Studying Socio-Economic Problems in the Mekong Delta, Vietnam: An Agent-based Modelling Approach

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To my parents, Nguyen Quan and Lan Phuong,
my sister, Khanh Huyen,
my wife, Ngoc Bich, and my son, Hung Son

Statement of Originality

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision.

The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968.

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Acknowledgement of Authorship

I hereby certify that the work embodied in this thesis contains published papers/scholarly work of which I am a joint author. I have included as part of the thesis a written declaration endorsed in writing by my supervisor, attesting to my contributions to the joint publications/scholarly work.

Khanh Hung Nguyen

By signing below I confirm that Khanh Hung Nguyen made major contributions in conducting the literature review, designing and developing the models and writing all papers that are listed in Section 1.6.

Dr Raymond Chiong

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Abstract

The Mekong Delta (MKD), located in the far south of Vietnam, is known as the 'Rice Bowl of Vietnam'. The region accounts for half of the country's total rice production and 95% of its rice exports. Despite its increasing standard of living, the MKD has lagged behind the national average in terms of many socio-economic development indicators, such as employment, education, health care, and housing welfare. In this research, we address two pressing problems influencing the socio-economic progress of the region: (i) the failure of implementing the agricultural contract-farming scheme in the MKD rice supply chain, and (ii) the high out-migration rate from the MKD to the South East (SE) region.

We use agent-based modelling (ABM), which is a computational approach that focuses on a population of autonomous and interacting agents. ABM has the unique power of modelling individual decision making while also incorporating heterogeneity, social interaction/feedback and the dynamic impacts of different external factors. We present two agent-based models to tackle the above-mentioned socio-economic problems in the MKD region. Simulation results from the two agent-based models are then validated, providing further scenario-based insights into the related problems.

For the first problem, we investigate obstacles to the expansion of contract rice farming in the MKD region. We develop an agent-based contract-farming model and focus on two critical components of the contractual relationship: financial incentives and trust. The agent-based model is then used to predict emergent system-wide behaviour and compare different counterfactual scenarios of different policies and initiatives on maintaining contract rice farming. The results of this model showed that a fully equipped contractor who opportunistically exploited only a relatively small proportion of the contracted farmers in most instances could

outperform spot-market-based contractors in terms of achieved average profit. In addition, a committed contractor who offered lower purchasing prices than the typical rate could obtain better earnings per ton of rice and a higher profit per crop. However, in both of those cases, the contractors could not enlarge their contract-farming scheme, as either the farmers' trust towards them gradually decreased or their offers could not compete with those of a competitor or the spot market. Another important observation was that the contract-farming scheme is not a cost-effective method for buyers with limited rice-processing capacity, which is a common situation among the contractors in the MKD region. The model also identified the ranges of contracted purchasing prices for two rice types, in which both parties – the contractor and farmer – might find it beneficial to remain committed to contract rice farming.

For the second problem, the aim is to understand the dynamics of migrants' decision-making processes in the MKD region and explain why the MKD is the main migration-sending region in the country, with the highest out-migration rate and the highest deficit of net migration. We incorporate the Theory of Planned Behaviour into the agent-based model to break down migration intention into three related components: behavioural attitude, social network and perceived behaviour control. Different economic, social and environmental circumstances are considered to model the way an individual makes migration decisions. Outputs of the model are automatically calibrated via real province-level data using a genetic algorithm. This automated calibration yields some significant results, with most observed net- and out-migration data captured within the 95% confidence interval. Parameter exploration and sensitivity analysis are carried out to understand the impact of critical migration determinants. We further explore the migration behaviour of people in certain demographic groups and delineate the migration flows across cities and provinces from the MKD to the SE region.

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Chapter 1

Introduction

1.1 Background

The Mekong Delta (MKD) region, located in the far south of Vietnam, is one of the most populated areas of the country, with nearly 17.8 million people in 2018, according to the General Statistics Office of Vietnam (GSO Vietnam 2018a). This region comprises 12% of the country's landmass and about 20% of the Vietnamese population. It has a comparatively high population density of 436 inhabitants per square kilometre, compared to a national average of 286.

The MKD has a province-level municipality of Can Tho, which is regarded as the regional centre. The other 12 provinces include Long An, Dong Thap, Tien Giang, An Giang, Ben Tre, Vinh Long, Tra Vinh, Hau Giang, Kien Giang, Soc Trang, Bac Lieu and Ca Mau. In 2018, only 25% of the region was urbanised, compared to the national average of approximately 36%, leaving most of the population living in the rural area (GSO Vietnam 2018a).

The agricultural sector has long played an essential role in the region. The delta has comparative advantages of fertile soils and abundant fresh-water resources from the Mekong River, enabling highly productive agriculture and fishery. According to the Vietnam Institute for Economic and Policy Research (VEPR), the MKD has the highest percentage of agricultural land use with almost two-thirds of the region area (VEPR 2015). The delta is known as the 'Rice Bowl' of the country, supplying half of the total national rice production and

95% of rice exports (IPSARD 2014). The region is the most productive agricultural region of Vietnam in producing vegetables, fruits and seafood. The delta accounts for 70% of the national fruit production and 65% of aquaculture exports (GSO Vietnam 2018a). Exported agricultural products from the MKD in 2017 valued around US$37 billion, accounting for 18% of the national GDP (GSO Vietnam 2018a). The annual performance of rice, fruit and seafood production has given the MKD region a vital role in the health of Vietnam's overall economy (Cosslett et al. 2014, Renaud and Kuenzer 2012, Royal and Deltares 2013).

Rice has been the most important crop of the MKD region, contributing significantly to Vietnam's food security, not only domestically but also internationally. The bulk of the MKD's expanded rice production has been channelled abroad, a major factor in Vietnam becoming one of the top rice-exporting countries in the world (World Bank 2011). In 2018, there were 5.7 million tons of milled rice exported from the MKD, accounting for 15% of the world's rice exports (Quyen et al. 2018).

It was estimated that the MKD's designated rice area covers 1.5 million hectares and accounts for over 70% of the total cultivated land of the region in 2015 (GSO Vietnam 2018a). Despite the recent decline in the rice growing area due to structural changes of the regional economy, the total annual rice planted area and production have increased over the last decade. The expansion and intensification of high-yielding rice contributed significantly to transforming the delta into the country's main rice cultivation region. Many MKD farmers grow two to three crops with high-yielding rice variety instead of one tradition crop per year.

The importance of the agricultural sector is reflected through its high share of the working labour force. According to the most recent labour force report, 43.2% of the employed workforce in the MKD region in 2018 was involved with agriculture, forestry and fishery activities. The proportion of labour engaging into the agriculture sector has remained the highest, compared to 22.6% in industry and construction and 34.2% in services in the region (GSO Vietnam 2018b). In the rural areas, the most significant proportion of income for

approximately 60% of households was from the agricultural sector, either from their main job or from self-employment activity (GSO Vietnam 2017).

While the delta is considered the largest granary in Southeast Asia and has been reasonably successful in increasing people's living standards and reducing the general poverty rate, the development of the region is moving in a different direction from the approved socio-economic development objectives (Royal and Deltares 2013). The MKD region has lagged behind the national average in terms of many socio-economic development indicators such as employment, education, health care and housing. Under stress from multiple socio-economic pressures and environmental risks, many people are increasingly having difficulties securing a stable livelihood (Garschagen et al. 2012, Renaud and Kuenzer 2012, Royal and Deltares 2013).

During the past decade, structural changes in the MKD region towards industrialisation and modernisation of the economy have not generated much employment in the agricultural sector. The share of labour within this sector either stagnated or decreased in all MKD provinces, especially in the rural areas (Garschagen et al. 2012, Royal and Deltares 2013). Statistics from the recent survey of labour force indicated that the MKD rural areas have had one of the highest unemployment rates among the six socio-economic regions and nearly equal to 1.4 times higher than the average of the country from 2010 to 2018. Similar patterns have also been observed in the under-employment rate of the labour force. The under-employment rate in the MKD rural area in 2018 is the highest at 3.22%, compared to only 1.78% in the country (GSO Vietnam 2018b).

According to the 2018 official statistics, the annual average income per capita in the MKD region was approximately 43 million VND (around US$1,900). Although the MKD's income per capita has been growing during the last decade, it was less than the national average in the same year (GSO Vietnam 2018a). Results extracted from the income module in the 2016 national surveys indicated apparent changes in the structure of household

income in the region. From 2010 to 2016, the share of income from agricultural activities in total household income decreased from 29.9% to 20.8%, while the share of income from wage activities increased significantly from 26% to 34.9% (GSO Vietnam 2017). These observations underlined the fact that agricultural activities provide only low incomes and poor livelihood. Research also indicated that poorer people who engage with farming, especially in the rural areas, have unstable jobs and limited off-farm employment opportunities (Cosslett et al. 2014, Garschagen et al. 2012, Royal and Deltares 2013).

In a nutshell, Garschagen et al. (2012), Renaud and Kuenzer (2012) and Royal and Deltares (2013) pointed out the following most pressing and influential factors influencing socio-economic progress in the MKD:

- The institutional mechanisms for agricultural transformation and production planning (notably with rice) are insufficiently enforced.
- Poor and inadequate transportation infrastructure leads to high transportation costs, constraining the commercialisation of business activities.
- The area's vulnerability to natural disasters and the effects of climate change impacts makes the region risky and less attractive for investments.
- The low educational level of the population in the region results in a shortage of qualified labourers, especially in the agricultural sector.
- There is a high volume of out-migrants from the MKD to the South East (SE) region, mostly to Ho Chi Minh City.

1.2 Problem Statement

One of the most critical issues related to the process of agricultural transformation in the MKD region has been the introduction of the contract-farming scheme. The Government has made several attempts to modernise the fragmented rice supply chain but it has failed

to expand the contracting programme in the region. Therefore, many smallholder farmers are not benefiting from the contracting programme. The comparatively low profitability in the agricultural sector, coupled with limited off-farm employment and insufficient industrial growth, has resulted in many people leaving for more economically developed areas. This is examined in detail in the next section, followed by an examination of the dynamics of inter-provincial migration flows in the MKD and its neighbouring regions.

Contract Farming

Contract farming is a common practice in agriculture all around the world (Eaton and Shepherd 2001), particularly in Asia and Africa (Shepherd 2013, Swinnen and Maertens 2007). Contract farming presents a particular contractual relationship in which the farmers produce and deliver designated agricultural commodities, while the contractors, who are usually food processors, acquire the commodities at a predetermined price (Eaton and Shepherd 2001, Shepherd 2013, Swinnen and Maertens 2007). Contract farming is of particular interest to contractors, who seek guaranteed outputs of high quality and consistency. The use of agricultural contracts has also become attractive to many smallholder farmers as well, as they can assure a stable income and access to reliable markets in the modern food supply chain.

According to the International Institute for the Unification of Private Law (UNIDROIT), the agricultural contracting programme was first applied in Vietnam in 2002 under Decision 80 (UNIDROIT 2014). Despite this effort, contract rice farming in the MKD region was unsuccessful, with many reported cases of unilateral breaches by either the contractors or farmers (Khiem and Emor 2005). In 2013, the Vietnamese Government proposed a 'large-scale paddy field' model under Decision 62. The contracting programme under Decision 62 was considered a promising approach in the context of MKD's rice supply chain, addressing several of the existing constraints in Decision 80 with some successful case studies (Can

2014, Ngan et al. 2015). Most studies and reports have agreed that the application of contract farming would increase the welfare of rice-farming households and contribute to poverty reduction in the region (Nhan and Yutaka 2019, Pham and La 2014).

Although the advantages of participating in contractual agreements are obvious for rice farmers, progress in the expansion of the contract rice farming has been comparatively slow and has even tended to decline (Ho Chi Minh City Federation of Labour 2019, Saigon Times Group 2019, Vietnam Farmer Union 2017). The proportion of total paddy land used for contract farming in the MKD region was 11% in 2017 (Vietnam Farmer Union 2017), reducing to 9.2% in 2018 (People's Army of Vietnam 2019), with several companies significantly narrowing their contracted paddy field areas (Ho Chi Minh City Federation of Labour 2019, People's Army of Vietnam 2019). Therefore, it is crucial to understand the barriers to the growth of contract rice farming and to provide insights for the Vietnamese Government to better create an effective enabling environment.

Inter-provincial Migration

Unbalanced states of development and living standards among regions and provinces have been considered the fundamental driver of internal migration in Vietnam during recent decades (Kim Anh et al. 2012, Marx and Fleischer 2010, Phan and Coxhead 2010). The SE region, which is the most economically developed, is the primary migrant-receiving region in Vietnam. Conversely, the MKD is the main migration-sending region of the country, with the highest out-migration rate and the highest deficit in terms of net migration. The fact that the two regions are close together explains why the flow of migrants from the MKD to the SE region has been recognised as the largest migration corridor in Vietnam (GSO Vietnam and UNFPA 2016a,b).

Migration contributes to widening economic disparities between origin and destination places, creating challenging social problems in rural and urban areas. Out-migration from

the MKD rural area results in a significant shortage of agricultural labourers, especially in peak planting and harvest periods. Strong migration flows into urban areas in and around Ho Chi Minh City create major issues such as unemployment, traffic congestion, lack of housing and pollution. Therefore, a thorough exploration of the drivers of migration in the MKD region is critical to providing inputs to future policy formulation regarding the relationship between migration and socio-economic development.

Many empirical studies on migration in Vietnam and national demographic surveys have identified a range of factors influencing migration decisions at the national level. However, only a limited number of migration research and reports have focused on the MKD as the main migration-sending region in Vietnam. In addition, no previous work related to migration in Vietnam has specified how different socio-economic factors form migration intention, which is considered the primary determinant of migration behaviour (Ajzen 1991, Fishbein and Ajzen 2011). This highlights the need to apply a well-established migration theory that accommodates the relevant components to examine the decision-making process of the migrants and the dynamics of migration flows in the MKD region.

1.3 Research Objectives

Contract Farming

A number of socio-economic issues are responsible for the lack of expansion of contract rice farming in this area. This section addresses four specific issues, from the contractor perspective, in the context of the MKD rice supply chain. First, many contractors in the region failed to build trust and invest in long-term relationships with farmers (Dung 2014, UNIDROIT 2014). According to Fafchamps (2003) and Will (2015), trust is the most basic and critical factor in preventing opportunistic behaviour and in identifying problems early and resolving them effectively. It is claimed that contractors in the MKD failed to remain

trustworthy by honouring the contract obligations when there was an unexpected fluctuation of market price at the end of the cropping season (Roberts and Khiem 2005, UNIDROIT 2014, Vietnam Television 2017). This research aimed to investigate the way variations in contractors' commitment levels have affected the success rate of contract rice farming.

Secondly, according to Tran et al. (2013) and the World Bank (2013), opportunities for contractual relationship in the MKD have been limited by the processing capacity of a small number of export firms who were interested and able to provide an appropriate package of support. A realistic cost-benefit analysis for the contracting programme, considering the availability of the required facilities, is crucial for the enterprises (Shepherd 2013, Will 2015). This research aimed to evaluate and compare the profitability of contractors against the performance of pure spot-market-based buyers in accordance with different scenarios.

Thirdly, studies by Can (2014) and Khiem and Emor (2005) revealed that contracts offered by the large buyers were usually unable to compete with the benefits and services provided by collectors in the open market. The disadvantages of contracts include low prices, high or unclear quality standards and sometimes, the need to transport paddy to the firm's warehouse. Rice farmers might decide not to participate, or to sign and then break the agreement because of the inconvenient and unattractive conditions. This research aimed to study different cases of contracted purchasing prices and their impacts on the contracting programme performance.

Finally, from world experience, it has been shown that the agricultural contracting scheme is not a cost-effective method for every product (Bijman 2008, Will 2015). Contract farming is commonly found in high-value commodities. When the products are relatively undifferentiated and unspecialised, the costs of organising contracts in the supply chain are comparatively high compared with engaging in the spot-market trades (Minot et al. 1986). This research aimed to examine the performance of contract farming for the two main rice varieties grown in two cropping seasons in the MKD region, with distinct paddy yields and

production costs, and in accordance with different farm categories. By comparing different rice types from financial and economic perspectives, this research aimed to gain a better understanding of the viability of the contract-farming scheme in the region.

Inter-Provincial Migration

In terms of migration, the overall aim was to understand the dynamics of the decision-making process and the way migration intention has led to the final decisions of migrants in the MKD region. The first research objective was to take advantage of a well-established theory from social psychology, the Theory of Planned Behaviour (TPB) (Ajzen 1991). The TPB offers a behavioural approach, which is suitable for applying to deliberate migration behaviour. This research utilised the TPB to break down the cognition process of individual migration behaviour into separate components and subsequently embed these into the decisions of the migrants.

Based on the TPB framework, the most critical components forming the migration intention were identified and consequently, the migration behaviour. In addition, the effects of different socio-economic factors, environmental factors and influence of peers or social network among the migrants were examined. This second objective aimed to answer one of the most popular questions in the migration literature: why these people chose to migrate.

The third objective aimed to provide insights into migration patterns among people in certain demographic groups and to estimate the average volume of migration flows in the migration corridor between the MKD and the SE region, to provide a snapshot of people's origins and their intended destinations. Empirical migration data across cities and provinces in the MKD and SE region for a 13-year period, from 2005 to 2017, was used to calibrate the results.

1.4 Research Methodology

In both economics and the social sciences, econometrics has become an established approach in many research areas (Cerulli et al. 2015). Social scientists and economists have long applied econometric models to test hypotheses and to derive quantitative estimates of the relationship between the studied variables. In the literature of both contract farming and migration in the context of the MKD region, econometrics has been a preferred approach. Different statistical estimation and regression tools have been used in recent studies on contract farming (Ba et al. 2019, Nhan 2019, Nhan and Yutaka 2019, Pham and La 2014). The popularity of econometrics has been proved with its extensive use in many migration research works, including Huy and Khoi (2011), Kim Anh et al. (2012), Nguyen et al. (2008), Nguyen-Hoang and McPeak (2010) and Coxhead et al. (2015).

Instead of applying an econometric model, this research took advantage of a different approach, computer simulation, to examine the social and economic problems in the MKD region. According to Helbing (2012), computer models can naturally complement traditional statistical and econometric modelling methods in socio-economic sciences. Computer simulation can be seen as an experimental technique to test theories, explain empirical phenomena, analyse scenarios and deliver forecasts. In addition, it can produce reliable results in cases that cannot be solved numerically. One computer simulation technique that is considered suitable for investigating socio-economic problems is agent-based modelling (ABM) (Epstein 2006a, Farmer and Foley 2009, Gilbert and Troitzsch 2005, Tesfatsion 2006).

1.4.1 Agent-based Modelling

ABM, also known as agent-based computational economics, is an approach that simulates a population of diverse, autonomous and interacting agents (Bonabeau 2002, Tesfatsion 2006).

Each agent is defined by a distinct set of attributes and behaviours, which are the fundamental constructs of agent-based models. The agents act according to their own rules that allow them to make changes in response to their interactions with other agents and the environment in which they are located (Bonabeau 2002, Gilbert 2008, North and Macal 2007). An agent might represent a person, a group of people, an organisation or a country, depending on the problem of interest.

ABM has three specific advantages over traditional statistical and econometrics approaches in modelling socio-economic problems. First, ABM takes a 'bottom-up' approach to include an agent's heterogeneous characteristics, such as demographic attributes, economic resources, skills, knowledge and information (Macal 2016, Squazzoni 2010). Standard analytical models, on the other hand, generally do not have agents in place, or use homogenous agents with perfect rationality. These models cannot take into account individual evaluation for analytic tractability.

Second, ABM's focus on agents can reflect the complexity of social interactions without complication. ABM can use simple decision rules to model the way agents interact and influence each other's behaviour, consequently affecting the agents' adaptation and evolution. Inclusion of social interaction/feedback is considered one of the most significant differences between ABM and econometrics in their application to socio-economic systems (Hamill and Gilbert 2016, Helbing 2012, Squazzoni 2010).

ABM allows modelling of the dynamics of unforeseen social interactions and social networks in human systems (Epstein 2006b). These social adaptations and feedback at the individual level, which often produce non-linear effects at the population level, are a critical component in explaining the emergence of 'herd behaviour' in socio-economic problems (Gilbert and Troitzsch 2005, Hamill and Gilbert 2016). In contrast, traditional econometric models cannot explain emergent phenomena or self-organisation. These models assume that each participant makes separate decisions, independently from others, with no social

interaction, and that they cannot change their behaviour parameters. Therefore, it might be difficult to capture emergent system-wide behaviour in a social and economic system with the use of mathematical and statistical approaches.

Third, a distinctive advantage of ABM is its ability to integrate external factors into agent decision-making processes (Epstein 2006a, Gilbert 2008). Behaviours and interactions among agents could be influenced by geographic location, market conditions (e.g. changing customers' demand, unstable market prices), social/institutional factors (e.g. personal values, trust, solidarity) and environmental uncertainties (e.g. weather variabilities, natural disasters). ABM is particularly relevant in examining the realistic stochastic impacts of different outer components on the micro-mechanisms and local processes and the way lead to the macro changes of the whole system (Bonabeau 2002, Epstein 2006a, North and Macal 2007).

According to Helbing (2012), ABM and econometrics are different but complementary techniques that offer deeper insights into socio-economic problems. Econometrics, which is the application of statistical methods, offers a macroscopic approach based on rational decision making. ABM establishes a natural link between the micro- and macro-level description considering heterogeneity, social interaction and dynamic impacts of external factors. ABM allows exploration of the dynamics and emergent outcomes of the system that can be beyond analytical tractability. Helbing (2012) suggested that each approach has its own advantages and disadvantages and they should be employed to best accommodate the specific problem of interest.

This research aimed to model the two socio-economic problems under examination – contract farming and inter-provincial migration – at the microscopic level, focusing on the individual human decision-making process and how it could reproduce overall system-wide behaviour that could be validated with existing empirical data. Agent-based simulations appeared to be a promising approach to make scientific progress in these two topics. The

strength and weakness of ABM in the literature of contract farming and migration are discussed in Section 3.1 and Section 5.1 respectively.

1.4.2 Desk Research and Expert Interview

Desk research and interviews with experts were conducted as well, to assist in implementing the empirical agent-based models of the two MKD socio-economic case studies. The main aims of applying desk research and expert interviews were to (i) provide a relevant literature review and background, (ii) design overall process and scheduling of the two socio-economic phenomena, (iii) prepare a detailed model parameter configuration and input data in the context of the MKD region, and (iv) contribute to the validation of the agent-based models.

First, desk research was conducted to gather both qualitative and quantitative data to build empirically grounded agent-based models. Data was collected through publicly available sources, including journal papers, policy-advice reports, research reports, surveys, model documentation and online platforms. The data was intended to explain the micro-level behaviour and reasoning of the agents, their individual decision-making processes and their forms of social interaction and adaptation (Janssen and Ostrom 2006). Macro-level emerging patterns of the related socio-economic problems were collected as well, to validate the models in terms of theoretical and empirical analyses (Robinson et al. 2007).

In the case of contract rice farming, the desk research activities started with an in-depth analysis of various research papers, official reports and surveys. Key sources of data included the World Bank, the Food and Agriculture Organization (FAO), Asian Development Bank, the GSO Vietnam, the Ministry of Agriculture and Rural Development in Vietnam, the Institute of Policy and Strategy for Agriculture and Rural Development (IPSARD) and the agricultural trading price database, AgroInfo. The information from these different sources was combined to analyse the application of contract farming in the overall MKD rice supply chain. The analysis provided insights into contract-farming configuration, related parties and

their contractual relationships. In addition, the findings supplied empirical data with regard to farm sizes, farming practices, paddy yields, crop prices and production costs.

However, the literature provided insufficient information about individual behaviour and input data for the agent-based contract-farming model. The information gaps were filled by conducting semi-structured interviews with a group of experts. Semi-structured interviews can quickly produce rich and detailed data about how people think, make decisions and interpret information (Fallon 2008).

Three experts were chosen for the semi-structured interviews to provide a range of perspectives. These experts were working at the IPSARD and were actively involved in the Government project 'The restructuring rice value chain for a more competitive Vietnam' that directly contributed to the formulation of the strategy for Vietnam's rice sector up to 2020 and vision to 2030. The experts have extensive knowledge of the large-scale paddy model and have published research papers in the related field. Many of their modelling studies were also conducted in the MKD region.

The semi-structured interviews contained open-ended questions, but guided by a list of topics. The main topics were to ensure that the purposes of the interviews were fulfilled. Besides, the interviews allowed discussions to be shaped by the experts' own knowledge and understanding about the topic (Bernard 2017). Collected data from the interviews includes notes and memos.

There were two face-to-face semi-structured interviews during the model development and evaluation phase. The first interview aimed to elicit (i) a detailed description of the contract rice-farming process and (ii) the factors affecting the decisions of the related participants with a focus on trust, risk and the role of the contractual and non-contractual relationship. The agents' decision-making processes were extensively revised through consultation with these experts. The process map was also developed during the discussion and shared with the experts at the end of the interviews.

A follow-up, semi-structured interview was organised to examine the outcome of the agent-based model. As a form of verification, the experts were asked how the contract farming model behaved and whether the results were sufficiently accurate and close to the observed reality. We also paid attention to evaluating the assumptions that were made during the model development phase.

In the case of inter-provincial migration, a comprehensive review of the literature was conducted, focusing on the way general social and psychological theories could explain the individual's migration decision-making process and whether these theories could cover the qualitative aspects of the ABM approach. In addition, a range of socio-economic indicators was collected as the input for the agent-based migration model, such as business activities, employment rates, and income and expenditure per capita. Other quantitative data was utilised to validate the dynamics of inter-provincial migration flows from the MKD to the SE region. Most of the statistical data was analysed and evaluated through the Government database and surveys conducted by the GSO Vietnam and the United Nations Population Fund. The most important data sources were as follows:

- GSO Vietnam - Socio-economic statistical data of all provinces and cities in the MKD and SE region from 2005 to 2017.
- Vietnam Household Living Standards Surveys (VHLSS) - 2006, 2008, 2010, 2012 and 2014.
- National Internal Migration Surveys - 2004, 2009, 2014 and 2015.

1.5 Thesis Outline

The content of this thesis is organised into two parts and seven chapters. Chapters 2 and 3 constitute Part I of this thesis. The second chapter presents basic information about contract farming. Chapters 3 focuses on the application of ABM with regard to the viability of contract

rice farming. Chapters 4, 5 and 6 constitute Part II of this thesis and focus on the dynamic patterns of inter-provincial migration flows in the MKD region, as revealed through the use of ABM. Finally, Chapter 7 summarises the results of this thesis and provides concluding remarks. Details about the content of each chapter are described below.

Chapter 2 describes concepts related to the agricultural supply chain (ASC) and contract farming. While the contract-farming scheme is of interest to both contractors and farmers, it might not be a cost-effective process for producing low-value products such as the rice produced in the MKD region. The traditional rice supply chain is discussed, including the prevalence of the spot market in the region. Lastly, the application of the contracting programme and reasons for its failure from the contractors' perspective are reviewed.

Chapter 3 provides a literature review of ABM in the ASC and contract farming. An agent-based contract-farming model in the specific context of the MKD rice supply chain is proposed. The performance of the contracting programme is compared with a pure spot-market-based buyer in different scenarios. The model results, which were validated by domain experts, provide insights into the difficulties with regard to expanding contract rice farming in the region.

Chapter 4 provides an overview of migration in Vietnam and the way inequalities have driven migration across the regions. The focus is on the largest migration corridor, between the MKD and the SE region, and the dynamic patterns of inter-provincial migration flows. In addition, the socio-economic-related determinants that people consider in their migration decision-making process are presented.

Chapter 5 describes the advantages of ABM over the traditional gravity model. The application of TPB in the migration decision-making process is outlined, followed by a

review of agent-based models integrating the TPB. Agent-based migration models relying on direct observations and empirical data are also reviewed.

Chapter 6 proposes an agent-based model with the focus on inter-provincial migration flows from the MKD to the SE region. For this part of the research, a genetic algorithm (GA) was used to conduct automated calibration and parameter exploration sensitivity analysis, which are part of model validation activities. Insights into impacts of the different components and socio-economic factors on the formation of migration intention and the final behaviour of migrants in the MKD region are then discussed.

Chapter 7 summarises results of the two agent-based models presented in this thesis and includes concluding remarks and ideas for future research.

1.6 Research Contributions and Publications

Contract Farming

In Part I, an agent-based model is presented to investigate four obstacles to the expansion of contract rice farming in the MKD region from the perspective of large-scale contractors. The focus is on the financial incentives and trust factors affecting the decisions of the relevant parties in engaging and honouring the contracting agreement. This is the first time ABM has been applied to examine contract farming in the context of the MKD rice supply chain.

First, regarding the failure to build long-term, trust-based relationships, the results showed a significant reduction in the rice volume and profit achieved from the large-scale field programme, if a contractor decided to dishonour a large proportion of the participants. The results revealed an interesting observation when the contractors chose to break their contract with a relatively small proportion (e.g. 10%) of smallholder farmers. In this case, they could still earn more profit per crop than a spot-market-based buyer could earn.

Second, the results showed that the contract-farming scheme for both ordinary and jasmine rice was not cost effective for contractors who were not equipped with husking, processing and polishing machines. The higher cost they had to incur to transform paddy rice into export-ready rice by utilising external services prevented them from engaging in the contracting programme. These results were in agreement with the judgement of the World Bank (2013). Since most of the contractors in the MKD region have limited rice-processing facilities (Tran et al. 2013), the large-scale paddy field model was not being adopted by the majority of enterprises and could not be expanded sustainably.

Third, committed contractors proposing a higher price were able to expand the contract-farming scheme with a larger volume of rice but earned less profit per ton of rice. In contrast, contractors with a lower offer could obtain better earnings per ton of rice as well as higher total profit per cropping season, but they could not easily establish contractual agreements with more farmers. The better financial incentives possibly discouraged contractors with a lower paddy-purchasing price to enlarge their large-scale model.

Fourth, the results identified scenarios of offering prices through which the related parties could find sufficient benefits to remain committed to contract rice farming. In these scenarios, a large buyer could maintain a higher rate of profit that a pure spot-market buyer could, while the farmers were more attracted to the scheme, as reflected through the increased volume of contracted rice. For ordinary rice, the purchase prices ranged from 15% to 20% higher than the spot-market prices and for jasmine rice, from 10% to 15% higher.

Inter-provincial Migration

In Part II, dynamics of the migration decision-making process of MKD people is examined, to help explain the formation of the migration corridor to the SE region. The TPB, a well-known theory derived from social psychology, is used to break down the cognition process of individual migration behaviour into different components, to allow the inclusion of many

different factors that the migrants consider. This is likely the first time in the literature on internal migration in Vietnam that migrants' behaviour has been explained by the formation of migration intention, separated into the behavioural attitude, the subjective norm and the perceived behavioural control.

The results showed that the behavioural attitude component made the largest contribution in forming the migration intention of people in the MKD region. These results were in agreement with the existing literature, indicating that economic reasons, including employment prospects and potential income, were by far the most important factors. Perceived behavioural control was the second most important component in predicting the migration intention and behaviour of people in the MKD region. The subjective norm, representing support from the migrant network, was the least significant of these elements.

The rich output data generated from the agent-based model showed that people in higher income quintile groups (i.e. wealthier people) were less likely to migrate. The migration flows across cities and provinces from the MKD to the SE region showed that Ho Chi Minh City and Binh Duong province were the favourite destinations, with an average of 63,000 and 30,000 MKD people migrating to them each year, respectively. The main sources of MKD out-migration were Long An, Dong Thap, An Giang, Tien Giang and Ben Tre provinces, which are located close to major industrial areas in the SE region.

This study was consistent with the current research trend of applying agent-based computation models to examine the dynamics of migration behaviour (Billari and Prskawetz 2012, Klabunde and Willekens 2016). A systematic approach was implemented to validate the agent-based model, using a GA to conduct automated calibration, parameter exploration and sensitivity analysis as the main validation tools.

Publications

The material presented in this thesis is mainly based on the following papers:

- Nguyen, Hung Khanh, Marquez, Leorey, Talebian, Masoud, and Middleton, Richard H. Increasing the resiliency of Vietnam's rice supply chain: a simulation approach. In International Workshop on Food Supply Chains. Sep 2016. **Peer-reviewed conference paper**
- Nguyen, Hung Khanh, Chiong, Raymond, Chica, Manuel, and Middleton, Richard H. Agent-based simulation of contract rice farming in the Mekong Delta, Vietnam. In Conference 21st Asia-Pacific Symposium on Intelligent and Evolutionary Systems (IES). IEEE, Nov 2017. **Peer-reviewed conference paper**; [doi:10.1109/iesys.2017.8233574]
- Nguyen, Hung Khanh, Chiong, Raymond, Chica, Manuel, Middleton, Richard H, and Dung, Thi Kim Pham, Contract farming in the Mekong Delta's rice supply chain: Insights from an agent-based modeling study. **Journal of Artificial Societies and Social Simulation**; [doi:10.18564/jasss.4008]
- Nguyen, Hung Khanh, Chiong, Raymond, Chica, Manuel, and Middleton, Richard H. Agent-based Modeling of Inter-provincial Migration in the Mekong Delta, Vietnam: A Data Analytics Approach. In Conference on Big Data and Analytics. IEEE, November 2018. **Peer-reviewed conference paper**; [doi:10.1109/icbdaa.2018.8629751]
- Nguyen, Hung Khanh, Chiong, Raymond, Chica, Manuel, Middleton, Richard H, and Dhaka, Sandeep. Agent-based modeling of migration dynamics in the Mekong Delta, Vietnam: Automated calibration using a genetic algorithm. In Congress on Evolutionary Computation (CEC). IEEE, June 2019. **Peer-reviewed conference paper**; [doi:10.1109/cec.2019.8790008]
- Nguyen, Hung Khanh, Chiong, Raymond, Chica, Manuel, and Middleton, Richard H. Understanding the dynamics of inter-provincial migration in the Mekong Delta, Vietnam: An agent-based modeling study. **Submitted to Simulation: Transactions**

of the Society for Modeling and Simulation International, conditionally accepted on 30/04/2020, subject to minor revision

In addition, presentations relevant to this thesis have been made in different conferences such as the Congress on Evolutionary Computation (CEC 2019), International Conference on Principles and Practice of Multi-Agent Systems (PRIMA 2018), Conference on Big Data and Analytics (ICBDA 2018), Annual Systems Modelling Conference (SMC 2018), Operations, Supply Chain and Services Management Symposium (ANZAM 2018), and Asia-Pacific Symposium on Intelligent and Evolutionary Systems (IES 2017).

Part I

Contract Rice Farming

Chapter 2

Contract Rice Farming in the Mekong Delta

This chapter, and also Chapter 3, focus on contract rice farming and constitute Part I of this thesis. The current chapter is organised into three main sections. It first introduces the notion of the ASC, before moving to the concept of contract farming. While the contract-farming scheme is of interest to both contractors and farmers, it might not be a cost-effective process for producing low-value products such as the rice produced in the MKD region. The traditional rice supply chain in the MKD region, with the prevalence of the spot market, is described in the second section. Lastly, the application of the contracting programme and reasons for its failure from the contractors' perspective are reviewed.

2.1 Agricultural Supply Chain and Contract Farming

2.1.1 Agricultural Supply Chain

The term 'supply chain' emerged in the 1980s to describe a network of organisations working together in different processes and activities to bring products and services to the market, with the purpose of satisfying the demand of the final customers (Christopher 2005, Mentzer

et al. 2001). Organisations manage their supply chains to maximise their profitability and create a sustainable competitive advantage. In general, enterprises are required to jointly plan, control, execute and transform the flow of goods from the stage of acquiring raw materials, through production, to the final stage of delivery to customer (Tracey et al. 2005).

Tsolakis et al. (2014) indicated that agribusiness and food industries have only embraced the concept of supply chain management to increase their competitiveness and resilience during the last 10 years. Operating in a complex and dynamic environment, agricultural enterprises have cooperated in the value-added chain of food products to achieve mutual benefits, reduce their costs and investments, and improve customer service (Aramyan et al. 2007, Mangina and Vlachos 2005). In this respect, an ASC is defined as a connected network of individuals and organisations that are responsible for managing the flow of agricultural products from the farm to the table.

The ASC, which is depicted in Figure 2.1, is generally involved with different agricultural activities including (i) land cultivation and the production of crops, (ii) processing and packaging, (iii) transportation and distribution, and (iv) marketing and consumption (Dani 2015). These operational activities are closely associated with a variety of flows, including physical material and product flows, financial flows, information flows and process flows. The successful implementation of supply chain management in the agriculture sector requires these flows to be interchanged in a streamlined and cost-effective way across activities and among the relevant stakeholders (Ahumada and Villalobos 2009, Van der Vorst et al. 2000).

