A System Dynamics analysis of the causes of Australian recycling rates plateauing below full potential

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I certify this PhD thesis as my own work unless otherwise acknowledged

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Abstract

As Australia enters the 21st century, there is increasing discussion around waste and circular economies. The mindset of landfilling waste is becoming more difficult to justify and as natural resources are depleting is it increasingly necessary to move toward a circular economy. An existing option to improve sustainability is the recycling of waste materials, a process that has a long history in Australia. However, we are now seeing Australian Municipal Solid Waste (MSW) and certain material recycling rates plateauing below their full capacity. To continue recycling momentum, it is necessary to identify barriers preventing improvement in recycling rates.

Existing research on recycling has commonly concentrated upon a part of the recycling system, but ignored the whole. This thesis uses System Dynamics (SD) to address the MSW recycling plateau problem and to resolve the following issues: (a) how do MSW recycling plateaus relate to material recycling plateaus, (b) what role do recycling influences play with MSW recycling plateaus and bin contamination, and (c) are the forces driving MSW recycling rates exogenous or endogenous to the waste control system?

A case study on Old Newspaper (ONP) recycling plateaus addressed the link between a material experiencing plateauing recycling rates and its relationship to MSW plateauing recycling rates. The intention of this study was to determine whether the barrier to higher ONP recycling rates was the capture of ONP in the MSW recycling system (supply) or the demand for ONP as a raw material for remanufacture. The key limiting factor in ONP recycling rates was found to be supply, predominantly from MSW, thus emphasising the importance of MSW recycling systems in material recovery and leading to the analysis of MSW to better understand recycling plateaus.

The role of recycling influences on MSW recycling plateaus and bin contamination was investigated via a local government case study. Recycling influences refers to the ten variables found via the literature review that could possibly act as barriers to recycling rates; demographics, policy, disposal knowledge, waste collection service quality, dwelling type, attitude toward recycling, time devoted to recycling, recycling social norms, MRF sorting quality and household consumption trends. These variables were investigated using Australian census data, a household survey and a waste audit. It was determined that the level of plateau was primarily caused by consumption trends. If a higher proportion of recyclables was in the waste stream, then the recycling plateaus would also rise.

MSW bin contamination was also an important factor in determining recycling rate levels, with incorrectly disposed waste showing potential to inflate or deflate recycling rates. Household disposal knowledge and biases when making uncertain decisions were found to be the key influences on bin contamination levels.

When using System Dynamics to model the municipal waste system, a purely endogenous explanation for plateauing recycling rates could not be found. Recycling rate plateau level was largely determined by exogenous waste stream proportions, which could also be described as residential consumption trends. The only endogenous feedback was in the form of council education campaigns, responding to increased recycling bin contamination. When this feedback loop was active it resulted in significant decreases in bin contamination and a small increase in the recycling rate plateau.

From this research, two potential endogenous pathways for increasing MSW recycling rates were identified and recommended for further research; (a) councils influencing consumption habits, and (b) council influencing retail packaging types. Both feedback loops represented a means for Australian local government to influence their recycling rates through behaviour change.

Publications

1. Moloney, B & Doolan, M. (2016). A Comparison of Obstacles in Emerging and Developed Nation Dry Waste Recovery. *Procedia CIRP*, 40.

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List of Acronyms

SD	System Dynamics
MSW	Municipal Solid Waste
C&I	Commercial and Industrial
C&D	Construction and Demolition
ONP	Old Newspaper
PCA	Principal Component Analysis
TPB	Theory of Planned Behaviour
NAT	Norm Activation Theory
PBC	Perceived Behavioural Control
GW	General Waste
MRF	Municipal Recycling Facility
NSW	New South Wales
ABS	Australian Bureau of Statistics
CZ	Collection zone
SA	South Australia
CLD	Causal Loop Diagram
S&F	Stock and Flow
MUD	Multi Unit Dwelling

Introduction

1.1 Context and Statement of the Problem

The earth is a closed system – radiant energy can enter and leave but matter generally does not. At the same time we have an economic system that emphasizes growth, resulting in growing demand for soil, fossil fuels, minerals and water (Daley, 2004). The consequence is existing or inevitable future stress on finite stocks. Therefore, it is essential that we use limited stocks efficiently and ensure there is little or no waste, assisting in the transition to a closed loop economy.

