A GAME THEORETIC APPROACH

FOR SURPLUS FOOD REDISTRIBUTION

WITH GOVERNMENT INTERVENTION

STUDENT NAME: Juehui Zhou
STUDENT NUMBER:
DEGREE: Master of Research in Economics
COURSE NAME: MRES PROGRAM
COURSE CODE: MRES899
DEPARTMENT: Department of Economics
FACULTY: Faculty of Business and Economics
UNIVERSITY: Macquarie University
SUPERVISOR: Andrea Chareunsy and Wylie Bradford

DATE OF SUBMISSION: 13 October 2019

ACKNOWLEDGMENTS

Throughout the writing of this thesis, I have received a great deal of support and assistance. I would first like to thank my supervisors, Dr. Andrea Chareunsy and Dr. Wylie Bradford, whose expertise was invaluable in the formulating of the research topic and methodology in particular.

I would like to acknowledge my MRES coordinators A.P. Tony Bryant and Dr. Edwin Franks for all of the opportunities I was given to conduct my research, their advice and time.

I would also like to thank Dr. Frank Song for his constructive advice on academic writing.

In addition, I would like to thank my family to be always there for me.

Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Juehui Zhou________________________ Date: 12/10/2019__________

Candidate's name

CONTENTS

ABSTRACT

Reducing food waste advocates efficient resource utilisation and could achieve a sequence of economic, social, and environmental benefits. One of the food waste reduction initiatives is to redistribute surplus food to food rescue organisations. This paper establishes a series of food rescue “games” with or without government interventions to model and to analyse the economic impacts resulting from the surplus food redistribution. The results show that voluntary cooperation between food donors and food rescue organisations could be achieved without government intervention if food waste management costs are greater than food donation costs. In the situation that food waste management costs are less than the food donation costs, proper government policy and financial support are needed to form the coalition and to maximise the coalition’s payoff.

1. Introduction

The demand for food is positively correlated with population growth and economic development. The world population is projected to reach 9.7 billion by 2050 (Booth & Whelan, 2014), and the food supply chain is under pressure to meet the increasing demand from the growing population. Due to the resource and energy-intensive nature of food production, there is no simple solution to scale up food production without depressing the ecosystem further. The cultivation activities are the prime causes of the loss and degradation of our ecosystem. Food production demands land, water, and energy. Agriculture accounts for one-third of the planet's landmass usage and 70 percent of total freshwater withdrawals (FAO, 2017). The current food supply and distribution chain require 30 percent of global energy (FAO, 2011). While scarce resources are used to produce food, one-fourth of the nutrition embedded in food (calories based) is wasted along the food supply chain (HLPE, 2014). If half of the wasted food can be avoided, the gap between food demand and food supply can be condensed by one quarter by 2050 (FAO, 2014).

Food waste not only undermines food security in the future but also entails economic, social and environmental consequences. The largest economic losses from food waste are the forfeited revenue and associated waste management cost. The Food and Agriculture Organisation of the United Nations (FAO) estimated that 936 billion USD worth of edible food was wasted annually worldwide (FAO, 2014). A common practice for Municipal Solid Waste (MSW) management is landfill (Callan & Thomas, 2001). Food waste is a major component of MSW. In Australia, food waste composes up to 30 percent of MSW (Reynolds et al., 2016). In 2016-2017, Australian generated 4.3 Million Tonne (Mt) of non-hazardous food waste, and 87 percent of which was sent to landfill (DEE, 2018). The noticeable increase in waste management cost is due to the fast depletion of landfill airspace. Food waste mitigation can efficiently lessen the exhaustion of landfill airspace and decelerate the waste management cost escalation (Vlaholias et al., 2015).

Food waste triggers social and moral issues alongside economic losses. While millions of tonnes of edible food are perishing in the landfill, over 800 million people are suffering from hunger and malnutrition around the world (FAO, 2019). Globalization and unbalanced economic development exacerbate income inequality. Food waste unnecessarily exaggerates the actual food demand and pushes up food prices (Headey et al., 2010). The higher food price deteriorates food security and deepens the inequality in our society. In Australia, food insecurity affects many disadvantaged communities as well. One out of eight Australian people is somehow in the food insecurity condition. How to reduce edible food being wasted and to alleviate food insecurity simultaneously is crucial from the social welfare perspective. Reducing food waste can decrease overall food demand. Therefore, stable food prices can be achieved, and food security can be improved (Rutten, 2013). Donating surplus food to Food Rescue Organisations (FROs) (Eriksson et al., 2005) has been recognized as a mechanism to mitigate food waste and improve food security (Reynolds et al., 2015; Warshawsky, 2015).

Reducing food waste can significantly improve the global environment as well as social benefits. The major environmental concerns regarding wasted food consist of air pollution, land occupation, water depletion, biodiversity loss, and deforestation (Thyberg & Tonjes, 2016). Food waste is bio-degradable, so it decomposes and generates methane under landfill's anaerobic conditions. Methane contributes 25 times more than carbon dioxide (CO_2) towards climate change (Pan & Voulvoulis, 2007). FAO estimated that 8% of global anthropogenic greenhouse gas emissions (4.4 Gt of CO_2 eq per year) stemmed from food waste (FAO, 2015). "Reducing food loss and waste can also be an adaptive and mitigation option to reduce the food security risks of new climate scenarios" (APEC, 2019).

Food waste prevention has been gaining increasing attention due to its magnitude and substantial impacts on the economy, society, and environment (Cicatiello et al., 2016; Giuseppe et al., 2014; Muriana, 2015). Food waste prevention has profound implication for efficient resource usage and future food security. While food loss mainly happens at harvest stage in developing countries caused by lagging techniques and low standard storage facilities, a significant amount of food waste generates at retailing and consumption sectors in developed countries (Giuseppe et al., 2014; Mena et al., 2011; Thyberg & Tonjes, 2016). These two sectors are the most decentralized components along the food supply chain and have great potential to address the food waste problem. The Australian government has announced the National Food Waste Strategies (DEE, 2017), aiming to halve Australia's food waste by 2030. This initiative aligns with the United Nations' Sustainable Development Goal (SDG) 12.3 on food loss and waste. Among all the strategies, diverting surplus food from landfill to the FROs takes a priority over compost, anaerobic digestion (AD) and waste-to-energy (WTE) incineration. Food rescue for human consumption is at the second tier of the food waste hierarchy (Papargyropoulou et al., 2014) and has been the dominant form of providing emergency food assistance in many developed countries.

Food Rescue Organisations (FROs) are not-for-profit organisations who collect the existing surplus food in the food supply chain and redistribute food to the charitable welfare agencies (Booth & Whelan, 2014). Before the emergence of the FROs, the traditional emergency food relief organizations (e.g. the community kitchen, shelter and soup kitchen) wholly relied on the monetary donation to purchase food and feed people. FROs provide a low-cost solution to obtain food. The FROs use their leased or donated vehicles and warehouses to collect and store surplus food from various food donors (FDs), and then redistribute the food to charitable welfare organisations. The latter will serve the food to food insecurity people in the form of food parcels or cooked meals. The FROs facilitate the redistribution of surplus food to reduce the amount of food waste sent to landfill and enhance food security. The largest international food rescue network is the Global FoodBank Network (GFN), consisting of 32 member countries. Foodbank Australia is a nation-wide not-for-profit, non-denominational organisation. Charitable welfare agencies pay a symbolical "handling fee" to obtain food from the FoodBank. Another two leading food rescue organisations are OzHarvest and SecondBite in Australia. While FoodBank focuses on non-perishable food, OzHarvest and SecondBite are engrossed in redistributing fresh vegetables and fruits, branding their food as healthy and nutritious. The charitable partners of these two organisations receive the rescued food for free. Australian food rescue value chain is highly concentrated with these three FROs accounting for 98 percent of food rescued (DEE, 2019). This oligopolistic food rescue industry has attracted many critiques regarding the efficiency and the proper utilisation of public funding.

While many researchers have focused on the aggregate gain from surplus food donation, little has been done to find the deep-rooted motivation for food donation practice (Booth & Whelan, 2014; Vlaholias et al., 2015). Despite the reciprocity advantage of surplus food donation, the quantity of donated food only accounts for a very small percentage of food waste. In Australia, the highest donation rate is from retailing at 7 percent. Stakeholders in the food supply chain gave different reasons for not donating surplus food (Hermsdorf et al., 2017). The lack of economic incentives seems like the largest obstacle. The costs of food donors have been qualitatively enumerated but not quantitively studied. This study aims to answer two questions in terms of food rescue practice in Australia. (1) What is the FD's fundamental motivation for donating food to FROs? (2) What kinds of government intervention are needed to initiate food donation? To answer these two questions, we need to analyse the individual financial gains or losses which are critical in terms of the FD's willingness to donate and the food rescue organisation's ability to survive. Therefore, a food donation framework can be established and benefits the overall society.