The ASC consists of interconnected actors that can be classified into public authorities and private stakeholders. The former category includes mainly international organisations, national governments, associated administrative authorities and research centres. This group has a significant influence in every link of the ASC by providing legal and regulatory requirements and creating a supportive environment for the agriculture sector at the macro-level. The latter group consists of feedstock suppliers, agri-chemical manufacturers, farmers,

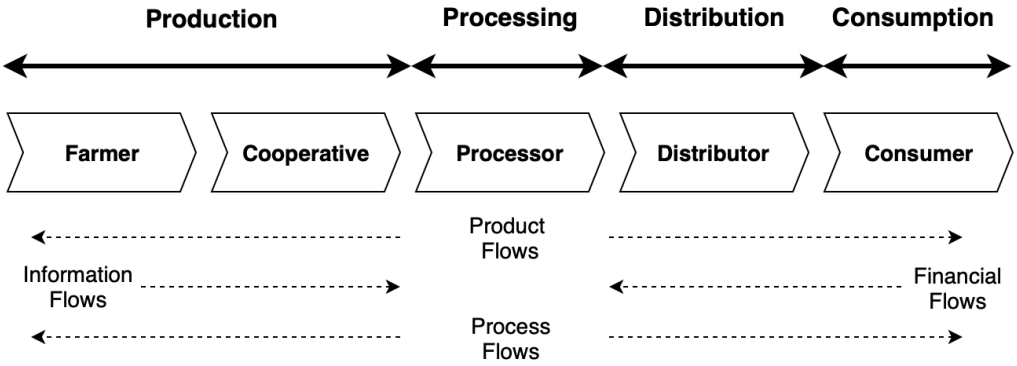


Figure 2.1 The Agricultural Supply Chain (adapted from Tsolakis et al. 2014)

agricultural cooperatives, financial institutions, brokers, industrial processors/manufacturers, packaging suppliers, logistics providers, traders, transport companies, supermarket chains, food retailers, consumers and waste processors (Jaffee et al. 2010, Tsolakis et al. 2014).

Different types of agri-food require different supply chains with specific production, storage, manufacturing and distribution processes that consider the inherent attributes of the food. The supply chains for fresh fruits and vegetables, for example, have a short shelf life and rapid turnover. Fresh produce is generally purchased at the farm gate by a wholesaler and is then sold directly to retailers. Dry goods and frozen foods have a longer shelf life; their supply chains are longer and involve processing and inventory between the farm gate and wholesaling and retailing that is more complex (Dani 2015).

The food supply chain is different from other traditional supply chains of complex assembled products, such as automotive or electronics. The fact that the ASC has a set of unique characteristics, in which created values are dependent on multiple factors throughout the supply chain, requires specific management capabilities (Tsolakis et al. 2014, Van der Vorst et al. 2000). Some of the distinct features of ASC are as follows:

- Perishability: The biological nature of agricultural products makes them perishable, which usually results in a limited shelf life and thus requires efficient supply chains in terms of time. In most cases, short food supply chains characterised by short distances

or few intermediaries between producers and consumers are critical (Ambekar et al. 2015).

- Seasonality: In the ASC, both demand and supply significantly depend on seasonality. Agribusinesses need to structure and manage their supply chains around the seasonal cycles. A long production lead time, due to the time lag between the sowing and harvesting stages, must be considered in managing the variations in agricultural production and consumption due to seasonality (Dani 2015, Handayati et al. 2017, Tsolakis et al. 2014).
- Safety, traceability and visibility: Since food has a direct impact on consumers' health, issues of food quality, safety and risk management are crucial. Continuous monitoring of products and agricultural supplies throughout the network must be implemented and comply with international/national food safety and public health standards. Logistics operations are key factors in enabling food visibility and traceability across the ASC (Dani 2015, Guo et al. 2016).
- Volatility in demand: Demand is sensitive to a variety of factors, such as changing consumer behaviour, special events (including holidays) and promotions. The responsiveness of the ASC has become increasingly important, to enable faster reactions to the dynamic nature of food habits and patterns. This trend has affected the entire food industry and companies have to improve their supply chains continuously to stay competitive (Dani 2015, Jaffee et al. 2010).
- Uncertainty in supply: There is a high level of external uncertainty in agricultural production, related to weather conditions, climate change, geographical characteristics, the availability of land use, the fluctuations of demand, and Government policies related to the trading and pricing systems. In addition, the food supply is affected by many operational activities and processes across the ASC, including inputs, crop

yields, irrigation facilities, processing technologies, logistical and financial capability, and the availability of suppliers and producers (Ahumada and Villalobos 2009, Jaffee et al. 2010).

- High levels of product differentiation: Diversification can lead to difficulties in production forecasting, especially with the marketing of new products. Poor forecasts can cause unnecessary costs related to inventory, warehousing and distribution activities and eventually lead to demand amplification in the upstream supply chain (Tsolakis et al. 2014).

- Impact on the environment: The ASC, from production through processing to retail, has a disproportionate effect on the environment because of its extensive use of natural resources. Environmental impacts include the direct use of energy on farms and indirect use in storage and transportation operations. Fertiliser and pesticide use emits greenhouse gases. Chemical inputs can have toxic effects on water and land. In addition, there is a great deal of food and packaging waste at each stage of the ASC. Corporations in the ASC must pay particular attention to standards and regulations related to environmental initiatives (El Yasmine et al. 2014, Tsolakis et al. 2014).

- Globalisation: Modern ASCs are facing global challenges, with increasing competition and complex supply networks. This means the food chain is now longer and more differentiated and fragmented, which makes it more sensitive to disruption and makes managing supply chain operations increasingly complex. In addition, the structure of the global food supply chain facilitates shifting more power to large multinational corporations, especially in the retail industry. The increasing pace of these structural changes in recent years requires proactive adaptation from every stakeholder in the interconnected food system (Dani 2015, El Yasmine et al. 2014).

The rapid industrialisation of agricultural activities, the increasing concerns about food quality and safety requirements as a prominent societal issue, the emergence of multinational corporations, as well as the recent advancement of information technology have further stimulated integration and collaboration among different organisations in the agricultural sector. Many agribusinesses have recently embraced the concept of coordination in the supply chain (Chen 2006, Taylor and Fearne 2006, Van der Vorst et al. 2000). Coordination among ASC stakeholders/actors aims to smooth food production variation, reduce supply chain risks, lower transaction costs, increase flexibility, guarantee the scheduled supplies and enhance competitiveness (Mangina and Vlachos 2005). There are two types of coordination among ASC actors: (i) horizontal coordination, which occurs among members within the same group and (ii) vertical coordination, which occurs among different groups (Krejci and Beamon 2015).

Several institutional coordination modes link farmers, traders, processors closely into the ASC. Two ends of the vertical coordination continuum are open spot markets and vertical integration (Minot et al. 1986, Peterson 2001). The former is the simplest institutional mode of vertical coordination, in which there are no advance agreements regarding the purchase of agricultural produce between farmers and buyers. In the latter, all supply chain stages, ranging from production, through processing to distribution, are carried out by one firm. Contract farming is one of the hybrid forms in between the two poles of the continuum (Minot 2018).

2.1.2 Contract Farming

Contract farming is a common practice in agriculture all around the world (Eaton and Shepherd 2001) and has recently been expanding, particularly in Asia and Africa (Shepherd 2013, Swinnen and Maertens 2007). According to Shepherd (2013), contract farming can be defined as: "*agricultural production carried out according to an agreement between farmers*

and a buyer, which places conditions on the production and marketing of the commodity" (pp. 1).

In a legal approach, contract farming presents a particular contractual relationship between the farmer and another party (contractors, processors or exporters). In this relationship, the farmer undertakes to produce and deliver designated agricultural commodities, while the contractor undertakes to acquire the product at a predetermined price and possibly provides a degree of production support, mainly through the supply of inputs and the provision of technical advice. Thus, contract farming presents a particular contractual relationship in which the farmers produce and deliver designated agricultural commodities, while the contractors acquire the commodities at a predetermined price (Eaton and Shepherd 2001, Shepherd 2013, Swinnen and Maertens 2007).

In an economic approach, contract farming has been described as a mechanism for governing transactions in the ASC. It is adopted by firms to secure access to agricultural products, raw materials and supplies that meet the desired quality, quantity, location and timing specifications. It is deployed as a rural development tool as well, to promote the linking of smallholder farmers with markets, especially in developing countries.

Contract-farming schemes can be classified according to either the nature of the contract or the way the stakeholders are organised within the scheme. The latter categorisation depends on the intensity of relationship among the contractors, the farmers and the other relevant actors. Eaton and Shepherd (2001) determined the following five types of contracting programmes: (i) centralised, (ii) estate, (iii) multi-partite, (iv) informal and (v) intermediary models.

Centralised and estate models are strict forms of vertical coordination between a centralised buyer and a large number of small producers. They generally require specific quota allocation and high-quality products (Eaton and Shepherd 2001, Prowse 2012). These two models are commonly used for perennial crops or high-value products. In an estate contract,

the contractor owns the estate or plantation. Multi-partite contracts involve the participation of public entities, including local government, research institutes, private firms and farmers. The informal model is based on verbal contracts between small firms and a limited number of producers. This type of contract requires minimal processing and is popular with fruit and vegetable producers (Bijman 2008, Eaton and Shepherd 2001). In the intermediary contract, local traders are subcontracted with a large buyer to trade directly with farmers. In this model, assurance of output quality is limited because of the distance between the large buyer and the producers (Eaton and Shepherd 2001).

Contract farming is most popular for cash crops (e.g. tobacco, cotton, sugarcane), horticulture (vegetables and fruit), tree crops (e.g. coffee, tea, cocoa), livestock, poultry and aquaculture. Agricultural contracting is commonly found in exporting commodities that are destined for high-income consumers who are willing to pay a premium for quality and food safety. Growing these high-value commodities is considered cost effective when large-scale buyers, such as processors or exporters, have the incentive to obtain unique product characteristics, as well as organisational and production methods (Minot et al. 1986). Successful implementation of the agricultural contracting programme with staple crops such as rice, wheat, maize is limited, with a few exceptions for differentiated products (Will 2015).

Advantages of Contract Farming

According to the literature, the benefits for agribusiness of entering into contracting agreements are clear and convincing (Bijman 2008, Prowse 2012, Shepherd 2013, Will 2015), as follows:

- The contractor can acquire a steady and high quality of raw material via economies of scale in procurement. Stable supplies can help the buyer to reduce the costs involved with large-scale production and reduce the risks associated with up-front investments.

- Higher quality and consistency of outputs: A contractor entering the contract-farming scheme can achieve greater control over the production process through the provision of technical support and standard settings. Technical assistance and close supervision can help to raise the quality of the products, obtain more uniformity and strengthen the compliance to the eventual buyers' requirements, including food quality and safety. Output traceability related to the source of production can be assured, especially when there is concern for food safety and visibility.
- Production reliability: Contract farming can ensure reasonable supply reliability and reduce the risk of having insufficient produce of the right quality and at the right time. This advantage is crucial for the business of agricultural products that are largely dependent on external factors such as weather conditions.
- Reduction of the coordination cost: A contracting programme can reduce coordination costs for large buyers, giving them greater flexibility in managing their production chain. A more regular and stable supply allows greater coordination of in-house processing activities and opportunities to optimise the capacity and workforce, consequently fulfilling customers' demands. This benefit is essential for the tight linkage between upstream and downstream actors in the food supply chain.
- Reduction of the transaction cost: Contract farming helps to decrease the overheads related to output screening and selection processes, since the contractor has better control over the input supply and production. Large-scale contracts can reduce post-harvesting losses because of the more efficient logistics and transportation activities.
- Establishment of long-term partnerships with farmers: The contractor can enhance long-term business planning through a sustainable relationship with the farmers. This helps agricultural firms to overcome the constraints in accessing land and labour. These improved connections with many small producers can bring greater flexibility in

production capacities, such as the introduction of new product lines with the desired quality and quantities. This increase in on-farm diversification cannot be achieved by trading on the open spot market.

- Foundation to improve firm's reputation: Contracting systems can enable enterprises to develop a reputable brand name and to enhance their competitiveness. They allow companies to attract government subsidies (e.g. access to land, financial support), which reduce the costs and risks in their ASC. In addition, the contractor might benefit from involvement with international development programmes or research projects that offer extended services and collaboration opportunities.

Contract farming offers many potential benefits for farmers. In the pre-harvesting stage, farmers can obtain some forms of credit to finance their production inputs, which helps to reduce their transaction costs and increase their yield (Prowse 2012, Shepherd 2013). In many cases, farmers receive productivity-enhancing inputs, such as seed, fertilisers and pesticides, from the contractor on credit, requiring no payment until the crop is delivered. In addition, farmers who participate in contract farming with enterprises can apply for credit from commercial banks or government agencies to purchase the inputs. In many countries, smallholder farmers outside contract farming have difficulty in accessing stable and high-quality inputs (Oxfam Vietnam 2012).

Bijman (2008) indicated that one of the most important benefits that farmers receive from the contract-farming scheme is the technical assistance and knowledge transfer from the contracting company. Improved techniques and efficiency under the agricultural contracting programme, especially for high-risk crops, results in lower production costs and increased income for farmers. Private agribusiness may support with land preparation, such as field cultivation to ensure the crop practices achieve the expected yields and quantities. Technological support and skills can spill over onto adjacent fields and areas and subsequently improve the productivity of other farmers (Eaton and Shepherd 2001).

Contracts assure farmers that their produce can reach a reliable market (both traditional and new markets), normally at a predetermined price (Prowse 2012). Under the contracting system, farmers grow crops to the specification of the firms and they are guaranteed that they can access markets for their produce. The contract-farming scheme can provide guaranteed pricing structures that reduce uncertainties from price volatility in the open market. Therefore, contract farming increases the stability of the farmers' incomes and livelihoods (Prowse 2012).

In summary, contract farming can open doors to stable markets for a farm's produce, stimulate technology and skill transfer, and support farmers in meeting higher standards in the modern ASC. These incentives attract and bind farmers to contract-farming schemes with agribusinesses and form long-term relationships (Prowse 2012, Will 2015).

Disadvantages of Contract Farming

Firms can face potential disincentives when they implement contract farming as a governance mode in their supply chain, as follows:

- Firms in contracting agreement need to invest large up-front capital and incur potentially high costs in managing supplies from many producers (Da Silva et al. 2005). Organising and coordinating smallholder farmers scattered over a region is a complex task and requires a considerable amount of investment in infrastructure and personnel. The contractor can face high transaction costs of dealing with a large number of farmers, together with providing services such as transportation, financing, technical assistance and quality-monitoring activities (Eaton and Shepherd 2001).
- Managers who have insufficient management skills and knowledge to develop good relationships with farmers can result in unproductive contract-farming projects (Bijman 2008). If the costs and responsibilities of the agribusiness firms are not fully reckoned and internalised into their management decisions, the contracting programme can be

unprofitable. In addition, Eaton and Shepherd (2001) pointed out common mistakes in estimating yields and farm incomes by staff who coordinate the contract-farming scheme for the first time without having relevant experience.

- Farmer dissatisfaction can result in their withdrawal from the contract-farming scheme in several situations, such as late payment, changes in the predetermined price and discrimination in buying (Da Silva et al. 2005). If the contract-farming arrangements break down, the contractor might not be able to reclaim the credits they have provided for the farmers as production inputs and services. The consequent failure to supply the agreed contracts could put future sales at high risk and damage the firm's reputation.
- Extra-contractual sales are one of the reasons for the failure of contract-farming schemes. When market conditions change, smallholder farmers are tempted to choose to sell all or part of their production to a third party who offers higher prices. Side selling by farmers results in an undersupply of the firm's needs. Extra-contractual sales are common when contractual enforcement in the scheme is weak and an alternative market is easily accessible (Eaton and Shepherd 2001, Will 2015).
- Some smallholder farmers can have an unreliable business approach. They can be tempted to use inputs provided on credit for other purposes, rather than for the contracted crop. The frequent occurrence of this behaviour can lead to a reduction in crop yield and crop quality. To overcome this problem, firms are generally required to invest further in training and monitoring services with extension staff (Da Silva et al. 2005, Shepherd 2013).
- An unsupportive enabling environment (mostly related to land tenure policy and financial credit service) offered by the Government and associated local authorities can discourage agricultural enterprises and the private sector from participating in contract-farming schemes (Shepherd 2013).

Even though contract farming offers many opportunities for farmers, the contracts can have several disadvantages for them. One of the most obvious negative impacts is the possibility that firms could renege on their contracts if conditions for opportunistic behaviour arise, such as when market prices at crop-harvesting time are substantially different from the prices agreed in the contract (Shepherd 2013). The contractors could force a price renegotiation or reject the delivery of the products. A firm's failure to honour the contract could stem from the introduction of a new crop, or inaccurate forecasting of market size or price levels by the company. Major problems can occur if the company is unwilling to share any of the risks or the losses with the farmers (Bijman 2008).

Another possible disadvantage is that farmers could lose their autonomy in the choice of farming and trading activities. They become locked into a contracting agreement that cannot easily change to other crops or adjust production mix and they can lose their bargaining power with the firm. In this case, small producers can be controlled and exploited by big companies or monopolistic enterprises and they are unable to benefit from market opportunities (Eaton and Shepherd 2001, Will 2015). Contractors might exert this uneven power by intentionally avoiding transparency in the price mechanism or by adjusting the delivery schedule to gain benefits from contractual hold-up, especially in the case of market volatility. Without effective enforcement mechanisms, it is problematic for small farmers to justify the contractor's claims.

Moreover, not all farmers are suited to contract farming. Firms generally identify a location that is suitable for the large-scale farming system by considering several factors, such as the agronomic suitability of the land and climate, as well as the availability of basic infrastructure and services such as transportation, communications and electricity. Firms then choose the available farmers in the region that have a number of the required features, such as assets and resources, land size, education and willingness to follow modern cultivation instructions. One strand of literature indicates that the poorest farmers are typically excluded from contract-farming schemes (ActionAid 2015, Shepherd 2013, Will 2015).

2.2 Rice Supply Chain and Spot Market in the Mekong Delta

2.2.1 Traditional Rice Supply Chain

Rice is the most important commodity of agriculture in Vietnam, consumed by nearly 89 million of its people. Rice production is an important source of income for more than 60 million people living in agricultural and rural areas. In recent decades, the rice industry has made significant progress on land productivity gains and the increased intensification of crops, which has helped Vietnam's rice production to grow substantially and steadily (Chen et al. 2015). At the aggregate national level, Vietnam is very secure with regard to food availability. The rice 'success story' has made a critical contribution to transforming Vietnam from one of the poorest countries in the world into a lower middle-income country (Jaffee et al. 2011a).

The MKD region has long been the most favourable area for rice growing and is often called the 'Rice Bowl' of Vietnam. The MKD and the Red River Delta are considered the two major rice-producing regions in Vietnam. Over the past decade, the MKD region has accounted for approximately half of Vietnam's total rice production (IPSARD 2014). This region plays a central role in Vietnam's food security, not only domestically but also internationally. The bulk of the MKD's expanded rice production has been channelled abroad through commercial exports and government-to-government programmes. In recent years, the region has produced 95% of Vietnam's rice exports, a major factor in Vietnam becoming one of the top rice-exporting countries in the world (VEPR 2015, World Bank 2011).

Even though the MKD rice-growing system has been remarkably successful in meeting the basic needs of consumers, it has developed without a strong orientation towards product quality and without strong competitive pressures to achieve technical efficiency in all stages of the supply chain. In the upstream supply chain, the structure of rice production is

fragmented. Approximately 1.46 million farmers in the MKD region grow paddy, mostly in marginal or small fields with the average size of 1.29 hectares (ha) (World Bank 2011). MKD rice production is characterised by lower adoption rates of sustainable practices, using an excessive amount of seeds, fertiliser, pesticides and herbicides. This traditional cultivation method adds considerable production costs for farmers and reduces the sustainability and competitiveness of the harvested crop (IPSARD 2014).

Between the harvest and the downstream activities, the rice supply chain incurs considerable physical and quality loss and contributes relatively little added value (Chen et al. 2015). Smallholder farmers tend to rely primarily on household labour, utilising little mechanisation (Pham and La 2014). Most farmers harvest the paddy manually, without the use of harvesters. These farmers are either incapable of owning the required equipment or their landholdings are too small and fragmented to be accessed by external harvesting services. Jaffee et al. (2011b) estimated that these labour constraints cause 2 to 3% of physical crop losses and adverse effects on paddy quality.

Post-harvest losses also occur because of inadequate paddy drying technology and the lack of storage facilities (World Bank 2011). In the MKD, most farmers prefer to have paddy sun-dried to save cost, which results in physical and quality losses. The physical losses are estimated to be 2.12% on average (Jaffee et al. 2011a). In addition, most farmers have no storage facilities, or use small storehouses and cannot deal with the developing double and triple cropping per year. If the weather conditions are not favourable for sun drying, most farmers choose to sell wet paddy to local traders at significantly low prices (Pham and La 2014).

In the traditional MKD rice supply chain, the milling process is done in two or three stages, using different actors. After buying semi-dried or wet paddy from farmers, local collectors transport it to small-scale paddy millers. These millers mostly have rudimentary and limited storage capacity. Improperly dried paddy with high moisture content decays

quickly and consequently leads to a lower grain rate, broken grain, humidity and impurities. Physical losses in this stage are estimated at 1.7% (Jaffee et al. 2011a), which add up to approximately 1 million tons of damaged or lost paddy between the farm gate and the first stage of processing.

The intermediate product is then delivered to larger millers, who produce white rice for both the domestic and export market. According to (World Bank 2011), only a small proportion of the larger millers have modernised operations. Further physical losses in the latter parts of the domestic and export supply chains also occur, with hundreds of millions of American dollars deducted from the potential value of the product (World Bank 2011).

In general, the MKD rice supply chain has remained underdeveloped from both the physical and institutional perspectives. Most of the rice in the region is undifferentiated and of low quality. This could be because of Vietnam's national food security strategy in the past decades, when the growth track was based mainly on high production of low-quality rice, with weak incentives and support systems for quality management (World Bank 2011). A dozen varieties of rice, with different degrees of maturity, are generally mixed in the supply chain activities such as transportation, storage and processing. The supply chain players, especially local traders and small huskers/millers, are generally constrained from maintaining the quality of the product because of a lack of capital and the required equipment.

Vietnam's current rice-exporting prices are among the lowest when compared against other top rice-exporting countries such as Thailand, India and Pakistan. Few Vietnamese brand names are recognised, which reduces the competitiveness of their rice in international markets (Chen et al. 2015). The MKD rice produced for the domestic market is of a standard quality as well (VEPR 2015). Most of the rice products are not distinguished by their geographical origins.

Figure 2.2 shows a traditional rice supply chain in the MKD, with five actors between the farm gate and final consumers: paddy collectors (brokers), paddy millers, rice polishers, rice

traders, and exporters and domestic wholesalers/retailers. The rice supply chain is long in comparison to other agricultural product supply chains in Vietnam and rice supply chains in other leading rice-producing countries. Informal commercial ties are common between local collectors and other supply chain players, both at the upstream and downstream ends. According to Loc and Son (2013), the most popular supply chain was through collectors in the spot market with more than 93% of total paddy produced by farmers. The most direct supply chain, a vertical linkage from the farmers to the exporter, accounted for only 4.2% of the harvested paddy (as shown in Figure 2.2).

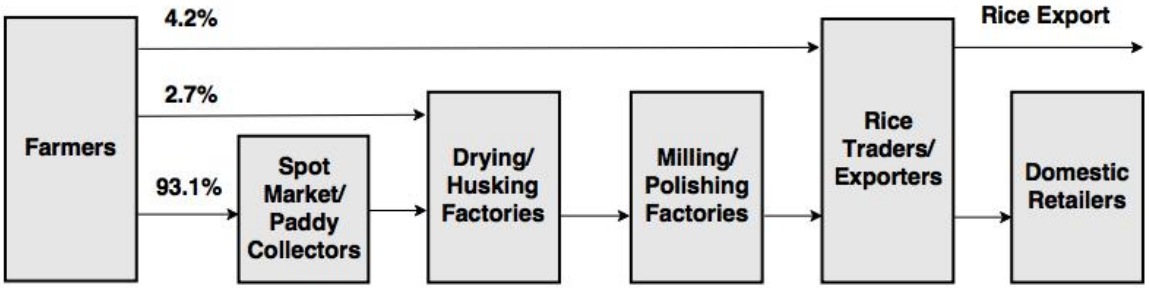


Figure 2.2 A traditional rice supply chain in the MKD region

The rice supply chain features a modest level of horizontal coordination (World Bank 2011). There are millions of small farmers in the MKD region; however, instances of collective action among farmers are limited, with few effective farmer's production groups and cooperatives. In addition, there is a lack of vertical integration and coordination in the MKD rice supply chain. Few agricultural firms operate at more than one level in the supply chain. Players commonly trade with actors who are just above and below them. Traders, millers and exporters have little formal ways to cooperate and are not part of any long-term contractual relationship (Jaffee et al. 2011b).

2.2.2 Spot Market

The spot market comprises several thousand collectors/traders who operate at localised levels in the MKD region. The spot market has long been prevalent in the MKD rice supply chain. One of the main reasons for this is related to transportation and transaction costs. The MKD has complex interlacing drainage and irrigation canal systems, which serve as the main means for transporting paddy from the fields to the market. It is costly and less convenient for processors and exporters to buy directly from a large number of individual farmers. Local collectors, who own barges and boats, are more efficient in gathering and transporting paddy to large buyers. Therefore, the spot market has been playing a key role in the MKD, connecting many small farmers, who produce only limited volumes of rice for sale, with downstream players who require larger volumes of paddy to fulfil their contracts.

Apart from the capability of connecting many individual small farmers with processors and exporters through transportation, collectors usually pay farmers 'on the spot'. Most farmers are poor and they need to sell their output in the spot market as quickly as possible, to settle the debts incurred at the beginning of the growing season. Additionally, collectors normally only require low-value paddy, which requires simple growing techniques; therefore, they are preferred by many farmers (VEPR 2015). Collectors sometimes even provide market information, financial credit and farming inputs to farmers.

A further reason for the dominance of the spot market here is related to the imperfect competition among Vietnamese rice exporters. State-owned enterprises have accounted for a large proportion of exported rice, mostly from government-to-government contracts. These contracts normally involve lower-grade rice and the public exporters have little incentive to search for a new market (Tran et al. 2013). The lack of capability of these exporters to improve the quality of Vietnamese rice, or to bargain for a higher exporting price and search for new markets, puts pressure on them and other downstream players along the supply chain to reduce the purchasing price of rice. Therefore, the state-owned exporters and processing

factories prefer to buy rice from the spot market, rather than directly from farmers. Collectors, who are non-registered entities operating in informal trades, can avoid paying the official farm-gate price for paddy (the minimum price set by the Government), which explains why most of the paddy in the MKD rice supply chain is traded in the spot market (Tran et al. 2013).

2.3 Contract Rice Farming in the Mekong Delta

Much empirical research on the MKD rice value chain suggests that farmers, especially those who own small landholdings, have received the most modest benefits compared with the other supply chain players (Chen et al. 2015, Loc and Son 2013, Pham and La 2014, Tran et al. 2013, VEPR 2015, World Bank 2011). Rice has contributed a comparatively small proportion to the farmers' main incomes. Most of the rice growers in the MKD region are net buyers of rice. Farm households are increasingly reliant on non-rice and off-farm sources of income and employment. Only farmers with large landholdings located in favourable agro-ecological conditions are able to improve their livelihood with the cultivation of specialised and high-quality rice varieties (Jaffee et al. 2011a).

In the event of increasing costs of inputs or fluctuations in trading price, the farmers are the most affected supply chain actors (Tran et al. 2013, World Bank 2011). As shown in Figure 2.2, most of the paddy produced by the rice producers is sold to local traders. The collectors, who have more market power than the farmers have, usually put pressure on the trading, setting low purchasing prices. When rice prices increase, the farmers receive little benefit and when there is a good cropping season and the price decreases, the farmers suffer the most significant impacts (VEPR 2015). MKD rice growers lack bargaining power partly because the majority of farmers produce generic paddy rice, harvest at almost the same time and have insufficient capacity to dry and store wet paddy effectively. In addition, the farmers

receive little support and investment to improve their performance from the upstream supply chain players, who capture the most profit (Pham and La 2014, Tran et al. 2013).

The Vietnamese Government has been concerned that these problems might provide MKD farmers with disincentives to grow rice and consequently, threaten the country's national food security. Therefore, the contract-farming scheme has been endorsed by the Government as a strategy to increase quality management in the supply chain, stabilise trading prices and improve farmer incomes (Can 2014, Dung 2014). Accordingly, the Vietnamese Government has issued several Decisions and models to promote contract farming between agribusinesses and rice producers, as outlined in the next sections.

2.3.1 'Linking Together the Four Houses' Model

Contract farming was first implemented under Decision No.80/2002/QD-CP (Decision 80) in 2002. Decision 80 originally aimed to increase the use of agricultural contracts to improve procurement and efficiency and to promote technological innovation in the rural economy within Vietnam (UNIDROIT 2014). Decision 80, also known as the 'Linking together the four houses' policy, directly bound parties who had entered into the contract. The 'four houses' refers to the involvement of four key actors: the Government, entrepreneurs, researchers and farmers (Can 2014), as follows:

- government agencies - organising, linking key players in the agricultural food supply chain and creating a supportive environment with policies to facilitate the linkages
- agro-industrial firms (mostly state-owned enterprises) – coordinating contracts with farmers, providing input supplies and finding market outlets for the products
- farmers – applying technologies and ensuring the quality and quantity of the output
- researchers (research institutions, universities) – providing technologies and supporting farmers in increasing productivity and produce quality.

Decision 80 was one of the few explicit ways the Vietnamese Government has attempted to foster the establishment of cooperatives and farmer groups, as well as the participation of related parties into the contractual arrangements to improve the vertical linkages in the agricultural sector. The contract-farming scheme was applied with a variety of agricultural products, ranging from staple food (rice), industrial crops (sugarcane, cassava), forestry products (timbers, herbs), livestock (poultry, milk) and fishery products (fish, shell, shrimp). One of the first comprehensive documentations of contract farming in Vietnam was conducted by Asian Development Bank (2007). Decision 80 was expected to be an effective way to draw millions of small farmers in the MKD region into a commercialised supply chain (Asian Development Bank 2007).

However, contract rice farming under Decision 80 was largely unsuccessful in the MKD, with a high level of implementation failures in many provinces (Dung 2014, Khiem and Emor 2005, Roberts and Khiem 2005, UNIDROIT 2014). The proportion of contract sales was comparatively low in 2003, with only 10% of contracted rice being delivered in the MKD (Khiem and Emor 2005). In An Giang, the first province to promote the 'Linking together the four houses' model actively, 90% of signed paddy contracts were not fulfilled (Khiem and Emor 2005, Roberts and Khiem 2005). In 2012, after 10 years of contract promotion under Decision 80, only 2.1% of total rice production was produced and marketed under the contracting programme between farmers and agribusinesses. However, for some agricultural products with high processing requirements, such as sugarcane, tea, rubber, milk and cigarettes, the share of sales from agricultural contracts reached 30% (Son and Tien 2005, UNIDROIT 2014). According to Nhan et al. (2015) and the Asian Development Bank (2007), most contract-farming schemes under Decision 80 failed, particularly the contracts with low-quality products such as rice, vegetables and fruit.

In contract rice farming, breaches have been common from both contractors and farmers (Roberts and Khiem 2005, UNIDROIT 2014). Breaches occurred because of the opportunistic

choices made by contracting parties. Farmers have reneged on contracts when offered a higher price and buying arrangements that were more efficient from paddy collectors. These farmers have refused to deliver paddy and have declined to repay the advances on inputs provided at the beginning of the cropping season. Consequently, the processors or exporters have been forced to purchase paddy or rice of inconsistent quality from collectors, normally at costly prices. Large buyers have been reported to fail to honour the contract as well, especially when there is a good harvest. They have delayed their purchases to manipulate the prices, forcing the farmers to sell at a lower price, or they have tightened the quality standard to reject excess paddy (Roberts and Khiem 2005). The weakness of the regulations to enforce the contracts and the lack of support from the Government have been considered the major factors leading to the failure of the contracting rice programme in the MKD region (Dung 2014, Roberts and Khiem 2005, UNIDROIT 2014).

2.3.2 'Large-scale Paddy Field' Model

To address the existing constraints in Decision 80 and achieve a sustainable practice, the Vietnamese Government proposed the 'Large-scale paddy field' model under Decision 62/2013/QD-TTG in 2013. Decision 62 aimed to improve the vertical linkages between the exporting, processing and marketing of agricultural products with the construction of large-scale paddy fields (UNIDROIT 2014). Decision 62 provided a supportive, enabling environment, which clearly specified the obligations of the related parties in the cooperation, with farmers and contractors being the main subjects. A standard form of contract with guidance was provided to ensure all the agricultural arrangements included the required conditions. Settlement mechanisms for contract breaches were regulated, to prevent opportunistic behaviours. In addition, Decision 62 allocated the capital resources and budgets to conduct assistant policies and to examine and supervise the implementation process (Pham

and La 2014, Viet 2015). This Decision aimed to fill the gaps in the legal system, to protect the rights of all parties and foster the application of contract rice farming.

The large-scale field model first appeared in An Giang in 2007. Several private enterprises, including the An Giang Plant Protection Joint Stock (AGPPS) Company, Gentraco Corporation and Trung An Hi-Tech Company, actively built regional models to ensure the rice quality was consistently high, to meet the requirements of their target markets. Similar models were then spread to many provinces in the MKD region under different names such as 'large field', 'material field', 'linkage field' and 'smaller farmer, large field'. These models aimed to develop a sustainable rice production system in the MKD region and they were the foundation for the issuance of Decision 62.

Figure 2.3 shows the design of a contract rice-farming model that is based on the case of AGPPS (Ngan et al. 2015). It is an upgraded model of the conventional rice supply chain (see Figure 2.2), with vertical coordination between farmers and exporters. Paddy produced by farmers can be sold directly to exporters. Transporters, milling and polishing factories act as service providers for exporters.

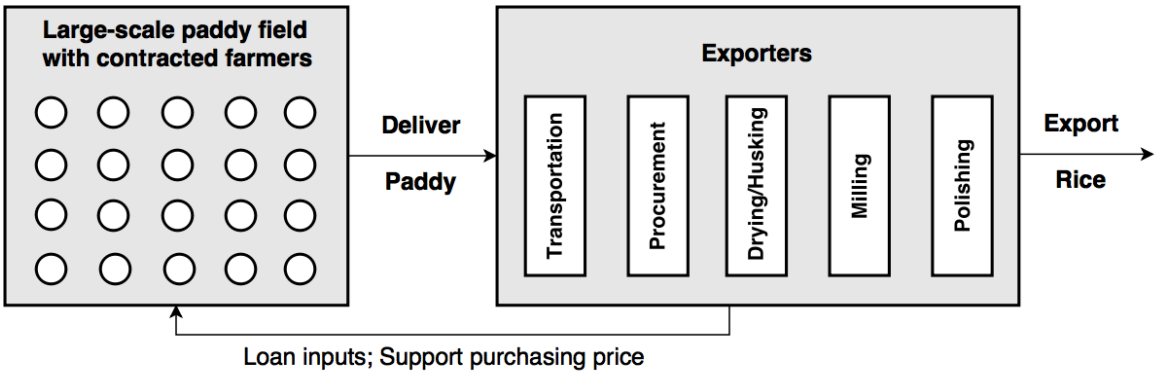


Figure 2.3 The contract rice-farming model in the MKD region

A 'large-scale paddy field' is established when the contractor coordinates a group of small farmers and forms an aggregated large area, to achieve efficiency and maximise profit. Contracted farmers operate with a common agreement and are responsible for the rice

cultivation (Can 2014). Farmers might receive a production loan as an agricultural input and technical support from the technical experts, also known as 'farmer friends' (Ngan et al. 2015). Farmers are guided to apply environmentally friendly growing methods to produce high-quality rice. Traditional transportation methods by barges and boats provided by the local collector are unnecessary, as the field is large enough to have on-farm grain silos. The contractors subsequently attain a stable supply source of high-value paddy rice and then trade in the international market. The profits are shared between the contracted farmers through an increased farm-gate price and the contractors, to compensate for the services provided to farmers and operational activities (Can 2014).