One method of improving the efficiency of material use is the recycling of materials within the human economy. However, in recent times there has been evidence that recycling rates have begun to plateau below their full potential. Full potential being 100 per cent of a recyclable material or materials.

Materials and waste sources have been described as experiencing recycling plateaus in a variety of literature. Australian newspaper recycling was described as experiencing a 'plateau of recovery' below full potential with about 75% of newspaper being recovered (PNEB, 2010; Industry Edge, 2013). It was indicated that it would be difficult to improve recycling rates since a proportion of old newspaper (ONP) is unrecoverable or is uneconomic to recover (PNEB, 2010). Australian paperboard (i.e. cardboard) was 'at or near international best practice' also with about 75% being recovered (Industry Edge, 2015; Industry Edge, 2016). Additionally, EU paper recycling was described as getting 'close to achievable limits' with about 72% being captured (European Recovered Paper Council, 2012).

Aside from paper and cardboard recycling rates, plateaus have also been reported for some plastics and metals. US PET bottle recycling was described as experiencing a 'plateau' at around 31% (Recyclers, 2016). Similarly in the US, some aluminium producers are experiencing recycling declines or plateaus in the US at about 65% (Miralla, 2011; The Aluminum Association, 2016).

There have also been numerous reports of plateauing Municipal Solid Waste (MSW) recycling rates in the US, UK and Australia (DNREWMB, 2006; Nowatzki, 2008; Northeast Waste Management Officials Association, 2012; Milton Keynes Council, 2013; Victorian Government, 2013; SLR Consulting, 2015; Priestly, 2016). For instance, in both US and UK, national waste flow data indicates plateaus are occurring at about 27% (US EPA, 2012; EuroStat, 2014).

While national MSW data is not available in Australia, there have been several reports of plateauing MSW recycling rates. The Burnie City Council in Tasmania found a rapid rise in recyclables recovered when they introduced a comingled recycling system in 2009, however recovery of recyclables had plateaued by 2013 (Burnie City Council, 2013). The Shire of Campaspe in northern Victoria also stated in 2012 that increases in recycling rates were plateauing (Shire of Campaspe, 2012). The major Australian industry waste publication 'Inside Waste', has also written that although there was rapid MSW recycling improvement in the late 20th century recycling rates were now plateauing (WMAA, 2016).

The level at which municipal waste is plateauing also appears to be below full potential, demonstrated by the loss of recyclables via incorrect disposal (APrince Consulting, 2011; APrince Consulting, 2016). In this case, the full potential recycling rate is defined as the proportion of the MSW stream composed of recyclables. It can be difficult to determine the full potential recycling rate of MSW as the proportion of recyclables in the waste stream may vary. Waste audits performed in the UK and Australia show a proportion of dry recyclables in the waste stream between 32% to 36% (SA EPA, 2002; Weitz, 2002; Burnley, 2007; OEH, 2011; NSW EPA, 2014).

To summarise the problem; we are depleting our natural resources (Daley, 2004), meaning we need to create a circular economy to sustain the natural environment

(Porter R. C., 2002). The recovery and recycling of materials within the human economy is a key step towards this circular economy. Unfortunately, we are seeing plateauing in recycling rates below their full potential, suggesting we have encountered a barrier to the circular economy that needs to be overcome.

1.2 Aim

The aim of this thesis is to find the specific set of factors that are causing recycling rates to plateau below full potential.

This will provide a foundation for creating strategies to rectify the plateauing of recycling rates.

1.3 Scope

This project will concentrate on the Australian waste environment and will focus upon one of the three waste streams mentioned to be experiencing plateaus: MSW recycling rates. However, it should be noted that there is overlap between MSW and material waste flows. Materials such as ONP, PET, aluminium and paperboard are components of the MSW stream. ONP and paperboard are the two materials that also show evidence of recycling plateaus in Australia. From these two materials, ONP recycling plateaus were chosen to investigate in greater detail to determine what the recycling barriers may be, and if they relate to MSW recycling plateaus. Therefore, there will also be a case study on ONP recycling rates to provide insight into how the two waste streams relate.

