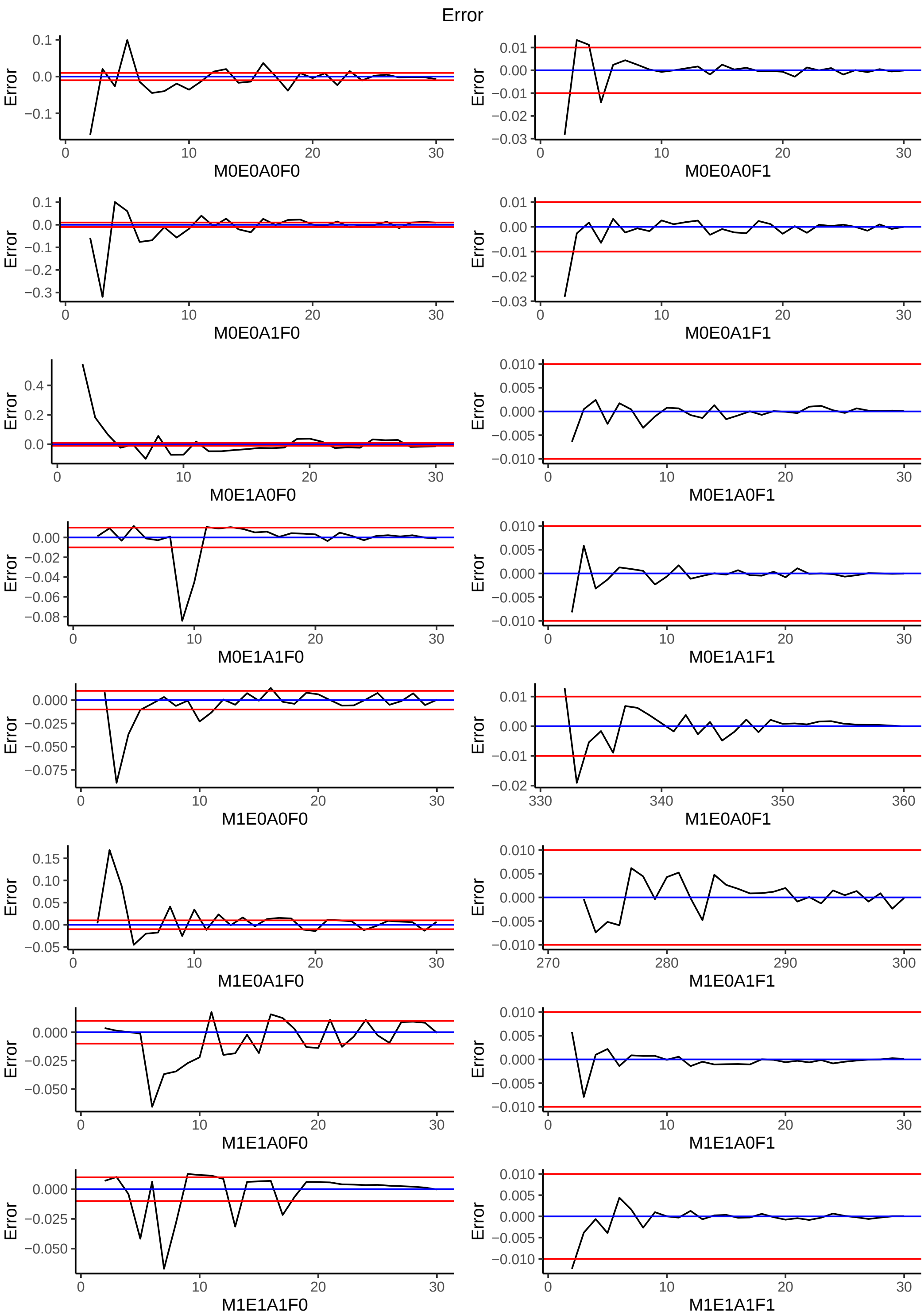


Figure A.16: Changes in the error of the average of the last organisational ROR in the last iteration of cognitive model (see Table 7.6 for a definition of societies)