To accomplish the mission, it is necessary to find the key parameters of the food rescue industry's efficiency and how these parameters influence the performance of the industry. A set of game-theoretic models is used to study the strategies and the payoffs of the FRO population and the FD population. Game theory provides mathematical solutions for payoff redistribution and is also an effective method for finding solutions which require stakeholders' collaboration.

The rest of the paper is organised as follows. In Section 2, a literature review is presented. Section 3 presents the noncooperative game without government intervention and the cooperative game with government intervention, the assumptions, and the model definitions. Section 4 is for numerical samples. Section 5 is allocated to the discussion in terms of the results of the cooperative game. Finally, conclusions and future research suggestions are presented in Section 6.

2. Literature review

Food waste is not a new problem (Thyberg & Tonjes, 2016). Since the establishment of FAO in 1945, many studies and programs have been designed and implemented to address the concerns. One initial hurdle that researchers encountered is to define food waste. Because of the variety of countries, demographics, cultures and study purposes, a harmonised definition of food waste is difficult to achieve. (Girotto, Alibardi, & Cossu, 2015; Gustavsson & Stage, 2011). FAO (2014) separates food wastage into food loss and food waste. Food loss refers to the quantity and value reduction at the upstream stages of the food supply chain (i.e. agricultural production, postharvest, and storage) on grounds of financial, technical, and infrastructural constraints. Food waste refers to the food that was removed from human consumption at downstream stages (i.e. retail and consumption) as a consequence of cosmetic standards, dietary patterns, and lifestyles (Facchini et al., 2018). For this study, the definition of food waste in the Australian National Food Waste Strategy is adopted, i.e. food waste refers to the solid and liquid food, including edible parts and inedible parts, which are produced (domestically or internationally) for human consumption but are disposed of in landfill (DEE, 2017). This definition is the most relevant description in terms of food rescued in Australia.

FAO has published a series of reports in terms of food waste mitigation. Around the world, food loss and food waste were significant and increased with population growth and economic development. Data used in these reports were collected from different countries. As a result of the discrepancy among the food waste definitions between different countries, the accuracy of the consolidated data is unverified (Reynolds et al., 2016). Reliable data on food waste are limited or never exists. The value or magnitude of crops left in fields caused by market turbulence or severe weather conditions has never been included in statistics. The impact of food waste on society, environment, and economy has been estimated, but not quantified.

Despite the disadvantage of data availability, food waste studies at an aggregate level were abundant. Research studies the whole food supply chain at the country level (Facchini, et al., 2018; Hamilton, et al., 2015; Reynolds et al., 2015). Some studies focused on the policy and industrial structure innovation. Facchini et al. (2018) argued that government intervention was the key driver for food waste prevention in the UK. Facchini et al. estimated the UK's annual food mass flows which consisted of all food resources, namely imports, exports, distribution, consumption, food redistribution, and final disposal. They found that although the percentage of food redistributed was small compared to the amount of food waste, governmental support through fiscal incentives could boost the development of a coherent food rescue system and recover embedded multidimensional value in food (Facchini et al., 2018). Mourad (2016) compared the food waste generation along the food supply chains in the United States and France. Data collected from the United States was juxtaposed with data from France. Most of the food donors in both countries supported food redistribution ideas. Mourad suggested that the social, economic, and environmental achievements in food redistribution required food industry structural changes. His argument was supported by Chen & Chen (2018) in their study of two government food waste recognition programs in the US. They concluded that without food supply chain innovation, source reduction and food donation were not optimal choices for food supply chain stakeholders (Chen & Chen, 2018).

Hamilton et al. (2015) studied the food waste prevention from a nutrition cycling perspective. They proposed a multiplayer systems framework to compare the impacts of food waste strategies on Norwegian national biomass, energy, and phosphorus (P) cycles. They concluded that the most effective solution is a combination of prevention and recycling from both an energy and phosphorus perspective (Hamilton et al., 2015).

While policy and industrial innovation are important in mitigating food waste, detailed analyses of food waste generation can provide solutions to address the problems. Halloran and colleagues focused on analysing the causes of food waste and discussing the attitudes of different stakeholders towards €1.18 billions of wasted edible food in Denmark annually. They suggested that improving communication, adopting more efficient food packaging, and implementing more comprehensible food labels could promote food waste prevention (Halloran et al., 2014). Garrone et al. (2014) presented a bottom-up approach (ASRW, Availability-Surplus-Recoverability-Waste) to address surplus food management in terms of food supply chain sustainability in Italy. They scrutinised the whole food supply chain and divided the food supply chain into five stages and 12 segments. Each segment was given a degree of recoverability to assess the possibility of surplus food recovery. They suggested that the government and FROs should focus on segments with high recoverability to achieve better food waste reduction goals with the same effort (Garrone et al., 2014). This study implied that the amount of rescuable food might be an important parameter in terms of overall benefits.

The aforementioned food waste mitigation strategies require not only time but also investment. One could expect that the profit maximising nature of the food industry may distort the implement of food waste prevention guiding by food waste hierarchy. Cristóbal et al. stated that the financial budget was a key element for food waste prevention. They applied Life Cycle Assessment (LCA) on different food waste prevention programs to locate those cost-efficient and low environmental impact food waste reduction strategies along the whole food supply chain. The results were in line with the waste hierarchy (Papargyropoulou et al., 2014), i.e. food waste prevention had the priority among all of the food waste management solutions. On the other hand, food waste reuse or recycling could be considered as better options than food waste prevention under a fixed budget (Cristóbal et al., 2018).

Interests generated around food waste reuse and recycling may also stem from the alarming speed of landfill depletion across all countries recently (Booth & Whelan, 2014; Callan & Thomas, 2001; Chen et al., 2014; Kollikkathara et al., 2010). Local governments found that waste management became a critical challenge for the sustainability of society regardless of the countries' wealth (Dijkgraaf & Vollebergh, 2004). Food waste is clarified as organic waste and constitutes a great proportion of MSW (Halloran et al., 2014; Liu, 2014). Reducing food waste can significantly reduce the mass of MSW. Thus, a significant reduction of GHG emissions from landfill is realised. The environmental issues associated with food waste urged the food supply chain to adopt more efficient usage of resources (Halloran et al., 2014).

In affluent countries, retailing and consumption are the major food waste generating section. Due to the fast urbanisation, the majority of food retailers and consumers reside in cities and rely on the urban waste management system to handling their food waste. The soaring waste management costs forced businesses and organisations to seek alternative solutions for handling their food waste (Booth & Whelan, 2014). Cicatiello et al. collected a one-year worth of food donation data from an Italian supermarket. Their study recorded 23.5 tonnes of rescued food which had a total value of €46,000. They identified bread and bakery as the largest types of food donated. As a result of the detailed data, Cicatiello et al. managed to calculate the environmental value, social value, and economic value against the investment from the government funding (Cicatiello et al., 2016). The return on investment multiplier was 4.5, which represented a positive usage of public funding. Kulikovskaja and Aschemann-Witzel also addressed the important role of retailers in food waste prevention. They identified 22 food waste avoidance initiatives of the Danish retail industry and suggested that the marketing of suboptimal food was an efficient way to reduce food waste in Denmark (Kulikovskaja & Aschemann-Witzel, 2017). At the same time, Hermsdorf, Rombach, and Bitsch (2017) investigated the German retailing market in terms of food waste reduction. They interviewed retailers who involved in donating their surplus food to charities. They found that marketing suboptimal food in Germany could reduce food waste at the retail stage but was an unfavourable strategy due to the fear of losing customers. Their findings suggested that the lack of logistics and strict food regulatory framework were the main obstacles to food redistribution in Germany. In Australia, all of the big supermarkets (Woolworths, Coles, Aldi, and IGA) have made some commitment to address the problem of food waste. The common practices consist of in-store initiatives (such as better labelling and packaging innovations) and consumer education campaigns (e.g. free online recipes and meal planning information). Retailers have significantly reduced promotional strategies on fresh food that could lead to food waste in the home (e.g. Buy One Get One Free). Also, big supermarkets established partnerships with charitable organisations to ensure their edible surplus food is donated to people living in food insecurity.

Donating surplus food to charitable organisations is prevalent in developed countries. The previous studies of retailer food waste reduction suggested cooperation with FROs. Therefore, studies of how retailers can cooperate with FROs flourished in the food prevention literature (Booth & Whelan, 2014; Giuseppe et al., 2014; Hamilton et al., 2015; Hermsdorf et al., 2017; Kulikovskaja & Aschemann-Witzel, 2017; Mena et al., 2011; Nair et al., 2017; Schneider, 2013). Food rescue operation redistributes non-marketable edible food, with or without inedible parts, to charitable organisations for human consumption before the surplus food become food waste (Reynolds et al., 2015). Food donation at the organisation level is regarded as environment-friendly and promote resource efficiency. Muriana studied the integrated links between the fresh food shelf life, the food recovery amount and the loss of profit with a simulated model. The author argued that government incentives on food donation could encourage an optimal quantity of food donation and improve business profit under uncertainty. If Retailers implemented routine inspections on fresh food, then donating fresh food to FROs did not contribute to the loss of profit (Muriana, 2015).