It is necessary to emphasise that two different equations were used to calculate MSW and ONP recycling rates. For instance, MSW recycling rates were found by finding the ratio between the amount of material placed in recycling bins and the entire MSW waste stream (Equation 1.1) (WA, 2010). This approach was applied as it is the method used by the Australian government and due to the manner data was recorded by Landfill and Municipal Recycling Facility (MRF) weighbridges.

$$MSW\ recycling\ rate = \frac{material\ in\ recycling\ bin}{total\ MSW\ stream} \quad [1.1]$$

In contrast, the ONP recycling rate was found by calculating the ratio between the amount of ONP recovered and the total amount of ONP consumed, as seen in Equation 1.2.

$$ONP\ recycling\ rate = \frac{amount\ of\ ONP\ recovered}{total\ ONP\ consumed} \quad [1.2]$$

As stated, this thesis will focus upon the Australian continent and will assume an Australian regulatory environment. This encompasses three levels of government; local, state and federal. Local or municipal government bears the responsibility for the day-to-day waste management operations which encompasses municipal waste collection, landfill management, Municipal Recycling Facility (MRF) management, waste data recording and reporting, and the setting of bin contamination and recycling targets (Blue Environment, 2014). The federal and state government oversee broader waste policy such as Extended Producer Responsibility (EPR) programs, landfill levies and Container Deposit Schemes (CDS) (Amcor, 2010). Although the federal and state have the potential to be highly influential on MSW recycling rates, they have generally been content to delegate responsibility to local government. For this reason, this thesis will focus upon the local government level of waste policy.

As a final point, when a MSW system is referred to in this thesis, it pertains to the generic model used in Australia. This is a household kerbside collection service for up to three bins; a 240l recycling bin, a 120l GW bin, and 240l garden waste bin. The garden waste bin is considered outside the scope of this thesis, as garden waste is subject to different influences than manufactured materials. This thesis will encompass the flow of materials through households and their passage to a MRF or landfill.

1.4 Overview of the Study

This thesis contains 7 further chapters. Chapter 2 carries out a critical analysis of existing literature relating to recycling rate plateaus. A major goal of Chapter 2 is the distillation of recycling rate influences using past research. There is also a review of waste related System Dynamics (SD) literature. Chapter 3 continues the focus on SD, presenting the dynamic hypothesis of the research. The dynamic hypothesis is presented using a Stock and Flow Model and a Causal Loop Diagram. A large part of Chapter 3 explains how existing theory around learning and uncertain decision making informed the model construction.

Chapter 4 involves a case study on Australian Old Newspaper (ONP), a material experiencing plateauing recycling rates. The chapter looks at ONP in terms of supply and demand, and aims to determine whether it is supply or demand causing the plateau below full potential. This chapter also provides some insight into the impact of waste origin on recycling plateaus, particularly MSW and C&I waste. Chapters 5 and 6 investigate the list of potential influences on recycling rates collated in Chapter 2. Chapter 5 delves into the relationship between demographic variables and MSW recycling rate plateaus. Data is sourced from the Australian census and is analysed using Principal Component Analysis (PCA) and correlation. The results from a household survey are explored in Chapter 6, providing insight into recycling behaviour within households. Chapter 7 uses the results from Chapter 5 and 6 to inform the creation of a SD model. The chapter discusses the structure of the model before outlining the various model tests. Conclusions of the thesis and answers to the research questions are presented in Chapter 8.

1.5 Significance of the Study

This thesis will contribute to; (a) advancing knowledge in the field of waste and recycling research, and (b) assist with solving practical problems faced by waste policy makers.

Knowledge will be advanced in a variety of analyses. For instance, the recycling leverage points of a material (Old Newspaper) and waste originating from MSW will be investigated. Additionally, new techniques will be used to collect high quality demographic data from the Australian census and analysed in relation to recycling rates. Also, a new recycling rate influence was proposed and its impact on recycling rate plateaus tested. Finally, a SD interpretation of the Australian recycling environment will identify key feedback loops driving recycling rates.

The creation and testing of a simulation model also assisted with solving practical problems faced by waste policy makers. The model may be used to identify the variables that will have the greatest impact on recycling rate plateaus or bin contamination (i.e. leverage points). Policies can subsequently be designed to target these leverage points.

Literature Review

This chapter summarises the literature to identify potential influences on recycling rates and investigates why some are plateauing. As stated previously, three types of recycling rate in Australia have shown plateau like trends; ONP, paperboard and MSW. MSW was the chosen focus of this thesis as it constitutes a significant portion of waste, making up an estimated 25% of the Australian waste flow (Blue Environment, 2014). The recycling system consists of several stages, from material recovery to processing and finally sales of recycled material. This thesis will focus upon the material recovery phase.