Although the advantages for all parties of participating in contractual agreements are obvious, progress in the expansion of the contract-farming scheme in the MKD region under Decision 62 has been comparatively slow (Ho Chi Minh City Federation of Labour 2019, Saigon Times Group 2019, Vietnam Farmer Union 2017, Vietnam Television 2017). In 2017, the proportion of total available paddy land used for contract farming in the MKD region was 11% (Vietnam Farmer Union 2017) and in 2018, 9.2%, approximately 380,000 ha (People's Army of Vietnam 2019). Several pioneering companies that had been successful in implementing the contractual programme have recently reduced the scale of their paddy fields significantly. AGPPS reduced its contract-farming scheme from 90,000 ha of paddy land in 2015 to 30,000 in 2018 (People's Army of Vietnam 2019). The size of paddy fields under contract with Trung An Company decreased from 8,000 to 5,000 ha (Ho Chi Minh City Federation of Labour 2019). Cases of unilateral breaches and opportunistic behaviours from both sides have been reported (People's Army of Vietnam 2019, Saigon Times Group 2019, Vietnam Television 2017).

2.3.3 Problems of Contract Rice Farming

A number of reasons have contributed to the failure of Decision 80 and the slow progress in the expansion of Decision 62 for contract rice farming. This research examined four specific issues from the contractors' perspective, aiming to understand the way they impede the success of the contracting programme in the MKD rice supply chain.

First, many contractors in the region failed to build trust and invest in long-term relationships with farmers, resulting in a low rate of success in contract farming (Dung 2014, UNIDROIT 2014). According to Fafchamps (2003), Shepherd (2013) and Will (2015), trust is the most basic and important factor in preventing opportunistic behaviour and ensuring the success of the contracting agreement. A trust-based relationship between contractors and farmers is critical in identifying and effectively resolving problems early. Contractors in the MKD failed to remain trustworthy by honouring their contract obligations when there was an unexpected fluctuation of market price at the end of the cropping season (Roberts and Khiem 2005, UNIDROIT 2014, Vietnam Television 2017). The agricultural contracting process cannot work without trust between farmers and enterprises.

Second, a clear understanding of the profitability of both contractors and farmers for different crop activities is necessary to create a viable business for the large enterprises, as well as a sustainable livelihood for smallholder producers (Shepherd 2013, Will 2015). According to Tran et al. (2013), World Bank (2013), the opportunities for contractual relationship in the MKD have been limited by the processing capacity of a small number of export firms who have been interested and able to provide an appropriate package of support. A realistic cost-benefit analysis for the contract rice-farming scheme, in comparison with pure spot-market-based trading, is essential.

Third, a study by Khiem and Emor (2005) revealed that the contracts offered by the large buyers were usually unable to compete with the benefits and services provided by collectors in the open market, leading to high rates of contract failure. Most farmers perceived the

potential advantages of participating in the agricultural contracting programme. However, several obstacles have constrained the farmers from fulfilling their contracts successfully. The disadvantages of the contracts have included low purchasing prices, high or unclear quality standards and sometimes, the need to transport paddy to the firms' warehouses (Can 2014, Roberts and Khiem 2005). With the current design of contracts, the farmers might decide not to participate, or to sign and then break the agreement because of the inconvenient and unattractive conditions. Roberts and Khiem (2005) indicated that mutual benefits for both parties in the partnership would need to be achieved before better enforcement mechanisms could improve the contract success rate.

Fourth, from world experience, it has been shown that the agricultural contracting scheme is not a cost-effective method for every product (Bijman 2008, Will 2015). Contract farming is commonly found in high-value commodities, such as tobacco, sugarcane, coffee and tea, which are intended for high-income consumers who are willing to pay extra for quality and food safety. When they are growing these commodities, large-scale buyers have more incentive to obtain specific product features, organise good agricultural methods, add significant value along the chain and sell the products at a higher profit margin. When the products are relatively undifferentiated and less specialised, the costs of organising contracts in the supply chain are comparatively high compared with engaging in market-based trades (Minot et al. 1986). As most of the rice grown in the MKD is of low value, the issues of rice quality and processing are not critical. The contract rice-farming scheme may be disadvantageous compared with the spot market because of the high transaction costs of coordinating many smallholder farmers. The 'one-size-fits-all' approach of Decisions 80 and 62 might produce more difficulties for both rice contractors and rice farmers in the MKD region.

Chapter 3

Agent-based Modelling of Contract Rice Farming in the Mekong Delta

While Chapter 2 introduces the background of problems related to the MKD's contract rice farming, this chapter presents the agent-based model and insights gained from the results. The chapter starts with a literature review of ABM in the ASC and contract farming. An agent-based contract-farming model is described next, followed by a specific case study of the MKD rice supply chain. After that, the initialisation of input data is discussed. Lastly, the performance of the contracting programme is compared with a pure spot-market-based buyer in different scenarios. The model results, which were validated by domain experts, provide insights into the challenges in regard to expanding contract rice farming in the MKD region.

3.1 Agent-based Modelling of Agricultural Supply Chain and Contract Farming

3.1.1 Agricultural Supply Chain

In the field of ASC management, research on ABM has recently become more common (Higgins et al. 2010, Krejci and Beamon 2012, Nolan et al. 2009, Utomo et al. 2018). Recent

literature review works (Hilletofth and Lättilä 2012, Huber et al. 2018, Kremmydas et al. 2018, Oliveira et al. 2016, Utomo et al. 2018, Zimmermann et al. 2009) have noted an increase in the number of papers on the topic of ABM in the areas of ASC, agricultural systems and quantitative agricultural policy analysis. ABM has been widely accepted as one of the analytical tools that are suited for modelling the dynamics and complexity of agricultural systems and evaluating the impacts of policies (Huber et al. 2018, Kremmydas et al. 2018, Utomo et al. 2018).

Higgins et al. (2010) suggested that ASC should be modelled as a complex adaptive system, which consists of diverse and autonomous agents that make choices as a collective, adapt to changes and evolve over time (Pathak et al. 2007). ABM takes a 'bottom-up' approach that adequately represents the heterogeneous characteristics and dynamic interactions of the actors in the ASC. In addition, ABM can incorporate non-economic factors, including the spatial, environmental and social conditions that the agents' decisions depend on, through which the emergent behaviours of the entire agricultural system emerge (Huber et al. 2018, Kremmydas 2012). These distinct features of ABM make it an appropriate tool in the domain of ASC management.

One of the major advantages of ABM is its ability to accommodate heterogeneous and autonomous agents (An 2012). This capability is particularly relevant in modelling the ASC, in which the actors differ widely in their resources, capabilities and preferences. For example, individual farmers can be different in their farm size, cultivation knowledge and harvesting equipment. Farmers' choices might depend on many factors, including the economic driver of maximising profit and personal intrinsic values such as risk attitude and the autonomy of farm production (Krejci and Beamon 2015, Kremmydas 2012). In addition, it is unlikely that all farmers perceive the same level of information to help them optimise their decisions and behave rationally (Krejci and Beamon 2012). Kremmydas (2012), Kremmydas et al. (2018)

indicated that conventional modelling approaches that fail to incorporate the heterogeneity of agents in the agricultural system might lead to faulty evaluation and prediction results.

ABM is well suited for capturing the stochastic and dynamic features of interaction of the different supply chain agents (Ambekar et al. 2015, Zimmermann et al. 2009). In agent-based models, interactions among the actors are mostly handled as dynamic negotiation processes (Krejci and Beamon 2012). In addition, ABM can incorporate different behavioural parameters, such as impacts of the social network, collective learning and feedback mechanisms that lead to the adaptation and the evolution of the decision-making process (Kremmydas et al. 2018). The complexity of the agricultural system, which stems from the multiplicity and variability of the interactions of the agents, is usually ignored in traditional mathematical programming or econometric models (Kremmydas 2012).

ABM is appropriate for modelling the multi-echelon ASC, as it has the capabilities to handle a large, integrated problem with a wide range of internal sub-systems and stochastic shelf-life features in different echelons of the ASC (Ahumada and Villalobos 2009, Ambekar et al. 2015). The ASC consists of a complex network of actors who do not usually form linearly integrated businesses; therefore, their objectives may be in conflict (Higgins et al. 2010). ABM can not only explicitly simulate the decision-making processes of the actors but also provide a holistic view of how individual decisions affect the performance of the ASC over time (Higgins et al. 2010, Nolan et al. 2009).

A distinctive advantage of ABM is its ability to integrate external factors into agent decision-making processes (Epstein 2006a, Gilbert 2008). The ASC agents' behaviours in the models could be influenced by spatial location, market factors (e.g. customer demand, crop-selling prices), social factors (e.g. personal values, social networks) and environmental uncertainties (e.g. weather variability, natural disasters). ABM is particularly relevant for examining the realistic stochastic impacts of different outside components on the entire food

supply chain and the way they lead to the long-term structural change of the agricultural system (Ambekar et al. 2015, Krejci and Beamon 2012).

An agent-based model is considered a virtual laboratory for experimenting, quantifying and evaluating a particular agricultural intervention programme or a set of policies (Ambekar et al. 2015). The application of ABM in the domain of agricultural policy analysis has been appropriate. Much past research on the subject of land use and land cover change has used agent-based models to describe the behaviours and interactions of the actors in the agricultural landscape (Krejci and Beamon 2012, Kremmydas 2012, Zimmermann et al. 2009). Utomo et al. (2018) recently indicated that an increasing number of agent-based models are focusing on the way the ASC and the practical policy-oriented system can yield insights for decision makers.

Although ABM has some advantages compared with traditional modelling methods, modellers can have difficulty in applying this approach to the ASC, especially for large-scale assessment (Krejci and Beamon 2012, Kremmydas et al. 2018). The disadvantages of agent-based models are closely related to the advantages described above. First, the robustness and flexibility of ABM in modelling in detail pose one of the most significant challenges to modellers, the danger of over-specification (Huber et al. 2018, Zimmermann et al. 2009). Agent-based modellers might be tempted to reflect the reality as closely as possible by modelling the heterogeneous supply chain actors together with their dynamic behaviours and human decision-making processes. Focusing on excessive model details and assumptions could lead to directions that deviate from their models' original objectives (Huber et al. 2018, Krejci and Beamon 2012).

Second, ABM requires tremendous input data for the modelling because of the complex nature of the ASC, especially in the farming stage (Huber et al. 2018, Nolan et al. 2009, Zimmermann et al. 2009). Finding sources of high-quality quantitative and qualitative data to fulfil the requirements can be challenging because most of the publicly available agricultural

data is generally in an aggregated format (Krejci and Beamon 2012, Zimmermann et al. 2009). Third, because of the intensive data requirements, uncertainty of the input parameters and complexity in representing the decision-making processes of the agents (Huber et al. 2018), empirical agent-based models face difficulties in their model calibration, verification and validation. Lastly, since most agent-based models of the agricultural system are built with varying approaches that best suit their purpose and specific regions (Huber et al. 2018), it might be a challenge to replicate and customise the models into another context.

3.1.2 Contract Farming

There has been limited use of ABM approaches in the existing literature on contract farming. Most of the research on contracting agreements in agriculture has been either empirical or case-based studies, with only a small number focusing on analytical models (Federgruen et al. 2015, Huh and Lall 2013). Three agent-based models have focused on the agricultural contracting programme.

Handayati et al. (2017) applied ABM in contract farming of tomatoes in the Pangalengan region, Indonesia. They examined how different scenarios of contract farming, together with farmer commitment, affected the supply chain performance, measured by farmer profits and service levels. Farmer agents were modelled according to whether they decided to participate in the contracting programme at an early stage. If they were in contract farming, they grew contract-quality products and sold their harvest to structured market at a fixed price. Otherwise, the farmers produced non-contract-quality products that were bought at a free-market price. The farmer agents were divided into three categories based on their cultivation practices. Farmers might adapt their practices based on the observation of their neighbours' strategies and their achieved profits. In addition, the farmer agents were modelled to experience social punishment for not being able to fulfil their contract requirements. The study found that the farmers' commitment to the agreement was crucial to the success

of contract farming. The model was validated through qualitative interviews with farmer associations in the region.

A second agent-based model of contract farming, known as inclusive business, was presented in the work of Verwaart et al. (2016) and Dijkxhoorn et al. (2019). The purpose of this model was to evaluate the inclusive business project under the context of agricultural contracts between a local sorghum processor and smallholder farmers in Meru County, Kenya. The rational decisions of the farmer agents, based on the expected utility of selling produce, were influenced by social factors including risk attitude, horizontal cooperation in farmer groups and vertical trust between the farmers and the buyers. The opportunistic behaviours of farmer agents were explicitly modelled based on their characteristics parameters, financial situations and variations of market prices. The parameters of trust, trust development, honesty and risk attitude of the farmers were estimated through value chain games. The agent-based model indicated that a contract-farming scheme would lead to higher levels of trust, the critical factor for integrating the farmers into the formal value chain in the area.

Nguyen et al. (2017) used ABM to present a model of contract farming in the MKD's rice supply chain. The decision-making processes of both the farmer and contractor agents were based on two factors: cost-benefit analysis and the role of trust. Their preliminary results regarding the way the farmer and contractor agents' commitments affected the contracting programme performance were discussed. The agent-based model introduced in this chapter, which is viewed as an extension of the model proposed by Nguyen et al. (2017), focuses on the obstacles to the expansion of contract rice farming in the MKD region. These obstacles, which were described earlier in Chapter 2, include (i) contractors' failure to build trust-based relationships with farmers, (ii) low purchasing price offered from contracts and (iii) limited rice-processing capacity. In this thesis, these four specific issues are discussed from the contractors' perspective to understand how they impede the success of contract rice farming in the region.

3.2 Agent-based Model of Contract Farming

3.2.1 The Process of Contract Farming

This model involves two types of agents - *farmer* and *contractor* - who are involved directly with the contract-farming scheme. Figure 3.1 illustrates the two stages of the contractual programme in one cropping season: pre-harvesting and post-harvesting. The process is based on the analysis of the practice of contract farming in the MKD region, as well as the conceptual contract-farming framework in developing countries proposed by Barrett et al. (2012). The process map was also revised through consultation with a group of three experts in the area of the rice value chain in Vietnam.

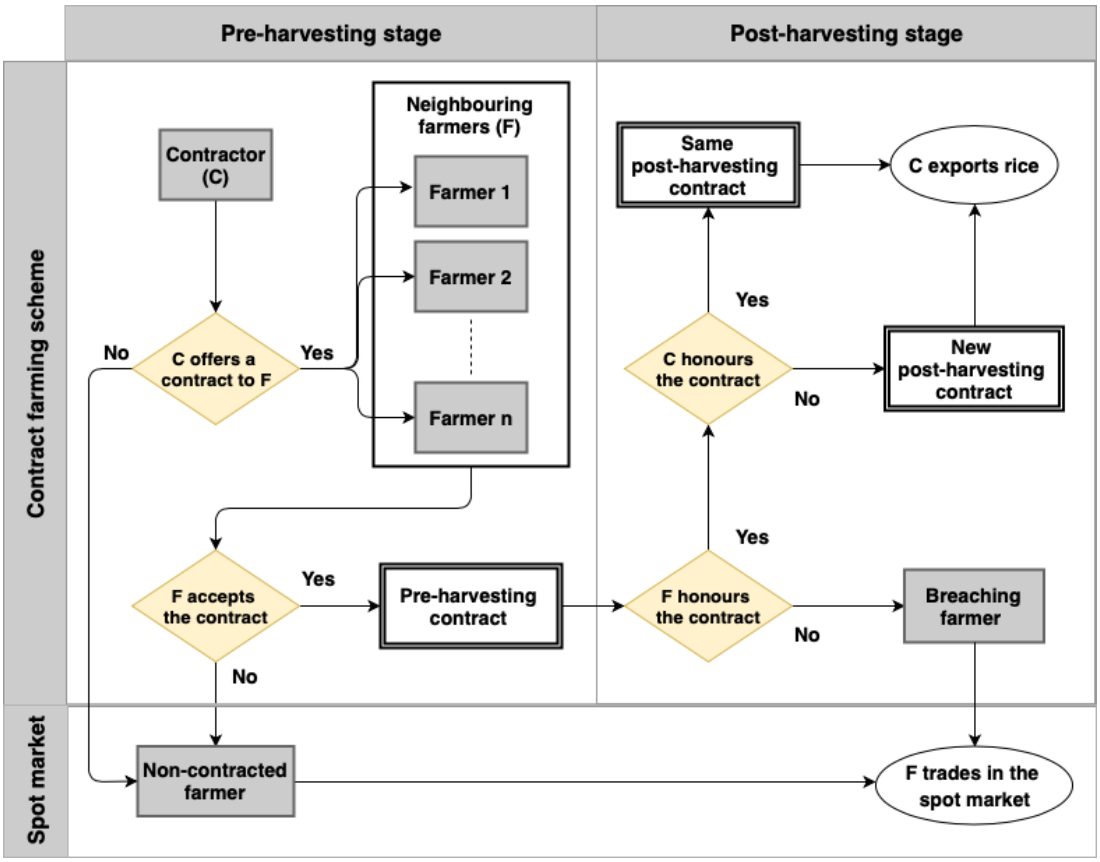


Figure 3.1 Contract rice farming in the MKD region

In the pre-harvesting stage of this model, contractors and farmers communicate to establish a contractual relationship. Each contractor determines how to coordinate adjacent farmers into the large-scale paddy field programme to fulfil their exporting volume. Pre-harvesting contracts are initiated only when a farmer accepts one of the offers. Expert advice from the semi-structured interview indicated that the MKD large-scale field, in general, was established under a common agreement among all participating small farmers. The contracted farmer would receive verified paddy seeds, fertilisers and pesticides for the production as a financial loan from the buyer. The contracted farmer would also get technical support to apply sustainable cultivation methods and is required to deliver and sell paddy back to the contractor. A non-contracted farmer, who either declines or receives no offer, would grow paddy with traditional practices and trade with the traders at local spot market.

In the post-harvesting stage, farmers and contractors observe changes in spot-market prices and decide whether to honour or break the contract. If a farmer decides to breach the contract, they can sell to a local collector at a higher spot-market price. If the contractor decides to infringe the contract, they can force the contracted farmers to sell at a lower contract price than the predetermined price. Contract breaches from both contractors and farmers are also brought up by the experts. If there is no breach by either party, the pre-harvesting contract remains. The farmer sells the harvested paddy and returns the loan to the contractor. The contractor then acquires revenue by exporting polished rice to international buyers. The experts shared agreement with the literature that MKD smallholder farmers, who produce only limited volumes of rice, sell all harvested paddy to buyers; that is, either contractors or local collectors (Loc and Son 2013, VEPR 2015). The process map and the agents' decision-making processes were extensively revised through consultation with these experts in the model development stage.

3.2.2 Decision Making Rules

The agents in the model are assumed to be rational, making decisions based on preference rankings, which are expressed in scores over their potential trading partners. The higher the score an agent allocates to a potential partner, the higher the likelihood they will form a trading relationship. The score calculation that agent i assigns to agent j at time t is the Cobb-Douglas functional form of utility and trust adapted for the proposed function by Klos and Nooteboom (2001) and Nooteboom (2015):

$$score_{ij}(t) = \big(utility_{ij}(t)\big)^{\beta_i} \cdot \big(trust_{ij}(t)\big)^{1-\beta_i}, \tag{3.1}$$

where $score_{ij}(t)$ is the score agent i allocates to agent j; $utility_{ij}(t)$ is the utility value mapped from the benefit $m_{ij}(t)$ that agent i earns in the partnership with agent j; and $trust_{ij}(t)$ is agent i's trust in agent j. $\beta_i \in [0,1]$ is a weight to measure the preference of utility over trust for agent i. β_i is assumed to be fixed during the simulation run.

The utility value is expressed in an exponential utility function (Garvey 2008, Krejci and Beamon 2015):

$$utility_{ij}(t) = \frac{1 - e^{\frac{-\left(m_{ij}(t) - m_{i(min)}(t)\right)}{R_i}}}{1 - e^{\frac{-\left(m_{i(max)}(t) - m_{i(min)}(t)\right)}{R_i}}}, \tag{3.2}$$

where $m_{i(min)}(t)$ and $m_{i(max)}(t)$ are the benefit levels at which agent i has minimum and maximum benefits during the simulation; and R_i is the risk tolerance of agent i, which is the amount of risk that agent i is willing to take. The risk tolerance R_i for both farmer and contractor agents is set to $m_{i(max)}$. This exponential utility function is a special type of utility function to represent a broad class of utility and risk attitudes (Kirkwood 1997). The function is scaled in the range of 0 to 1, which fits into the calculation of score in Equation 3.1.

It is assumed that all agents are risk-averse, and that $utility_{ij}$ is concave for all values of m_{ij} (Krejci and Beamon 2015). The assumption was based on results from the literature

and semi-structured interviews conducted (Khor et al. 2018, Paik et al. 2020, Tu et al. 2018). During the interviews, experts indicated that most rice farmers tended to adhere to rice farming, especially those who were in the specialised rice production provinces in the MKD region.

The agents in the model tend to prefer the partnership in which they achieve higher expected utilities. These rational behaviours are attenuated by the introduction of the trust relationships that affect the decisions of agents. Equation 3.3 defines an adaptive trust process between two agents in their ongoing relationship, as presented by Klos and Nooteboom (2001):

$$trust_{ij}(t) = b_{ij}(t) + (1 - b_{ij}(t)) \cdot \left(1 - \frac{1}{f_{CF} \cdot n_{ij}(t) + 1 - f_{CF}}\right), \tag{3.3}$$

where $b_{ij}(t) \in [0,1]$ is the trust base of agent i towards agent j; $n_{ij}(t)$ is the number of successful trades the agents have been involved in together; and parameter f_{CF} is the trust factor, determining the pace at which the trust relationship has developed. The calculated $trust_{ij}(t)$ is also between 0 and 1. In this model, it is assumed that if both parties honour rather than break the contract, as the relationship lasts mutual trust will increase as the relationship continues (Gulati 1995) (see Figure 3.2). The trust-base level between agents reflects a foundation of trust, which is an institutional feature of a society (Nooteboom 1999).

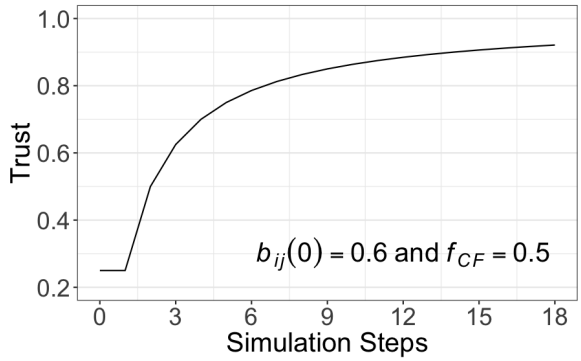


Figure 3.2 Trust increases when agents have trustworthy behaviour

Contractor Contract Offer

At the pre-harvesting stage of each crop t_{pre}, each contractor firstly identifies all the prospective farmers located within their farming coverage, u_C. Since it is critical for the buyer to form a large, aggregated rice field, the contractor prefers engaging neighbouring farmers into the contract-farming scheme. In each round, the buyer sends agricultural contracts to farmers who are located in the range of $\bar{u}_C$ further from their location, to achieve their targeted purchasing rice volume. The contract-farming proposal continues until either the contractor's objective is fulfilled or the farming coverage is reached to the limit, u_C. In addition, the contractor is modelled to repeat the offering one more time with different prospective farmers in the same round, to reflect their effort to establish the aggregated paddy-growing area.

In each offer round, the contractor calculates the benefits they can earn through the contract with the farmers. The contractor loans inputs and provides technical support for contracted farmers. Contractor i agrees to purchase the harvest from farmer j at the proposed price $p_{ij}(t_{pre})$, processes the dry paddy into export-ready rice and eventually gains revenue by selling it to international buyers. The exporting price, π_{CF}, is assumed to be fixed during the simulation run:

$$m_{ij}(t_{pre}) = \left(\pi_{CF} - p_{ij}(t_{pre}) - c_{opr}\right) \cdot q_j - g_{j,k} \cdot c_{p,k} \cdot l_{CF} - g_{j,k} \cdot c_{o,CF} \tag{3.4}$$

At the pre-harvesting stage, the offered price $p_{ij}(t_{pre})$ is based on the contractor's prediction of the spot-market price $p_{SM}(t_{pre})$, with a certain higher rate λ_i. Both the contractor and the farmer agents are modelled to predict the spot market price at time t_{pre} to be the average of the actual spot-market price of the last two seasons:

$$p_{ij}(t_{pre}) = p_{SM}(t_{pre}) \cdot (1 + \lambda_i) \tag{3.5}$$

where c_{opr} is the total cost associated with rice husking, milling, polishing and exporting activities. It is assumed that if the contractor does not have the necessary facilities to convert paddy into rice, they will pay a higher cost from the spot-market services. Contractor i also incurs the overheads, $c_{o,CF}$, per contracted farmer in organising the contract-farming scheme.

In the large-scale paddy field programme, all participating farmers are assumed to acquire the crop yield and incur production costs in the large-scale farmer category, regardless of their actual farm size. The volume of rice, q_j delivered by farmer j after the conversion, is estimated as:

$$q_j = v_{large} \cdot g_j \cdot r_{conv} \tag{3.6}$$

At this stage, the contractor assumes that the contracted farmers will commit to the agreement without any breaches. Following Equations (3.1), (3.2) and (3.3), contractor i calculates a $score_{ij}(t_{pre})$, which it allocates to farmer j. The contractor then sends contracts to the farmers, who are allocated with the highest score (sorted in descending order) and historically have not breached past contracts, to gather its targeted rice volume.

Farmer Contract Acceptance

In the pre-harvesting stage of this model, farmers always have the option to cultivate the paddy by themselves. They receive a credit l_{SM} paid in advance from a local collector, on the condition that they sell the harvested paddy to the trader in the post-harvesting stage. Farmer i calculates the potential benefit, $m_{i,SM}(t)$, with the predicted spot-market price, $p_{SM}(t_{pre})$, crop yield, v_k, production cost, $c_{p,k}$, in accordance to their farm-size type k:

$$m_{i,SM}(t_{pre}) = p_{SM}(t_{pre}) \cdot v_k \cdot (1 + l_{SM}) \cdot g_i - c_{p,k} \cdot g_i \tag{3.7}$$

In addition, farmers might have contracts offered to them. The benefit, $m_{ij}(t_{pre})$, of farmer i is their expected profit from the contract farming scheme plus the production loan

received from large buyer j. The profit is presumed to be reduced by the autonomy premium, α_i, which represents how strongly the farmer values their ability to work independently (Key and MacDonald 2006, Krejci and Beamon 2015). To keep the model simple, a value of a_i is initially assigned to each farmer and remains the same during the simulation runs:

$$m_{ij}(t_{pre}) = \frac{(p_{ji}(t_{pre}) \cdot v_{large} - c_{p,large}) \cdot g_i}{1+\alpha_i} + c_{p,large} \cdot g_i \cdot (1+l_{CF}) \tag{3.8}$$

Implementing Equations (3.2) and (3.3), the utility and trust values of the options with the spot market and the contractors are achieved. The farmer then evaluates all available options and proceeds with the one that yields the highest score. If the farmer decides to grow paddy rice and sell the harvest to a local collector, it is assumed that both parties will fulfil their responsibilities in the post-harvesting stage. If the farmer engages in a contractual relationship, they will later decide whether to honour or break the contract, since the predicted spot-market price, $p_{SM}(t_{pre})$, for the crop might be different from the later trading price, $p_{SM}(t_{post})$.

Farmer's Decision to Honour the Contract

In the post-harvesting stage of this model, if a farmer commits to the initial agreement, they expect to sell the harvested produce at the pre-determined price, $p_{ji}(t_{pre})$ and to return the production loan borrowed from contractor j:

$$m_{ij,honour}(t_{post}) = \frac{(p_{ji}(t_{pre}) \cdot v_{large} - c_{p,large}) \cdot g_i}{1+\alpha_i} \tag{3.9}$$

If a farmer decides to breach the contract, they sell to a local collector at a higher spot-market price, $p_{SM}(t_{post})$, and decline to repay the loan to the contractor. $p_{SM}(t_{post})$ is randomly selected among the trading prices in the harvesting period, since each farmer decides to sell at different times after observing the fluctuation of prices on the open market.

In addition, a dishonouring farmer also considers their future trade suspension with the breached contractor (Fafchamps 2003). The benefit that farmer i considers in this option is decreased by the value of the lost relationship with the contracted partner j:

$$m_{ij,breach}(t_{post}) = \frac{(p_{SM}(t_{post}) \cdot v_{large} - c_{p,large}) \cdot g_i}{1+\alpha_i} - \theta_F \cdot m_{ij,loss} \tag{3.10}$$

where θ_F is the number of future cropping seasons that the farmer expected to be in the contractual relationship with the partner; and $m_{ij,loss}$ is the difference between the benefit farmer i might earn from that trading relationship with contracted partner j and from the second-best option available to them in the pre-harvesting stage.

The trust value in the contract-honouring option is updated with Equation (3.3), while the trust value in the breaching option is $trust_{SM}$. If farmer i decides to renege on the contract, the breached contractor, j, will set their trust base in farmer i to $b_{ji(min)} = 0$ and the number of trades to initial value $n_{ji} = 0$.

Contractor Decision to honour the Contract

After farmer j complies with the agreement, contractor i decides to either honour or breach the contract. The trust value towards the farmer in both choices is updated with $trust_{ij} = 1$, since the farmer has already delivered the harvested paddy and returned the production loan to the contractor.

If contractor i decides to infringe the contract, they force the contracted farmer, j, to sell at a lower contract price reflecting the reduction in the current spot-market price at the time. The new contracting price, $p_{ij}(t_{post})$, is be based on the average of spot-market prices during a three-month post-harvesting time. The contractor's benefit at the post-harvesting stage, $m_{ij}(t_{post})$, is computed according to Equation (3.11). If the contractor reneges on the previous contract, the breached farmer will set their trust-base value in the contractor at

$b_{ji} = 0$, and the number of trades together $n_{ji} = 0$:

$$m_{ij}(t_{post}) = (\pi_{CF} - p_{ij}(t_{post}) - c_{opr}) \cdot q_j - g_{j,k} \cdot c_{CF} \tag{3.11}$$

If the contractor commits to the agreement, the benefit in this honouring option is calculated with Equation (3.11) using the predetermined price, $p_{ij}(t_{pre})$, instead of the lower breaching price, $p_{ij}(t_{post})$. The number of trades from both sides, n_{ij} and n_{ji}, then increases by 1 to indicate the growing trust.

Farmer Trust Update and Contractor Demand Update

At the end of a cropping season in this model, the farmer updates their trust in the contractor partners through communication within the neighbourhood defined by the range, u_F. The trust-base level of farmer i will be reduced to a certain extent if there is dishonouring behaviour from a large buyer j with their neighbouring farmers. At the same time, farmer i might have higher trust in contractor j if their neighbours have successfully contracted with the buyer. The change of trust-based level depends on the number of adjacent farmers who had negative or positive experiences with contractor j over the total neighbours of farmer i:

$$b_{ij}(t+1) = b_{ij}(t) \cdot (1 - \frac{n_{breach}}{n_{total}}) \cdot (1 + \frac{n_{honour}}{n_{total}}) \tag{3.12}$$

At the end of the season, each contractor is modelled to adjust their targeted rice demand for the following crop based on the performance of their contract-farming scheme for the prior crops. The large buyer calculates their targeted rice demand as the average of total rice volume achieved through their agricultural contracts in the previous two seasons. If the contractor has completely fulfilled their objectives in the last two crops, the demand is expected to be higher at a rate, r_d, than the usual calculation to reflect the potential expansion of the large-scale paddy field programme.

3.3 Case Study of Contract Rice Farming in the Mekong Delta

3.3.1 Farmer Agent

As noted earlier, rice production in the MKD is fragmented, comprising approximately 1.46 million farmers who grow paddy in small fields, with the average size of 1.29 ha (World Bank 2011). Smallholder farmer agents in this model were classified into three categories on the basis of their farm size: marginal (0.5–1 ha), small (1–2 ha) and medium (2–3 ha) (Chen et al. 2015). The farmer agents were further divided into two groups, non-contracted and contracted farmers, which were derived from their participation in the contract-farming scheme. The cultivation land of the farmer agents who participated in the contract-farming scheme was aggregated into a large-scale paddy field.

Non-contracted farmers usually apply traditional cultivation methods, with an excessive amount of seed, fertiliser, pesticides, and herbicides, since rice production in the MKD is characterised by high levels of input use. In contrast, contracted farmers are required by the contractors to pursue better crop husbandry with fewer inputs, in order to save on costs and produce a higher yield. Crop yields and production costs were collected from a World Bank (2013) research report in the An Giang province, one of the provinces in the MKD region. The data for this model was for ordinary rice, which is of low value, and jasmine rice, which is one of the high-quality varieties grown in the region.

There are two major crops in the MKD region: Winter-Spring (WS) and Summer-Autumn (SA) (FAO 2017). Each growing season has distinct agro-ecological and hydrological conditions that create differences in the cultivated area, crop productivity and production cost. The most productive season is the WS crop, which is the main period to grow and harvest rice for export. The second most important season is the SA crop. Jasmine paddy is not grown in the SA season, as frequent floods occur during the harvesting period, while

Table 3.1 Parameters of farmer agents

Parameter	Description	Non-Contracted				Contracted	
		WS crop	**SA crop**	**WS crop**	**SA crop**	**WS crop**	**SA crop**
g	Farm size (ha)	$[0.5-1]$		$[1-2]/[2-3]$		Large-scale	
v	Crop yield - ordinary rice (ton/ha)	6.08	4.68	6.75	5.2	7.40	5.75
	Crop yield - jasmine rice (ton/ha)	6.38		7.09		7.77	
c_p	Production cost - ordinary rice (million VND/ha)	21.777	16.522	20.536	15.461	18.532	13.653
	Production cost - jasmine rice (million VND/ha)	23.257		22.336		19.083	
θ_F	Commitment level	Triangular Distribution $[0.0, 2.0, 4.0]$					
u_F	Farmer neighbourhood range	50					
l_{SM}	Rate of loan (over the total value of produce) from the spot market	0.15					
α	Autonomy premium	Uniform Distribution $[0.1-1.0]$					
β_F	Weight attached to utility over trust	Uniform Distribution $[0.1-0.9]$					
$b_{ij}(t_0)$	Initial trust base of farmer i to contractor j	Uniform Distribution $[0.1-0.5]$					
$n_{ij}(t_0)$	Initial number of trades between farmer i and contractor j	0					

ordinary paddy is cultivated at both times (World Bank 2013). A third crop is sometimes grown in the MKD region between the WS and SA crop but as this accounts for only a small proportion of output (VEPR 2015), it was not included in the model. The crop yield and production-cost data for each type of rice, grown in each cropping season and in accordance with the different farmer groups and categories, is shown in Table 3.1.

According to Nhan et al. (2015) and Viet (2015), one of the critical reasons for smallholder farmers in the MKD region to decline to participate in the contract-farming scheme is that they lose their autonomy of production. The farmers, who are familiar with conventional cultivation practices, have difficulty in adapting to advanced farming techniques and the strict

quality standards of inputs and outputs required from the contractors. Therefore, the farmers' decisions regarding whether to participate in the agricultural contracting programme can depend on how much their autonomy is worth and how much autonomy they lose through the coordination scheme. In the model, the autonomy premium, α_i, was assigned to each farmer agent i following a uniform distribution between $[0.1, 1.0]$.[1]

In this model, it was presumed that the farmer agents had an unreliable business attitude, as there have been breaches by smallholder producers reported in contract rice farming in the MKD region (Dung 2014, Khiem and Emor 2005, Roberts and Khiem 2005, Vietnam Television 2017). The low level of commitment of the farmer agent, nF, was randomised following a triangular distribution $[0, 2.0, 4.0]$. This implies that the longest/maximum time to which the farmer agent would commit in the contractual relationship was four cropping seasons.

Because of the past failure of contract farming under Decision 80 (as mentioned in Section 2.3), the farmer agents were assumed to have low trust in the success of the large-scale paddy field programme. The trust base of farmer i towards contractor j, $b_{ij}(t_0)$, was randomly determined at the start of each simulation run and varied between $[0.1, 0.5]$. Since there has been no previous empirical study of the way small-holder farmers in the MKD region value utility over trust, the weight parameter, β_F, was assigned to each farmer agent, utilising a uniform distribution in the range of $[0.1, 0.9]$.[2] The chosen types of distribution and corresponding ranges of values were discussed extensively with the domain experts to reflect the case study of contract rice farming in the MKD region.

3.3.2 Contractor Agent

At the pre-harvesting stage, the contractors usually give farmers verified paddy seeds as a financial loan, accounting for 7.5% of the total production cost (Loc and Son 2013, Viet

[1] Testing for $[0.01, 1.0]$ and $[0.1, 0.5]$ did not change the results significantly.
[2] Testing for $[0.01, 0.99]$ did not change the results significantly.

2015). Contracted farmers are expected to return the loan after selling the crops to the buyer. In addition, the contractor incurs the operational overhead, which is the cost of hiring workers to support the contracted farmers with technical practice (World Bank 2013). At the post-harvesting stage, the contractor processes the harvested dry paddy into polished rice and exports it to international buyers. In this model, the rice conversion rate r_{conv} was specified at 0.5 for ordinary rice in both seasons and 0.48 for jasmine rice in the WS season. The rate was applied for 5% broken and colour-graded exporting rice (World Bank 2013).