The food waste prevention literature examines different legislations and social frameworks on the surplus food donation practice (Cristóbal et al., 2018; Facchini et al., 2018; Hamilton et al., 2015; Kulikovskaja & Aschemann-Witzel, 2017; Papargyropoulou et al., 2014; Stangherlin & de Barcellos, 2018). The first legislation in terms of food donation is the Bill Emerson Good Samaritan Food Donation Act signed in 1996 by former US President Clinton. Many countries have passed similar bills to encourage food redistribution activities. The Civil Liability Amendment (Food Donations) Act 2005 is the Australian Federal legislation regulating food donation. Good Samaritan Acts protect food donors from liability when donating surplus food to charitable organisations. In the meanwhile, food safety legislation still applies.

The food supply chain can be defined as six stages, namely (1) agriculture production, (2) postharvest handling and storage, (3) manufacture processing and packaging, (4) wholesale distribution, (5) retail marketing, and (6) consumption. Surplus food generates at all of the stages along the food supply chain. This phenomenon extends the potential food donors to farmers, manufacturers, wholesalers, and retailers. Consumers are excluded from the food donors in view of the fact that the FROs do not accept food donations from individuals due to legislation constraints in Australia. This exclusion does not mean that consumers are not important in food waste prevention. Consumers can play critical roles to influence the food supply chain with respect to food waste reduction strategies (Abd Razak, 2017; Bernstad & Andersson, 2015; Cecere et al., 2014).

FROs have experienced booming expansion in recent years but with constant critiques for their impacts and efficiency (Huck & Kübler, 2000; Schneider, 2013; Vlaholias et al., 2015; Vlaholias-West et al., 2018; Warshawsky, 2015). Lindberg et al. (2014) scrutinized the operation of SecondBite, which is the leading food rescue organizations in Australia. This descriptive study used field data and interviews to study the reason for food rescue and the stakeholders involved in the operation. This research provided first-hand information for a particular Australian food rescue organization, its gains, and its challenges. Although not much economic data were presented in the paper, some valuable insight was produced (Lindberg et al., 2014). Similar studies were conducted in terms of Australia's FoodBank (Booth & Whelan, 2014) and OzHarvest (Nair et al., 2017). Booth and Whelan argued that FoodBanks have grown themselves into the industry since they were "preferred industry method of food disposal" (Booth & Whelan, 2014). They used South Australia as a sample to show how the food supply chain avoided large food waste disposal costs by donating surplus food to FoodBanks. FROs are criticised as failing to address the root cause of food insecurity, i.e. poverty. The fast growth of FROs, per se, is a clear proof that food donation cannot solve hunger (Schneider, 2013). While food rescue may provide emergency food access, on the other hand, it uncouples the government's responsibility from poverty in society.

Despite all the critiques, food rescue operation has supported people suffering from food insecurity especially those children, disable and aged population who have limited ability to obtain enough food without emergency food assistance. Since the social value and environmental value of rescuing surplus food is not negligible, the Australian government has planned to encourage food rescue operations in Australia (DEE, 2019). Questions arise in terms of public funding allocation and the equipment investment required to expand the services. How could government policies encourage frequent small donations from downstream donors (supermarkets, institutions, and restaurants)? To what extent could the public funding efficiency be checked in the FROs industry? What are the benchmarks for those checks? From the review of the food prevention literature, one major obstacle in downstream food waste prevention is that food donors bear economic losses without any compensation. In another way, the benefits and costs are not fairly distributed between food donation stakeholders.

This paper attempts to analyse the impact of different government interventions on the food rescue operation with a game-theoretic approach. Game theory uses mathematical models to understand the human being's interactions. Game theory is versatile in simulating the various facets of the conflict and integrating incompatible characteristics of the problem in the absence of quantitative payoff information. Any interaction involving two or more intelligent and rational decision-makers (identified as players in game theory) can be modelled and analysed in the framework of game theory. Game theory has extensive applications in economic problems involving multi-criteria and multi-stakeholders. Many game-theoretic models have been made in supply chain optimal problems (Hafezalkotob et al., 2016; Hennet & Mahjoub, 2010), and in waste management problems (Soltani et al., 2016). One of the characteristics of game theory is that game theory allows individuals to give priority to their objectives. Game theory eliminates the strong assumption in the conventional optimal problems that all the stakeholders involved cooperate perfectly.

Games are categorised as noncooperative games and cooperative games. In noncooperative games, players choose their strategies independently, and Nash equilibria are the solutions from which no player can unilaterally deviate to improve his or her payoff (Nash, 1951). Whereas in cooperative games, coalition and joint actions are allowed (Nash, 1953). Payoffs replace the strategies at the central stage. The self-optimizing attitude of players often results in noncooperative behaviours even when cooperative behaviour is more beneficial to all parties. In this study, the government was introduced as a central agency that is not a player but a rule-maker (Huck & Kübler, 2000). The government makes rules to affect players' payoffs. The players have to form some kind of coalitions to maximise their payoffs. In cooperative game theory studies, the concept of core was adopted to seek the stable cooperation between players (Shapley & Shubik, 1969; Hennet & Mahjoub, 2010; Izquierdo & Rafels, 2018; Sinayi & Rasti-Barzoki, 2018). There have been only a few studies that used game theory for waste management decision-making. Jørgensen used game theory for a regional waste disposal problem (Jørgensen, 2010). Karmperis et al. (2013) proposed a framework called the waste management bargaining game to help players negotiate over the surplus profit of various MSWM options (Karmperis et al., 2013). Many studies compared stable solutions with or without government interventions (Aanesen, 2012; Jamali & Rasti-Barzoki, 2018).

Cooperative Game Theory has been applied in waste management and supply chain analyses. The two common payoff allocation concepts are Shapley Value and Core. Shapley Value captures the marginal contributions of agent i, averaging over all the different sequences according to which the grand coalition could be built up. The formula for calculating Shapley Value is as below:

$$\phi_i = \frac{1}{N!} \sum_{S \subseteq N \setminus \{i\}} |S|!\,(|N| - |S| - 1)!\,[v(S \cup \{i\}) - v(S)]$$

Aldashev, Marini, and Verdier proposed a cooperative game between food rescue organizations who competing to obtain donated food. The results suggested that the stability of voluntary coordination agreements between food rescue organizations depends on the depth of their cooperation (Aldashev et al., 2014). Soltani, Sadiq, and Hewage proposed a cooperative game theory solution when waste management stakeholders had conflicting priorities. After computing the relevant costs and investigating stakeholders' different preferences, three pure strategy solutions were presented with specific money term payoffs. The stakeholders, cement industry and Vancouver local government were represented as player 1 and player 2 in the game. With a small amount payable to Vancouver local government, the new proposed waste management project was stable in a mutual setting (Soltani et al., 2016). Rajendra & Arvind simulated one series of cooperative games involving key stakeholders in electronic waste (e-waste) management in India. Both of noncooperative and cooperative games were explored with different numbers of stakeholders. Government, producer, recycler, and consumer formed different coalitions in these games. Each of the key stakeholders had two different strategies. The government could either punish (penalties for the producer who does not comply with recycling law) or stimulate (subsidies for the producer who recycles). The producer chose whether charging consumers an e-waste management fee on top of the purchasing price or hiding the Extended Producer Responsibility (EPR) charge in the retail price. Recycler decided whether collecting e-waste from the producer or the consumer. Consumer's choices were to recycle or to disposal of the electronic product in the landfill (Kaushal Rajendra & Nema Arvind, 2013). Peng and Tao proposed a cooperative game-theoretic model to analyse China's spot electricity market. (Peng & Tao, 2018)

3. Methodology

Game theory suggests that in a noncooperative game, players should choose their best strategies to maximise their payoffs. While in a cooperative game, players obtain the optimal payoff vector by forming coalitions or achieving binding agreements. In the food rescue operation, the food rescue organisations and the food donors have different objectives in terms of rescuing edible surplus food. The food rescue organisations work diligently to rescue edible food as much as possible to meet the demand of charitable welfare organisations. While the food donors' priority is to reduce their waste management costs. Ideally, the more edible food is donated, the better payoffs for both of the food rescue organisations and the food donors. Nevertheless, any business operation demands resources. The food rescue operation needs capital and labour. The maximum capacity of the food rescue organisations depends on their physical facilities for collection and storage. The motivation of the food donors is subject to the savings they may achieve. For these conflicts and potential cooperation, this study considers a game-theoretic approach for analysing the food rescue operation as a section in the waste management system (Reynolds et al., 2015). To overcome the limitation of the number of players in the present study, a group of stakeholders, which have a similar degree of interest and ability to contribute in the coalition, is considered as a single player. Food rescue organisations and food donors are represented by the FRO and the FD, respectively. Due to the limitation of data availability, the payoffs are simulated in both of the sequential game and the cooperative game where the players sign a binding agreement under government intervention. The government intervention could be punishment (environmental tax on the FD) or incentive (grant for the FRO and sustainability tax deduction for the FD).