The three major sections of the literature review include a qualitative literature review discussing specific recycling influences, a quantitative literature review summarising those influences, and a discussion of previous System Dynamics (SD) waste analysis. The qualitative literature review will explore past literature, comparing research methods and results with aim of finding similarities, discrepancies and research gaps. The quantitative literature review will distil relevant information from a large amount of literature and provide a foundation for the discussion of systems analysis. The SD literature review provides an opportunity to ponder how the collection of influences may interact to form recycling rate dynamics.

2.1 Qualitative Literature Review

After an extensive review of current literature, potential influences on MSW recycling rates were divided into seven categories; attitude based theories, norm based theories, MSW recycling economics, context related theories, knowledge related theories, demographics and waste policy. MSW recycling economics discusses the correlation between commodity markets and full potential recycling rates while context related theories probe the influence of the recycling environment on recycling rates. Intangible recycling influences are reviewed via attitude, social norm and knowledge based theories. Further discussion of intangibles is had around demographics and related back to attitude, social norm and knowledge theories. There is also a discourse on types of waste policy and how this may affect recycling rates.

2.1.1 Attitude based theories (Theory of Planned Behaviour)

The Theory of Planned Behaviour (TPB) has frequently been used to study the major influences on recycling behaviour (Figure 2.1). It emphasises the impact of an individuals' perceptions influencing the likelihood of performing a behaviour.

The TPB suggests that the major influences on behaviour adoption are 'attitude toward the behaviour', 'the subjective norms of the behaviour', and 'the perceived behavioural control (PBC)' a person has when performing the behaviour (Ajzen, 1986). The term 'attitude' refers to the degree to which an individual has a positive or negative evaluation of the behaviour in question, while subjective norms signify the perceived social pressure to perform or not to perform a behaviour. In addition, PBC represents a persons' belief as to how easy or difficult it is to perform a behaviour. The TPB also suggests that there is interaction between these three variables, which then collectively influence the intention to perform the behaviour. The magnitude of the intention to perform behaviour influences the likelihood of the behaviour being performed.

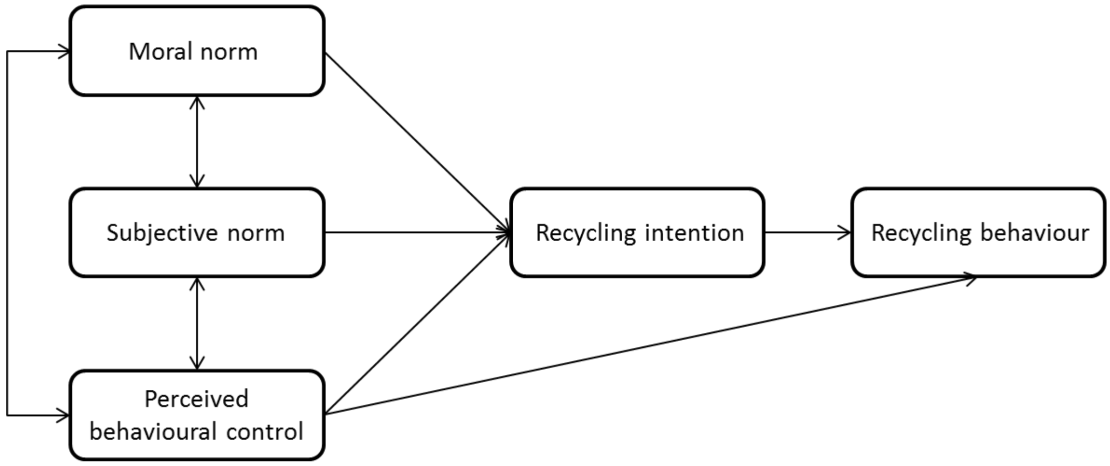


Figure 2.1 Theory of planned behaviour (Ajzen, 1986)

The research methodology for testing the TPB commonly uses questionnaires for data collection, containing question groupings that correspond with the major TPB concepts; attitude, social norms, PBC, and behavioural intention (Ajzen, 1986; Barr S. G., 2001; Oom Do Valle, 2005). Behavioural intention is often considered the dependent variable in TPB studies, meaning there is the assumption that people act as they intend to.