Table 3.2 Parameters of contractor agents

Parameter	**Description**	**Ordinary rice**	**Jasmine rice**
$k(t_0)$	Initial purchasing demand (tons)	4000	
r_d	Increasing rate of rice demand	0.1	
$\bar{u}_C$	Range contractors considered in each offer round	100	
u_C	Contractor farming coverage	500	
l_{CF}	Rate of loan (over production cost) to farmers	0.075	
$c_{o,CF}$	Overheads in organising contract farming (million VND/ton)	0.408	
$c_{h,SM}$	Husking cost in the spot market (million VND/ton)	1.225	1.737
$c_{m,SM}$	Milling cost in the spot market (million VND/ton)	1.066	1.899
$c_{h,CF}$	Husking cost with contractors' facilities (million VND/ton)	0.734	0.938
$c_{m,CF}$	Milling cost with contractors' facilities (million VND/ton)	0.725	1.158
c_e	Exporting cost (million VND/ton)	0.52	
π_{SM}	Exporting price for spot market rice (million VND/ton)	8.761	12.933
π_{CF}	Exporting price for contract-farmed rice (million VND/ton)	9.596	13.350
β_C	Weight contractor attached to utility over trust	0.9	
$b_{ij}(t_0)$	Initial trust base of contractor i to farmer j	0.5	
$n_{ij}(t_0)$	Initial number of trades between contractor i and farmer j	0	

For this model, the cost of husking, milling and polishing activities for both rice varieties were extracted from a research report conducted by (IPSARD 2014) during a field trip in An

Giang. In a traditional rice supply chain, the paddy produced is traded through local collectors in the spot market, transformed into rice through different actors and eventually bought by exporters. In the contract-farming scheme, large buyers collect paddy rice directly from the farmers. The contractors can reduce the cost of rice processing if they have facilities instead of utilising relevant services from the spot market — see Table 3.2 for details. Exporters associated with the contract-farming scheme can negotiate a better price with buyers because of greater control over the quality of the rice. For this model, the exporting prices, π, for two types of rice, from either the spot market or the contract-farming programme, were taken from the World Bank (2013).

Since large buyers coordinate the contract-farming scheme to pursue higher and more stable profit, in this model the parameter $\beta_C = 0.9$ was fixed for the contractor agents. The initial trust-base level of contractor i in farmer j was set neutrally at $b_{ij}(t_0) = 0.5$. If an agent, whether a contractor or a farmer, might consider trading with local collectors, its trust in the spot market was fixed, $trust_{SM} = 0.9$, to reflect a well-established conventional relationship in the MKD region (VEPR 2015). The trust factor remained at $f_{CF} = 0.5$ during the simulation run for both the farmer and contractor agents.

3.4 Experimental Set-up

This agent-based model was implemented in Java using the MASON framework (Luke et al. 2005). Its code can be found on the CoMSES Network website at https://goo.gl/QhLbEY. We ran the simulation 18 steps for ordinary rice and 9 steps for jasmine rice, with each step representing one cropping season. All simulation steps were repeated for 500 independent Monte Carlo (MC) trials.

At the start of every MC simulation, 3,000 farmer agents were created. The proportions of marginal, small and medium-sized farmers were 54.4%, 32.1% and 13.5%, respectively.

These values were calculated based on research reports from the MKD region (Chen et al. 2015, IPSARD 2014). The simulation model incorporated two contractor agents implementing contract-farming activities. All agents were located in a continuous space of size 1,000 by 1,000 representing a geographic region (see Figure 3.3). The farmer agents were located randomly, while the two contractor agents were set with specific locations: 250,500 and 750,500. The locations of the agents were set to resemble an agricultural landscape in developing countries, where smallholder producers are typically scattered throughout the region, while large buyers are located in convenient places (Chen et al. 2015). The two squares in Figure 3.3 represent two contractor agents, while the circles, which are different in size, denotes farmer agents with different farm-size values. The farmer agents trading in the open market are in green, while those participating in a large-scale rice field programme are filled in either blue or orange, depending on the contractor with whom they have relationships.

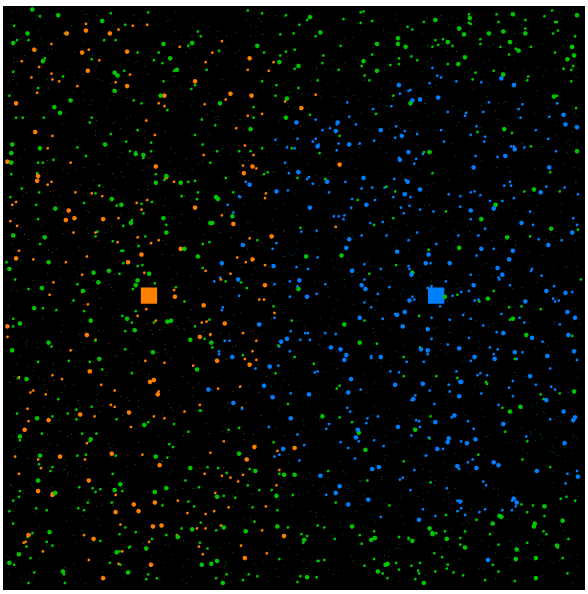


Figure 3.3 Simulated geographic region of the contract rice-farming model

All parameters of individual farmer and contractor agents were initialised according to the values in Tables 3.1 and Table 3.2. Among those parameters, the trust base b_{ij}, the number of successful trades n_{ij} between agent i and agent j, and the purchasing demand k of

the contractor agents were updated dynamically during the simulation run. The other listed parameters were set with fixed values.

Available data of monthly spot-market prices of dry ordinary paddy in the An Giang province from 2009 to 2017 was gathered from the Information Centre for Agriculture and Rural Development (AgroInfo 2017). Figure 3.4 shows the volatility of trading prices in the MKD's ordinary rice supply chain (Chen et al. 2015), with recurrent fluctuations over a nine-year period. The minimum price traded on the spot market was 3.5 million Vietnamese Dong (VND)/ton in September 2009 while two years later, the maximum was more than double, at 7.3 million VND. Because of the lack of data for jasmine dry paddy, the spot-market prices were calculated based on the assumption that they were 1.4 million VND/ton higher than the dry ordinary paddy prices (World Bank 2013).

For simplicity's sake, the dry paddy price traded on the spot market in each crop was calculated as the average of prices in the three-month harvest period. The harvesting periods were from February to April for the WS crop and from August to October for the SA crop (FAO 2017). In addition, the forecast spot-market prices, $p_{SM}(t_{pre})$, at the pre-harvesting stage of the first two crops t_1 and t_2 in Equation (3.5) were set equal to the median value of actual spot-market prices during the nine-year period.

The agent-based model was used to examine the main obstacles to the expansion of contract rice farming in the MKD region from the perspective of large-scale buyers (i.e., contractors). These obstacles were the failure of many contractors to build trust and long-term relationships with smallholder farmers; the offered prices from the contract-farming scheme being unable to compete with the benefits provided by local collectors; and the limited husking, milling and polishing capacity of many rice exporters in the region, which prevented them from participating in the large-scale paddy field programme. The three corresponding parameters of the contractor agent used for the simulation experiments were as follows:

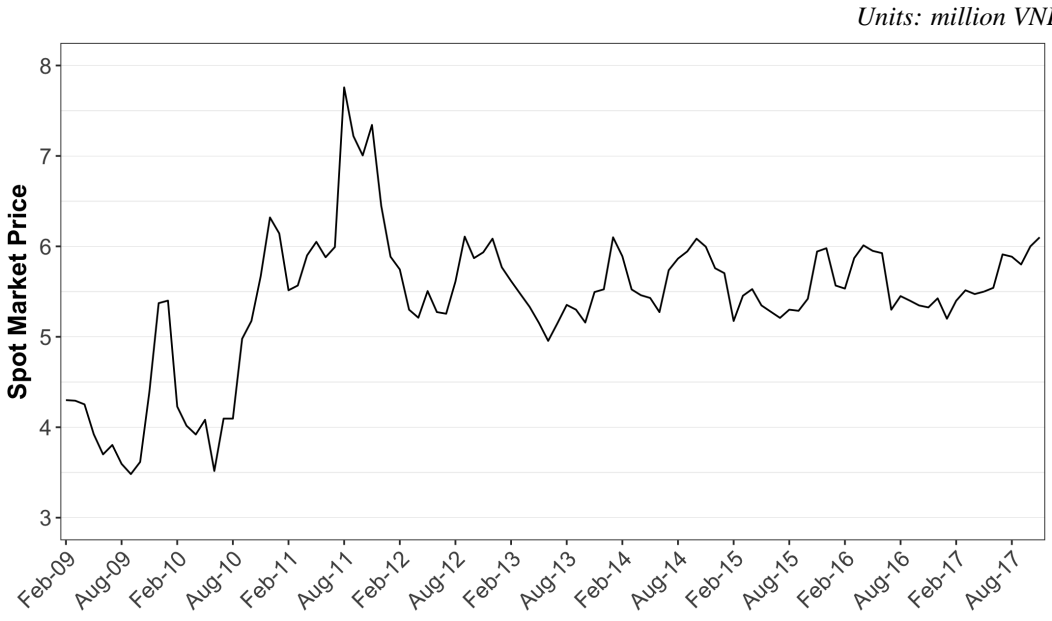


Figure 3.4 Monthly spot-market prices of dry ordinary paddy from 2009 to 2017

- level of commitment, θ_C, in terms of the percentage of contracted farmers with whom the large buyers had breached their contractual relationship with;
- higher rates for the contracting price over the spot-market price, λ, that the contractor offered to the farmers;
- the contractor's access to rice-processing facilities, δ.

Different scenario-based values of these three parameters were examined, as shown in Table 3.3. The values remained the same during the simulation steps of each MC run.

In every simulation experiment, one of the two contractor agents (Contractor A in Table 3.3) was set with fixed values for the three scenario-based parameters. The contractor was modelled to be constantly committed to all farmer agents, $\theta_C = 0\%$. The contract price proposed by this contractor was set at the most typical (higher) rates in the MKD region, with $\lambda = 0.2$ for ordinary rice or $\lambda = 0.1$ for jasmine rice (World Bank 2013). This large buyer agent was modelled to have all adequate capacity ($\delta = True$) for processing export-ready rice products.

Table 3.3 Experimental settings of scenario-based parameter values

Parameter	Contractor A	Contractor B
Commitment level	0%	[0%, 10%, 20%, 30%]
Higher offered rates for		
ordinary rice	0.2	[0.0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3]
jasmine rice	0.1	[0.0, 0.05, 0.1, 0.15, 0.2]
Processing facilities	*True*	[*True*, *False*]

The other contractor agent in the model (Contractor B in Table 3.3) was set with varied values in different scenarios. The commitment in the contractual relationship was varied from being committed to being untrustworthy with 10%, 20% and 30% of the contracted participants. The rate λ was in the range [0.0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3] for ordinary rice or [0.0, 0.05, 0.1, 0.15, 0.2] for the jasmine variety. The buyer was modelled either with necessary husking, milling and polishing facilities ($\delta = True$) or with no rice processing capacity ($\delta = False$), which required the utilisation of services from other supply chain actors with higher costs.

Different outputs reflecting the contract-farming performance of contractor B were then evaluated in different combinations of scenarios. The simulation model calculated four output variables in each cropping season: the rate of the contracted farmers' breaches, farmers' trust in the contractor, exporting rice volume, and total profit achieved by the contractor. The contract-farming simulation was run separately for the two rice varieties. The reported results were calculated by averaging the 500 MC trials.

3.5 Experimental Results and Discussion

3.5.1 Evolution of Contract Farming Performance

Figure 3.5 shows the time-series evolution of contract-farming performance with the different combinations of scenarios for both ordinary and jasmine rice. The results of each rice variety included two separate experiments. One experiment examined three scenarios in which fully committed contractors proposed different paddy-purchasing prices. Another experiment involved the study of contractors who all offered the typical rate $\lambda = 0.2$ with ordinary rice and $\lambda = 0.11$ for jasmine rice, with varied commitment levels. All contractors in the above settings were set to be equipped with adequate rice-processing facilities ($\delta = True$). The performance of a buyer who completely traded on the open market was included in the results as well.

The top two plots in Figure 3.5 represent the fact that high purchasing prices offered by a trustworthy contractor could discourage breaching behaviours from the participants (Eaton and Shepherd 2001, Prowse 2012, Will 2015). Both ordinary and jasmine rice results show a significant decrease in farmer breaches with committed contractors who set the highest rate, especially when there are 'jumps' in the paddy prices on the open market (see Figure 3.4 for details). In the sixth crop for ordinary rice, less than 7% of contracted farmers under scenario $\lambda = 20\%$ decided to sell to traders, while the rate of farmer breaches doubled at 14% with scenario $\lambda = 10\%$. A similar pattern can be seen in the case of the third crop of jasmine rice. These results indicate that it is necessary for large buyers to recognise that farmers are tempted to break their contracts when local market prices are higher than the pre-agreed price. Contractors need to have more flexibility, with different pricing mechanisms in their contracts to take into account unexpected events such as high prices in the spot market or bad weather.

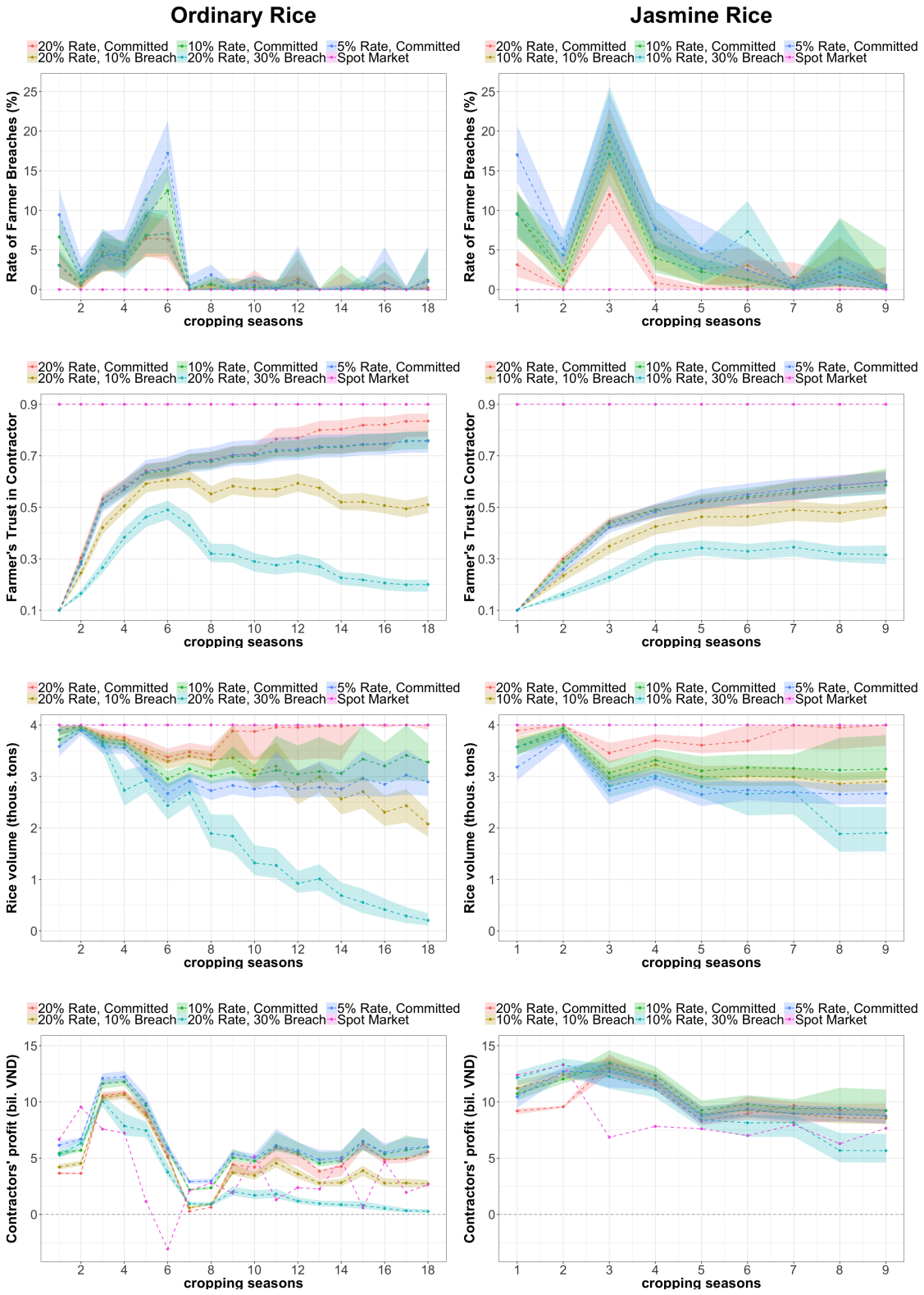


Figure 3.5 Time-series evolution of contract farming performance with both rice varieties

Contractors who persisted in being committed could sustainably establish long-term trust-based relationships with the existing participants. The figures show that farmers' trust in these contractors grew rapidly during the first crops and maintained an increasing trend for all simulation runs. There were no significant differences in the farmers' trust in the trustworthy contractors who proposed different contract rates. However, contractors that offered a higher purchasing price achieved a higher volume of rice. In both ordinary and jasmine results, the contractors who advocated their contracted farmers at $\lambda = 20\%$, subsequently attained the initial targeted demand after experiencing shortages of rice supply due to farmer breaches in the early cropping seasons. The contractor with a lower paddy-purchasing price could not achieve $k = 4000$ tons of rice, as some surrounding farmers considered their option less attractive than services from another large-scale buyer or the local collector.

The bottom two plots in Figure 3.5 show the obtained profits of contractors in a time-series format. In general, trustworthy contractors of the two rice varieties could achieve more stable profitability than the local market-based buyers, whose performance was significantly affected by the frequent fluctuations of the traded spot prices. In the case of ordinary rice, the profit of the buyer who operated in the open market decreased rapidly, with a loss of more than 4 billion VND in the sixth crop, and kept varying until the end of the simulation runs. The contractors from the contract-farming scheme experienced reductions in their financial gains as well, especially after the 'jumps' in the spot-market prices, but they quickly secured their steady profitability, with increasing trends for the following cropping seasons.

Among scenarios of the same proposed contract-farming rates, contractors with untrustworthy behaviour lost trust with the farmers whose contracts had been breached, as well as with other neighbouring farmers. For the contractors who had the lowest commitment level, breaching contracts with 30% of the participants, there were downward trends with regard to farmers' trust for the results of both rice types. Fewer farmers accepted their proposals for the following crops, leading to a considerable decrease in the total rice volume

achieved through their large-scale programme. In the case of ordinary rice, the untrustworthy contractor collected very little rice and made no profit from the contract-farming scheme in the last cropping season.

In the semi-structured interviews, expert advised that the agent-based model results were expected and accurate. The experts emphasised the critical role of trust in preventing opportunistic behaviour. AGPPS and the Gentraco Corporation were mentioned to be of the few companies in the MKD region to invest in long-term trust-based relationships with farmers that result in a high rate of success in the contracting programme. Both companies have provided a range of support such as on-site technical assistance, and commitment to buying at minimum market prices when there are 'jumps' at the end of the cropping seasons.

The results reported here were also in agreement with the existing evolutionary game theory literature on contractual agreements from both experimental (Chen and Komorita 1994, Dannenberg et al. 2014) and theoretical (Han et al. 2015, 2017, Sasaki et al. 2015) perspectives. The literature suggests that arranging prior commitments leads to a high level of long-term beneficial cooperation. Contractors who consistently lend on agricultural inputs, provide technical support and acquire rice from the contract-farming scheme at a predetermined price from contracted farmers can significantly enhance trust from the participants as well as reduce the number of free-riders. However, the level of prior commitment can also lead to different cooperation rates and interactions (Chen and Komorita 1994). In the results of this current research, trustworthy contractors with an attractive purchasing price achieved a higher volume of rice from the large-scale programme and reduced the rate of farmer breaches.

3.5.2 Viability of the Contract Farming Scheme

Figure 3.6 shows the analysis of the viability of the contract rice-farming scheme from the perspective of large-scale contractors. First, a ratio of average profit in all cropping

seasons was computed between the contractor and spot-market-based buyer to examine the profitability of the scheme. If the profit rate was larger than 1, the contractors were performing better than the spot-market buyers were. Otherwise, the contracting programme was not a cost-effective method in comparison with complete open-market trading. The percentage of average rice volume achieved through the contracting programme was calculated according to the contractor's initial demand $k(t_0) = 4000$ tons. The larger value shown in Figure 3.6 indicates that more smallholder farmers were benefiting from the large-scale paddy field model. In each heatmap, the y-axis describes different scenarios of contractor commitment $\theta_C = 0\%$ (breach00), $\theta_C = 10\%$ (breach10), and $\theta_C = 30\%$ (breach30), while the x-axis represents varied values of higher contract-farming rates over the spot-market price.

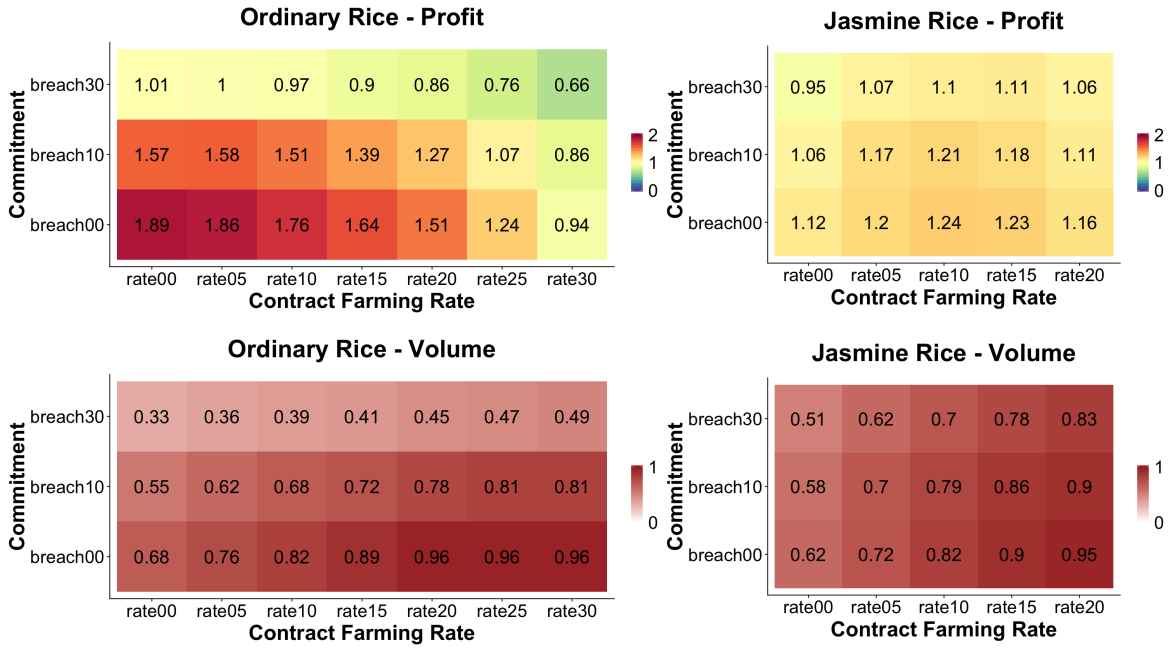


Figure 3.6 Comparison between fully equipped contractors and spot-market-based buyers

As shown in the top two heatmaps of ordinary and jasmine rice, committed contractors could earn up to 89% and 24% higher profits, respectively, than a buyer trading the same rice variety on the spot market. The contractor with jasmine rice performed at a lower profit rate, as exporting prices for jasmine rice from the contract-farming scheme in the MKD region

were only 2.45% higher than rice from the open market (World Bank 2013). Ordinary rice could be sold to an international buyer at 9.5% more if it was grown and harvested from the large-scale field programme (see Table 3.2 for details). However, jasmine rice could yield a higher profit per ton of rice because it is of high value in the MKD region. The spot-market-based buyer could obtain on average 3.43 billion VND per cropping season with ordinary rice and more than double that with jasmine rice, at 8.54 billion VND (see the bottom plots of Figure 3.5).

In this simulation, if contractors breached a large proportion of contracted farmers, they were not as profitable as the spot-market-based trading, especially in the case of contract farming with ordinary rice. In the case of $\theta_C = 30\%$ with ordinary rice, the contractor performed at a lower profit rate than the buyer from the open market in most of the offered price scenarios. In addition, the large-scale paddy field programme was not a cost-effective method for contractors when an unreasonably high contract-farming rate was offered. In the scenario of $\lambda = 30\%$ with ordinary rice, for example, the contractor incurred a high transaction cost to buy paddy from the participants, which had negative impacts on their earnings.

The simulation results showed that contractors who were untrustworthy to a relatively small proportion (e.g. 10%) of the participants still outperformed buyers from the open market in terms of profitability. The contractors in this scenario gained up to 58% and 21% higher profit rates with ordinary and jasmine rice, respectively. This interesting observation might be one reason for contractors reneging on their contract obligations, especially when they could obtain the same type of rice at a lower price on the spot market. Experts involved in the interviews also agreed on this specific insight and further linked to the contract breaches from buyers, especially among the small to medium enterprises. The untrustworthy companies were said to coordinate the contracting programme in a few cropping seasons to

take advantage of the Government's supporting policies before discontinuing the business model.

Prowse (2012) and Oxfam Vietnam (2012) suggested innovative arbitration and dispute-resolution mechanisms beyond the judicial system to prevent opportunistic behaviour from the related parties. One of the proposed solutions was a proactive role for intermediary bodies such as non-governmental organisations or farmer cooperatives. These organisations should be closely integrated into the establishment and operations of the agricultural contracting programme. These bodies could act as a third-party reconciliation service to promote dispute resolution, overcome conflict and protect the rights of both smallholder farmers and large contractors.

For results related to the ordinary rice, the simulation showed that the contractors earned the most profit when low contract-farming rates were offered to the participating farmers. However, unattractive paddy-purchasing prices limited the expansion of the contract-farming scheme, as fewer smallholder farmers gained any benefits from the programme. The lower left heatmap in Figure 3.6 6 indicates that if the contractors offered attractive contract-farming prices at rates (λ ranging from 20% to 30%) higher than the spot-market price, more farmers were willing to participate in the large-scale paddy field programme. These contractors, especially those who were committed, could eventually fulfil 96% of the total rice demand on average, even though they earned less profit compared with scenarios in which lower contract rates were offered. Dishonest contractors achieved a significantly lower rice volume, particularly when unattractive purchasing prices (λ ranging from 0% to 10%) were offered or a large percentage of contracts with farmers ($\theta_C = 30\%$) were breached.

Similar observations can be seen in the results related to the jasmine rice. Honest contractors with $\lambda = 20\%$ could establish a stable relationship with farmers to attain 96% of the maximum required volume. In addition, the results show that contractors who were untrustworthy to 30% of the contracted farmers were still able to attain a certain volume of

rice through their scheme and outperform the spot-market-based buyer in terms of profit. Because of the high level of productivity of jasmine rice, the contractors could initiate agricultural contracts with new members among the 3,000 farmers initially set up in the model to fulfil their demand. As displayed in the top right heatmap of Figure 3.6, contractors with jasmine rice earned the most profit when they offered the typical rates being set in the MKD region, $\lambda = 10\%$.

It is clear from the simulation results that to create a sustainable contract rice-farming scheme in the MKD region, it is critical for fully equipped contractors to be trustworthy and build long-term, trust-based relationships with farmers. In addition, the large buyers need to offer attractive purchasing prices, not only to motivate farmers to participate in the scheme but also to maintain their competitive profitability rates. Figure 3.6 shows the λ should range from 15% to 20% for ordinary rice and close to 15% for jasmine rice. With these proposed purchasing prices, the contractors could achieve above 89% of the required volume of exporting rice for both rice varieties.

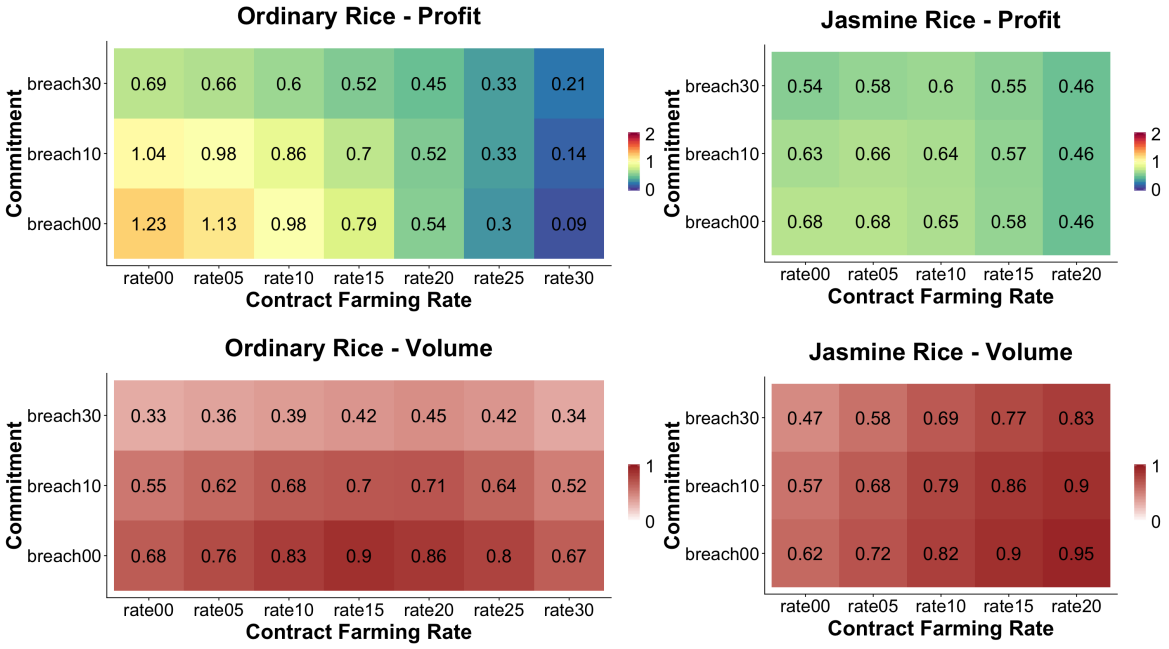
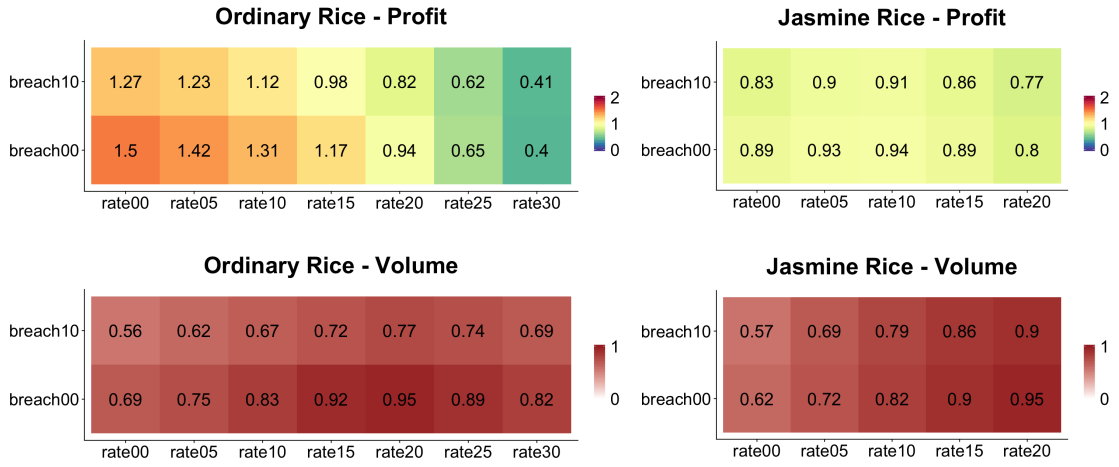


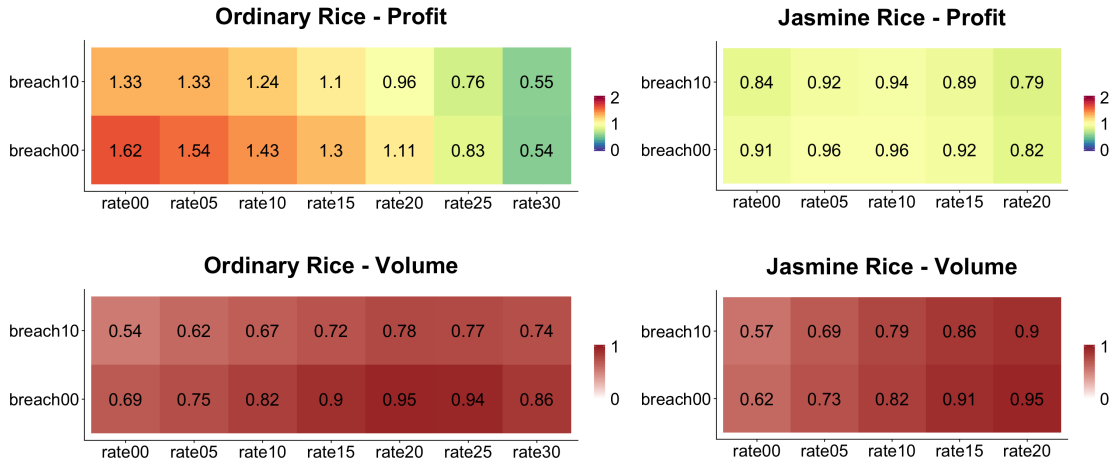
Figure 3.7 Comparison between non-equipped contractors and spot-market-based buyers

Figure 3.7 shows the profitability of contractors who were not equipped with rice-processing facilities in their contract-farming scheme, in comparison with open-market-based buyers. The results indicated that for these contractors, the large-scale field programme with either ordinary or jasmine rice was not a cost-effective agricultural production method. Contractors with limited husking, milling and polishing capacity needed to utilise relevant services from other players in the rice supply chain, leading to higher costs. The profit acquired by exporting high-quality rice could not compensate for the supporting services to the contracted farmers and their operational activities. Since most of the contractors in the MKD region have limited rice-processing facilities (Tran et al. 2013, World Bank 2013), the large-scale paddy field model might not be adopted by the majority of enterprises. Groups of experts were also in agreement with the importance of each oganisation conducting a comprehensive and realistic cost-benefit analysis of the contract-farming model.

We also examined the viability of contract rice farming in the MKD region with two cases in which the contractors were equipped with either milling or husking facilities. Figure 3.8 shows that for jasmine rice, a large-scale contractor needed at least one of the required processing facilities to be viable in the contract-farming scheme. The spot-market-based buyers could achieve a better profitability rate than the contractors in all scenarios of commitment and offering prices. However, for ordinary rice it seemed to be practical to be involved in the contracting programme when the purchasing price offered was 15% higher than the spot-market rate. For both cases with regard to the available equipment, the committed contractors could still achieve more than 90% of the required rice volume from contract rice farming and earn better profits than those of the buyers trading on the open market. The experts highlighted the necessity of financial support from the Government and local authorities to enhance contractors' rice-processing capacity, to help them engage more effectively into the contracting programme, particularly with ordinary rice. They also



(a) Contractors with milling facility but no husking facility



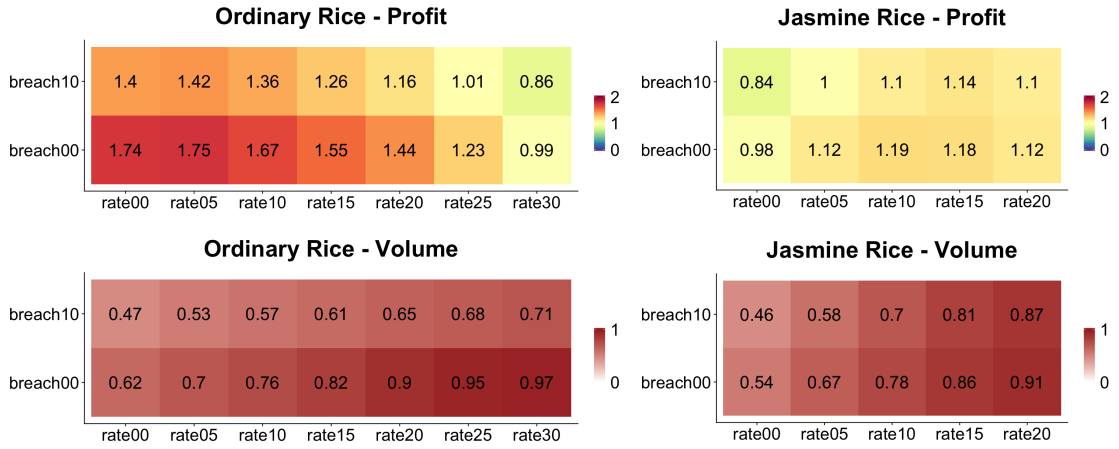
(b) Contractors with husking facility but no milling facility

Figure 3.8 Scenarios for contractors related to the availability of processing capacity

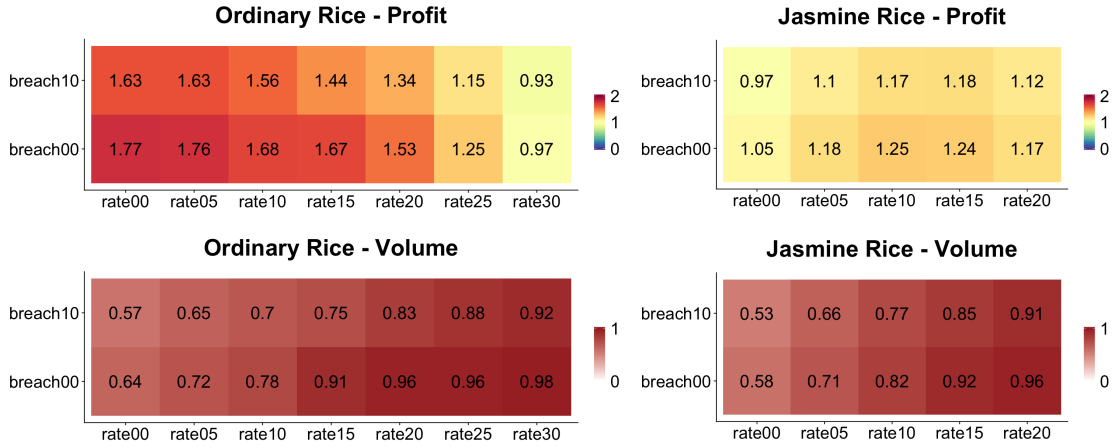
indicated that policies supporting infrastructure development and processing facilities should only focus on the main specialised rice production areas instead of the whole MKD region.