# B
# Sensitivity analysis

Here we present the sensitivity analysis of the output variables and the values of the parameters of Chapter 5. The presented figures show the sensitivity of mean and standard deviation of output variables to the parameters. For this purpose, we took 1500 random samples of different combinations (already Aiello-Lammens & Akçakaya, 2017; Becker et al., 2018, showed that between 500 and 1000 samples can reasonably represent the real model). The range of parameters was defined so that they can present some real-world scenarios (e.g. we considered a lower bound of 0.5 for agents' discount factors). Also, we considered relationships between the wages and profits as stated in other studies (Stasz & Brewer, 1999). Table B.1 explains the parameters and variables shown in Figures B.1–B.6. Also, apprenticeships without any contribution to the GDI after iteration 100 were considered as failed and were removed from sensitivity analysis. The numbers of such instances for artisans, company trainers, and contractor trainers were 80 (5.3%), 36 (2.4%), and 80 (5.3%), respectively.

Table B.1: Parameters and variables employed in the simulation.

| No. | Abbreviation | Explanation |
|---|---|---|
| 1 | #No ed Adeq | Number of not educated/adequate |
| 2 | #Adeq | Number of adequate |
| 3 | #Apprentices | Number of potential apprentices |
| 4 | #Big | Number of big companies |
| 5 | #Ed Adeq | Number of educated/adequate |
| 6 | #Ed Exc | Number of educated/excellent |
| 7 | #Exc | Number of excellent |
| 8 | #Inadeq | Number of inadequate |
| 9 | #No ed Exc | Number of not educated/excellent |
| 10 | #Small | Number of small companies |
| 11 | #Small Trainers | Percentage of small companies who train |
| 12 | Ad Thresh | Adequate skill threshold |
| 13 | Alpha | Discount factor |
| 14 | Bad Train Spd red. | Impact of bad training on speed of learning |
| 15 | Check Job | Percentage of agents who check for jobs |
| 16 | Completion | Completion ratio |
| 17 | Cost Good Train | Cost of good training |
| 18 | Decision Horizon | Decision Horizon |
| 19 | Demand rate | Demand rate for artisans |
| 20 | Ed Thresh | Threshold for academic skills |
| 21 | Ex Thresh | Threshold for excellent skills |
| 22 | Guild? | Is there a guild in effect |
| 23 | Info Apprentice | Weight of recent information for apprentices |
| 24 | Info Artisan | Weight of recent information for trainers |
| 25 | Init Wage Adeq | Initial wage for adequate |
| 26 | Init Wage Ed Adeq | Initial wage for educated/adequate |
| 27 | Init Wage Ed Exc | Initial wage for educated/excellent |
| 28 | Init Wage Exc | Initial wage for excellent |
| 29 | Learn Overestim | Overestimation of learning speed |
| 30 | Max Waiting | Maximum waiting years |
| | | Continued on next page |

Table B.1 – continued from previous page

| No. | Abbreviation | Explanation |
|---|---|---|
| 31 | No passion | Impact of low passion on learning speed |
| 32 | Open? | Open society? |
| 33 | Prepay? | Prepayment requirement |
| 34 | Pr Be Trainer | Probability of being a trainer |
| 35 | Prof Big Adeq | Profit of adequate for big companies |
| 36 | Prof Big Ed Adeq | Profit of educated/adequate for big companies |
| 37 | Prof Big Ed Exc | Profit of educated/excellent for big companies |
| 38 | Prof Big Exc | Profit of excellent for big companies |
| 39 | Prof Small Adeq | Profit of adequate for small companies |
| 40 | Prof Small Ed Adeq | Profit of educated/adequate for small companies |
| 41 | Prof Small Ed Exc | Profit of educated/excellent for small companies |
| 42 | Prof Small Exc | Profit of excellent for small companies |
| 43 | School Speed Accel | Impact of school on accelerating learning |
| 44 | School? | Any school is engaged? |
| 45 | Small Spd Red. | Negative impact pf small companies on skill learning |
| 46 | Stickiness | Stickiness of wages |
| 47 | Train Years | Number of training years |
| 48 | Wage Adeq | Wage of educated agents with adequate skills |
| 49 | Wage Ed Adeq | Wage of agents with adequate skills |
| 50 | Wage Ed Exc | Wage of educated agents with excellent skills |
| 51 | Wage Exc | Wage of agents with excellent skills |
| 52 | Wealthy (%) | Percentage of wealthy families |