The generic approach to studying the link between TPB and recycling involves testing the statistical significance of the relationship between 'intention to recycle' and 'attitude', 'social norms' and 'PBC'. Variations of this include placing greater emphasis on one of the explanatory variables, such as Fornara *et al.* (2011) who investigated injunction and descriptive social norms and their potential effect on household recycling intentions. Other TPB work has involved the comparison of related behaviours, to determine if there are differences. Barr *et al.* (2001) used this technique and TPB to investigate whether household recycling, waste minimization behaviour and reuse behaviour had significant differences.

Across the many studies performed on TPB and participation in recycling there have been conflicting results. With regards to PBC, a measure of perception of recycling difficulty, there have been several studies that have found that PBC does not significantly link with intention to recycle (Boldero, 1995; Tonglet, 2004; Nigbur, 2010). These studies are generally based in regions with established kerbside recycling systems, with limited time commitment required from households to sort waste and many of years of experience for participants to learn the disposal process. The results suggest that when recycling is easy to perform, PBC is not the major obstacle limiting recycling participation.

There have also been numerous studies that have concluded that PBC is significantly linked with recycling intention or behaviour (Oom Do Valle, 2005; Davis, 2008; Fornara, 2011; Chan, 2013). These studies have differed from the former in similar ways; recruitment bias towards a certain type of participant and no description of the associated waste disposal system (Boldero, 1995; Fornara, 2011; Chan, 2013). Chan *et al.* (2013) recruited participants from university websites and Facebook, resulting in most contributors being university students. Fornara *et al.* (2011) quizzed citizens of four Italian cities in public spaces about their waste disposal habits. The younger demographic in Chan's study may affect perception of recycling behavioural control due to lifestyle factors; such as shared housing or living with parents. Also, the lack of significant information on the type of waste disposal system in Fornara's work raises the possibility it may be a location where it is difficult to recycle. As it is likely that PBC decreases as a recycling system becomes more complex, it may be a significant reason for non-participation in these contexts. Other studies also described waste disposal systems that had greater complexity. For example, Oom do Valle *et al.* (2005) studied waste disposal systems in Portugal, which required householders to sort and transport their waste to a local neighbourhood bin thus requiring a more time consuming disposal by householders.

The subjective (social) norms of a population have been proposed as a significant influence on waste disposal behaviour, with support from multiple studies (Barr S. G., 2001; Oom Do Valle, 2005; Nigbur, 2010; Fornara, 2011; Chan, 2013). For Oom do Valle *et al.* (2005), this may be due to the high visibility of disposal behaviour with recycling taking place at a community bin. The mode of data collection should also be considered as Fornara's *et al.* (2011) data collection involved face-to-face interviews which, considering the social desirability of recycling, may have exaggerated the social norm effect on recycling behaviour. A social norm effect was also seen for some kerbside systems (Barr S. G., 2001; Nigbur, 2010). Kerbside waste disposal could also be considered a highly visible behaviour and may directly affect participation levels, although housing patterns and level of community cohesion could temper this relationship.

Housing patterns and community cohesion may partly explain why some studies have not found significant relationships between social norms and participation in recycling (Boldero, 1995; Tonglet, 2004; Davis, 2008). The age of a waste disposal system may also impact the significance of social norms. People develop their own habits over time and when experienced in recycling may pay less attention to their peers. Additionally, Boldero (1995) carried out her studies with a focus on one product, newspaper, with participants observing newspaper disposal in their household. With previous studies looking at norm effects on disposal behaviour between households, Boldero was observing norm effects within the household.

When looking at the pattern of results relating attitudes toward recycling and intention to recycle there is evidence of a strong relationship (Boldero, 1995; Barr S. G., 2001; Davies, 2002; Tonglet, 2004; Oom Do Valle, 2005; Davis, 2008; Nigbur, 2010; Fornara, 2011). However, when attitude towards recycling is tested against recycling participation this link does not always hold (Boldero, 1995; Nigbur, 2010). In other studies, a significant relationship between attitudes and recycling participation was found (Oom Do Valle, 2005). All the studies cited have used self-reporting measures to indicate the level of intention to recycle or actual recycling behaviour. The first factor to consider is the positive perception of recycling behaviour. There is evidence that participants in self-report studies will overestimate the likelihood of performing norm behaviour (Tonglet, 2004; Paulhus, 2007). The second factor to consider is the strength of the link between intention to recycle and recycling participation. In some studies, there was evidence that intention does not always lead to action (Davies, 2002; Davis, 2008).