Simulations were conducted for four contractors and 6,000 farmers. Untrustworthy large buyers were set to breach the contracts of 10% of the participants. The simulations were run for 100 independent MC trials. An interesting observation from the results related to ordinary rice was that when more neighbouring contractors exhibited untrustworthy behaviour, a large buyer was tempted to lower the purchasing price or to exploit the contracted farmers

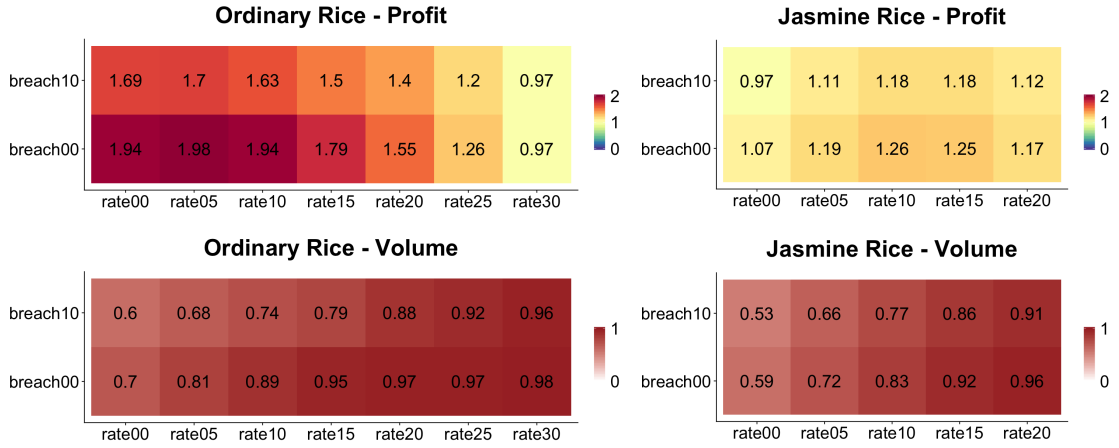
opportunistically, to obtain much better profits per crop. In the scenario with three other untrustworthy contractors (see the bottom plots of Figure 3.9), a large buyer of ordinary rice could choose to stay committed and offer a low purchasing price at $\lambda = 5\%$ and obtain the highest profit rate. In addition, the corporation could decide to breach the contracts of a small proportion of producers and achieve a 50% higher profit than the spot-market-based buyers. In both cases, the contractor could still maintain their contract rice-farming programme and acquire an exporting volume of up to around 80% throughout the simulation steps.



(a) Three other committed contractors



(b) One trustworthy contractor and two other committed contractor



(c) Three other untrustworthy contractors

Figure 3.9 Scenarios for four contractors with different commitment behaviours

Part II

Inter-Provincial Migration

Chapter 4

Dynamics of Inter-provincial Migration Flows

This chapter, together with Chapters 5 and 6, constitute Part II of this thesis, focusing on the dynamics of inter-provincial migration flows in the MKD region, as revealed through the use of ABM. The current chapter starts by providing an overview of migration patterns in Vietnam, and the way inequalities have driven migration across the regions. The focus is on the largest migration corridor, between the MKD and the SE region, and the dynamic patterns of inter-provincial migration flows. In addition, socio-economic-related determinants that people consider in their migration decision-making process are discussed.

4.1 Migration in Vietnam and the Mekong Delta

4.1.1 Overview of Internal Migration in Vietnam and the Mekong Delta

Internal migration is a prominent feature of many developing countries, especially those participating in globalisation and economic integration (Lucas 1997). This globalisation and integration change the whole structure of the economy, moving its base from agriculture to industry and service, stimulating economic and social development across the country. This

structural transition typically creates inequality in development among regions, spontaneously triggering migration from the least-developed regions to the more-developed regions (Skeldon 2002). India, Nepal, Bangladesh, Thailand, China, Indonesia and other Asian nations have recently experienced dramatic increases in migration, especially in inter-regional and inter-provincial migration (Deshingkar 2006, Lucas 1997).

Vietnam officially introduced Economic Renovations (Doi Moi) in 1986, moving from a centrally planned economy with public ownership of production towards a market economy that encouraged individual entrepreneurship and foreign investment. The transformation led to not only significant economic growth and poverty deduction but also changed the patterns of internal migration (Marx and Fleischer 2010, Phan and Coxhead 2010). The benefits of Doi Moi have been unequally distributed and they have subsequently created unbalanced states of socio-economic development and living standards among regions across Vietnam[1], as shown in Figure 4.1.

While the South East region and the Red River Delta region, with large urban cities such as Ho Chi Minh City and Hanoi, have received high levels of industrial capital, the Northern Midlands and Mountains, the North Central Coast, the Central Highlands, the MKD region and other rural areas have lagged behind. These disparities have triggered a substantial flow of rural-to-urban migration and shaped the dynamics of both regional and inter-provincial migration in Vietnam (Kim Anh et al. 2012).

In the context of globalisation, the fact that Vietnam has become increasingly integrated into the world markets has been affecting industries, with the concentration of economic zones in certain areas creating jobs for millions of people annually (GSO Vietnam and UNFPA 2005b). In addition, the increasing commercialisation of agriculture and the replacement of labour with capital inputs have released the rural workforce and prompted them to migrate

[1] Vietnam is geographically divided into seven administrative regions, which include the Northern Midlands and Mountains, the Red River Delta, the North and South Central Coast, the Central Highlands, the SE and the MKD. There are five municipalities and 58 provinces. Ho Chi Minh City and Can Tho are two of the five centrally governed cities in the SE and the MKD regions, respectively.

Figure 4.1 A regional map of Vietnam. Source: GSO Vietnam 2018a

in search of better economic opportunities (GSO Vietnam and UNFPA 2005a). Migrant labour from the rural provinces has recently become an important resource to meet the increased demand for the labour and service market in industrial centres, inevitably leading to greater migration of certain groups of the population. The social networks created among the increasing number of migrants have further fuelled the movement across regional and provincial boundaries within the country (GSO Vietnam and UNFPA 2016b).

The nature and the scale of migration flows have varied during the last 25-year period, from 1989 until 2014 (GSO Vietnam 2010, GSO Vietnam and UNFPA 2005b, 2016a). The

development of migration in Vietnam can be divided into two main phases. The first phase covers the first two decades following the Doi Moi reforms, from 1989 to 2009. This phase saw an increasing trend in the number of migrants in both absolute and relative terms. The number of inter-provincial migrants rose from 1.3 million in the five-year period prior to 1 April 1989, to 2 million people in the five-year period before 1 April 1999 and 3.4 million people in the five-year period to 1 April 2009. The share of inter-provincial migration over the total population increased from 2.5% in 1989 to 2.9% in 1999 and 4.3% in 2009. In the first decade, migration grew mainly because large movements to new economic zones occurred as a strategy of population resettlement and national security. In the second decade, the migrant population soared as the economy thrived in response to the restructuring from agriculture to industry and services. The strong development of industrial and export processing zones attracted a large number of labour migrants during this period(GSO Vietnam and UNFPA 2011).

In the second phase, from 2009 to 2014, internal migration was closely related to economic opportunities and social development in the urban and industrial cities. This phase saw a decrease in the number of migrants, mainly because of the 2007–2008 global financial crisis. In the global economic downturn, the Vietnamese economy grew only slowly and industrial zones no longer attracted as many migrant labourers. Even so, the number of migrants accounted for a substantial proportion of the population, with 2.6 million inter-provincial migrants comprising 3.1% of all the residents in Vietnam in 2014. In addition, the economic disparities between the urban and rural areas and between regions were reduced by the Government's rural development policies, contributing to the decrease in the number of migrants in this period.

In the most recent migration survey at the national level conducted in 2015, GSO Vietnam and UNFPA (2016b) provided several key facts about internal migration in Vietnam. First, internal migration accounted for a considerable proportion (13.6%) of the total population of

Vietnam. Approximately 12.4 million out of 91 million people had migrated during the five years from 2010 to 2015. Second, among the four migration flows (rural-urban, urban-rural, rural-rural and urban–urban), the rural-urban flow accounted for the largest proportion, at 36.2%. In the MKD region, the rural-urban flow was five times higher than the urban-rural flow. Third, migrants were mainly young people between the ages of 15 and 39. Most of the young migrants in this age group were moving for education or employment opportunities. Fourth, job seeking and economic improvement were the most important determinants cited by the migrants. Fifth, a higher percentage of migrants than non-migrants pursued education (college/university level or higher) and had professional or technical qualifications.

It is worth noting that this thesis focuses primarily on two migration flow types: regional and inter-provincial. This classification of migration by administrative level is based on the three latest national internal migration surveys conducted by the GSO Vietnam in 2009 (GSO Vietnam and UNFPA 2011), 2014 (GSO Vietnam and UNFPA 2016a), and 2015 (GSO Vietnam and UNFPA 2016b) by the General Statistics Office of Vietnam. Regional migrants are defined as people whose region of residence in the previous year was different from their current region of residence and inter-provincial migrants are people whose province of residence in the previous year was different from their current province of residence. This classification allows an analysis of the patterns of different types of migration flows in Vietnam generally and in the MKD specifically.

It is also essential to point out that international migration, or immigration, is not discussed in this thesis. Most national migration surveys and population census data did not cover international migration. The main reasons are because of the small actual immigrant population, and many Vietnamese who live overseas were not captured in the census enumeration. In our literature review, international migration has also been excluded from the analysis.

The key terminologies used to assess internal migration flows within this thesis are as follows:

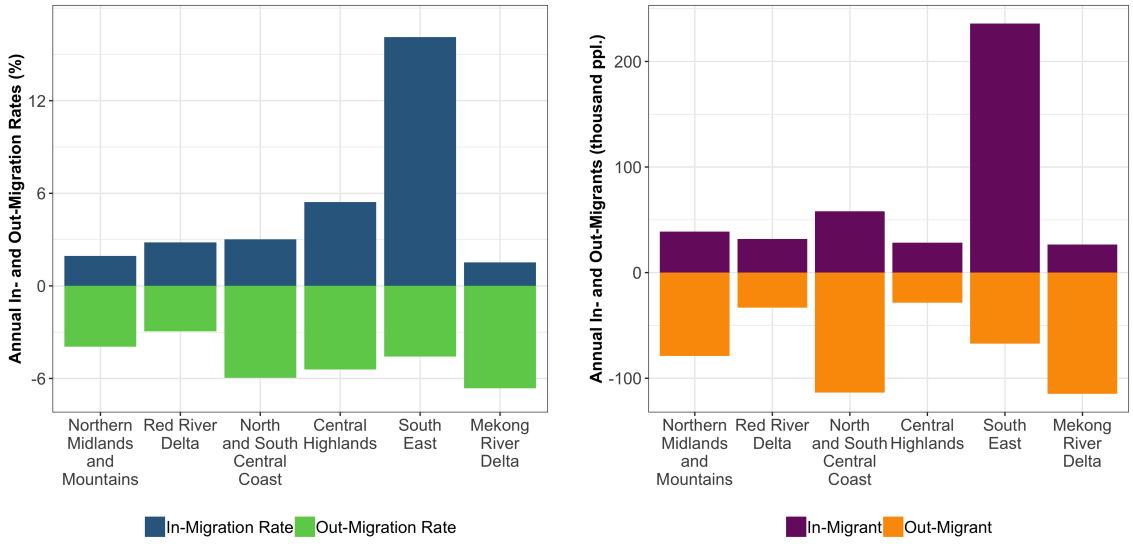
- The in-migration rate refers to the number of people arriving from other regions or provinces during an observed period per 1,000 persons in the destination region or province.
- The out-migration rate refers to the number of migrants departing from one region or province during an observed period per 1,000 persons in that region or province.
- The net migration rate refers to the difference between in-migration rate and the absolute of out-migration rate in the region or province.
- The number of in-migrants (or the gain of the population through migration) refers to the mean of the absolute in-migration population during an observed period in the region or province.
- The number of out-migrants (or the loss of the population through migration) refers to the mean of the absolute out-migration population during an observed period in the region or province.
- The term net migrants refers to the difference between the number of in-migrants out-migrants in the region or province.

4.1.2 Differentials in Regional Migration

Since the beginning of the Doi Moi economic transition, Vietnam has experienced considerable socio-economic disparities between the rural and urban areas of the country and between regions. Diversity in natural conditions, socio-economic development policies and different levels of economic investment in different regions have contributed to these disparities. These inequalities are considered the fundamental drive for migration across the regions of Vietnam

during the last decades (Huy and Khoi 2011, Kim Anh et al. 2012, Marx and Fleischer 2010, Phan and Coxhead 2010).

In general, the SE region and the triangle of three cities and provinces, comprising Ho Chi Minh City, Binh Duong and Dong Nai, have been attractive to migrants. The SE region is the most economically developed, with the highest per capita income and level of living standards during the last two decades. The variations in regional migration in Vietnam between 2005 and 2017 (see Figure 4.2) have further emphasised the popularity of the SE region, which has been the primary migrant-receiving region of the country, with a clear difference between the in-migration and out-migration flows. On average, this region attracted more than 230,000 people from other regions annually during this period. This number was approximately four times higher than that of the second most favourite region, the North and South Central Coast, with nearly 58,000 in-migrants.



(a) Differential of in- and out-migration rates (b) Differential of in- and out-migrants number

Figure 4.2 Differential of migration patterns among regions in Vietnam in the 13-year period between 2005 and 2017

Three regions had high negative net migration rates during the period (i.e., the absolute values of the out-migration rates are higher than the in-migration rates), namely (i) the

Northern Midlands and Mountains, (ii) the North and South Central Coast and (iii) the MKD. Of these, the MKD had the highest negative net migration rate and was the main migration-sending region of Vietnam. Over the 13-year period from 2005 to 2017, slightly more than 25,000 on average entered the MKD region annually, whereas more than 110,000 people left the MKD region annually for other cities and provinces. Similar observations were captured in the five-year migration trends shown in the 2009 and 2014 population and housing census (GSO Vietnam and UNFPA 2011, 2016a).

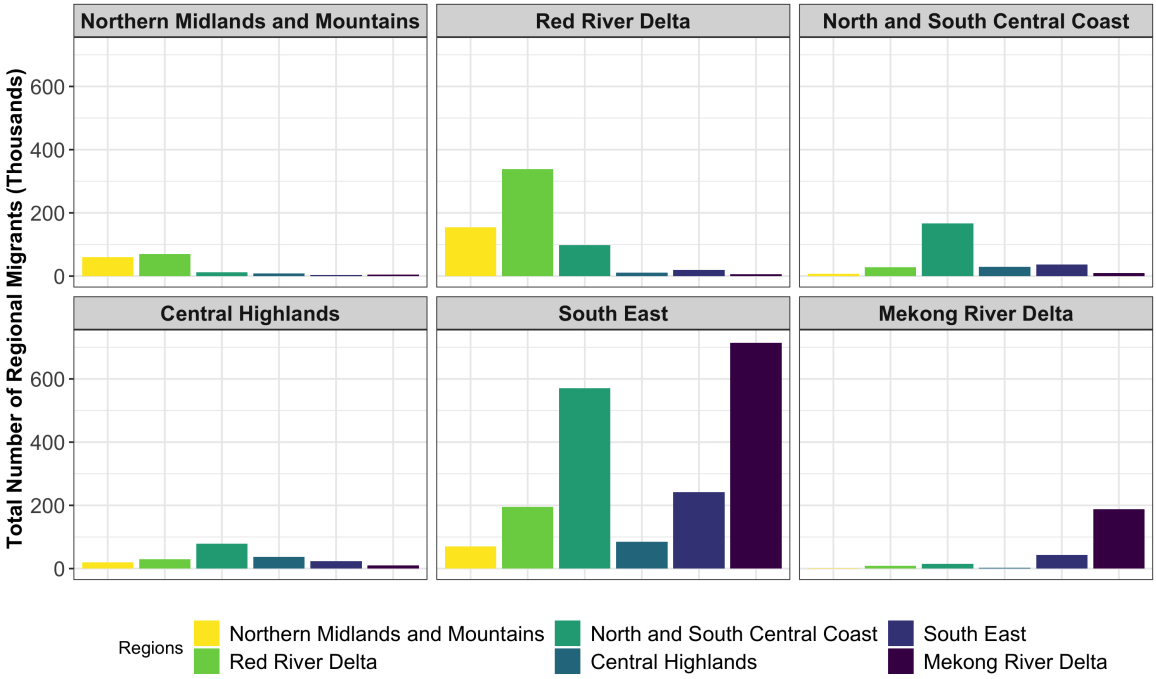


Figure 4.3 Number of regional migrants in five-year period from 2004 to 2009

Both Figures 4.3 and 4.4 show similarities in the directional migration flows among the socio-economic regions of Vietnam by the total number of migrants from 2004 to 2009 and from 2009 to 2014, respectively. In general, the most favoured destination of the migrants was the SE region and the major regions of origin were the MKD and the Central Highlands. In the 2009 population census (see Figure 4.3), the MKD region was the largest area of emigration (GSO Vietnam 2010), with 714,626 people migrating from the MKD to the SE

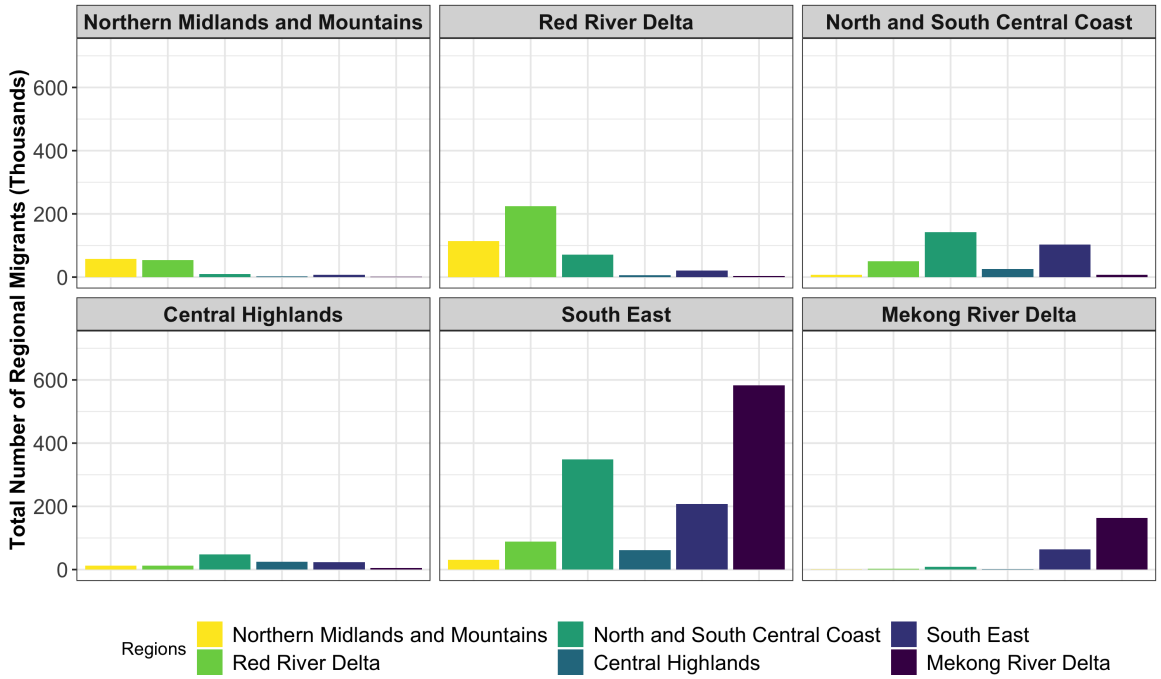


Figure 4.4 Number of regional migrants in the five-year period from 2009 to 2014

area between 2004 and 2009, representing the largest migration corridor in Vietnam (GSO Vietnam and UNFPA 2016b). The second-largest flow was from the North and South Central Coast to the SE region, with more than 570,000 people. The third-largest flow was more than 195,000 people moving from the Red River Delta to the SE region.

Figure 4.4 indicates that the SE region attracted a large number of migrants from other regions as well: 76.5% came from the MKD, 55.5% from the North and South Central Coast and 50.4% from the Central Highlands. More than 1.1 million people moved into the SE region during this five-year period. The closeness of these three regions to the SE region is a further reason for more in-migrants to depart from these regions. Figure 4.4 clearly shows that the Northern Midlands and Mountains, the Central Highlands and the MKD were the three least attractive regions for migrants, with approximately 127,000, 130,600 and 242,000 people moving to them, respectively, between 2009 and 2014.

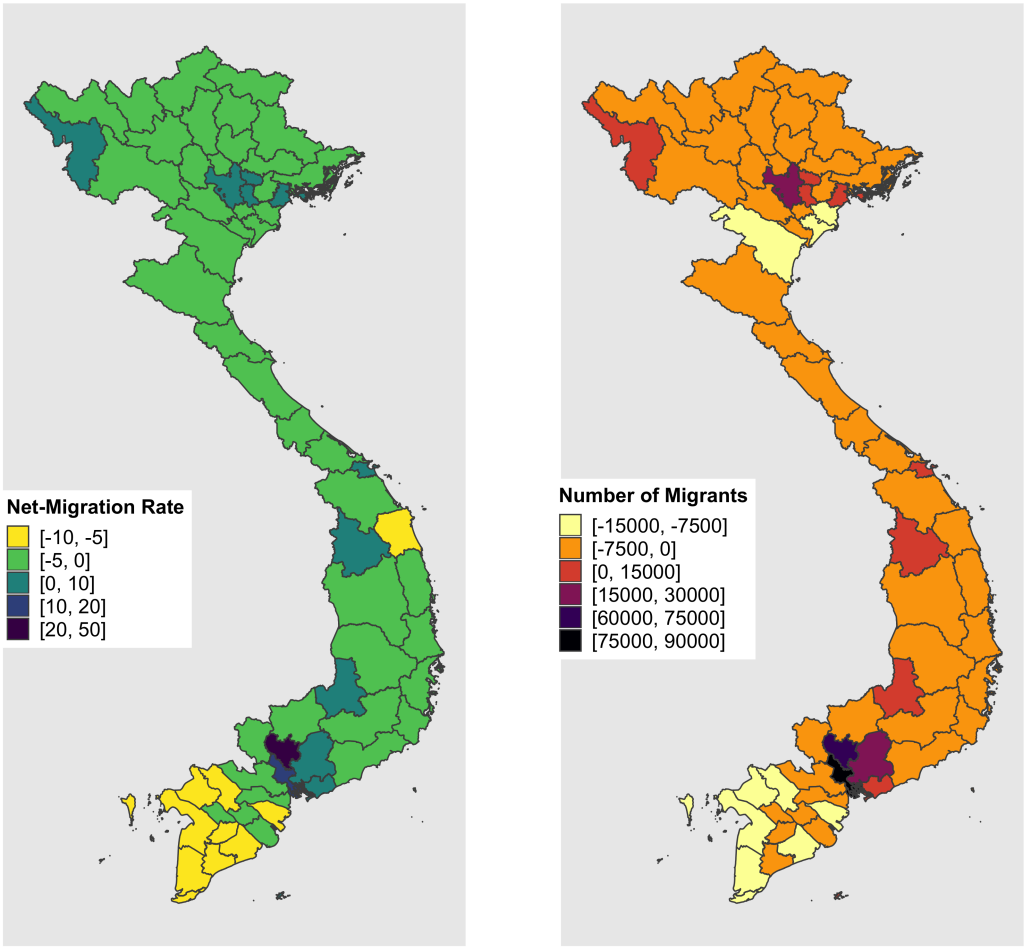
In addition, a large number of people moved within the regional boundary of the Red River Delta and the SE region in both of the five-year periods covered by Figures 4.2 and 4.3. More than 224,000 and 207,000 intra-regional migrants moved within the SE region and the Red River Delta, respectively, between 2009 and 2014. Intra-regional migration took place within the MKD as well, particularly to the main urban areas, such as Can Tho, Long An and Kien Giang provinces. In-migration rates towards the MKD from other regions (mostly from the SE region) were low (GSO Vietnam and UNFPA 2016a).

4.1.3 Dynamics of Inter-provincial Migration

During the 13-year period between 2005 and 2017, there were large variations in migration across cities and provinces in Vietnam. Figure 4.5 visually presents the differentials, at the provincial level, in the average net migration rates (see the map on the left) and the number of net migrants (see the map on the right).

Three out of the six cities and provinces in the SE region, including Ho Chi Minh City and Binh Duong and Dong Nai provinces, were among those with the largest positive net migration rates. These three cities and provinces have received numerous foreign capital investments, developed large industrial zones and experienced rapid economic growth and subsequently, high monthly incomes for their populations. These economic developments have made them ideal destinations for migrants. The province with the highest annual net migration rate (40.46) during the period 2005 to 2017 was Binh Duong, which attracted nearly 88,000 migrants from other provinces. Ho Chi Minh City achieved the next-highest net migration rate (12.44), attracting more than 143,000 people, the largest number of in-migrants in the country. Dong Nai had a very high number of migrants as well, with an average of 43,364 people moving in annually during this 13-year period.

It is worth noting that all of the provinces and cities in the MKD region had negative net migration rates during this period, indicating that they were all migrant-sending areas.



(a) Differentials of net migration rates (b) Differentials of net migration numbers

Figure 4.5 Differentials of migration among the provinces in Vietnam in the 13 years period from 2005 to 2017

Most of the provinces with the highest negative average net migration rates in Vietnam between 2005 and 2017 were concentrated in the MKD region. The primary out-migration provinces with the greatest annual number of out-migrants were An Giang (-19,590), Kien Giang (-15,647), Dong Thap (-14,325), Ca Mau (-13,174) and Ben Tre (-12,637). Table 4.1 summarises the dynamics of migration flows in the cities and provinces in the MKD and SE region in the 13 years between 2005 and 2017.

Table 4.1 The average of migration rates and number of migrants across the cities and provinces in the MKD and the SE regions, from 2005 to 2017

Province	Rates			Number of People		
	Net-migr	Out-migr	In-migr	Net-migr	Out-migr	In-migr
MKD						
Ca Mau	-9.15	-10.88	1.73	-11,084	-13,174	2,091
Bac Lieu	-6.95	-8.75	1.80	-6,034	-7,573	1,546
An Giang	-6.76	-9.11	2.35	-14,550	-19,590	5,040
Soc Trang	-6.58	-8.84	2.27	-8,547	-11,465	2,928
Ben Tre	-6.52	-10.02	3.50	-8,220	-12,637	4,417
Dong Thap	-5.93	-8.57	2.65	-9,921	-14,325	4,429
Hau Giang	-5.34	-9.35	4.01	-4,077	-7,131	3,054
Kien Giang	-5.33	-9.09	3.75	-9,249	-15,647	6,372
Vinh Long	-4.18	-8.79	4.61	-4,304	-9,066	4,766
Long An	-3.49	-7.71	4.23	-5,030	-11,155	6,136
Tra Vinh	-2.65	-7.38	4.73	-2,683	-7,488	4,797
Can Tho	-1.36	-8.21	6.87	-1,642	-9,931	8,302
Tien Giang	-0.98	-7.24	6.26	-1,626	-12,204	10,584
SE region						
Binh Duong	40.46	-13.41	53.88	66,271	-21,622	87,907
Ho Chi Minh City	12.44	-7.26	19.72	89,166	-53,977	143,278
Dong Nai	8.27	-7.95	16.24	22,551	-20,746	43,364
Vung Tau	2.51	-7.02	9.53	2,579	-7,115	9,693
Binh Phuoc	-2.37	-9.08	6.71	-2,071	-8,044	5,981
Tay Ninh	-2.77	-5.97	3.20	-2,957	-6,419	3,456

4.2 Determinants of Migration

According to the 2015 national internal migration survey in Vietnam (GSO Vietnam and UNFPA 2016b), there are four main groups of migration-determining factors: (i) economic motivation, (ii) pursuit of education, (iii) family-related (marriage, being close to family) and (iv) others (environmental impact, medical treatment). These findings are similar to those of previous national migration surveys in 2004 (GSO Vietnam and UNFPA 2005b) and 2009 (GSO Vietnam 2010). Results extracted from the migration module in the 2012 VHLSS (Coxhead et al. 2015) confirmed these four main reasons for migration.

Empirical evidence has shown that economic development is the most critical factor for migration within Vietnam (Coxhead et al. 2015, Dang et al. 1997, Huy 2012, Kim Anh et al. 2012, Phan and Coxhead 2010, Phuong et al. 2008). Both of the national internal migration surveys, in 2004 (GSO Vietnam and UNFPA 2005b) and 2015 (GSO Vietnam and UNFPA 2016b), indicated that economic reasons were by far the most important migration determinants, cited by 68.6% and 62.8% of migrants, respectively. This economic driver of migration included both looking for employment and increasing the migrants' incomes and working and living conditions if they were working before they moved (GSO Vietnam and UNFPA 2005b, 2016b).

Economic Motivations - Employment Opportunities

According to the analysis of VHLSS 2012, more than half (54.4%) of the migrants in Vietnam moved for employment purposes (Coxhead et al. 2015). Nguyen-Hoang and McPeak (2010), Kim Anh et al. (2012) and Coxhead et al. (2015) claimed that foreign investment and industrial zones, which have been distributed unequally through the country, were the impetus for the internal migration in Vietnam for better employment opportunities. Table 4.2 illustrates the large disparities both in regional and provincial levels in foreign direct investment (FDI) flows.

Table 4.2 2 shows that at the regional level, the SE has attracted the most FDI projects and the most substantial amounts of FDI-registered capital effective as of 2017: seven times more than in the MKD region. At the provincial level, four out of the five cities and provinces that have attracted the most FDI capital – Ho Chi Minh City, Binh Duong, Dong Nai and Vung Tau – are in the SE region. This clearly explains why the SE region has received the highest number of working migrants from the MKD region who were moving for employment availability. In addition, the 2015 internal migration survey indicated that FDI companies and businesses in the private sector were one of the main sources of employment for migrants:

Table 4.2 Accumulation of registered FDI projects and total registered capital effective as of 31/12/2017 by region and top five cities and provinces

Regions, Cities and Provinces	Number of Projects	Total Capital (mil. USD)
Regions		
Red River Delta	7,896	88,445
Northern Midlands and Mountain	826	15,124
North Central and Central Coastal	1511	56,860
Central Highlands	147	910
SE	12,946	135,418
MKD	1,426	20,085
Top 5 cities and provinces		
Ho Chi Minh City	7,333	43,879
Binh Duong	3,305	30,339
Ha Noi	4,500	27,638
Dong Nai	1,472	27,349
Vung Tau	363	26,838

the proportion of migrants employed in the FDI and private sector (41.4%) was nearly twice as high as that of non-migrants (20.9%) (GSO Vietnam and UNFPA 2016b).

Economic Motivations - Better Income and Poverty Reduction

An income differential between a migration origin and destination is essential (Coxhead et al. 2015). Based on the analysis of data from different surveys in the population and the VHLSS, Kim Anh et al. (2012) and Phan and Coxhead (2010) suggested that provinces with a high monthly income per capita were more likely to have higher rates of in-migration. The SE region, with a higher level of income per capita and living standards during the last decade, is the most popular destination for migrants from other parts of the country, especially the MKD region. Migrants from the MKD move to the neighbouring region in search of better income and living conditions.

Migration, particularly internal migration, is a helpful way for many poor and rural families in developing countries to escape poverty and improve their livelihoods. The

relationship between migration and poverty is widely known and has been found in both the theoretical literature (De Haas 2010, Skeldon 2002) and empirical studies (Deshingkar 2006, Lokshin et al. 2010). In the MKD region, poverty is an important factor driving people to migrate. Although the poverty rate in the MKD has declined rapidly in recent years, it has remained worse than the average level of the country and especially in comparison with the neighbouring SE region. Both Huy and Khoi (2011) and Phan and Coxhead (2010) found that a high rate of migration is closely associated with poverty, particularly for migration flows into Ho Chi Minh City.

Pursuit of Education

Education has been cited as the second most popular determinant of migration in Vietnam since 2004 (GSO Vietnam and UNFPA 2005b, 2011, 2016a,b). The proportion of migrants who moved because of study has increased from 4.5% in 2004 (GSO Vietnam and UNFPA 2005b) to 23.4% in 2015 (GSO Vietnam and UNFPA 2016b). This increase in the education incentive, which is found in all regions of the country, reflects the fact that education has become more important for accessing well-paid employment in Vietnam. The 2015 national internal migration survey found that the percentage of migrants who had education at college/university level or above was higher than in the group of non-migrants. Similarly, a higher percentage of migrants than non-migrants had professional or technical qualifications (31.7% and 24.5%, respectively) (GSO Vietnam and UNFPA 2016b). This particularly applies for young people in the MKD region, who migrate to larger urban centres such as Can Tho or Ho Chi Minh City to have access to higher education.

Family-related Factors

Reasons related to family include marriage, being close to relatives and lack of relatives residing in the place of origin. The results of the 2004 migration survey (GSO Vietnam and

UNFPA 2005b) found that 20.8% of migrants moved to be close to their relatives. More recently, the 2015 national internal migration survey (GSO Vietnam and UNFPA 2016b) showed that 31.4% of migrants had moved from their place of origin with family members such as spouses, children and parents and approximately 7% had migrated with their friends or others. The qualitative interviews confirmed that family-related issues were an essential consideration in current or future migration decisions, especially among migrants who were married and had children.

Environmental Impacts

In addition to the socio-economic determinants of migration, the natural environment is being increasingly recognised as influencing internal migration trends in Vietnam and especially in the MKD region. Vietnam, which is located in a tropical monsoon region, with a long coastline of around 3,440 kilometres, combined with diverse and complex topography, is prone to many different types of natural hazards, such as floods, storms, droughts, heavy rainfall, landslides and earthquakes. More than 70% of the population is exposed to risks from such hazards (Nhu et al. 2011). The MKD region is considered one of the most vulnerable deltas in the world with regard to natural disasters and the effects of gradual climate change (Smajgl et al. 2015). Its low-lying area has been particularly affected by flooding of the Mekong River, by erosion and increasingly, by salinisation and sea-level rise. Further, the exposure and vulnerability of this region to these hazards are significant because of the high level of dependency of the population on agriculture and fisheries, which are profoundly affected by changing environmental conditions (Noy and Vu 2010, Smajgl et al. 2015). There is evidence of internal migration in the MKD being induced by both natural disasters and the effects of gradual climate change (Dun 2011).

Migration appears to be one of the coping and adaptation mechanisms for people in the MKD region to deal with natural hazards to ensure their safety and livelihood stability. In the

2015 Vietnam Internal Migration Survey, approximately 4.5% of migrants from the MKD region indicated that they had moved for a more suitable natural environment (Entzinger and Scholten 2016). Rapid-onset events, such as erosion, cyclones or floods, appear to have contributed to migration flows in the south of Vietnam, with a key migration corridor between the rural areas in MKD region and large cities such as Can Tho and Ho Chi Minh City, as well as Binh Duong province. Slow-onset events such as salinisation and sea-level rise were mentioned less often as major environmental stressors in the region. However, their significant impacts are expected to grow and become a major challenge to the livelihood of people living in the MKD (Anh et al. 2016, Entzinger and Scholten 2016).