3.1 The sequential Food Rescue Game

In this section, we consider a food rescue Stackelberg game with two players, namely, a food rescue organisation and a food donor (FD). In the decentralized model, government intervention does not exist. The FRO is the leader and the FD is the follower (Figure 1).

The notions are summarised as below:

P_{frdAa} is the payoff of the FRO when the FRO chooses strategy A and the FD chooses strategy a.

P_{frdAb} is the payoff of the FRO when the FRO chooses strategy A and the FD chooses strategy b.

P_{frdBa} is the payoff of the FRO when the FRO chooses strategy B and the FD chooses strategy a.

P_{frdBb} is the payoff of the FRO when the FRO chooses strategy B and the FD chooses strategy b.

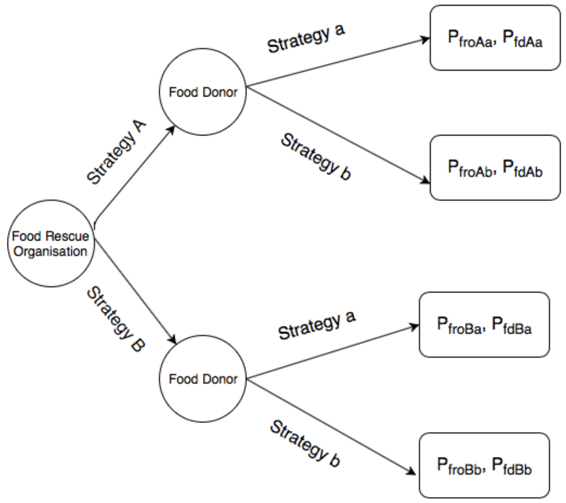

Figure 1. The sequential game tree of Food Rescue Game

P_{fdAa} is the payoff of the FD when the FRO chooses strategy A and the FD chooses strategy a.

P_{fdAb} is the payoff of the FD when the FRO chooses strategy A and the FD chooses strategy b.

P_{fdBa} is the payoff of the FD when the FRO chooses strategy B and the FD chooses strategy a.

P_{fdBb} is the payoff of the FD when the FRO chooses strategy B and the FD chooses strategy b.

p_m is the market price which is a weighted average market price for a bunch of food.

R_{pr} is the private donation received by the FRO.

Q_0 is the amount of edible surplus food.

C_{fro} is the FRO's cost of handling donated food, e.g. employee costs and logistics costs.

θ $(0 < \theta < 1)$ is the percentage of donated food out of the whole amount of edible surplus food.

c_{wm} is the unit waste management cost of the FD.

c_{fd} is the unit handling cost of the FD associated with donating food.

$c_{logistic}$ is the unit logistics cost of the FD associated with donating food.

L_{fw} is the waste levy on food waste.

γ is the food waste levy rate based on the weight of food waste.

T_{fd} is the tax rebate for the FD based on the market value of the donated food.

t is the tax rebate rate.

R_g is the Government grants for the FRO.

φ is the government grants rate based on the weight of the donated food.

The assumptions of the game are summarised as below:

Assumption 1. Players are rational participants, maximizing their payoffs.

Assumption 2. Each player faces a set of feasible payoffs.

Assumption 3. The demand of rescued food is greater than the supply of the rescued food.

Assumption 4. The FRO recruits volunteers to drive their vehicles for collecting surplus food from the FD. The drivers will sort out suitable food on-site when they visit the FD.

Assumption 5. The amount of food the FRO receives is the same as the amount of food the FD donates. This means there is no food loss during the transport of donated food.

Assumption 6. The amount of food the FRO distributes is the same as the amount of food the FRO rescues.

Assumption 7. The variety of food rescued satisfies the nutrition requirements and only the insufficient quantity requires extra purchase at market price p_m. The market price is a weighted average market price for a bunch of food. The FRO can only purchase up to $(\frac{R_{pr}}{p_m})$ amount of food due to the financial constraint. R_{pr} is the revenue of the FRO from private donations.

Assumption 8. The FRO and the FD know the complete information of the game, i.e., the number of players, the strategies each player has, and the payoffs associated with each strategy.
Assumption 9. Waste management cost is based on the weight of food waste.
The FRO observes that a substantial number of charitable welfare agencies are struggling to obtain enough food supply to feed their clients. On the other hand, supermarkets, restaurants, and institutions are dumping edible food to landfill. The FRO visits the potential FD and suggests that the FRO can redistribute their edible surplus food to feed people suffering food insecurity. The FRO has two strategies: (A) collect food from the FD (Collect); (B) Do not collect but accept food dropped by the FD (Do Not Collect). When approached by the FRO, the FD has two strategies to choose from: (a) donate edible surplus food (Donate); (b) do not donate edible surplus food (Do Not Donate).

The FRO's objective is to maximise the quantity of rescued food subject to the funding constraint. If the FRO chooses the "Collect" strategy, the amount of rescued food is Q_0 and the associated cost is C_{fro}. The food procurement of the FRO is ($\frac{R_{pr}-C_{fro}}{p_m}$). When the FRO selects the "Do Not Collect" strategy, the amount of rescued food is (θQ_0), and the associated cost is θC_{fro} $(0 < \theta < 1)$. The food procurement of the FRO is $\frac{R_{pr}-\theta C_{fro}}{p_m}$.

$$P_{froAa} = Q_0 + \frac{R_{pr}-C_{fro}}{p_m} \quad (1)$$

$$P_{froBa} = \theta Q_0 + \frac{R_{pr}-\theta C_{fro}}{p_m}, \quad 0 < \theta < 1 \quad (2)$$

$$P_{froAb} = \frac{R_{pr}-C_{fro}}{p_m} \quad (3)$$

$$P_{froBb} = \frac{R_{pr}}{p_m} \quad (4)$$

$$P_{froAa} - P_{froBa} = Q_0 + \frac{R_{pr}-C_{fro}}{p_m} - \left(\theta Q_0 + \frac{R_{pr}-\theta C_{fro}}{p_m}\right) = (1-\theta)\left(\frac{Q_0 p_m - C_{fro}}{p_m}\right) \quad (5)$$

$Q_0 p_m$ is the market value of the rescued food. It is assumed that the cost of the food rescue operation is less than the market value of food rescued. So $Q_0 p_m > C_{fro}$. Since $0 < \theta < 1$, it is concluded that

$$P_{froAa} > P_{froBa} \quad (6)$$

$$P_{froAb} - P_{froBb} = \frac{R_{pr} - C_{fro}}{p_m} - \frac{R_{pr}}{p_m} = -\frac{C_{fro}}{p_m} \quad (7)$$

Since $C_{fro} > 0$, it is concluded that

$$P_{froAb} > P_{froBb} \quad (8)$$

The FD’s objective is to minimise the cost associated with food waste. Suppose the FD has Q_0 edible food which is suitable for donation, and the FD chooses a "donate" strategy. If the FRO provides logistic service, then Q_0 food is donated, and the FD can save $Q_0 * (c_{wm} - c_{fd})$. c_{wm} is the unit waste management cost and c_{fd} is the unit handling cost of the donated food. If the FRO does not provide logistics service, then only θQ_0 edible food is donated, and the FD can save $\theta Q_0 * (c_{wm} - c_{fd} - c_{logistic})$. $c_{logistic}$ is the unit logistics cost of the donated food. If the FD adopts the "Do Not Donate" strategy, the FD saves 0, regardless of the FRO will collect the food or not.

$$P_{fdAa} = Q_0 * (c_{wm} - c_{fd}) \quad (9)$$
$$P_{fdAb} = 0 \quad (10)$$
$$P_{fdBa} = \theta Q_0 * (c_{wm} - c_{fd} - c_{logistic}) \quad (11)$$
$$P_{fdBb} = 0 \quad (12)$$

Consider scenario 1, if

$c_{fd} < c_{fd} + c_{logistic} < c_{wm}$, then

$$P_{fdAa}, P_{fdBa} > 0 \quad (13)$$

This is the situation where donating food is a dominant strategy for the FD if the FD can always reduce the cost by donating food. When the FRO knows that the FD will donate, the FRO will choose to collect donated food from the FD to maximising its payoff. There is only one Nash Equilibrium in the game. The FRO provides logistic service and the FD donates surplus food. The equilibrium payoff vector is (P_{froAa}, P_{fdAa}).