Figures B.1 and B.2 present the correlation between average ($\mu$) and standard deviation (SD) of the simulation output variables with parameters/variables of artisans, respectively. We discuss the correlations with an absolute value more than 0.3. As can be seen, $\mu$ and SD of GDI are negatively impacted by an increase in the percentage of agents who check for jobs. An increase in demand rate increases $\mu$ and SD of GDI. $\mu$ and SD of completion ratio are negatively impacted by the number of training years and the percentage of agents who check for jobs. Also, the averages ($\mu$s) of wages are positively correlated to initial wages, profits, and demand that mirror studies in economics regarding the impact of the stickiness of wages, company's earnings, and demand on system dynamics. The averages ($\mu$s) of the

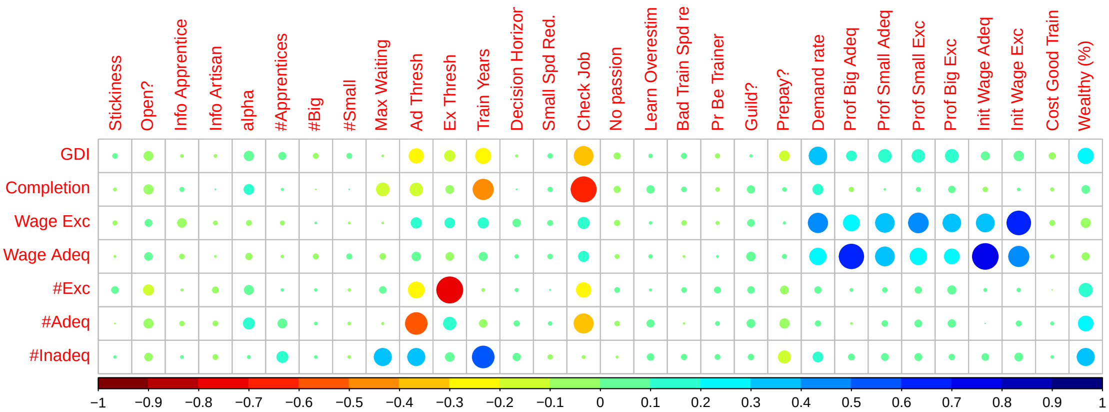


Figure B.1: The sensitivity of average of output variables to changes in parameters (artisans)

number of skilled agents is negatively correlated to the thresholds and the percentage of agents checking for jobs.

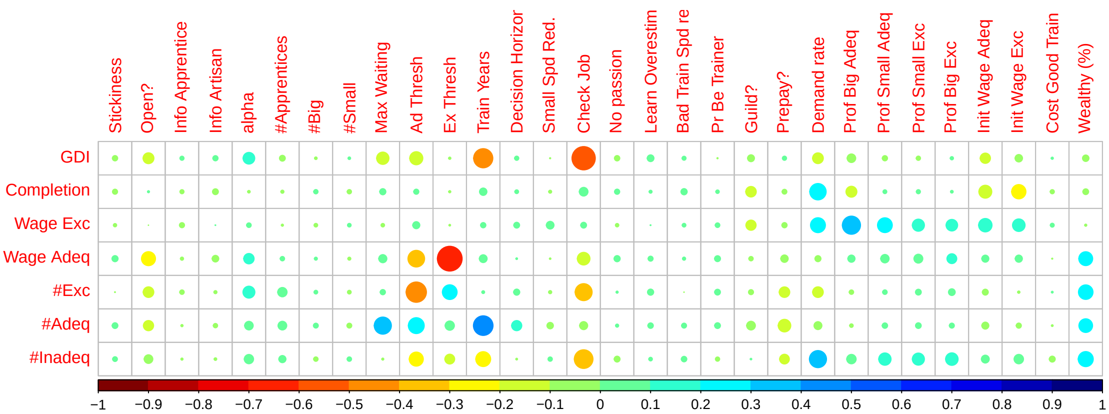


Figure B.2: The sensitivity of standard deviation of output variables to changes in parameters (artisans)