Social Network

Empirical studies and surveys on internal migration in Vietnam have found specific factors (e.g. social networks among the migrants, household income and migration costs) that could either facilitate or impede the final decisions of the migrants. The social network is one of the important sources of assistance in helping migrants to adapt to their new living environment (GSO Vietnam and UNFPA 2005b, 2016b). Qualitative interviews in migration surveys have shown that while most migrants make their own decisions about migration, they are influenced by the members of their social network. A family member or a friend who has influence typically provides information or other connections with regard to employment in the destination area. More than 60% of migrants who responded to the 2015 migration survey (GSO Vietnam and UNFPA 2016b) said they had families, relatives or friends from their place of origin currently living in the place of destination. These personal relationships can help to reduce the risks associated with migration, save on costs and link the migrants to the place of destination. Once the relationships have been tightly formed, the social network will develop and fuel further migration to that destination.

Household Income

Entzinger and Scholten (2016) found a correlation between household income and the probability of migration in the MKD region. Their survey of more than 1,000 households showed that the migrants usually came from households with a lower income, while non-migrants had better housing and were better off. Entzinger and Scholten (2016) depicted the probability of migration at each income level, with a sharp decline in the probability of migration as household income increased.

Their findings were in agreement with results from the migration module in VHLSS 2012. Coxhead et al. (2015) showed that household wealth matters to migration decisions in Vietnam; wealthier households with better housing, higher non-farm income and a larger farmland area were less likely to have migration of family members. High income appears to discourage people from migrating across provinces, since the gain from migration might not be sufficiently attractive.

Cost-related Reasons

The research literature has considered the geographical distance between a migration origin and destination an important determinant of migration cost. Distance, as a proxy for the cost of transportation, job search and information acquisition, as well as the psychological costs of migration, affects migration choice negatively (Anh et al. 2008, Nguyen-Hoang and McPeak 2010): a long distance is strongly associated with lower migration flows (Huy and Khoi 2011, Phan and Coxhead 2010). However, Coxhead et al. (2015) pointed out that contemporary migration in Vietnam is less costly than in the past because of near-universal access to mobile phones, computers and the Internet. Potential migrants can use their social network and other means of media and communication to reduce the migration costs by learning about transportation, resettlement costs and expenditures in the destinations before deciding to move. Currently, the differentials of migration costs among provinces might have

less effect on the decisions of migrants than they did in the past. Qualitative interviews in the 2015 national migration survey (GSO Vietnam and UNFPA 2016b) found that the cost of living in destinations affected the direction of migration, with many migrants preferring to move to a smaller urban centre rather than to a large city, as they wanted to live in a place with low living costs.

Chapter 5

Theoretical Models and Modelling Frameworks

Chapter 5 is organised into three sections. The first section describes the advantages of ABM over the traditional gravity model from the migration literature. The TPB, a psychological theory that consists of three core components: behavioural attitude, subjective norm and perceived behaviour control, is outlined, focusing on its application in the migration context. The second section is followed by a state-of-the-art review of agent-based models integrating the TPB. Lastly, agent-based migration models relying on direct observations and empirical data are also reviewed.

5.1 Agent-based Modelling of Migration

For decades, gravity models have been popular in the migration literature to structure explanations and to forecast migration flows (Lewer and Van den Berg 2008, Ramos 2016). The classic gravity model assumes that migration flows are proportional to the relative size of the source and destination area and are inversely related to the distance between the locations. Gravity models have been enlarged with additional variables related to different socio-economic and environmental factors that affect migration flows. Therefore, models for migration analysis have been involved with the concepts of 'push' factors in the origin

area, 'pull' factors in the destination area and 'intervening obstacles' between the locations, as proposed by Lee (1966).

One major drawback of gravity models is that they fail to consider properly the specific behaviour of individuals and the dynamic nature of the interactions among individuals, which ultimately determine the final migration decision (Klabunde and Willekens 2016, Kniveton et al. 2012). For an individual, deciding whether to migrate from one place to another is a complex process, based on their behaviours and perceptions with regard to different factors and circumstances. The ABM approach, with its ability to simulate explicit autonomous decision-making processes and smoothly incorporate high degrees of heterogeneity in human society (Gilbert 2008) has recently been considered to be a valuable tool in the discipline of demographic science and migration (Thober et al. 2018, Willekens 2017).

The ABM approach, which was first developed in computer science, is now commonly used in the interdisciplinary research of demographic, social and geographical sciences, as well as other disciplines (Billari and Prskawetz 2012). Agent-based models have become important tools for demographers who study social reality, including marriage markets (Bijak et al. 2013, Billari et al. 2008, Hills and Todd 2008), partnership and household formation (Noble et al. 2012) and fertility (An and Liu 2010, Fent et al. 2013). In these models, the analysis of population can be enhanced through the inclusion of processes that span different levels of aggregation, from individuals to societies (Gray et al. 2017).

Although migration is a trending topic in demographic research (Bijak et al. 2014), there has been little attention paid in the migration literature to the use of ABM (Kniveton et al. 2012). In 2016, Klabunde and Willekens (2016) indicated that this computational approach was just starting to develop. They expected the application of ABM in migration research to increase and establish a new generation of migration models in the future (Klabunde and Willekens 2016). Several research directions that might be greatly beneficial from the use of ABM include explanations and predictions for observed migration flows and justification of

the proportion of different socio-economic and environmental factors affecting the decisions of migrants.

ABM has several advantages over the traditional empirical and statistical approaches to research in this area. It offers a robust method for simulating autonomous and heterogeneous entities, whose individual circumstances and behaviour are different from that of an average meta-actor (Kniveton et al. 2012). The decision-making rules of an individual agent can vary depending on complex combinations of multi-level stimuli, including personal, economic, social, environmental and spatial factors. This capability provides realistic agent-based models based on observed empirical data to reflect a real-world situation (Kniveton et al. 2011).

ABM is the only method that allows modelling of the dynamics of unforeseen social interactions and social networks in human systems (Epstein 2006b). Social networks are typically modelled as social linkages such as remittance, information and experience exchange among migrants (Thober et al. 2018). Through such interactions, individuals learn and gain support from each other and may adapt their migration options in the future. These social adaptations and feedbacks at the individual (micro) level, which often produce non-linear effects at the population (macro) level, are a critical component in explaining the emergence of migration patterns. ABM, which provides the modeller with the ability to capture the explicit effects of social networks and allow the analysis of different mechanisms of social influence, represents a great opportunity for migration modelling (Klabunde and Willekens 2016). This advantage of ABM cannot be found in any statistical regression methods.

ABM has recently been used in migration models. In the literature, the aims of these models have been understandably varied, owing to the differences in the fields of study as well as the regions under study. In most of the cases, they have served three broad purposes. First, agent-based models have been developed to study the dynamics of migration flows, such as rural-urban migration (Silveira et al. 2006), circular migration (Klabunde 2014), inter-

provincial migration (Nguyen et al. 2018) and international migration (Klabunde et al. 2017). Second, researchers have applied ABM to explain the mechanism of migration affected by different factors such as environmental impacts (Entwisle et al. 2016, Kniveton et al. 2012, Smith 2014), demographic attributes (Klabunde et al. 2017) or a range of socio-economic factors (Nguyen et al. 2019). Lastly, ABM has been utilised to predict migration numbers or population distributions under different scenarios (Hassani-Mahmooei and Parris 2012, Kniveton et al. 2011).

5.2 Theory of Planned Behaviour

Klabunde and Willekens (2016) recently reviewed agent-based migration models regarding the way theoretical backgrounds are drawn to define decision-making rules. Klabunde and Willekens (2016) identified two popular behavioural theories, including the TPB, derived from social psychology, and random utility theory, implemented in the discrete choice model. This chapter focuses on the use of the TPB, owing to its ability to include relevant components leading to the individual's migration behaviour, especially the multistage decision-making process, the impact of peer influence and the role of uncertainty. The relevant choices are then identified regarding the modelling of individual decision-making processes in the development of these agent-based migration models. In section 5.3, agent-based migration models, which relied on direct observations without any application of theory, are reviewed.

The TPB was originally proposed by Ajzen (1991). This psychological theory holds that a choice of action or a particular behaviour is explained by an intention that is the result of a decision-making process, which consists of three core components: behavioural attitude, subjective norm and perceived behaviour control. The TPB, with its simple and straightforward way of determining the individual's decision-making process, has recently become favoured among modellers, who have developed computational models with the use

of ABM in the areas of demography and migration research (Muelder and Filatova 2018). The TPB within the context of migration is presented in Figure 5.1.

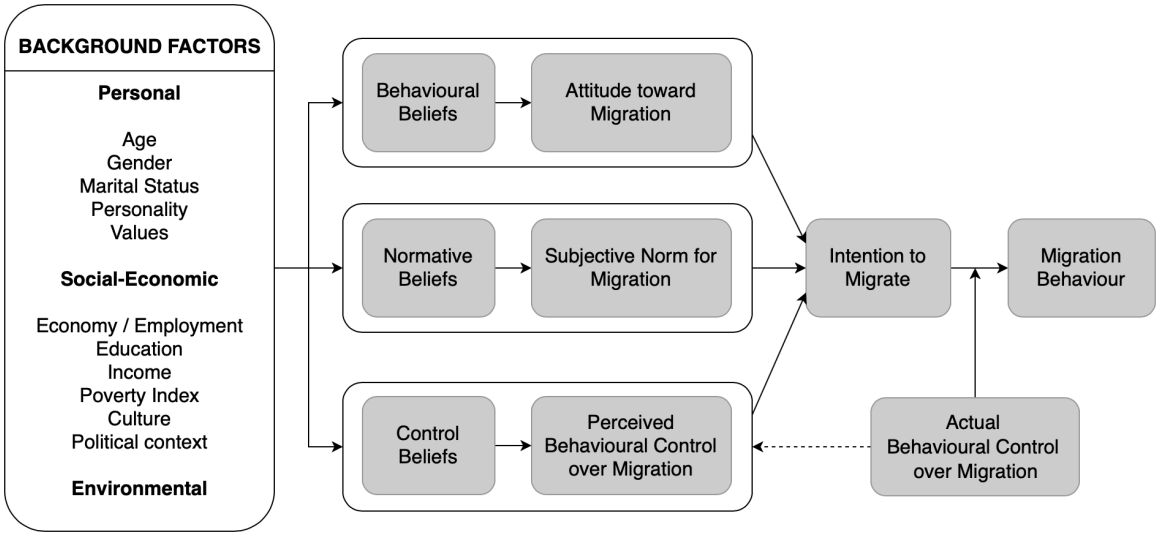


Figure 5.1 Presentation of the TPB in the migration decision-making process (adapted from Fishbein and Ajzen 2011, Willekens 2017)

Three types of beliefs (behavioural, normative and control) determine an intention to migrate. According to the TPB, the beliefs people hold regarding a migration option are influenced by a combination of different factors, including demographic characteristics (e.g. age, gender, marital status), socio-economic factors (e.g. employment opportunity, education, poverty, political context) and environmental factors (e.g. climate change, natural disaster). These background factors affect the formation of the beliefs and indirectly shape the individual migration intention and behaviour (Ajzen 1991, Fishbein and Ajzen 2011).

First, behavioural beliefs are considered the motives or reasons for people choosing to migrate. The evaluation of these beliefs in the different outcomes that migration may yield is the basis for forming the behavioural attitude towards migration. These behavioural beliefs are normally weighted by the subjective values that a person assigns to the outcomes. The individual assessment of behavioural beliefs can be based on their own knowledge and

judgement or through a biased and limited information exchange with other people (Klabunde and Willekens 2016, Willekens 2017).

Second, the normative belief of an individual is their perception of the social/normative pressure or of how their peers make choices related to migration. Supports from peers and their destination preferences can positively influence the way a person perceives a certain migration option and subsequently is willing to follow the choice (Kniveton et al. 2011). The normative belief governs the subjective norm for migration.

Third, the control belief determines the perceived behavioural control, which is the final component of the decision-making process with regard to the migration intention and behaviour. The perceived behavioural control is the individual's perception of their capability to take advantage of facilitators and to remove the barriers, to make an actual migration action. An individual considers the availability of financial capital, such as their income and savings, and of social and human capital, including peer referrals and family supports, which are required to perform the move. They also take into account the obstacles, such as physical and emotional distance and cultural barriers.

Behavioural attitude, subjective norm and perceived behavioural control are indicators of migration intention. The stronger the components are, the higher the possibility that the individual will undertake the migration behaviour. In addition, Ajzen (1991) introduced the concept of actual behavioural control to improve the prediction of a certain behaviour (e.g. migration) that partly depends on factors over which a person does not have complete control. In some cases, people choose not to act on their intention to migrate, even though they have motives, receive support from their peers and have resources to overcome the related barriers. Ajzen (1991) and Fishbein and Ajzen (2011) used the perceived behavioural control as a proxy to measure the actual behavioural control. Here, the actual behavioural control is considered a subjective probability that an individual is actually going to migrate.

There has been a growing interest in the integration of the TPB with agent-based models in the area of demographic study and migration behaviour (Muelder and Filatova 2018). The TPB can be utilised to break down the cognition process of individual migration behaviour and to be embedded in the agent's decision rules. Five recent agent-based migration models have done this. The first, which was proposed by Kniveton et al. (2011, 2012), studied migration in Burkina Faso. Smith (2014) developed a similar agent-based model to examine the migration in Tanzania. Willekens (2017) and Klabunde et al. (2017) introduced two further models to focus on the topic of international migration in Europe. Finally, Nguyen et al. (2018, 2019) implemented an agent-based model with the integration of the TPB to study the dynamics of inter-provincial migration flows across the MKD region in Vietnam.

Kniveton et al. (2011, 2012) - climate change-driven migration in in Burkina Faso

In Kniveton et al.'s (2011, 2012) model to study climate change-driven migration in Burkina Faso, attitude towards migration was defined as the probability of an individual with certain characteristics (age, gender, marital status) migrating from one location to another. The subjective norm function was used to assign the values of each of the migration options to an agent based on their peers' most recent migration decisions. Both the behavioural attitude and subjective norm values were based on a retrospective multi-level migration survey for the period of 1970 to 2000. The perceived behavioural control was computed from an assessment of whether the agent had sufficient assets and experience to undertake the migration action. The result was compared with a random number between 0 and 1 and was converted to a binary outcome. If the perceived behavioural control was 0, the agent would not develop a migration intention. Agents performed the intention calculation for each of the migration options, which included staying in the place of origin, migrating to one of the other four zones in Burkina Faso or leaving the country. Each option received an intention score and the one with the highest score was chosen as the likely outcome.

This migration model was run for 30 years, with each time step representing one simulated day. Agent birth/death, marriage and ageing were controlled on a monthly basis and migration occurred once a year. The results were well validated with the empirical evidence of migration in Burkina Faso between 1970 and 2000. Migration rates resulting from the model were found to correlate with the observed data at a 0.995 significance level at both the total migration and zone-migration levels. Further, the destination choices of the simulated migrants appeared to be similar to those in the survey data. After confirming the validity of the simulation model, the authors then utilised it to forecast the population fluxes under various scenarios of environmental, economic, demographic, political and social change in the country. One interesting outcome of the study (Kniveton et al. 2012) was that an increase in population growth led to a higher number of people choosing to migrate because of the climate change impacts.

Smith (2014) - rainfall-induced migration in Tanzania

Smith's (2014) model examined rainfall-induced migration in Tanzania. The model was largely based on the model introduced in the work of Kniveton et al. (2011) but was designed to accommodate a less data-driven and more heuristic case study-based approach. He analysed the available data with logistic regression to identify the main variables that would contribute to the prediction of migration of households. While individual migration intention was driven by the characteristics of age, gender, migration experience and social network, it was mediated by the household's ability to finance the move. The migration-intention value of each agent was then compared with a pre-calculated threshold for migration, which had been determined through survey data. A lower threshold value was included for non-resilient households with low capacity to fund the migration of their member. In addition, Smith (2014) also appropriately calibrated the model with survey and actual climate data. Different

rainfall and non-rainfall scenarios were tested to explore their effects on the resilience and migration of household members.

Willekens (2017) and Klabunde et al. (2017) proposed multistage stochastic process models, which were drawn from the TPB to study international migration behaviour. The emphases of both models are the different stages of the migration process, the waiting time between each stage and the random factors involved in the personal attributes and decisions. Willekens (2017) and Klabunde et al. (2017) extended the TPB into a process theory to account for the sequential nature of the decision process. It was assumed that an individual makes decisions in three main stages. First, they develop their behavioural beliefs, normative beliefs and control belief that subsequently determine the intention to migrate. The individual then moves to the planning and preparation phase, in which they consider the actual control over migration. The person might leave or stay in the country in the last stage. In each stage, an individual either proceed to the next stage or decide to drop out of the mental process.

Willekens (2017) and Klabunde et al. (2017) - international migration behaviour

Willekens (2017) and Klabunde et al. (2017) both proposed multistage stochastic process models to study international migration behaviour. The emphases of their models were the different stages of the migration process, the waiting time between each stage and the random factors involved in the personal attributes and decisions. These researchers extended the TPB into a process theory to account for the sequential nature of the decision-making process. It was assumed that an individual makes decisions in three main stages. First, they develop the behavioural beliefs, normative beliefs and control belief that subsequently determine the intention to migrate. The individual then moves to the planning and preparation phase, in which they consider their actual control over migration. In the final stage, the person might leave or stay in the country. In each stage, an individual either proceeded to the next stage or decided to drop out of the process.

Willekens (2017) and Klabunde et al. (2017) emphasised the stochastic process of the transitions between these stages. For example in Willekens's (2017) work, the age at which an individual would start considering leaving the country and the duration they would stay in each stage of the migration process were dependent on random factors drawn from an exponential waiting time distribution. Klabunde et al. (2017) embedded migration behaviour into an individual's life course; different transitions in the life course, such as having a child or changing marital status, might affect the migration decision at any stage. These transitions were incorporated into the model with the use of the continuous Markov decision-making process.

While the model by Willekens (2017) was validated by its ability to reproduce the stylised facts of international migration, the model by Klabunde et al. (2017) was calibrated and validated by using survey data from the migration between Africa and Europe, specifically from Senegal to France. Klabunde et al. (2017)'s model had six calibration parameters: five were used to calculate the migration intention and one was part of the transition-rates function. All other quantities were based on empirical data. Klabunde et al. (2017) used the Gaussian process emulator to perform the model calibration and sensitivity analysis, with the aim of reducing computation time. For the calibration, the mean-squared errors of the simulated results and observed data were minimised. Age- and period-specific migration rates were used for model validation. After the agent-based model was well calibrated and validated, it was used to generate future migration-related projections based on different income and fertility scenarios.

Nguyen et al. (2018, 2019) - migration flows across the MKD region

Nguyen et al.'s (2018, 2019b) model explored the dynamics of migration flows across the MKD region. Both models were calibrated with the actual data of the in-migration, out-migration and net migration rates of cities and provinces in the region. Their first model,

in 2018, was manually calibrated with three parameters: behavioural attitude, subjective norm and perceived behavioural control. Nguyen et al. (2019) refined this model to improve the cognition of the migration decision-making process and implemented a GA to perform automated model calibration and sensitivity analysis with three additional parameters relating to socio-economic attributes. This aimed to improve the calibration results and further understand the different critical factors that would affect the final migration decision of people in the MKD region. Details of this model are included in Section 6.1 and 6.3.

5.3 Purely Empirical Rules

Several agent-based models have been based purely or largely on empirical data, without the application of any particular theory. In these models, the decision rules in the individual migration process and the determinants of migration are specified from quantitative data through statistical analysis or from qualitative data through surveys and expert interviews. The main advantage of implementing observational rules into the simulation model is the high empirical accuracy of the outputs, especially in a particular context (Klabunde and Willekens 2016). The following sections describe the details of some of these models.

Hassani-Mahmooei and Parris (2012) - climate change-based internal migration in Bangladesh

To facilitate Government policy considerations, Hassani-Mahmooei and Parris (2012) utilised their model to predict the migration numbers because of climate change, as well as the possible distribution of population, within all 64 districts of Bangladesh over a period of 40 years. Their model was primarily based on data available from the Bangladesh Bureau of Statistics. In addition, observed migration decision rules, which were inferred from different micro-level studies within the context of Bangladesh, were used to form the decision-making

processes of the migrants. These rules were mostly based on local surveys and interviews (Hassani-Mahmooei and Parris 2012).

In this model, climate change was considered the most important exogenous factor inducing human displacement. The climate change attribute was presented in a time-series format in which each data point was a continuous variable with values between 0 and 1, produced by a Poisson distribution. During the simulation, the random-Poisson function yielded greater values, resulting in an increase in the frequency of climate shocks. Vulnerability due to the impacts of environmental factors included both rapid- and slow-onset events data distributed across all districts in Bangladesh.

District agents were used to represent the various probable destinations, with different state variables such as environmental impact, socio-economic level and population density. Each person agent was set to calculate the push and intervening factors that formed the migration intention for each destination. If the intention value exceeded a certain threshold, the agent would decide to migrate (Hassani-Mahmooei and Parris 2012).

Hassani-Mahmooei and Parris (2012) ran each experiment 20 times for a 10-year period and calibrated the model with available real-world data. The population projection was validated against the recently published primary results of the Bangladesh population census. Their predictions were close to the observed values, with a few exceptions. Therefore, the model was considered externally valid. The authors predicted between 3 and 10 million migrants over the next 40 years in Bangladesh, depending on various climate change scenarios.

Cai and Oppenheimer (2013) - climate change-induced agricultural labour migration in the United States

Cai and Oppenheimer (2013) studied the mechanisms of climate change-induced agricultural labour migration in the United States, with the migration intention mainly based on empirical

data. The authors decided on the factors that influenced the migration intention, as well as the calculation of migration intention based on those factors. They assumed that the probability of agricultural migration was determined jointly by crop yield and individual characteristics such as age, gender, assets, migration experience, risk attitude and social networks. They used a logistic function to calculate the migration intention, which consisted of three empirical-based parameters (age, gender and assets), as well as three calibration-based parameters (risk attitude, migration experience and social network). The impacts of climate change were assumed to influence the crop yield indirectly.

Cai and Oppenheimer (2013) distinguished between intentions and behaviour in the migration decision-making process for agricultural labour. The translation into actual behaviour followed the same approach proposed by Kniveton et al.'s (2012) work, to account for unobserved factors in the real world. The calculated migration-intention value was compared with a random number uniformly distributed between 0 and 1. If the intention value was larger than the random number, the agent would migrate. Otherwise, the agent would stay. In addition, agents who had temporarily migrated for three consecutive years were assumed to migrate permanently in the next time step.

To calibrate the model, Cai and Oppenheimer (2013) used historical agricultural employment data during the period between 1960 and 1995. The calibrated model predicted the historical trend well, with a minimum mean-squared error of 0.0038. Their model was then utilised to explain the effect of critical factors and drivers on agricultural labour migration, instead of focusing on the quantitative aspects with the prediction of any specific migration numbers in different climate change scenarios. The model showed a larger migration flow when there was a larger reduction in crop yield because of climate change. Their model was able to capture emergent migration patterns resulting from network effects as well.

Naivinit et al. (2010) - rice production and labour migration in north-east Thailand

Naivinit et al. (2010) applied a participatory approach to construct an agent-based model of rice production and labour migrations in one village of northeast Thailand. Their model was designed with an economically driven approach, with the focus on the possible economic gain to be made from migration rather than on the cognitive process that led the individuals to migrate. The decision-making process was a sequence of 'if-then-else' conditions that resulted in one of three possible options: seasonal migration, permanent migration and no migration. The different parameters of five main entities (individual, household, village, rice and water tank) were heavily specified by empirical data extracted from surveys, field workshops and reports. Naivinit et al. (2010) developed this purely deterministic model to evaluate better the impact of different irrigation policies and to enhance communication among the participants in the participatory agent-based model. The results of their model were interactively validated through the participation and acceptance of the local farmers.

Chapter 6

Agent-based Modelling of Inter-provincial Migration in the Mekong Delta

Chapter 6 wraps up Part II of the thesis by proposing an agent-based model, with the focus on inter-provincial migration flows from the MKD to the SE region. The decision-making process, which is largely based on the TPB framework, comprises two stages: an assessment of the migration intention towards different options and the development of final migration behaviour. For this migration model, a genetic algorithm was used to conduct automated calibration, parameter exploration and sensitivity analysis, which are part of the model validation activities. Insights into the impacts of the different components and socio-economic factors on the formation of migration decisions in the MKD region are then discussed.

6.1 Agent-based Model of Inter-provincial Migration

In this model, the main entities are *province* and *person* agents. Each province agent stores information about their population, socio-economic and environmental factors. Each person agent, which resides in a province agent, is classified into one of five quintile income groups,

earning a certain income and bearing a certain living cost. In addition, each person agent has distinct views on how the different socio-economic and environmental factors affect their migration decision-making process.

Each person agent makes a decision in two stages: an assessment of the migration suitability of different provinces and the development of their own behaviour towards migrating or staying. The model's individual migration decision-making process, adapted from Kniveton et al.'s (2011) work, is shown in Figure 6.1. The migration-intention assessment is based on the TPB framework, which was recently applied to model the migration decision-making process together with the use of ABM (Klabunde et al. 2017, Kniveton et al. 2011, 2012, Smith 2014, Willekens 2017).

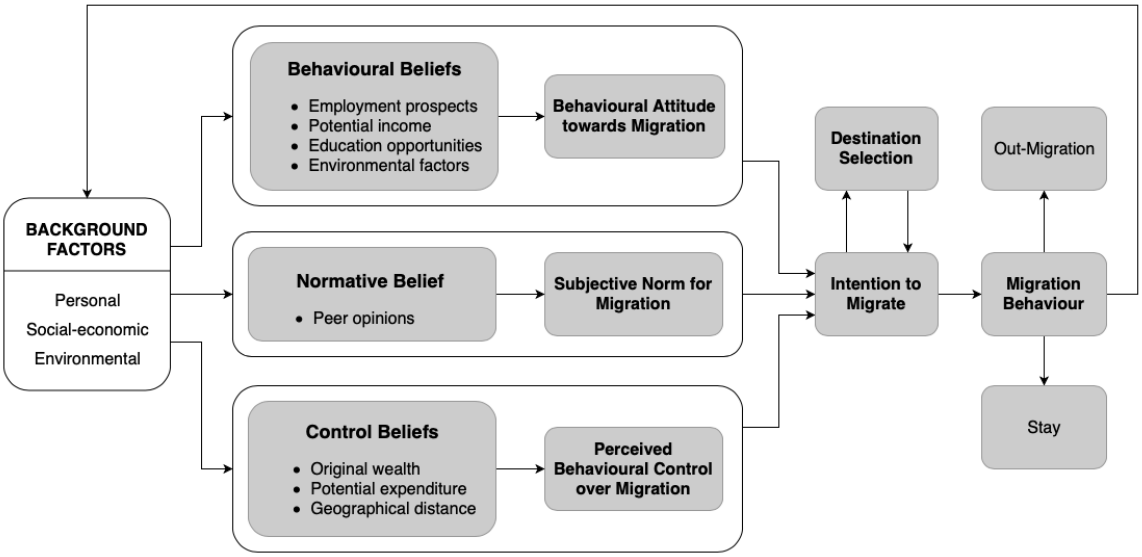


Figure 6.1 Individual cognition of the migration decision-making process

We chose the TPB because it is an established theory from social psychology that has been increasingly popular among recent migration studies with the use of ABM. The TPB offers a behavioural heuristic approach, which is suitable for deliberate migration decisions that involve high levels of uncertainty (Klabunde and Willekens 2016). The TPB can be used to break down the cognition process of individual migration behaviour into different

components, which subsequently allows the inclusion of many different background factors that the migrants might consider.

6.1.1 Assessment of migration intention

In the migration decision-making process, a person agent initially computes an intention score for each destination, including the province in which the person agent currently resides. In this model, migration intention, I, has three core components: behavioural attitude BA, subjective norm SN, and perceived behavioural control PBC. Agent i performs the intention calculation, $I_{i,j}(t)$, for each province agent j at time t as per the following equation:

$$I_{i,j}(t) = \alpha^1 BA_{i,j}(t) + \alpha^2 SN_{i,j}(t) + \alpha^3 PBC_{i,j}(t) \tag{6.1}$$

where α^1, α^2 and $\alpha^3 \in [0,1]$ are the first three parameters utilised for model calibration. Values of α can be varied during simulation to test the impact of different parameter settings and to match with real data.

Behavioural Attitude

In the model, the behavioural attitude, BA, of a person agent towards the migration assessment is assumed to be an outcome of a conscious calculation affected by different socio-economic levels and environmental factors for each province agent. These attributes constitute possible reasons for migration through the computation of the person agent's behavioural attitude, $BA_{i,j}(t)$, which is calculated based on the following function (Hassani-Mahmooei and Parris 2012):

$$BA_{i,j}(t) = \hat{\beta}_i^1 \overline{emp}_{i,j}(t) + \hat{\beta}_i^2 \overline{inc}_{i,j}(t) + \hat{\beta}_i^3 \overline{edu}_{i,j}(t) + \hat{\beta}_i^4 \overline{env}_{i,j}(t) \tag{6.2}$$

Here, person agent i considers the difference of four attributes - employment prospects $\overline{emp}_{i,j}(t)$, potential income $\overline{inc}_{i,j}(t)$, education opportunities $\overline{edu}_{i,j}(t)$ and environmental

factors $\overline{env}_{i,j}(t)$ - between the province in which the agent is currently allocated and another province agent j. Values of $\overline{emp}$, $\overline{inc}$, and $\overline{edu}$ of each province are normalised in the range of $[0,1]$ among all province agents at the time the person agent is making the migration assessment. The attributes $\overline{env}$ are inversely transformed with the intent that a province with less extreme weather factors will have a higher value. It is presumed that all province attributes are available without any error for the person agent during their migration assessment. Different factors contributing to each attribute in the MKD context are discussed later in Section 6.2.

Since there has been no previous study exploring the relative weights of different socio-economic attributes and environmental factors in affecting individual migration decisions in the context of the MKD region, each parameter $\hat{\beta}_i^n$ in Equation 6.2 is randomly assigned for individual person agent i. Each parameter $\hat{\beta}_i^n$ is initially drawn from a uniform distribution in the corresponding range of $[0,\beta^n]$ and then adapted to satisfy the constraint: $\hat{\beta}_i^1 + \hat{\beta}_i^2 + \hat{\beta}_i^3 + \hat{\beta}_i^4 = 1$. All four $\beta^n \in [0,1]$ are used as the following four calibration parameters to evaluate the weight of employment prospects, potential income, education opportunities and environmental factors. The unique combination of $\hat{\beta}$ defines the heterogeneity of agents and their different perceptions with regard to socio-economic background factors and environmental stimuli that will eventually affect their migration decision-making process.

The environmental factors, $env_j(t)$, of province agent j at time t is computed based on two components: the intensity of extreme weather events and the vulnerability of agent j to each event, vul_j. The intensity of the climatic hazard component is produced by a Poisson distribution function $P(x,\lambda)$, with x being the observed occurrence of hazards and λ being the expected number of hazard events in a given time interval. The configurations of both parameters are adapted from Hassani-Mahmooei and Parris (2012), calculated as follows:

$$env_{j,t} = P\left(\overline{hazards}_j + 1, hazards_j + t/steps\right) vul_j \tag{6.3}$$

where $\overline{hazards}_j$ is the rounded-up value of the average number of extreme weather events, $hazards_j$ that have occurred in the province and $t/steps$ provides an increasing trend for the intensity of hazard occurrence as t reached the max_{steps}.

Subjective Norm

In this model, the subjective norm, $SN_i(t)$, is updated at the same time as the behavioural attitude is calculated. Individual immigration decisions cannot be seen as being independent from one another - the literature (Radu 2008) has shown that subjective norm has contributed a substantial role in the decisions of the migrants. Potential migrants receive help, such as information exchange, job search and accommodation support, from the previous migrants. In this model, an individual agent is also modelled to adapt their behaviour accordingly to their neighbour's final migration decisions, as follows:

$$SN_i(t) = \hat{\gamma}_i \frac{\sum migr_i(t)}{\sum neig_i(t)} \tag{6.4}$$

The subjective norm is basically calculated as the proportion of agent i's neighbours who have migrated (Klabunde et al. 2017), reflecting the assistance of these neighbours on agent i's decision to migrate to a new destination. The value of $\hat{\gamma}_i$ is allocated randomly to each person agent, following a uniform distribution between $[0, \gamma]$. It is assumed that the support from neighbours has distinct effects on each person agent. γ is used as a calibration parameter to evaluate the weight of support from the migrant's network to a particular place. In this model, social closeness is modelled by means of spatial distance; the neighbours of agent i are those located within i's neighbourhood area, determined by a fixed range parameter, u.

Perceived Behavioural Control

In the context of migration, perceived behavioural control is considered an agent's perception of whether they have the assets/capability to overcome the barriers of migration. Therefore,

perceived behavioural control consists of two main components. The first is the individual's wealth, which is necessary to facilitate the migration option. The second component includes factors that can impede the migration process. In this model, income was chosen to be the only way of indicating the wealth of a person agent.

In this model, the perceived behavioural control, $PBC^k_{i,j}(t)$, of a person agent i in income quintile group k incorporates their current income as both a facilitator and a barrier. As discussed in Section 4.2, higher wealth can help migrants to overcome the cost of moving and resettling into a new destination but also can discourage people from migrating, since the migration might not yield sufficient benefit. Another barrier that person agent i needs to consider with regard to province agent j is the migration cost. In this model, the migration cost is determined by the living expenditure $exp_{i,j}(t)$ in the destination, province j. Lastly, the geographical distance between provinces, $dis_{i,j}$, is a critical determinant of migration cost in this model, including the cost of transportation, job search, information acquisition and the psychological costs of migration (Phan and Coxhead 2010), as follows:

$$PBC^k_{i,j}(t) = \frac{\dfrac{inc^k_i(t)}{inc^5_i(t)}\left(1 - \hat{\delta}^1_i \dfrac{inc^k_i(t)}{inc^5_i(t)}\right)}{\left(1 + \hat{\delta}^2_i \overline{exp}^k_{i,j}(t)\right)\left(1 + \hat{\delta}^3_i \overline{dis}_{i,j}\right)} \tag{6.5}$$

Here, $inc^k_i(t)$ is the actual income value of person agent i in the corresponding quintile group k. However, the income of person agent i is normalised in the range of $[0,1]$ by dividing the highest income within the same province, $inc^5_i(t)$. The values of $\overline{exp}^k_{i,j}(t)$ of each person agent in each quintile group are normalised among all province agents at each time t. $\overline{dis}_{i,j}$ is computed as the normalised distance between the centroids of two province agents.

Each parameter $\hat{\delta}^n_i$ is assigned to each person agent i, following a uniform distribution between $[0, \delta^n]$ to reflect the heterogeneity among the person agents' perceptions with regard to factors that could facilitate or hinder their migration options. δ_1, δ_2 and $\delta_3 \in [0,1]$ are

utilised as three other calibration parameters to examine the impact of original wealth, potential expenditure and geographical distance on the final decisions of migrants.

6.1.2 Development of final migration behaviour

By calculating the intention score following Equation 6.1, each person agent stores the intention values of the corresponding provinces. The person agent then develops their final migration behaviour through a destination-selection process and decides whether to migrate or stay. The agent is modelled to consider only the list of provinces with higher intention values than the value yielded from their current province. The agent identifies the highest intention score in the list and compares this with a random number $\in [0,1]$. If the number generated is less than the intention score, the agent migrates to the corresponding province. Otherwise, the next highest-scoring province will be considered (Cai and Oppenheimer 2013, Kniveton et al. 2012, Smith et al. 2010). If none of the preferred migration provinces is chosen, the agent will stay at their current location.

The stochastic 'roll-a-dice' process used in this model prevents person agents from migrating to provinces with only a marginally higher score and creating a disproportionate in-migration flow to a specific destination. Further, uncertainty is a critical factor in the final migration decision because of the many events, conditions and interactions affecting the judgement of the migrants (Willekens 2017). The development of final migration behaviour is modelled as a stochastic process to account for these uncertainties properly.

In this model, if a person agent decides to migrate, they notify the current surrounding agents about their choice. Those neighbouring person agents update the number of migrants in their network, $migr_i(t)$, with an increase of 1. The person agent who decides to migrate to another province is randomly located within the geographical boundary of that province. This person agent establishes a new neighbourhood and notifies the other person agents

residing in this area about their new neighbour. It is assumed that the person agent remains in the same income quintile group and has a similar living expenditure.