Consider scenario 2, if

$c_{fd} < c_{wm} < c_{fd} + c_{logistic}$, then

$$P_{fdAa} > 0,\ P_{fdBa} < 0 \tag{14}$$

There is no dominant strategy for the FD if the sum of handling cost and logistics cost is greater than the waste management cost. To explain the situation, one numerical sample is provided. The simulation payoff matrix is as in Figure 2. If the FRO and the FD act simultaneously, there are two Nash Equilibria in the payoff matrix: (3, 3) and (0, 0). The FRO and the FD may choose a payoff vector (0,0). Since the game is sequential, the FD will observe the action of the FRO firstly, and then choose the FD's strategy. To encourage food donation from the FD and maximise the payoff, the FRO will choose to collect food from the FD. The Nash Equilibrium payoff vector is (3,3). The generalised payoff vector is (P_{froAa}, P_{fdAa}), which is the same as when the waste management cost is greater than the costs associated with a food donation.

Figure 2. The simulated payoff matrix for Food Rescue Game

Consider scenario 3, if

$c_{wm} < c_{fd} < c_{fd} + c_{logistic}$, then

$$P_{fdAa} < 0,\ P_{fdBa} < 0 \tag{15}$$

In scenario 3, the waste management cost is lower than the food donation cost. The dominant strategy "Do not donate" for the FD. The FRO knows that the FD will not donate, so the FRO will not organise the logistic. The Nash Equilibrium is the payoff vector (P_{froBb}, P_{fdBb}).

3.2 The cooperative Food Rescue Game with government intervention

Unlike in the noncooperative games, the focal point of a cooperative game is what the players can obtain, separately and together. It is not important to know how they behave to achieve a particular outcome. What matters is that a particular set of payoffs is freely available to them if they choose to cooperate. In motivating a binding agreement, the cooperative game requires an outside authority that enforces any such agreements. This outside authority is normally represented by the government.

In cooperative games, the complete set of players is called the grand coalition. A subset of players that have the right to agree is called a coalition, and it is usually assumed that any subset of the players can form a coalition. A coalition with just one player is called singleton. A cooperative Food Rescue Game can be defined by a pair (N, v) v: $2^N \rightarrow R$. To simplify the analysis n is restricted to 2. $v(\emptyset) = 0$ is the characteristic function representing the payoff vector for the grand coalition. The payoff set S = $(\{\emptyset\}, \{FRO\}, \{FD\}, \{FRO, FD\})$ is closed, convex, non-empty and bounded.

If the FD's waste management cost is greater than the cost associated with food donation, the government does not need to do anything. In the sequential game scenario 1 and scenario 2, The FRO provides logistic service and the FD follows to donate surplus food. What happens in the noncooperative game scenario 3 requires the government intervention to establish a binding agreement. In scenario 3, the FRO and the FD do not cooperate due to the low waste management cost in the FD payoff function. In this cooperative game, waste management cost is assumed lower than the food donation cost, $c_{wm} < c_{fd}$.

Consider that the government wishes to improve social and environmental benefits by reducing food waste in the landfill. A "Battle Food Waste" program is proposed. The program aims to minimise the amount of food sent to the landfill. The government set the goal to rescue Q_0 surplus food. The government has two policy options. One is to introduce a food waste levy L_{fw} on the food waste destined to landfill. The levy will be applied based on weight. Consider a food waste levy rate at γ, the food waste levy on the edible surplus food that the FD can donate but disposed of is

$$L_{fw} = \gamma Q_0 \tag{16}$$

Another option for the government is to provide tax rebates if the FD donates food to the FRO. The FD can obtain tax refund T_{fd} based on the market value of the donated food. Suppose that the tax rebate rate is t. The amount of tax refund of the FD is

$$T_{fd} = t * Q_0 * p_m \tag{17}$$

Government grants R_g is available if the FRO rescues the surplus food from the FD and provides the logistics. The grants are based on the amount of food rescued, so

$$R_g = \varphi Q_0, \quad \varphi \geq 0 \tag{18}$$

In the cooperative Food Rescue Game, two players negotiate over a surplus generated through the food rescue operations. The players cooperate to some extent to achieve an agreement. If an agreement cannot be achieved, there is a payoff vector which is called the disagreement point d. It is a non-cooperative option. In the cooperative food rescue game, the disagreement points are different depending on different government interventions.

3.2.1 If the government announces the food waste levy policy, the disagreement point is $d(R_{pr}, -L_{fw})$.

$$v(FRO) = R_{pr} \tag{19}$$

$$v(FD) = -Q_0 * \gamma \tag{20}$$

$$\begin{aligned} v(FRO, FD) &= p_m Q_0 + \left(\varphi Q_0 - C_{fro}\right) + Q_0\left(c_{wm} - c_{fd}\right) \\ &= (p_m + \varphi) Q_0 - (c_{fd} - c_{wm}) Q_0 - C_{fro} \end{aligned} \tag{21}$$

The payoff vector is in the core, if

$$P_{fro} + P_{fd} = v(FRO, FD) \geq 0 \quad (22)$$

$$P_{fro} \geq \ v(FRO) \quad (23)$$

$$P_{fd} \geq v(FD) \quad (24)$$

Substitute equation (21), (19), (20) into equation (22), (23), (24), respectively

$$P_{fro} + P_{fd} = (\ p_m + \varphi)Q_0 - \left(c_{fd} - c_{wm}\right)Q_0 - C_{fro} \geq 0 \quad (25)$$

$$P_{fro} \geq \ R_{pr} \quad (26)$$

$$P_{fd} \geq -\gamma * Q_0 \quad (27)$$

Re-arrange equation (25)

$$\varphi \geq \left(c_{fd} - c_{wm}\right) + \frac{C_{fro}}{Q_0} - p_m \quad (28)$$

Sum up equation (26), (27),

$$P_{fro} + P_{fd} = R_{pr} - \gamma Q_0 \geq 0 \quad (29)$$

$$\gamma \leq \frac{R_{pr}}{Q_0} \quad (30)$$

Equation (25) + equation (27) * (-1)

$$P_{fro} \leq \left(p_m + \varphi - c_{fd} + c_{wm} + \gamma\right)Q_0 - C_{fro} \quad (31)$$

Equation (25) + equation (26) * (-1)

$$P_{fd} \leq (p_m + \varphi - c_{fd} + c_{wm})Q_0 - C_{fro} - R_{pr} \quad (32)$$

Consider equation (26), (27), (28), (30), (31), and (32), it is concluded that the payoff vector (P_{fro}, P_{fd}) is in the core if

$$P_{fro} \in [R_{pr}, \left(p_m + \varphi - c_{fd} + c_{wm} + \gamma\right)Q_0 - C_{fro}]$$

$$P_{fd} \in [-\gamma * Q_0, (p_m + \varphi - c_{fd} + c_{wm})Q_0 - C_{fro} - R_{pr}]$$

$$\varphi \geq (c_{fd} - c_{wm}) + \frac{C_{fro}}{Q_0} - p_m$$

$$\gamma \leq \frac{R_{pr}}{Q_0}$$

3.2.2 If the government announces the food donation tax rebate policy, the disagreement point is $d(R_{pr}, 0)$.

$$v'(FRO) = R_{pr} \quad (33)$$

$$v'(FD) = 0 \quad (34)$$

$$v'(FRO, FD) = p_m Q_0 + (\varphi Q_0 - C_{fro}) + Q_0 * (t * p_m + c_{wm} - c_{fd})$$

$$= (p_m + \varphi)Q_0 - (c_{fd} - c_{wm})Q_0 - C_{fro} + Q_0 * t * p_m \quad (35)$$

The payoff vector is in the core, if

$$P'_{fro} + P'_{fd} = v'(FRO, FD) \geq 0 \quad (36)$$

$$P'_{fro} \geq v'(FRO) \quad (37)$$

$$P'_{fd} \geq v'(FD) \quad (38)$$

Substitute equation (35), (33), (34) into equation (36), (37), (38), respectively.

$$P'_{fro} + P'_{fd} = (p_m + \varphi)Q_0 - (c_{fd} - c_{wm})Q_0 - C_{fro} + Q_0 * t * p_m \geq 0 \quad (39)$$

$$P'_{fro} \geq R_{pr} \quad (40)$$

$$P'_{fd} \geq 0 \quad (41)$$

Re-arrange equation (39)

$$\varphi + p_m * t \geq (c_{fd} - c_{wm}) + \frac{C_{fro}}{Q_0} - p_m \quad (42)$$

Equation (39) + equation (41) * (-1)

$$P'_{fro} \leq \left(p_m + \varphi - c_{fd} + c_{wm} + \ t * p_m\right)Q_0 - C_{fro} \quad (43)$$

Equation (39) + equation (40) * (-1)

$$P'_{fd} \leq (p_m + \varphi - c_{fd} + c_{wm} + \ t * p_m)Q_0 - C_{fro} - R_{pr} \quad (44)$$

Consider equation (40), (41), (42), (43), and (44), It is concluded that the payoff vector (P'_{fro}, P'_{fd}) is in the core if

$$P'_{fro} \in [R_{pr}, \left(p_m + \varphi - c_{fd} + c_{wm} + \ t * p_m\right)Q_0 - C_{fro}]$$
$$P'_{fd} \in [0,\ (p_m + \varphi - c_{fd} + c_{wm} + \ t * p_m)Q_0 - C_{fro} - R_{pr}]$$

4. Numerical application

In this section, five numerical examples are presented to demonstrate how different amounts of rescued food and government interventions affect the payoffs of the FRO and the FD.
In the Stackelberg games, if the FD’s waste management cost is greater than the cost associated with food donation, then the FRO and the FD will choose strategy A and strategy a respectively, and a cooperative food donation relationship can form without any outside intervention. In the noncooperative scenario 2, the FRO’s perception of the limited willingness of the FD to provide logistics motivates the FRO to provide the collecting service to maximising the amount of food donation. Once the logistics obstacle is removed, the FD is more likely to donate surplus food. This implies that the FD views the waste management cost and food donation handling cost as endogenous costs, and the logistics cost as exogenous cost. The FD calculates the saving by donating surplus food. If the saving is greater than zero, the FD decides to donate. Meanwhile, the FD tries to avoid bearing the exogenous cost by reducing the amount of food donation, which the FRO is reluctant to see. To maximising both payoffs, the FRO provides logistics service. Thus, the logistics cost is an endogenous cost for the FRO.