Figures B.3, B.5, B.4, and B.6 present the correlation between the average ($\mu$) and standard deviation (SD) of the simulation output variables with parameters/variables of companies and contractors, respectively. We discuss the correlations with an absolute value more than 0.3. As can be seen, $\mu$ of the GDI is negatively impacted by an increase in the percentage of agents who check for jobs. Also, the engagement of schools increases $\mu$ and SD of the GDI. Furthermore, $\mu$ and SD of completion ratio are negatively impacted by the number of training years and the percentage of the agents who check for jobs. The averages ($\mu$s) of wages are positively correlated to the initial wages and profits. This mirrors the studies in economics regarding the impact of the stickiness of wages and company's earnings on wages. Also, initial wages for high skilled agents increases associated SD with them. The

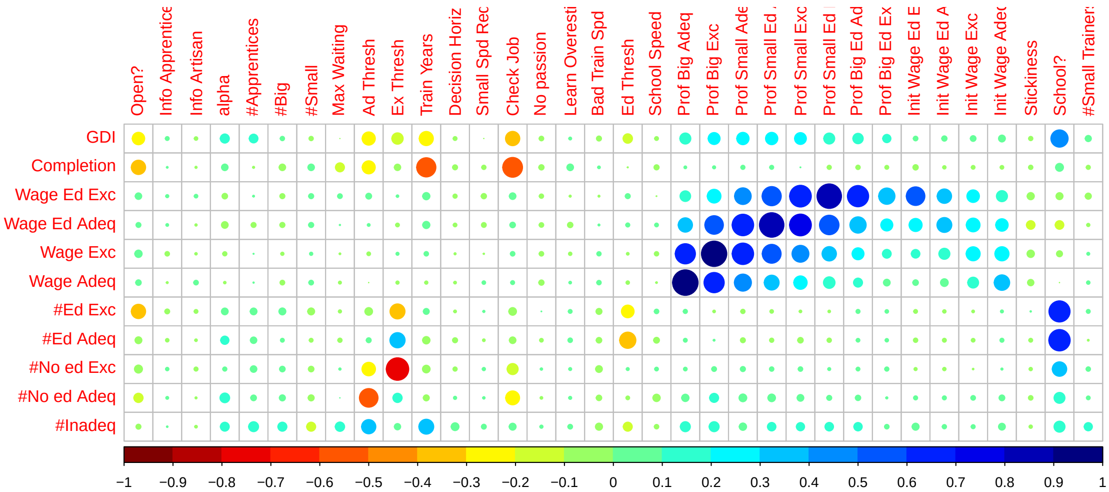


Figure B.3: The sensitivity of average of output variables to changes in parameters (manufacturers, companies)

averages ($\mu$s) of the number of skilled agents is negatively correlated to the thresholds. Also, engagement of schools improves the educational skills of apprentices.

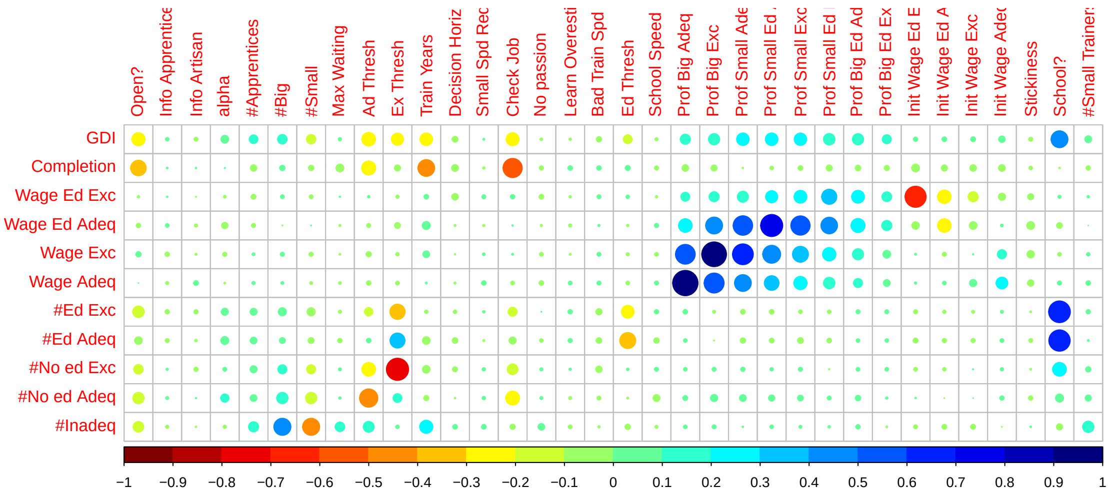


Figure B.4: The sensitivity of standard deviation of output variables to changes in parameters (manufacturers, contractors)