At the end of each simulation step, the province agent updates their population, which is affected by both the natural population growth rate and the number of net migrants, as follows:

$$pop_j(t) = pop_j(t-1)\,(1 + natRate_j(t)) + netMigr_j(t) \tag{6.6}$$

The birth and death rates are used to determine the natural population growth across the province agents, $natRate_j(t) = birthRate_j(t) - deathRate_j(t)$. The person agent is modelled to remain alive during the simulation runs, since a net population growth rate is applied. The number of in and out-migrants in each province agent, which are endogenously generated from the model, prescribe the flow of net-migrants, $netMigr_j(t) = inMigr_j(t) - outMigr_j(t)$. The in-migration, out-migration and net migration flow rates are calculated based on the number of in-migrants, out-migrants and net migrants per 1,000 persons in the province agent during each year.

6.2 Case Study of Inter-provincial Migration in the Mekong Delta

There are clear migration corridors from the MKD to the neighbouring SE region (Anh et al. 2016, GSO Vietnam and UNFPA 2016b). In both of the five-year periods from 2004 to 2009 and from 2009 to 2014, the migration flows from the MKD towards the SE region were the largest among the directional inter-regional migration flows in Vietnam. The SE region, especially the triangle of three cities and provinces comprising Ho Chi Minh City, Binh Duong and Dong Nai, have been attractive to migrants because of their rapid economic growth rates, a significant number of job opportunities and high living standards.

A total of 19 cities and provinces from the MKD and the SE region were incorporated into the agent-based migration model. Thirteen of these cities and provinces were from the MKD and the remainder were located in the SE region. Their locations and geographic boundaries, which were extracted from Vietnam's provincial-level map (Global Administrative Areas 2012) with the use of ArcGIS software, are shown in Figure 6.2. Islands of the selected provinces and cities were not included in the model.

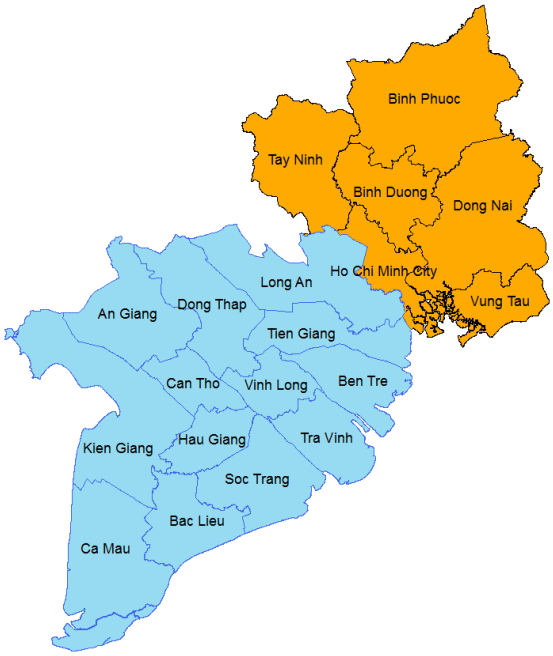


Figure 6.2 Locations and geographical boundaries of cities and provinces in the MKD and SE region

The relevant data from different sources was collected, mainly from public Government datasets. The data for migration flow rates, natural population growth rates and different socio-economic development indicators for each province were downloaded from GSO Vietnam (2018a) and VHLSS datasets for the relevant available years. All the collected data was read, cleaned and formatted using the statistical software R (Team et al. 2013) with the '*tidyverse*' package (Wickham 2017).

In this model, the data for each city or province was in yearly time series for the 13-year period between 2005 and 2017. Migration and natural population growth rates were expressed as rates per 1,000 population. The in-migration, out-migration and net migration rates were used as reference data for model calibration. The natural population growth rate and a variety of socio-economic attributes were the inputs of the agent-based migration model. The missing data of certain years was assumed to be the average of the corresponding values in the prior and later years.

Based on the review of migration determinants in Section 4.2 and the availability of data, different factors contributing to the socio-economic attributes that the migrants in the MKD region consider in the decision-making process were incorporated into this model. The list of attributes and relevant factors can be found inTable 6.1.

As indicated in Section 4.2, employment opportunity was the most important reason for internal migration in Vietnam. The SE region (especially Ho Chi Minh City, Binh Duong and Dong Nai province) was cited by a significant number of working migrants from the MKD region who moved for employment availability (GSO Vietnam and UNFPA 2016b). Five indications of the employment prospects for each province were considered in this model, with the weights of these indications, $\hat{\theta}$, used to calculate the value of employment opportunity, as follows:

$$\overline{emp}_{i,j}(t) = \hat{\theta}^1 \overline{fdi}_{i,j}(t) + \hat{\theta}^2 \overline{biz}_{i,j}(t) + \hat{\theta}^3 \overline{log}_{i,j}(t) + \hat{\theta}^4 \overline{agr}_{i,j}(t) + \hat{\theta}^5 \overline{opp}_{i,j}(t) \qquad (6.7)$$

where $\hat{\theta}$ are the weighted values of the five θ parameters and $\theta \in [0,1]$ are used as calibration parameters for this model. The employment opportunities generated from the FDI companies, represented by θ^1, were considered the main impetus for the internal migration in Vietnam, particularly for the migration flow from the MKD to the SE region (Coxhead et al. 2015, Kim Anh et al. 2012, Nguyen-Hoang and McPeak 2010). In this model, $\theta^1 = 1$ was fixed to maintain the persistence of the calibration results related to these θ values.

Table 6.1 Socio-economic development level, environmental impacts and the contributing factors

Attribute	Factors
emp	Number of FDI projects by province - sourced from FDI companies (fdi)
	Number of business by province - sourced from general business activities (biz)
	Number of freight traffic by province - sourced from logistic activities (log)
	Number of farms by province - source from agricultural activities (agr)
	Percentage of employed workers by province - employment opportunity (opp)
inc	Average monthly income per capita at current prices by province
	Monthly income per capita at current prices by income quintile by province
edu	Number of pupils in general education by province
	Number of teachers in general education by province
	Number of students in universities and colleges by province
	Number of lecturers in universities and colleges by province
exp	Monthly living expenditure per capita at current prices by income quintile by region
	Spatial cost-of-living index by province
env	Number of occurred natural hazard disasters by province
	Total number of fatalities and damaged housing caused by natural hazards

Education prospects have been cited as the second most popular reason among the people choosing to move across provincial boundaries (GSO Vietnam and UNFPA 2016a,b). In this model, three factors – the number of pupils in general education, the number of students in universities and colleges and the number of lecturers in universities and colleges – were assumed to account equally for the education attribute, *edu*.

For the income attribute, *inc*, it is important to note that while the general average monthly income per capita was used to calculate the behavioural attitude in Equation 6.2, the perceived behavioural control in Equation 6.5 was computed with the data of monthly income per capita by income quintile. The differences in the use of income data were also reflected in the notions of the two equations. The provincial-level data of monthly living expenditure

was computed by income quintile based on the relevant regional-level data and the spatial cost-of-living index, which was available across cities and provinces in Vietnam.

The data regarding the environmental factors was collected from the national disaster database of Vietnam, available from DesInvetar – Disaster Loss Databases (United Nations International Strategy for Disaster Reducetion 2018). Multi-hazard profiles for flood, storm, hailstorm, flash flood, cyclone, landslide, typhoon, heavy rain, tropical depression, cold wave and inundation were collected. The average frequency of climatic hazards in a year, $hazards_j$, was calculated as the average of all hazards that occurred between 1989 and 2015. The vulnerability index, $vul_j \in [0,1]$, of each province was the number of dead, injured or missing people and the number of damaged and destroyed houses caused by all climatic hazards in the 27-year period.

6.3 Experimental Set-up

6.3.1 Initialisation

We implemented our agent-based model in Java using the MASON framework (Luke et al. 2005). The geographic boundaries and locations of 19 provinces and cities in the MKD and SE regions were extracted in shapefile format using geoMASON (Sullivan et al. 2010). The model inputs were incorporated into the shapefile files and subsequently read by the agent-based model. The inputs were (i) the average population in 2004, (ii) the natural population growth rate between 2005 and 2017, (iii) different socio-economic factors from 2005 to 2017 (listed in Table 6.1) and (iv) the environmental factors represented by the annual occurrence of hazards and the vulnerability index. Specific values for the relevant attributes and factors were assigned to the corresponding province agents.

The model was initialised with 3,340 person agents distributed across 13 provinces and cities in the MKD region, representing the total estimated population of 16,700,000

people at the end of 2004 (GSO Vietnam 2018a). This meant each person agent in the model represented around 5,000 people. Person agents were populated into each province agent according to the population size of the province. The location of each person agent was assigned randomly in the corresponding region and parameter u was set so that the neighbourhood of each person agent was defined within 10 km of their location. Province agents representing six cities and provinces in the SE region were not initially populated with residents, as the focus of this study was the pattern of migration flows in the MKD region.

As indicated in Section 6.1, each person agent was initially categorised into one of five income quintiles, having certain values of income and living cost. In addition, each person agent had their own perceptions of how different socio-economic and environmental factors had influenced their migration decision-making process. The weights of the different attributes, which are represented by β parameters in Equation 6.2 and δ parameters in Equation 6.5, were initialised independently for each person agent and kept constant during the run but changed for different MC trials.

The simulation was run for 156 steps, with each step representing one month. The entire simulation was for a 13-year period, from 2005 to 2017. Since the data of province agents' attributes, *emp*, *inc*, *pov*, *edu* and *exp*, was only available annually, it was assumed that those attributes had the same values throughout the year. The environmental factor attribute, *env*, was updated endogenously for every month (as shown in Equation 6.3).

Each person agent was assumed to make migration decisions twice a year: in June and December. The number of in-migrants, out-migrants and net migrants for each province agent were generated endogenously from the model. In addition, each province agent updated its population based on the actual natural population growth rate and the number of net migrants at the end of each year. The results for each province were calculated annually by averaging 40 independent MC trials with the records of different statistical indicators including mean, standard deviation, minimum and maximum.

6.3.2 Genetic Algorithm of Calibration

An automated calibration was implemented as one of the main validation tools (Chica et al. 2017, Miller 1998, Oliva 2003) with the use of metaheuristic (Talbi 2009). Automated calibration is a computationally intensive process that aims to fit simulated data to real-world data. A model's fit is evaluated by iteratively running the computational model (the agent-based migration model in this context) and then tuning the parameters to identify a set of parameters that best match the specified reference data (Oliva 2003). Automated calibration can be considered an optimisation problem when the evaluation criterion is represented by an objective function, such as minimising an error measure. The modeller is advised to apply the automated calibration methods judiciously and study the results in a controlled way. Otherwise, the modeller might treat the model as a 'black box' and blindly accept the calibrated parameters without studying them (Chica et al. 2017).

In this study, the focus was to discover the best values for all calibration parameters in an attempt to obtain the best fit with real data at hand. Table 6.2 shows the set of 15 parameters, which were in the range $[0, 1]$, to be calibrated. They were three α parameters used in Equation 6.1 to determine the migration intention; four β parameters used in Equation 6.2 to compute the behavioural attitude, one γ parameter used in Equation 6.3 to specify the subjective norm; three δ parameters from Equation 6.5 used to calculate the perceived behavioural control; and four θ parameters from Equation 6.7 used to evaluate the employment prospects.

One of the most widely known types of metaheuristic is the GA (Goldberg and Holland 1988). A GA is involved with the evolution of a population of solutions, each of which represents a set of the model's parameters. These solutions are iteratively evolved until the best possible set is found for a given modelling goal. GA has been proved a useful tool for an automated calibration process in different kinds of non-linear models, including agent-based models (Chica et al. 2017, Lee et al. 2015, Stonedahl and Wilensky 2010a,b). In addition, GA

has advantages in terms of its capability to conduct automated sensitivity analysis (Stonedahl and Wilensky 2010a) and to explore wider ranges of parameters settings (Calvez and Hutzler 2005) with the consideration of potentially non-linear interactions between the parameters (Chica and Rand 2017, Chica et al. 2017).

In this study, we used the ECJ library (Luke 2010), a Java-based evolutionary computation package that can be utilised to integrate with the MASON framework, to implement a GA. As conducting the automated calibration of an agent-based model is a computationally expensive process, the model was coded with a multi-threading technique so that the whole process could be executed in multi-threads over High Performance Computing.

Table 6.2 Set of 15 calibration parameters in the agent-based migration model in the context of the MKD region

Parameter	**Description**	**Equation**
α^1	Parameter of *BA*	Equation 6.1
α^2	Parameter of *SN*	
α^3	Parameter of *PBC*	
β^1	Weight of employment prospects	Equation 6.2
β^2	Weight of potential income	
β^3	Weight of education opportunities	
β^4	Weight of environmental factors	
γ	Weight of subjective norm	Equation 6.4
δ^1	Weight of original wealth	Equation 6.5
δ^2	Weight of potential expenditure	
δ^3	Weight of distance	
θ^2	Source from general business	Equation 6.7
θ^3	Source from agriculture	
θ^4	Source from logistics	
θ^5	Employment rate	

We implemented a standard generational GA where every generation of the population replaces the previous one (Goldberg and Holland 1988). The generational GA had a population of 100 real-coded chromosomes consisting of the 15 parameters defined in Table 6.2. All calibration parameters were initialised with random values following uniform distribution within the range $[0, 1]$.

A 3-tournament selection mechanism (Talbi 2009) with weak elitism was applied, which meant the best parent was always preserved through every generation. We used the simulated binary crossover operator and polynomial mutation (Deb and Agrawal 1994) with a crossover probability of $p_c = 1$ and a mutation probability of $p_m = 0.2$. We also used standard values for the distribution indexes (Deb and Agrawal 1994, Luke 2010) for the crossover and mutation operators, i.e., $\eta_c = 20$ and $\eta_m = 20$. Each GA run for calibrating the migration model ended after 500 evaluations, which is the stopping criteria of the GA and is sufficient for finding a good quality solution. In addition, we also run the overall GA calibration model 20 times per model because the GA itself is non-deterministic. During the automated calibration process, 1,000,000 combinations of solutions were assessed. At the end of all the runs, the GA calibration method returned the fitness results. The parameters of this standard generational GA to calibrate the models is summarised in Table 6.3.

The fitness function of the GA measured the deviation or error of the model outputs with respect to the real data, which was the actual average of the in-migration, out-migration and net migration rates of each province and city in the MKD region between 2005 and 2017 (shown in Table 4.1). The GA calibration then identified a set of calibration parameters so that the error measure ε was minimised. We adopted the L^2 or Euclidean distance, which is equivalent to either the mean square error or root mean square error. The Euclidean distance was computed by:

$$L^2 = \sqrt{\sum_{i=1}^{3} |V_M(i) - V_R(i)|^2}, \tag{6.8}$$

Table 6.3 Parameter values for the GA calibration method

Parameter	**Value**
Number of GA runs (with different seeds)	20
Population size	100
Number of evaluations (stopping criteria)	500
k for the tournament selection scheme	3
Crossover probability (p_c)	1
Mutation probability (p_m)	0.2
Distribution index for crossover (η_c)	20
Distribution index for mutation (η_m)	20
ABM parameter	
MC simulation runs	40
Number of person agents	3,340
Number of province agents	19

where V_M and V_R were the vectors of three migration flow rates generated from the simulation model and attained from the historical data in each province. Owing to the stochastic nature of the model, the value of L^2 was calculated as the average of fitting errors in all 40 MC runs. The final model error measure ε was the sum of 13 calculated L^2 values accordingly for the 13 provinces and cities in the MKD region.

6.4 Experimental Results

6.4.1 Model Calibration Results

The GA calibration of the agent-based migration model ended with a Euclidean mean value of 50.6625 and a standard deviation of 10.682. Table 6.4 shows the list of 15 calibrated parameters using the standard generational GA for the agent-based migration model. This

set of parameter values returned the smallest error measure of $\varepsilon = 37.9587$ and therefore, was chosen to run the final model.

Table 6.4 Calibrated parameters using the GA

Component	Calibrated parameter & value				
BA	α^1	β^1	β^2	β^3	β^4
	0.001286	0.945240	0.995261	0.251187	0.10686
SN	α^2	γ			
	0.007979	0.69557			
PBC	α^3	δ^1	δ^2	δ^3	
	0.007753	0.407704	0.292088	0.810735	
Employment attribute	θ^2	θ^3	θ^4	θ^5	
	0.141884	0.54214	0.058531	0.592739	

We examined the normality of the results with Shapiro-Wilk's test, shown in Table 6.5. In most cases, the p-value > 0.05 implied that the distribution of the result was not significantly different from the normal distribution. Therefore, we assumed that the relevant results were normally distributed. In several cases of p-values < 0.05, the normality was visually checked with Q-Q plots (see Figure 6.3). We found that the simulation outputs in these cases were not significantly different from the normal distribution.

The outputs of the model with the 15 calibrated parameters were the respective mean and standard deviation of the averages of migration flow rates of each province in the 13-year period over the 40 independent MC trials. Figure 6.4 depicts three bar charts comparing the simulation results and actual migration dynamics across the cities and provinces in the MKD region between 2005 and 2017. Based on the assumption of the normality of the results, a 99% confidence interval was incorporated with the simulated mean value of each province. The order of cities and provinces is arranged in Figure 6.4 by the real values of the corresponding net migration flow rates.

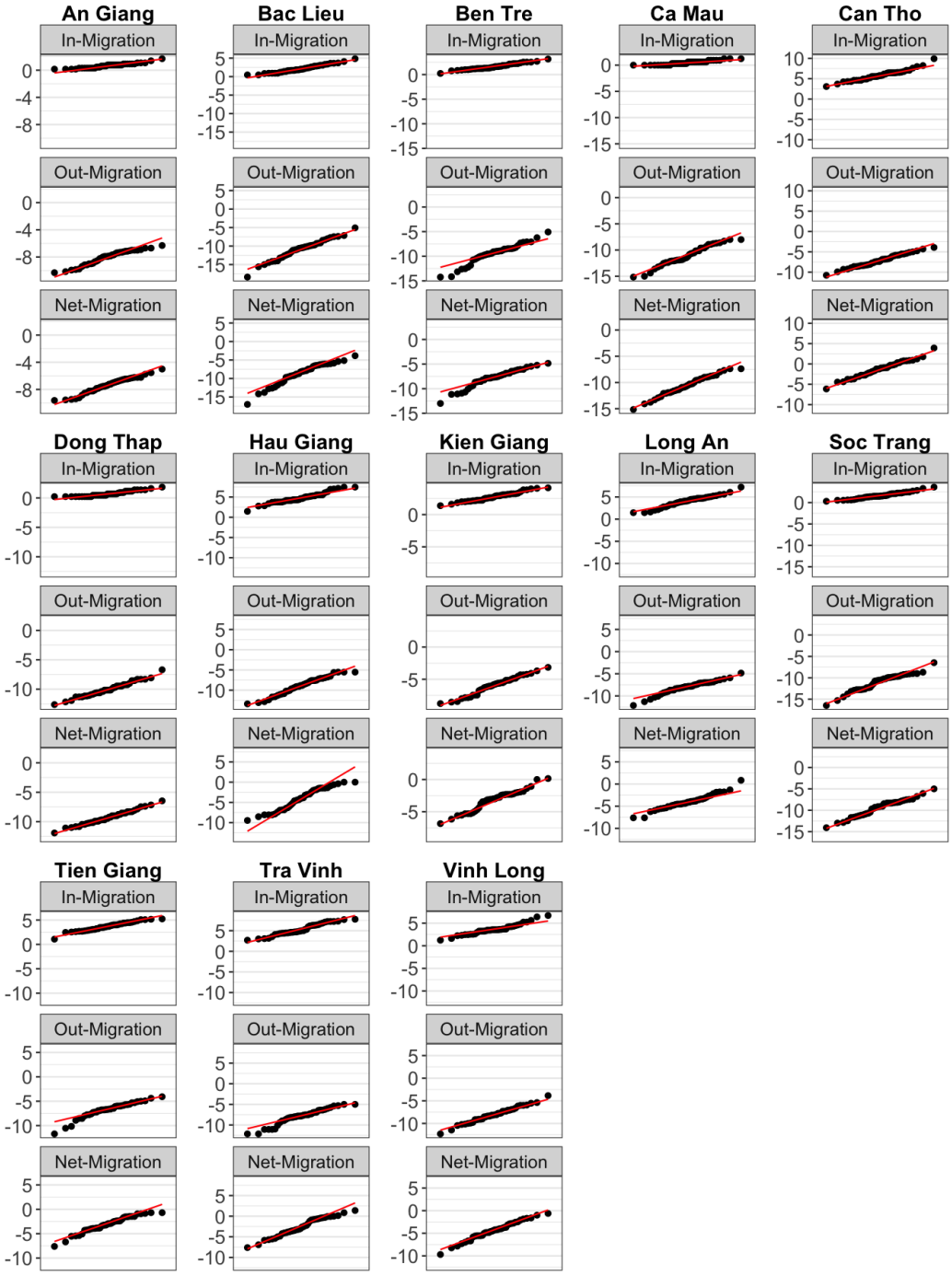


Figure 6.3 Q-Q Plots of the in-migration, out-migration, and net migration flow rates of several provinces in the MKD region

Table 6.5 Shapiro-Wilk's test of migration flow rates of the 13 cities and provinces in the MKD region

Province	**Net migration**		**Out-migration**		**In-migration**	
	W	p-value	W	p-value	W	p-value
An Giang	0.97	0.49	0.95	0.10	0.95	0.08
Bac Lieu	0.98	0.85	0.98	0.71	0.98	0.86
Ben Tre	0.96	0.21	0.98	0.66	0.97	0.31
Ca Mau	0.98	0.84	0.99	0.90	0.91	0.00
Can Tho	0.96	0.22	0.95	0.07	0.95	0.11
Dong Thap	0.96	0.16	0.96	0.19	0.94	0.05
Hau Giang	0.99	0.97	0.99	0.90	0.99	0.92
Kien Giang	0.99	0.94	0.95	0.08	0.95	0.10
Long An	0.96	0.14	0.95	0.07	0.97	0.40
Soc Trang	0.93	0.01	0.94	0.04	0.98	0.80
Tien Giang	0.95	0.08	0.98	0.59	0.94	0.04
Tra Vinh	0.93	0.02	0.94	0.03	0.97	0.27
Vinh Long	0.98	0.55	0.98	0.54	0.94	0.05

Figure 6.4 shows that most of the observed values of the in-migration, out-migration and net migration rates across the cities and provinces in the MD region were within the 99% confidence interval. On the net migration chart, it is clear that the simulation model produced very similar patterns to the real data, capturing both the smallest and largest negative net migration rates in the group of provinces positioned at the top and bottom halves of the chart. The only exception was Dong Thap province.

The automated calibration results were a good fit with the actual out-migration rates as well. The out-migration chart in the middle of Figure 6.4 shows that the observed data of 12 out of 13 provinces and cities were within the 99% confidence interval of the mean results generated from the agent-based model. The in-migration chart on the right shows that the simulation model was able to replicate the dynamics of migration flow across the MKD

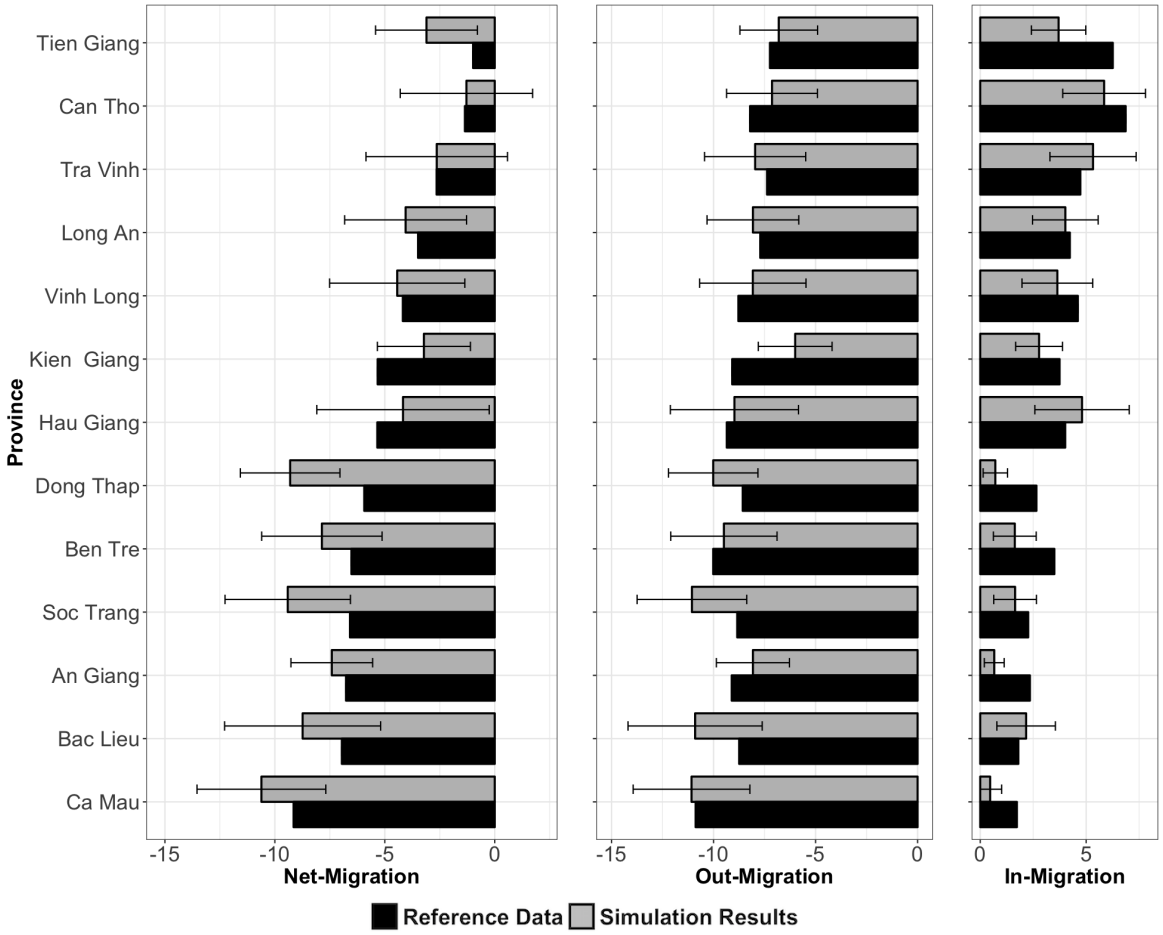


Figure 6.4 Comparison of simulated results and actual data of the average net-, out-, and in-migration rates of provinces in the MKD region from 2005 to 2017

region as well. Only five provinces had in-migration rates outside the intervals without any significant difference from the reference values.

6.4.2 Parameter Exploration

Together with calibration, parameter exploration is a crucial ingredient for model testing and verification (Oliva 2003). Population-based metaheuristics, such as the GA, have the advantage of generating a large set of solutions to a problem. This enables the exploration of an already-evaluated set of parameters and allows the examination of the distribution of these parameters (Chica et al. 2017, Miller 1998). The exploratory analysis of the input/output

variables helps to strengthen trust in the model results and to eliminate model factors that have insignificant influence on the output variability. By analysing the distribution of the model variables and parameters, the modeller can move forwards to simpler and more understandable model settings (Chica et al. 2017).

The ranges of calibration parameters were observed to understand the effects of these parameters on the final decisions of migrants in the MKD region. The focus was on the sets of solutions that provided the highest model validity or produced values of error measure ε between 38.9403 (the smallest) and 41 over 20 runs of the GA for the agent-based model. Ninety-nine sets of solutions satisfied the conditions. The boxplots in Figure 6.5, 6.6, 6.7 and 6.8 represent the distribution of the 15 parameters obtained from the best solutions and the relevant weighted values of these parameters.

The three boxplots in Figure 6.5 indicate that good values of behavioural attitude (α^1 - Param BA), subjective norm (α^2 - Param SN) and perceived behavioural control (α^3 - Param PBC) were significantly small compared with the initial maximum value, 1, set up to implement the GA. This was expected, as the values of the three parameters were utilised to calculate the behavioural intention (see Equation 6.1), which determined the probability of people deciding to migrate. According to Table 4.1, the migration flow rates (number of migrants per 1,000 population) were comparatively small.

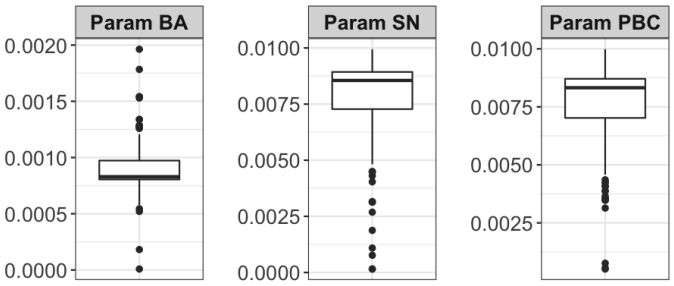


Figure 6.5 Boxplots showing the values of α^1, α^2 and α^3 from the best GA calibration solutions

In Figure 6.6, the top four boxplots display the range of good values of four β calibration parameters. As indicated in Section 6.1, each person agent had their own unique combination of perceptions with regard to their different socio-economic backgrounds and the environmental factors affecting their decision to migrate. The weights of four attributes of each agent, $\hat{\beta}$, were initially drawn from a uniform distribution between 0 and the corresponding β, and then were weighted among these attributes. The model was designed so that the weights of all migration determinant factors would add up to 1 to calculate the behavioural attitude (see Equation 6.2). The bottom four boxplots show the range of the weighted values of β parameters, that yielded the best fit to the reference data.

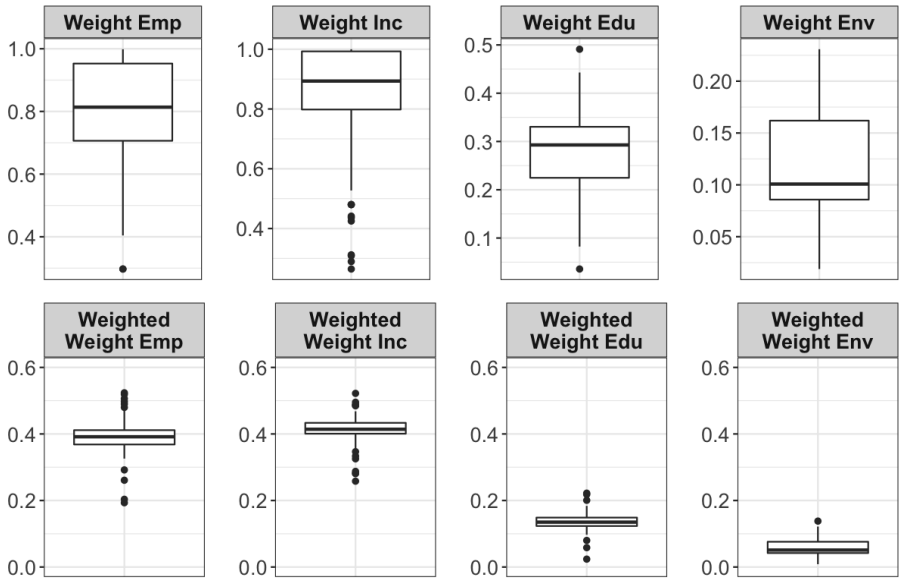


Figure 6.6 Boxplots showing the values of β^1, β^2, β^3 and β^4 from the best GA calibration solutions and the weighted values of relevant parameters

The bottom boxplots in Figure 6.6 show that the results generally supported the literature on the determinants of migration in Vietnam and the MKD region. Among the good weighted β values, values, the median weight of employment prospects attribute, represented by β^1, was the second highest, at approximately 0.39133. This result was in line with the fact that the employment-related factor has been noted as one of the leading reasons for people to

migrate from the MKD region (Coxhead et al. 2015, GSO Vietnam and UNFPA 2016b, Nguyen-Hoang and McPeak 2010). According to the latest national migration survey in 2015 (GSO Vietnam and UNFPA 2016b), the SE region is one of the most attractive industrial zones in Vietnam for employment to most neighbouring migrants coming from the MKD region.

For the potential income attribute, the interquartile range of the weighted good values of parameter β^2 was $[0.4008, 0.4333]$ and the median was 0.4135, which were the highest values among the all the β values listed in the bottom boxplots in Figure 6.6. This result was in agreement with the literature as well, indicating that the expected income differential between the origin and destination was crucial for migration in Vietnam and the MKD region (Coxhead et al. 2015). Provinces with high monthly income per capita, such as Ho Chi Minh City and Binh Duong province, were the most popular destination for migrants from the MKD in search of better income and living conditions (Kim Anh et al. 2012, Phan and Coxhead 2010). The calibration results provided further evidence that economic reasons, which comprised the employment prospects and potential income attribute, were by far the most important migration determinants in the MKD region (Coxhead et al. 2015, Huy 2012, Phuong et al. 2008).

The third boxplot from the left in the bottom of Figure 6.6 indicates the distribution of good values of the weighted β^3 parameter representing the education opportunities attribute. The median value was close to 0.1362, indicating that education-related factors accounted for more than 13% among the four reasons that the people from the MKD region considered to determine their behavioural attitude with regard to migration intention. This result was justified adequately by the fact that an increasing proportion of migrants, especially young people in the MKD region, have been migrating to Can Tho or Ho Chi Minh City to have access to higher educational institutions, from 4.5% in 2004 to 23.4% in 2015 (GSO Vietnam and UNFPA 2016b).

For the environmental factors attribute, most of the weighted values of β^4 parameters, that best matched with the real data, were close to 0.05. This result suggested a relatively small effect of climatic hazards (approximately 5% among the determinants) contributing to the attitude of person agents in their choice of potential destinations. In general, this result supported the recent literature on the influence of natural disasters and climate change in inducing migration in the MKD region; the 2015 Vietnam Internal Migration Survey showed that nearly 4.5% of migrants from the MKD region had chosen to move to a place with a more suitable natural environment (Entzinger and Scholten 2016).

Figure 6.7 displays the distribution of good values of different calibration parameters utilised in the calculation of Equations 6.4 and 6.5. We found that the median value of γ in Equation 6.4 was 0.928. This result indicated that people in the MKD region had different perceptions regarding the influence of neighbours on their migration decisions. It is worth noting that each person agent in the model had a distinct perception of the impact of the subjective norm ($\hat{\gamma}$), which was generated randomly by a uniform distribution between $[0, \gamma]$. We further analysed the effect of the subjective norm on the decisions of the migrants through the sensitivity analysis that is included in the next section (Section 6.4.3).

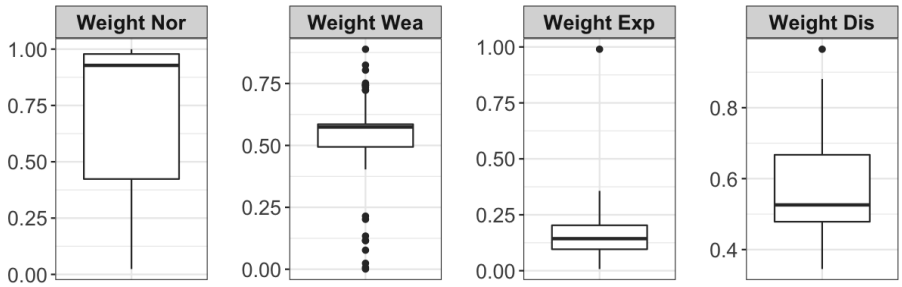


Figure 6.7 Boxplots showing the values of γ, δ^1, δ^2 and δ^3 from the best GA calibration solutions

In the remaining three boxplots, we see that most of the values of the three δ parameters that yielded the best fit to the reference data were larger than 0. These results indicated correlations between the corresponding attributes and migration behaviour in the MKD

region. For the original wealth and the potential expenditure factors, the higher the value of δ^1 and δ^2, the less likely it was that person agents in the high-income quintile would move to a different destination. The relevant results are further analysed in Section 6.4.4. For the weight of distance (δ^3), the median value was high at 0.526. This result was in agreement with findings from the study of Phan and Coxhead (2010) that geographical distance was a critical determinant in the decisions of migrants from the MKD region.

The top boxplots in Figure 6.8 shows the distribution of good values of θ parameters contributing to the employment prospect attribute. As described in Section 6.2, we fixed value of employment source from FDI companies $\theta^1 = 1$. The bottom boxplots display the ranges of the weighted values of the relevant parameters. The calibration results suggested three main indications (accounting for more than 25%): employment source from FDI companies ($\hat{\theta}^1$), employment source from general business ($\hat{\theta}^2$) and employment opportunities ($\hat{\theta}^5$).