If the FD's saving by donating surplus food is less than zero, the FD will not donate. In scenario 3, government intervention is needed to facilitate the food donation.

In the scenario 3.2.1, Rearrange equation (28) and (30),

$$\varphi Q_0 \geq (c_{fd} - c_{wm})Q_0 + C_{fro} - p_m Q_0 \tag{45}$$

$$\gamma Q_0 \leq R_{pr} \tag{46}$$

Equation (45) shows that government grants are not less than the discrepancy between the market value of rescued food and the costs associated with food rescue of the FRO and the FD. If the government grants fail to compensate for the overall costs generated by rescuing food, then the core is empty and the coalition between the FRO and the FD cannot keep a stable condition. The food rescue operation is likely to cease.

Equation (46) shows that the government food waste levy charged on food waste is required not greater than the private donation that the FRO may receive. Otherwise, the core will be empty and the whole game may be unstable.

The parameters are set as below:

$R_{pr} = C_{fro} = AUD5000$

$c_{wm} = AUD20/tonne$

$c_{fd} = AUD100/tonne$

$\varphi = AUD60/tonne$

$\gamma = AUD60/tonne$

$p_m = AUD800/tonne$

According to the conditions in the core, $Q_0 \geq 12\ tonne$. Here, *ceteris paribus*, the amount of food rescued is presented as 12 tonnes, 24 tonnes, 36 tonnes, 48 tonnes, and 60 tonnes to calculate the payoffs of the coalition under the food waste levy applied condition. After Substituting the numbers into Equation 21, the results are shown in Table 1.

The payoffs of the FRO and the FD coalition under the food waste levy applied condition

Q_0 (tonne)	$v(FRO, FD)$ (AUD)	growth of Q_0	growth of $v(FRO, FD)$
12	4360	100%	100%
24	13720	200%	314%
36	23080	300%	529%
48	32440	400%	744%
60	41800	500%	959%

Table 1.

If $Q_0 = 20\ tonne$, *ceteris paribus*, the government grant rate φ is set as AUD60/t, AUD80/t, AUD120/t, AUD180/t, and AUD240/t, and substituting into Equation 21, then the results are shown as in Table 2.

The payoffs of the FRO and the FD coalition under the food rescue grants condition

φ (AUD/t)	$v(FRO, FD)$ (AUD)	growth of φ	growth of $v(FRO, FD)$
60	10600	100%	100%
80	11000	133%	104%
120	11800	200%	111%
180	13000	300%	123%
240	14200	400%	134%

Table 2.

In the scenario 3.2.2, The parameters are set as below:

$R_{pr} = C_{fro} = AUD5000$

$c_{wm} = AUD20/tonne$

$c_{fd} = AUD100/tonne$

$\varphi = AUD60/tonne$

$\gamma = AUD60/tonne$

$p_m = AUD800/tonne$

$t = 10\%$

According to the conditions in the core, $Q_0 \geq 12\ tonne$. Here, *ceteris paribus*, the amount of food rescued is presented as 12 tonnes, 24 tonnes, 36 tonnes, 48 tonnes, and 60 tonnes to calculate the payoffs of the coalition under the food donation tax rebate policy. After Substituting the numbers into Equation 39, the results are shown in Table 3.

The payoffs of the FRO and the FD coalition
under the government food donation rebate scheme

Q_0 (tonne)	$v'(FRO, FD)$ (AUD)	growth of Q_0	growth of $v'(FRO, FD)$
12	5320	100%	100%
24	15640	200%	294%
36	25960	300%	488%
48	36280	400%	682%
60	46600	500%	876%

Table 3.

If $Q_0 = 20\ tonne$, *ceteris paribus*, the government grant rate φ is set as AUD60/t, AUD80/t, AUD120/t, AUD180/t, and AUD240/t, and substituting into Equation 39, then the results are shown as in Table 4.

The payoffs of the FRO and the FD coalition under the government food rescue grants

φ (AUD/t)	$v'(FRO, FD)$ (AUD)	growth of φ	growth of $v'(FRO, FD)$
60	12200	100%	100%
80	12600	133%	103%
120	13400	200%	110%
180	14600	300%	120%
240	15800	400%	130%

Table 4.

If $Q_0 = 20\ tonne$, *ceteris paribus*, the food donation tax rebate rate t is set as 5%, 10%, 15%, 20%, and 25%, and substituting into Equation 39, then the results are shown as in Table 5.

The payoffs of the FRO and the FD coalition
under the government food donation rebate scheme

t	$v'(FRO, FD)$ (AUD)	growth of t	growth of $v'(FRO, FD)$
5%	11400	50%	93%
10%	12200	100%	100%
15%	13000	150%	107%
20%	13800	200%	113%
25%	14600	250%	120%

Table 5.

5. Discussion

In the numerical examples, a sensitivity analysis was proposed to investigate the impact of the variation of the amount of food rescued and different government interventions on the payoffs of the coalition between the FRO and the FD. In particular, five sets of experimental figures were given to test the impacts shown in table 1 to table 5. The variation of the amount of food rescued moved from the low level to the high level was 100%. The variation of the government grants for the FRO moved from the low level to the high level was 33%, then 100% each level due to the core constraint. The variation of the surplus food donation rebate moved from the low level to the high level was 5% with the lowest level at 5%.

Table 1 demonstrated that the payoff of the FRO and the FD coalition was positively correlated with the amount of food rescued under the government food waste levy policy. The growth rate of the payoffs was greater than the growth rate of the quantities of the food rescued. While the amount of food rescued increased by 100%, the payoff increased at about 215%. This positive correlation showed that increasing the amount of food rescued can significantly increase the payoff of the coalition.

Table 2 showed that the payoffs did not change substantially as the government food rescue grants for the FRO moved from their low level to their high level. There was a positive correlation between the growth rate of the payoff of the coalition and the growth rate of government food rescue grants for the FRO. The percentual difference of the payoffs between the minimum and maximum values was only 34% while the grant itself grew four-folds. Generally, if the grant increased 100%, the payoff increased by about 11%.

Table 3 displayed that the payoff of the FRO and the FD coalition was positively correlated with the amount of food rescued under the government food donation rebate scheme. The growth rate of the payoffs was greater than the growth rate of the quantities of the food rescued. While the amount of food rescued increased by 100%, the payoff increased by 194%. This positive correlation showed that increasing the amount of food rescued can significantly increase the payoff of the coalition.

Table 4 illustrated that the payoffs of the coalition did not change noticeably as the government food rescue grants for the FRO increasing from AUD60 per tonne to AUD 240 per tonne. There was a positive correlation between the growth rate of the payoff of the coalition and the growth rate of government food rescue grants for the FRO. Every 100% growth of government grants increased the payoffs by 10%.

Table 5 showed that there was a positive correlation between the growth rate of the coalition's payoff and the growth rate of government food donation rebate for the FD. the payoffs did not change substantially as the government food rescue grants moved from their low level to their high level. The benchmark rebate rate was set at 10% (it has coincided with the GST rate in Australia). The lowest rate was 5% and the highest rate was 25%. Generally, if the grants increased 100%, the payoff increased by about 7%.

The results of the numerical examples implied that the food waste levy policy was better than the food donation tax rebate policy for several reasons. Firstly, when the amount of rescued food doubled, the coalition's payoffs grew 215% under the food waste levy policy, and 194% under the food donation tax rebate policy, respectively. Secondly, when the government grants for the FRO increased 100%, the coalition's payoffs grew 11% under the food waste levy policy, and 10% under the food donation tax rebate policy, respectively. Thirdly, the food donation rebate requires a large amount of public funding and is a costly policy for the government. According to the results in Table 5, the food donation rebate policy had very limited capacity to increase the coalition’s payoff.