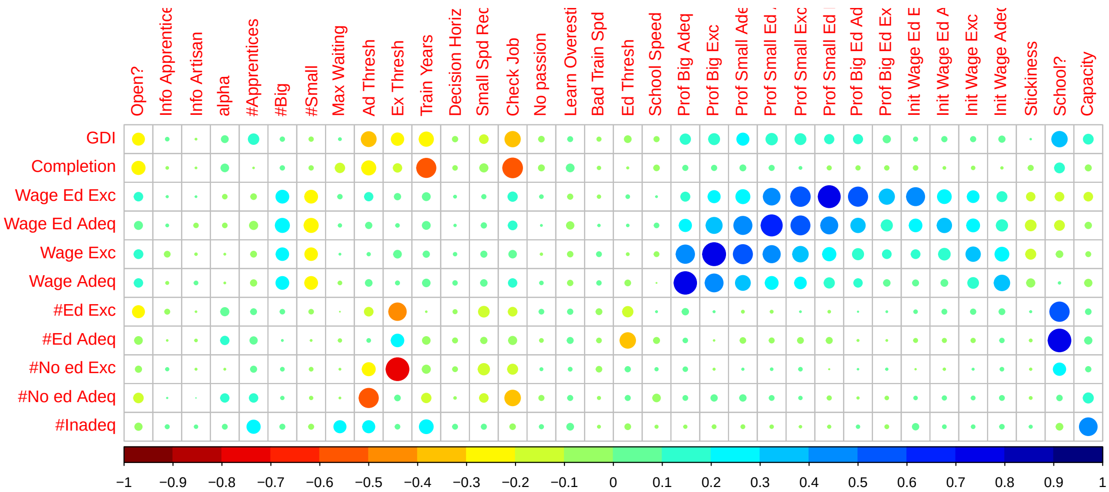


Figure B.5: The sensitivity of average of output variables to changes in parameters (manufacturers, contractors)

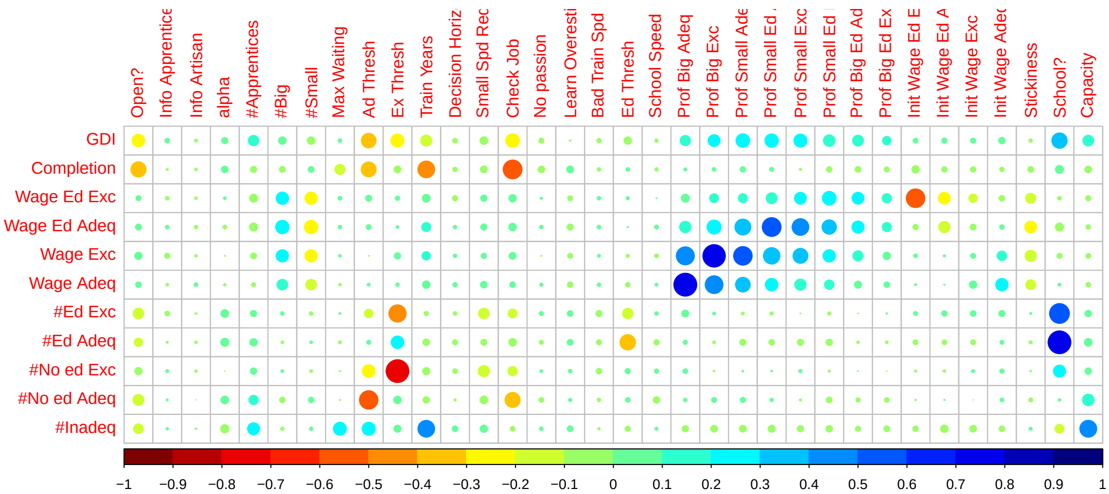


Figure B.6: The sensitivity of standard deviation of output variables to changes in parameters (manufacturers, contractors)