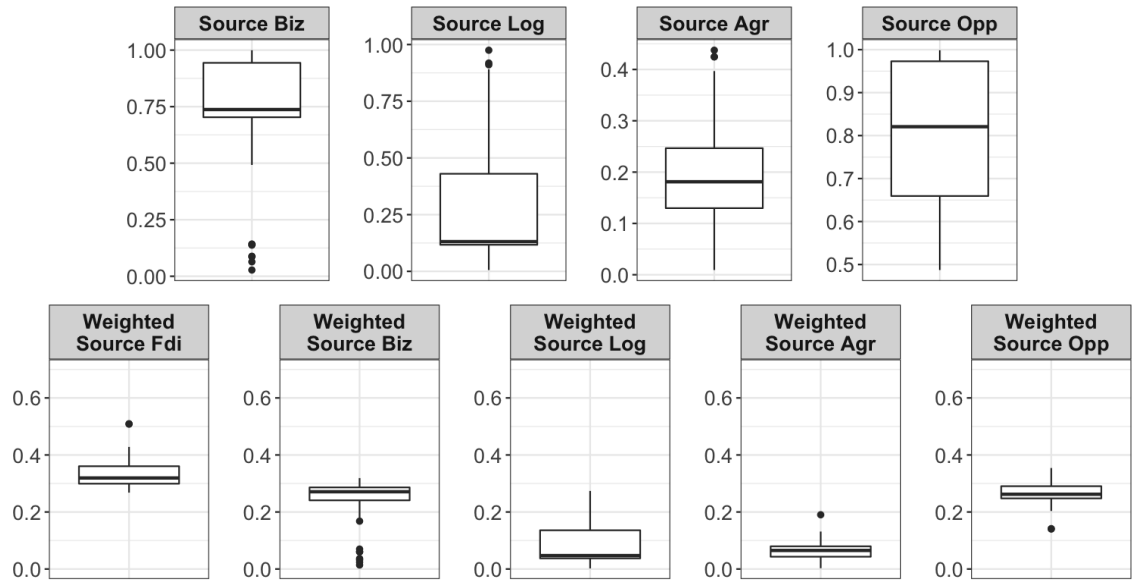


Figure 6.8 Boxplots showing the values of θ^2, θ^3, θ^4 and θ^5 from the best GA calibration solutions and the weighted values of relevant parameters

6.4.3 Sensitivity Analysis

Univariate Sensitivity Analysis

First, we run a sensitivity analysis following the one-factor-at-a-time methodology (Ten Broeke et al. 2016), which modifies each parameter in a separate way and keeps the other parameters fixed to their original value. We conducted a sensitivity analysis on parameters of *BA* (α^1), the parameter of *SN* (α^2) and the parameter of *PBC* (α^3). We aim to determine which factors among the behaviour attitude, subjective norm and perceived behavioural control caused the model results to change at what magnitude.

The calibrated values of the three parameters were used as the baseline, varied from -100% to $+100\%$, with fixed steps of 25% away from the calibrated values. The rest of the parameters were set at their corresponding calibrated values, as shown in Table 6.4. We then ran the agent-based model with each set of parameter values to calculate the error measures ε between the simulation results and the real migration data. The results of the univariate sensitivity analysis were presented as a heatmap in Figure 6.9.

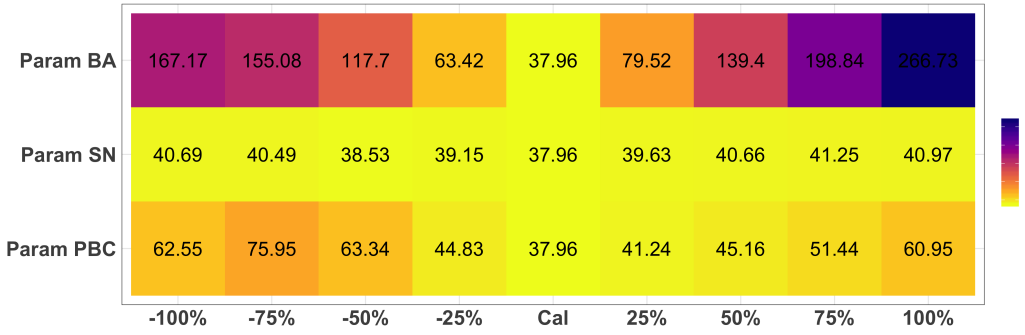


Figure 6.9 Heatmap indicating the sensitivity analysis on three parameters α^1, α^2, α^3

This heatmap shows that varying the calibrated values of the parameter *BA* (α^1) caused the most significant change in the model result. Doubling the calibrated value of parameter α^1 led to the largest error ($\varepsilon = 266.73$) in comparison with the errors generated by doubling the value of parameters α^2 ($\varepsilon = 40.97$) and α^3 ($\varepsilon = 60.95$). We found a similar pattern in

the case when the values of the three α parameters were each set to 0. The change in the parameter *BA* resulted in the highest value of error ($\varepsilon = 167.17$), which was four times larger than the error produced by the change in the parameter *SN* and nearly three times larger than the error produced by the change in the parameter *PBC*.

These results suggested that behavioural attitude was the most critical component in determining the intention of the migrants in the MKD region and subjective norm had the least impact. Figure 6.9 clearly shows how the values of error measurement moving further away from the smallest $\varepsilon = 37.9587$ when both the parameter *BA* and *PBC*'s values were varied from their respective calibrated values. Changing the *SN* parameter values did not yield significant differences in the ε values produced.

Multivariate Sensitivity Analysis

In addition, a GA was employed to conduct an automated sensitivity analysis Stonedahl and Wilensky (2010a) on the input parameters of the model. The default rule here is to use metaheuristics that emphasise diversity, often in the form of stochastic population-based metaheuristics. In general, sensitivity analysis reveals the parameters on which the behaviour of the model highly depends. Thus, sensitivity analysis, together with parameter exploration and calibration, is crucial for model validation (Chica et al. 2017, Oliva 2003).

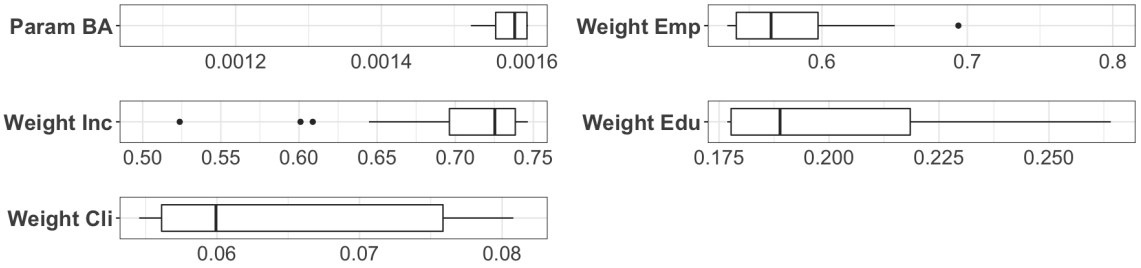
The sensitivity analysis was performed following Stonedahl and Wilensky's (2010a) approach of modifying a group of parameters (Ten Broeke et al. 2016). The approach chosen was a multivariate sensitivity analysis using the GA to maximise (rather than minimise) the error measure ε. The search space is constrained to a limited range within $\pm 10\%$ of the calibrated parameter values (Lee et al. 2015, Miller 1998, Stonedahl and Wilensky 2010a). The upper bound, which was set to 1, was applied to the variations in the weights of employment prospects and potential income.

We conducted sensitivity analysis on four groups of parameters (see Table 6.4) including those parameters related to (a) behavioural attitude, (b) subjective norm, (c) perceived behavioural control and (d) all three earlier groups. In each sensitivity analysis, the values of the related parameters were varied within a predefined range, while the values of the remaining parameters were fixed. The 40 worst sets of parameters were chosen for each sensitivity analysis to examine and plot the graphs. The results for the analysis can be seen in the corresponding groups of boxplots in Figure 6.10. The outer box defines the parameter ranges while the inner boxplots indicate the distribution of the relevant parameters obtained from the worst solutions.

The different GA searches found clear trends in different groups of parameter settings. The GA consistently found high values for the parameter of BA, while it selected low values for the parameters of PBC and distance. This meant the agent-based migration model was particularly sensitive to these factors. The other parameters' values, particularly in the last group, were relatively scattered throughout their ranges, indicating that it was not necessary for these parameters to be assigned a specific value to achieve large errors.

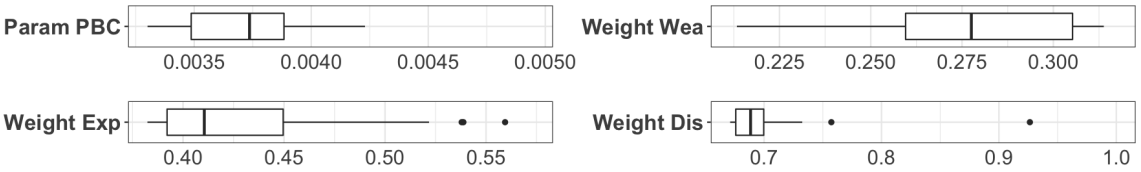
We also examined the distributions of all largest error measurements ε that were yielded from the multivariate sensitivity analysis by four groups of parameter settings. The summaries are displayed in Table 6.6. We found that the errors from the groups of behavioural attitude and perceived behavioural control are similar in all five quintiles as well as the mean (approximately 92). In addition, the error generated from the group of subjective norm parameters was relatively smaller, with the mean L^2 value close to 85. This result denoted the importance of the subjective norm component in migration intention, especially with the combination of the two relevant parameters.

In addition, it was clear that the errors discovered through the GA's search with all the parameters associated with the three groups were higher than the errors produced from each group individually. This disparity was due in part to the GA manipulating more parameters

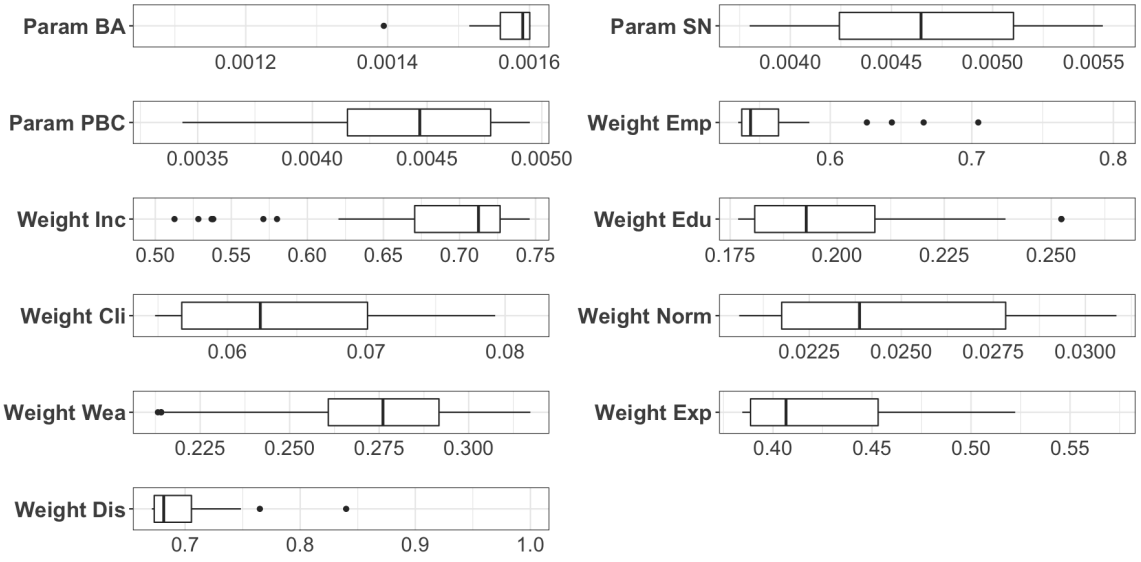


(a) Parameters relating to behaviour attitude

(b) Parameters relating to subjective norm



(c) Parameters relating to perceived behavioural control



(d) Parameters belonging to all three above groups

Figure 6.10 Boxplots showing the values of different groups of parameters obtained from the worst GA calibration solutions

to which the model was sensitive, as well as to the non-linear interactions between the parameters in all the groups.

Table 6.6 Statistical summary of the group of parameters obtained from all worst GA calibration solutions

Component	Min	1st Quin.	Median	Mean	3rd Quin.	Max
Behavioural attitude	50.72	64.85	79.66	92.67	112.57	285.74
Subjective norm	44.06	59.53	76.66	84.73	103.04	242.76
Perceived behavioural control	49.69	62.84	78.36	91.99	110.10	285.12
All	52.88	75.90	96.50	115.20	143.39	344.76

6.4.4 Further Analysis of the Results

Based on the final run of the agent-based model with the set of calibration parameters that generated the smallest error measure ε, the relevant results were further explored to validate the findings of this research. The focus was on the patterns of migration from the MKD region to the SE region and quantifying the proportion of migration flows across the cities and provinces.

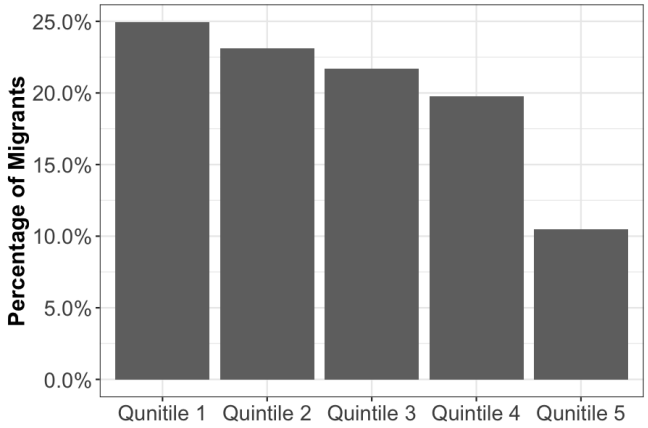
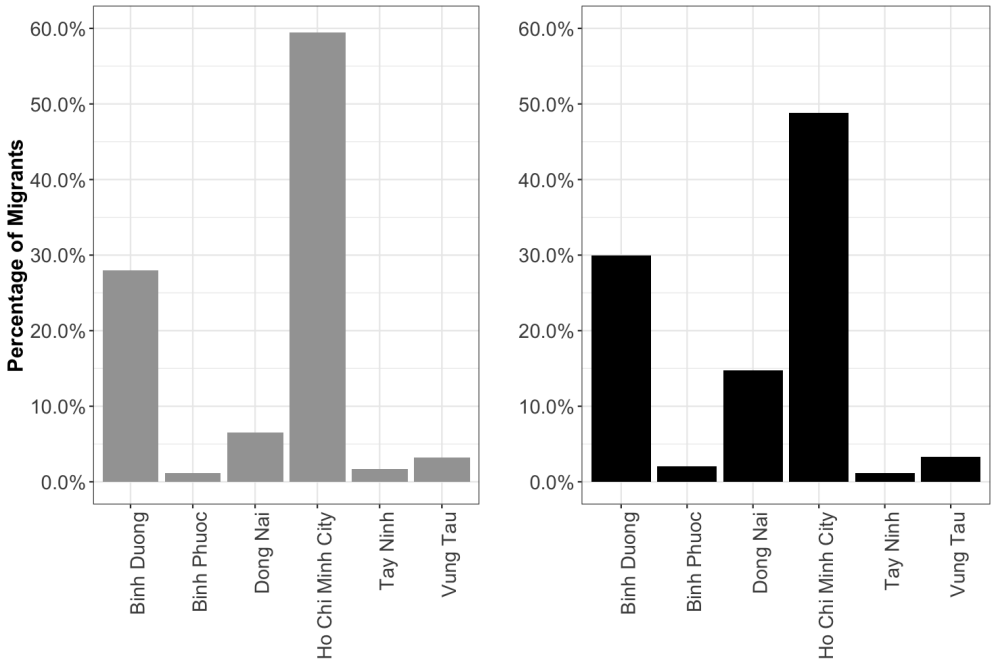


Figure 6.11 Percentage of total number of migrants from the MKD region by income quintiles

The simulation result showed that people in the higher income quintile groups in the total of migrants in the MKD region between 2005 and 2017 tended not to migrate. The proportions of migration in the first four income groups declined gradually, from 25% in the first income quintile to approximately 20% in the fourth income quintile. The percentage of the total migrating migrants who were in the last quintile (highest income) dropped sharply to 13.2%. This result, together with the exploration of the calibrated values of the two δ^1 and δ^2 parameters, supported the empirical findings of Entzinger and Scholten (2016) and Coxhead et al. (2015), that having a high income in the home region and high levels of expenditure in the destination region discouraged people from moving, since the results of migration might not be as beneficial as their current living conditions. A survey by Entzinger and Scholten (2016) also indicated that the probability of migration sharply decreased when household income increased.

The most preferred destinations in the SE region among the migrants from the MKD region were identified. The left bar graph in Figure 6.12 shows the simulation results regarding the proportion of in-migrants from the MKD region for the six potential destinations during the 13-year period being considered by this research. The right bar chart displays the actual data of the percentage of in-migration flows to the same destinations, but from all regions across Vietnam. (There was no available provincial-level data with respect to the migration flows from the MKD region, specifically to the neighbouring region.) The simulation results replicated the dynamic of the in-migration flows towards the cities and provinces in the SE region. Ho Chi Minh City and the provinces of Binh Duong and Dong Nai were the most popular destinations in the SE among the migrants from both the MKD region (according to the simulation results) or from all regions across Vietnam (according to the real data). The three areas that were less attractive to the migrants – Vung Tau, Binh Phuoc and Tay Ninh – were confirmed by the agent-based model as well.



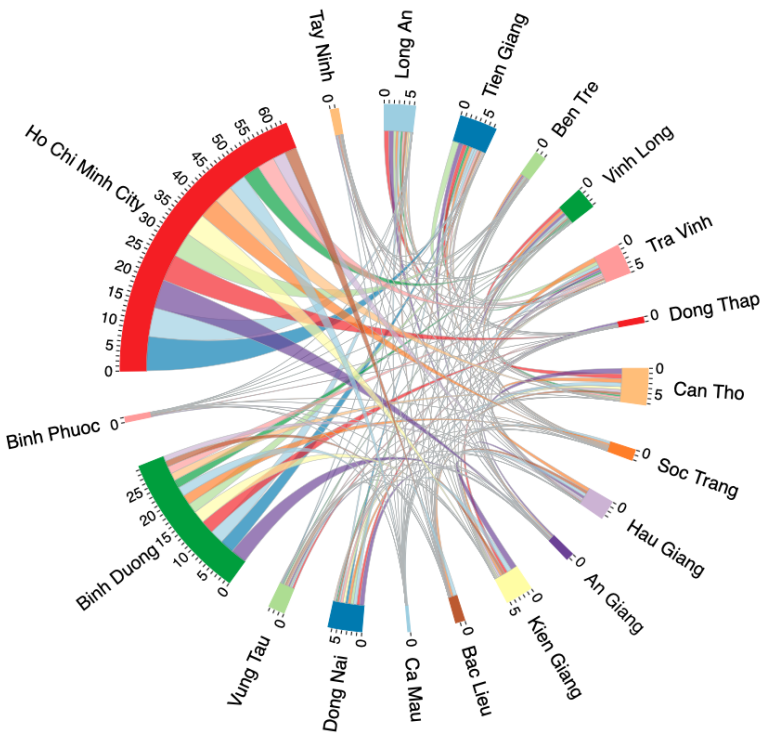
(a) Simulation results of in-migration flows to the South East from the MKD region

(b) Real data of in-migration flows to the SE from other regions in Vietnam

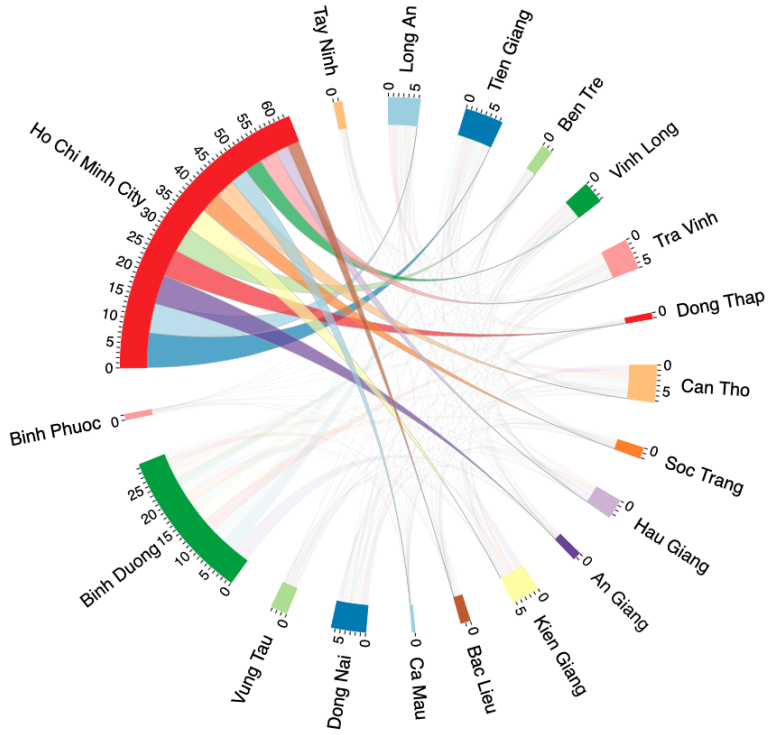
Figure 6.12 Comparison of in-migration flows to the SE region in the 13 years period from 2005 to 2017

The top chord diagram in Figure 6.13 shows the simulated migration flows across the MKD and the SE region, as well as the annual average number of in-migrants in each city and province between 2005 and 2017. Ho Chi Minh City and Binh Duong province were clearly the two most attractive destinations, receiving on average almost 63,000 and 30,000 people migrating from the neighbouring region each year, respectively. In the MKD region, most of cities and provinces received fewer than 5,000 intra-regional migrants in each year, except for the city of Can Tho and the provinces of Long An, Tien Giang, Tra Vinh and Kien Giang. The least-preferred destination among the migrants was Ca Mau, which is the southernmost of Vietnam's provinces, with only around 520 people on average moving there each year.

The bottom diagram in Figure 6.13 identifies Ho Chi Minh City as the most popular destination for migrants from the MKD region. The main sources of migration towards Ho



(a) In-migration flows across all cities and provinces



(b) In-migration flows into Ho Chi Minh City as the main migration destination

Figure 6.13 Provincial-level in-migration flows from the MKD to the SE region

Chi Minh City were Tien Giang, Long An, An Giang and Dong Thap provinces. Similar patterns were found in the in-migration flows into Binh Duong province. The interactive chord diagram in Figure 6.13 can be found at http://rpubs.com/hung_uon/501888.

Figure 6.14 displays out-migration flows from the MKD to the SE region and the simulated average number of out-migrants each year in each city and province during the 13-year period. As out-migration intention from the SE region was not specifically modelled, Figure 6.14 shows no people moving out of the cities and provinces in this region. The primary migrant-sending regions were An Giang (19,026 out-migrants), Dong Thap (16,677), Soc Trang (14,392) and Ca Mau (13,561).

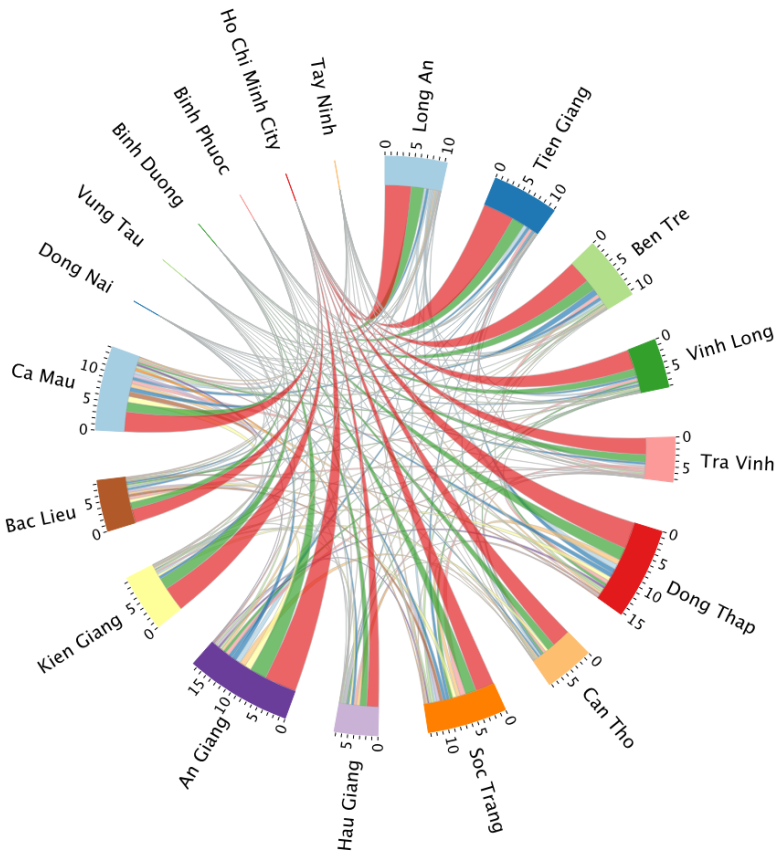


Figure 6.14 Provincial-level out-migration flows from the MKD to the SE region

Chapter 7

Conclusion

While the MKD region is considered the largest granary in Southeast Asia and has been reasonably successful in increasing people's living standards and reducing the general poverty rate, the development of the region is moving in a different direction from the approved socio-economic development objectives (Royal and Deltares 2013). The MKD region has lagged behind the national average in terms of many socio-economic development indicators. Garschagen et al. (2012), Renaud and Kuenzer (2012) and Royal and Deltares (2013) pointed out the most pressing and influential factors related to strong regulations of the agriculture section, inadequate transportation infrastructure, shortage of skilled labour and vulnerability to impacts of climate change.

Under stress from multiple socio-economic pressures and environmental risks, many small-scale farmers increasingly have difficulties securing a minimum level of profitability and a stable livelihood (Cosslett et al. 2014, Garschagen et al. 2012). As a result, migrants from the MKD have moved to the neighbouring SE region in search of better income and living conditions. The SE region, with a higher level of income per capita and living standards during the last decade, is the most popular destination for migrants from other parts of the country, especially the MKD region.

This research has studied two socio-economic problems in the MKD region: the failure of the contract rice-farming scheme and the formation of the largest out-migration corridor to the SE region. The unique power of ABM in modelling individual decision making was

used, with a focus on the micro level, rather than taking the traditional econometrics macro approach based on rational decision making. Heterogeneity, social interaction/feedback and the dynamic impacts of various external factors were incorporated into the models. The dynamic outcomes of the two agent-based models were validated, providing further insights into the related issues.

7.1 Concluding Remarks for Part I (Contract Rice Farming)

Part I presented an agent-based model to investigate four obstacles to the expansion of contract rice farming in the MKD region from the perspective of large-scale contractors. The focus was on financial incentive and trust factors, which affect the decisions of the relevant parties in terms of engaging with and honouring their contracting agreements. A simulation model was designed for the context of the MKD's rice supply chain with contractors engaging in the contract rice-farming scheme alongside an open market that meant both parties could renege on their agreements. The performance of contractors was then evaluated with different combinations of scenarios related to the four obstacles. The insights gained from the agent-based model can help policy makers and researchers in Vietnam understand the difficulties of expanding the contracting programme in MKD's rice supply chain.

First, regarding the failure of contractors to build a long-term trust-based relationship, the results showed a significant reduction in the rice volume and profit that contractors could achieve from the large-scale field programme if they decided to dishonour a large proportion of the participants' contracts. The results revealed an interesting observation, that when the contractors opportunistically broke their contracts with only a small proportion (e.g., 10%) of smallholder farmers, they could still earn more profit per crop than a spot-market-based buyer, because they could obtain the same type of rice at a lower price on the spot

market. While the Vietnamese Government has created legal frameworks to implement contract farming, including Decisions 80 and 62, they need to be enforced effectively. The local authorities should be more proactive in establishing innovative arbitration and dispute-resolution mechanisms beyond the judicial system, to prevent even the slightest level of opportunistic behaviours from the related parties.

Second, the research found that the contract-farming scheme for both ordinary and jasmine rice is not a cost-effective method for contractors who do not have husking, processing and polishing machines. The higher costs they incur by utilising external services to transform paddy into export-ready rice prevents them from engaging in the contracting programme. These results were in agreement with the judgement of World Bank (2013). As most of the contractors in the MKD region have limited rice-processing facilities (Tran et al. 2013), the large-scale paddy field model might not be adopted by the majority of enterprises. The 'one-size-fits-all' approach of Government policies could lead to unproductive results and hinder the sustainable expansion of contract rice farming. It is critical that contract farming is integrated into the Government planning and budget allocations, to facilitate access to credit for large-scale contractors, who can then enhance their rice-processing capabilities and engage more effectively in the contracting programme.

Third, the simulation results from this research showed that fully equipped contractors could implement the large-scale paddy field programme successfully if they remained committed to their contracts with farmers. Being trustworthy, especially in the first few cropping seasons, could help the contractors improve their trust-based relationship with farmers quickly. The results showed that committed contractors offering a higher price could expand the volume of rice in their contract-farming scheme but earn less profit per ton of rice. In contrast, contractors offering a lower price could obtain better earnings per ton of rice and a higher total profit per cropping season, but they could not easily establish contractual

agreements with more farmers. These financial factors could possibly discourage contractors with a lower paddy-purchasing price from enlarging their large-scale model.

The results of the simulation identified the scenarios of offering prices through which the related parties would find benefits to remaining committed to contract rice farming. In these scenarios, the large-scale contractor could maintain a higher rate of profit than a pure spot-market buyer could achieve, while the farmers could be more attracted to the scheme; this was reflected through the increased volume of contracted rice. For ordinary rice, the purchasing price needed to be 15% to 20% higher than the spot-market price and for jasmine rice, 10% to 15% higher. Both of these cases were for contractors equipped with milling and husking facilities. To support the expansion of the contract rice-farming scheme, calculated offering prices could be set as floor/ceiling prices by the local authorities, with all contractors required to apply them. In addition, large contractors should propose a flexible pricing system in the predefined ranges, in accordance with the fluctuations of spot-market prices, production seasons and crop value. This flexible pricing mechanism might lead to a more sustainable contracting programme in the MKD's rice supply chain.

For future work, we aim to explore the relationship between ABM and game theoretical models in the contractual agreements/commitments literature. Results from Han et al. (2013) are highly relevant to our findings that the contract-farming scheme might not be cost-effective for low-value rice in the MKD region. We also plan to integrate evolutionary game theory into the current agent-based model. Instead of assuming that the agents have sufficient information about their environment to make an optimal decision in advance, each agent will be modelled with the ability to adapt their strategy through learning by imitation. Some studies (Han and Lenaerts 2016, Han et al. 2015, 2017, Martinez-Vaquero et al. 2015) have already examined contractual commitments and proposing mechanisms to resolve cooperation issues with the use of evolutionary game theory. We hope to apply the same framework and examine mechanisms that could help to diminish opportunistic behaviours

in the context of MKD's contract rice farming. In addition, the model could be further employed to examine similar case studies of contracting programmes of different products and infrastructure under certain environmental 'noise' or market-price fluctuations.

Crop yield and production-cost data of the contract rice-farming scheme used in this study were based on statistics from the AGPPS, which is a pioneer in this area and one of the few successful rice contractors in the MKD region. Future work could focus on the variations in the relevant parameter values of different companies or locations across the MKD region, to assess the performance of the large-scale paddy field model further. The differences in the model predictions could be validated by surveying local farmers and contractors in the corresponding subregions or by interviewing experts.

The agent-based model used for this current research could be developed as a decision support system to evaluate enabling policies from the Vietnamese Government and local authorities related to the rice supply chain and contract farming in the MKD region. Similar tools can be found in the work of Croitoru et al. (2014) and Medda et al. (2017). We aim to develop a spatial agent-based model that incorporates a large smallholder-based production setting in a specific paddy concentration area. A model that integrates a geographical information system could assess the impact of the Government's land consolidation programme on the emergence of large-scale paddy fields. In addition, it would be of interest to use the ABM to evaluate the use of farmer organisations/cooperatives to secure direct contracts with contractors, reducing high transaction costs for large groups of smallholder producers and maintaining a sustainable contract rice-farming scheme in the MKD region.

7.2 Concluding Remarks for Part II (Inter-Provincial Migration)

Part II examined the dynamics of the migration decisions of MKD people, aiming to help explain the formation of the migration corridor to the SE region and fill the gaps in information on internal migration in Vietnam with regard to this region. The TPB, which is a well-known theory derived from social psychology, was used to break down the cognition process for individual migration behaviour into different background factors that migrants consider. It is likely that this is the first time that internal migration behaviour in Vietnam has been explained by the formation of a migration intention that is separated into the distinct elements of behavioural attitude, subjective norm and perceived behavioural control.

The research found that the behavioural attitude component was the most significant contributor to the migration intention of people in the MKD region. In this study, the behavioural attitude towards migration was evaluated via four socio-economic and environmental factors across potential destinations. The results were in agreement with the existing literature, indicating that economic reasons such as employment prospects and potential income were by far the most important factors, together accounting for more than 81% of the factors that people in the MKD region considered when deciding on their migration destination. Education opportunities and environmental factors contributed to the migrant's decisions as well, at 13% and 5% respectively.

Perceived behavioural control was the second most important component in predicting the migration intention and behaviour of people in the MKD region. This study mainly focused on the individual's perception of their ability to remove barriers against making an actual migration action. The results showed that people in the higher income quintile group, or wealthier people, were less likely to migrate. These results generally supported the existing literature in indicating the correlation between income and probability of migration in the

MKD region. Having a high income in the home region and expecting high expenditure in the destination region discouraged people from moving, as the results of migration might not be as beneficial as their current living conditions. Geographical distance was identified as next most important determinant that discouraged people from migrating.

The subjective norm, representing support from the migrant network, had the smallest effect among the three main elements determining the intention to migrate. The subjective norm was considered a relatively crucial component, especially with the involvement of both the individual's perception of the migrant network support and the weight of the subjective norm for the migration intention. In this model, the network of migrants was defined by means of spatial distance. Through multivariate sensitivity analysis, it found that the combination of the two factors related to the subjective norm had greater influence on the final decision of the migrants in the MKD region than each factor alone did.

Based on the richness of the output data generated from the agent-based model, the simulation results were further validated and the migration flows across cities and provinces from the MKD to the SE region were delineated. Ho Chi Minh City and Binh Duong province were the most popular destinations, with an average of 63,000 and 30,000 MKD people migrating there each year, respectively. The main sources of MKD out-migration were Long An, Dong Thap, An Giang, Tien Giang and Ben Tre provinces, which are close to major industrial areas in the SE region. These findings can assist policy makers and researchers in the fields of migration and socio-economic development.

In earlier research, Billari and Prskawetz (2012) and Klabunde and Willekens (2016) indicated that in the future, the application of ABM would continue to increase, establishing a new generation of computation models in the discipline of demographic science and migration. This study was in line with the current research trend of applying agent-based models to understand migration determinants and the dynamics of migration behaviours. Klabunde and Willekens (2016) noted that the validation process in most agent-based migration studies had

been performed at rudimentary levels and they advocated more studies in this matter. This research's systematic approach to validating the agent-based model addressed this issue. GA, which has been proved a useful tool for an automated calibration process, sensitivity analysis and parameter exploration in agent-based models, was used as the main validation tool.

This migration work with a focus on the dynamics of migration in the MKD region can serve as the basis for future work related to a comprehensive internal migration study in Vietnam, with seven socio-economic regions. The recent 2015 national migration survey (GSO Vietnam and UNFPA 2016b) pointed out the variations in the perceptions of people in different regions towards a range of factors in their final migration decision. We plan to replicate the migration flows across other cities and provinces to examine the differences in the migration behaviour of people in distinct regions. The insights from this model will facilitate the Government in controlling the distribution of the population across different regions of Vietnam.

The impacts of migration and remittances on poverty alleviation in the MKD region are another area of interest. It seems that migrant remittances to this region are a major source of funds for families to help them cope with their economic uncertainties (Coxhead et al. 2015, GSO Vietnam and UNFPA 2016b). The agent-based model could be revised to include family decision making in the formation of migration intention. A primary component of the model, the social module, could be used to simulate changes in individuals, households and their social linkages, including family status, household assets, remittances and information exchange. This would develop a model that could provide scenario-based predictions and evaluate the impacts of different migration and socio-economic policies on the development of rural areas.

Increasingly, the natural environment is being recognised as influencing internal migration trends in Vietnam and especially in the MKD region. Rapid-onset natural events have contributed to the formation of the migration corridor between the rural areas of MKD and

large cities in the SE region. The impacts of slow-onset events such as salinisation and sea-level rise are expected to increase and may become a major challenge to the possibility of people living in the MKD region in the future (Anh et al. 2016, Entzinger and Scholten 2016). We plan to incorporate a future model with relevant data to explore the correlation between climate change and the dynamic, large-scale migration flows in the MKD region. The predictive outcomes of this model could assist local authorities in implementing effective relocation projects to adapt to climate change in the MKD region.

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