If the government decided to implement the food waste levy policy, then increasing the amount of rescued food should be the best strategy to improve the coalition's payoff. The growth rate of the coalition's payoff was double the growth rate of the amount of rescued food. This finding shows that the amount of rescued food is the key parameter to improve the coalition’s payoff. The government does not need to set up a high food waste levy to motivate food donors to donate. The higher the levy rate is, the more incidents of illegal dumping and deliberately avoiding paying levies could happen. Thus, more administration costs will occur. The government should charge a reasonable low food waste levy to signal the potential food donors that food donation to food rescue organisations could avoid paying food waste levy and save them money. This signal could induce the stakeholders in the food supply chain to donate more surplus food to the FROs instead of sending food to landfill. Government policies should focus on how to improve the efficiency of the food rescue operation, i.e. to increase the amount of rescuable food.

Booth and Whelan argued that FROs were creditable in terms of providing temporary food solutions to people in poverty but were not efficient mechanisms to ameliorate long term structural problems on food poverty and hunger (Booth & Whelan, 2014). For the long-run solution to food waste, employment and education play critical roles. Regular income provides access to food with dignity. Educational programs in primary schools and high schools, in terms of food production and food waste generation, could establish respect for food and our ecosystems.

6. Conclusion

Given the large scale of the food rescue operation in industrialised countries, the FROs are not likely to disappear in the short run. Evolving from emergency food providers to the corporatised industry, the FROs have received positive and negative feedback from the public. the FDs and the governments have played important roles in shaping the current food rescue industry. Nevertheless, the FROs have achieved two goals: reducing food waste and relieving hunger. This paper discussed the key parameters of food rescue operations under government interventions and how the key parameters impacted the payoffs of the coalition between the FRO and the FD. It was concluded that the amount of rescued food was the most important parameter for the coalition's payoff function. There was a significant payoff increase when the amount of rescued food increased. Government grants rate for the FRO and food donation tax rebate rate were another two key parameters of the payoff function. These two parameters had positive correlations with the coalition's payoff.

Reducing food waste has multiple benefits. In the future, if time series data or panel data are available in terms of the amount of rescued food, the rate and the aggregate amount of government grants for the FRO, and the rate and the aggregate amount of government food donation tax rebate for the FD, then the more specific impacts of food rescue industry could be quantified.

References

Aanesen, M. (2012). Sequential bargaining, external effects of agreement, and public intervention. *Journal of Economics, 105*(2), 145-160. doi:10.1007/s00712-011-0220-1

Abd Razak, S. (2017). Household Food Waste Prevention in Malaysia: An Issue Processes Model Perspective. In S. S. Liu, A. Ramirez, & R. Watson (Eds.): ProQuest Dissertations Publishing.

Aldashev, G., Marini, M., & Verdier, T. (2014). Brothers in alms? Coordination between nonprofits on markets for donations. *Journal of Public Economics, 117*, 182-200. doi:https://doi.org/10.1016/j.jpubeco.2014.04.009

APEC. (2019). *Article 7 in Fifth APEC Ministerial Meeting Declaration on Food Security.* Puerto Varas, Chile. Retrieved from http://mddb.apec.org/Documents/2019/MM/FSMM/19_fsmm_jms.pdf

Bernstad Saraiva Schott, A., & Andersson, T. (2015). Food waste minimization from a life-cycle perspective. *Journal of Environmental Management*, *147*, 219-226. doi:https://doi.org/10.1016/j.jenvman.2014.07.048

Booth, S., & Whelan, J. (2014). Hungry for change: The food banking industry in Australia. *British Food Journal, 116*(9). doi:10.1108/BFJ-01-2014-0037

Callan, S. J., & Thomas, J. M. (2001). Economies of Scale and Scope: A Cost Analysis of Municipal Solid Waste Services. *Land Economics, 77*(4), 548-560. doi:10.2307/3146940

Cecere, G., Mancinelli, S., & Mazzanti, M. (2014). Waste prevention and social preferences: the role of intrinsic and extrinsic motivations. *Ecological Economics, 107*, 163-176. doi:https://doi.org/10.1016/j.ecolecon.2014.07.007

Chen, C. R., & Rachel, J. C. C. (2018). Using Two Government Food Waste Recognition Programs to Understand Current Reducing Food Loss and Waste Activities in the U.S. *Sustainability, 10*(8), 2760. doi:10.3390/su10082760

Chen, X., Fujita, T., Hayashi, Y., Kato, H., & Geng, Y. (2014). Determining optimal resource recycling boundary at regional level: A case study on Tokyo Metropolitan Area in Japan. *European Journal of Operational Research*, *233*(2), 337-348. doi:https://doi.org/10.1016/j.ejor.2013.01.054

Cicatiello, C., Franco, S., Pancino, B., & Blasi, E. (2016). The value of food waste: An exploratory study on retailing. *Journal of Retailing and Consumer Services, 30*, 96-104. doi:https://doi.org/10.1016/j.jretconser.2016.01.004

Cristóbal, J., Castellani, V., Manfredi, S., & Sala, S. (2018). Prioritizing and optimizing sustainable measures for food waste prevention and management. *Waste Management, 72*, 3-16. doi:https://doi.org/10.1016/j.wasman.2017.11.007

Davis, L. B., Jiang, S. X., Morgan, S. D., Nuamah, I. A., & Terry, J. R. (2016). Analysis and prediction of food donation behavior for a domestic hunger relief organization. *International Journal of Production Economics, 182*, 26-37. doi:https://doi.org/10.1016/j.ijpe.2016.07.020

Department of the Environment and Energy. (2017). *National Food Waste Strategy 2017*. Canberra. Retrieved from https://www.environment.gov.au/system/files/resources/4683826b-5d9f-4e65-9344-a900060915b1/files/national-food-waste-strategy.pdf

Department of the Environment and Energy. (2018). *National West Report 2018.* Canberra. Retrieved from *https://www.environment.gov.au/system/files/resources/7381c1de-31d0-429b-912c-91a6dbc83af7/files/national-waste-report-2018.pdf*

Department of the Environment and Energy. (2019). *National Food Waste Baseline Final*

Assessment Report – Executive Summary. Canberra. Retrieved from *https://www.environment.gov.au/system/files/pages/25e36a8c-3a9c-487c-a9cb-66ec15ba61d0/files/national-food-waste-baseline-executive-summary.pdf*

Dijkgraaf, E., & Vollebergh, H. R. J. (2004). Burn or bury? A social cost comparison of final waste disposal methods. *Ecological Economics, 50*(3), 233-247. doi:https://doi.org/10.1016/j.ecolecon.2004.03.029

Eriksson, O., Carlsson Reich, M., Frostell, B., Björklund, A., Assefa, G., Sundqvist, J. O., . . . Thyselius, L. (2005). Municipal solid waste management from a systems perspective. *Journal of Cleaner Production, 13*(3), 241-252. doi:https://doi.org/10.1016/j.jclepro.2004.02.018

Facchini, E., Iacovidou, E., Gronow, J., & Voulvoulis, N. (2018). Food flows in the United Kingdom: The potential of surplus food redistribution to reduce waste. *Journal of the Air & Waste Management Association, 68*(9), 887-899. doi:10.1080/10962247.2017.1405854

FAO. (2011). *Global food losses and food waste – Extent, causes and prevention.* Rome. Retrieved from http://www.fao.org/3/a-i2697e.pdf

FAO. (2014). *Mitigation of Food Wastage: Social costs and benefits.* Rome. Retrieved from http://www.fao.org/3/a-i3989e.pdf

FAO. (2015). *Food Wastage Footprint and Climate Change.* Rome. Retrieved from http://www.fao.org/3/a-bb144e.pdf

FAO. (2017). *Water for sustainable food and Agriculture.*Rome. Retrieved from http://www.fao.org/3/a-i7959e.pdf

FAO. (2019). *The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns*. Rome. Retrieved from http://www.fao.org/3/ca5162en/ca5162en.pdf

Garrone, P., Melacini, M., & Perego, A. (2014). Opening the black box of food waste reduction. *Food Policy, 46*, 129-139. doi:https://doi.org/10.1016/j.foodpol.2014.03.014

Girotto, F., Alibardi, L., & Cossu, R. (2015). Food waste generation and industrial uses: A review. *Waste Management, 45*, 32-41. doi:https://doi.org/10.1016/j.wasman.2015.06.008

Giuseppe, A., Mario, E., & Cinzia, M. (2014). Economic benefits from food recovery at the retail stage: An application to Italian food chains. *Waste Management, 34*(7), 1306-1316. doi:https://doi.org/10.1016/j.wasman.2014.02.018

Gustavsson, J., & Stage, J. (2011). Retail waste of horticultural products in Sweden. *Resources, Conservation and Recycling, 55*(5), 554-556. doi:https://doi.org/10.1016/j.resconrec.2011.01.007

Hafezalkotob, A., Alavi, A., & Makui, A. (2016). Government financial intervention in green and regular supply chains: Multi-level game theory approach. *International Journal of Management Science and Engineering Management, 11*(3), 167-177. doi:10.1080/17509653.2015.1004202

Halloran, A., Clement, J., Kornum, N., Bucatariu, C., & Magid, J. (2014). Addressing food waste reduction in Denmark. *Food Policy, 49*, 294-301. doi:https://doi.org/10.1016/j.foodpol.2014.09.005

Hamilton, H. A., Peverill, M. S., Müller, D. B., & Brattebø, H. (2015). Assessment of Food Waste Prevention and Recycling Strategies Using a Multilayer Systems Approach. *Environmental Science & Technology, 49*(24), 13937-13945. doi:10.1021/acs.est.5b03781

Headey, D., Malaiyandi, S., & Fan, S. (2010). Navigating the perfect storm: reflections on the food, energy, and financial crises. *Agricultural Economics, 41*(s1), 217-228. doi:10.1111/j.1574-0862.2010.00502.x

Hennet, J.-C., & Mahjoub, S. (2010). Toward the fair sharing of profit in a supply network formation. *International Journal of Production Economics, 127*(1), 112-120. doi:https://doi.org/10.1016/j.ijpe.2010.04.047

Hermsdorf, D., Rombach, M., & Bitsch, V. (2017). Food waste reduction practices in German food retail. *British Food Journal, 119*(12), 2532-2546. doi:10.1108/BFJ-06-2017-0338

HLPE. (2014). *Food losses and waste in the context of sustainable food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. Rome. Retrieved from http://www.fao.org/3/a-i3901e.pdf

Huck, S., & Kübler, D. (2000). Social pressure, uncertainty, and cooperation. *Economics of Governance, 1*(3), 199. doi:10.1007/PL00011015

Izquierdo, J. M., & Rafels, C. (2018). The core and the steady bargaining set for convex games. *International Journal of Game Theory, 47*(1), 35-54. doi:10.1007/s00182-017-0576-8

Jamali, M.-B., & Rasti-Barzoki, M. (2018). A game theoretic approach for green and non-green product pricing in chain-to-chain competitive sustainable and regular dual-channel supply chains. *Journal of Cleaner Production, 170*, 1029-1043. doi:https://doi.org/10.1016/j.jclepro.2017.09.181

Jørgensen, S. (2010). A dynamic game of waste management. *Journal of Economic Dynamics and Control, 34*(2), 258-265. doi:https://doi.org/10.1016/j.jedc.2009.09.005

Karmperis, A. C., Aravossis, K., Tatsiopoulos, I. P., & Sotirchos, A. (2013). Decision support models for solid waste management: Review and game-theoretic approaches. *Waste Management, 33*(5), 1290-1301. doi:https://doi.org/10.1016/j.wasman.2013.01.017

Kaushal Rajendra, K., & Nema Arvind, K. (2013). Game Theory–Based Multistakeholder Planning for Electronic Waste Management. *Journal of Hazardous, Toxic, and Radioactive Waste, 17*(1), 21-30. doi:10.1061/(ASCE)HZ.2153-5515.0000141

Kollikkathara, N., Feng, H., & Yu, D. (2010). A system dynamic modeling approach for evaluating municipal solid waste generation, landfill capacity and related cost management issues. *Waste Management, 30*(11), 2194-2203. doi:https://doi.org/10.1016/j.wasman.2010.05.012

Kulikovskaja, V., & Aschemann-Witzel, J. (2017). Food Waste Avoidance Actions in Food Retailing: The Case of Denmark. *Journal of International Food & Agribusiness Marketing, 29*(4), 328-345. doi:10.1080/08974438.2017.1350244

Lindberg, R. L., Lawrence, M., Gold, L., & Friel, S. (2014). Food Rescue -An Australian Example. *British Food Journal, 116*(9). doi:10.1108/BFJ-01-2014-0053

Liu, G. (2014). Food Losses and Food Waste in China: A First Estimate. *OECD Food, Agriculture and Fisheries Papers,* (66), 0_1-29. doi:doi:https://doi.org/10.1787/5jz5sq5173lq-en

Mena, C., Adenso-Diaz, B., & Yurt, O. (2011). The causes of food waste in the supplier–retailer interface: Evidences from the UK and Spain. *Resources, Conservation and Recycling, 55*(6), 648-658. doi:https://doi.org/10.1016/j.resconrec.2010.09.006

Muriana, C. (2015). Effectiveness of the food recovery at the retailing stage under shelf life uncertainty: An application to Italian food chains. *Waste Management, 41*, 159-168. doi:https://doi.org/10.1016/j.wasman.2015.03.028

Nair, D. J., Rashidi, T. H., & Dixit, V. V. (2017). Estimating surplus food supply for food rescue and delivery operations. *Socio-Economic Planning Sciences, 57*, 73-83. doi:https://doi.org/10.1016/j.seps.2016.09.004

Nash, J. (1951). Non-Cooperative Games. *Annals of Mathematics, 54*(2), 286-295. doi:10.2307/1969529

Nash, J. (1953). Two-Person Cooperative Games. *Econometrica, 21*(1), 128-140. doi:10.2307/1906951

Pan, J., & Voulvoulis, N. (2007). The Role of Mechanical and Biological Treatment in Reducing Methane Emissions from Landfill Disposal of Municipal Solid Waste in the United Kingdom. *Journal of the Air & Waste Management Association, 57*(2), 155-163. doi:10.1080/10473289.2007.10465317

Papargyropoulou, E., Lozano, R., K. Steinberger, J., Wright, N., & Ujang, Z. b. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner Production, 76*, 106-115. doi:https://doi.org/10.1016/j.jclepro.2014.04.020

Peng, X., & Tao, X. (2018). Cooperative game of electricity retailers in China's spot electricity market. *Energy, 145*, 152-170. doi:https://doi.org/10.1016/j.energy.2017.12.122

Reynolds, C., Geschke, A., Piantadosi, J., & Boland, J. (2016). Estimating industrial solid waste and municipal solid waste data at high resolution using economic accounts: an input–output approach with Australian case study. *Journal of Material Cycles and Waste Management, 18*(4), 677-686. doi:10.1007/s10163-015-0363-1

Reynolds, C., Piantadosi, J., & Boland, J. (2015). Rescuing Food from the Organics Waste Stream to Feed the Food Insecure: An Economic and Environmental Assessment of Australian Food Rescue Operations Using Environmentally Extended Waste Input-Output Analysis. *Sustainability, 7*(4), 4707-4726. doi:10.3390/su7044707

Rutten, M. M. (2013). *The Economic Impacts of (Reducing) Food Waste and Losses : A Graphical Exposition*. Retrieved from http://edepot.wur.nl/384845

Schneider, F. (2013). The evolution of food donation with respect to waste prevention. *Waste Management, 33*(3), 755-763. doi:https://doi.org/10.1016/j.wasman.2012.10.025

Shapley, L. S., & Shubik, M. (1969). On the Core of an Economic System with Externalities. *The American Economic Review, 59*(4), 678-684.

Sinayi, M., & Rasti-Barzoki, M. (2018). A game theoretic approach for pricing, greening, and social welfare policies in a supply chain with government intervention. *Journal of Cleaner Production, 196*, 1443-1458. doi:https://doi.org/10.1016/j.jclepro.2018.05.212

Soltani, A., Sadiq, R., & Hewage, K. (2016). Selecting sustainable waste-to-energy technologies for municipal solid waste treatment: a game theory approach for group decision-making. *Journal of Cleaner Production, 113*, 388-399. doi:https://doi.org/10.1016/j.jclepro.2015.12.041

Stangherlin, I. D. C., & de Barcellos, M. D. (2018). Drivers and barriers to food waste reduction. *British Food Journal, 120*(10), 2364-2387. doi:10.1108/BFJ-12-2017-0726

Thyberg, K. L., & Tonjes, D. J. (2016). Drivers of food waste and their implications for sustainable policy development. *Resources, Conservation and Recycling, 106*, 110-123. doi:https://doi.org/10.1016/j.resconrec.2015.11.016

Vlaholias, E., Thompson, K., Every, D., & Dawson, D. (2015). Charity Starts ... at Work? Conceptual Foundations for Research with Businesses that Donate to Food Redistribution Organisations. *Sustainability, 7*(6), 7997-8021. doi:10.3390/su7067997

Vlaholias-West, E., Thompson, K., Chiveralls, K., & Dawson, D. (2018). The Ethics of Food Charity. In P. B. Thompson & D. M. Kaplan (Eds.), *Encyclopedia of Food and Agricultural Ethics* (pp. 1-5). Dordrecht: Springer Netherlands.

Warshawsky, D. N. (2015). The devolution of urban food waste governance: Case study of food rescue in Los Angeles. *Cities, 49*, 26-34. doi:https://doi.org/10.1016/j.cities.2015.06.006