The discussion of previous studies has illuminated some of the flaws in the TPB literature. Firstly, TPB research has a limited perspective; whether someone participates or does not participate in the target behaviour. There is no insight into the performance of the behaviour. In the case of recycling this is important because an individual may take part in recycling but do so poorly, separating waste inaccurately or at the wrong time. There is also the issue of the context of the study. There is potential for the results of a TPB study to be dramatically different based on the waste disposal system that is being used. This emphasizes the importance in knowing the specifics of the disposal system in use, something that was not always present in the literature. A final point relates to the characteristics of self-report data collection. There is the potential for inaccuracies when there is possible bias, such as when behaviour is considered socially desirable. This was apparent when looking at the findings of the link between attitude and intention to recycle. This did not always translate to participation in recycling programs.

2.1.2 Norm-based Theories/Studies

The Norm Activation Theory (NAT) emphasizes the impact of social norms in the adoption of new behaviour (Figure 2.2). The major variables in the NAT include social norms, personal norms, awareness of consequences and ascription of responsibility (Guagnano, 1995). The theory proposes that social norms influence an individual's personal norms over time. As personal norms evolve to match surrounding social norms, and if this combines with an ascription of responsibility and an awareness of consequences for a concept or behaviour, then there is a high likelihood that the behaviour in question will be performed.

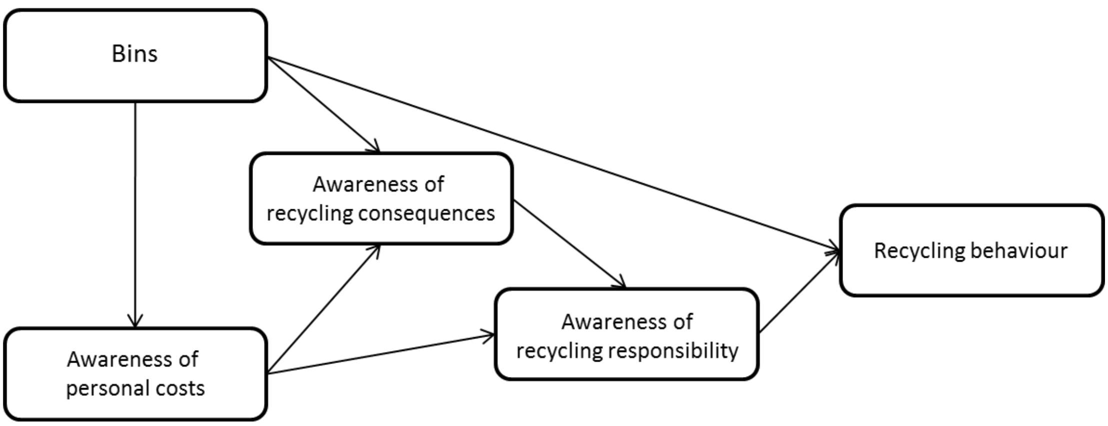


Figure 2.2 Norm activation model

There have been some studies analysing the impact of norms on recycling via the prism of the NAT (Hopper, 1991; Guagnano, 1995). Guagnano *et al.* (1995) used telephone survey interviews to collect data about residents of a US county. Questions related to some of the major variables seen in the NAT, self-reported recycling activities and demographic variables. The NAT related variables measured included ascription of responsibility, awareness of consequences, personal costs, general environmental attitude, and community behaviour. His findings supported the NAT only under the condition the household did not have access to a kerbside bin.

Hopper *et al.* (1991) also used surveys to collect data on NAT related variables; social norms, personal norms and awareness of consequences. However, recycling participation was measured via observation of bin set-outs over one year. Additionally, the surveys were applied before and after an experimental intervention; introducing a block leader, introducing weekly information brochures and monthly information brochures. Block leaders were defined as residents who would actively encourage their neighbours to recycle. Block leader intervention or feedback on community recycling performance was an attempt to increase recycling norms. The results showed that NAT was supported as a valid interpretation of the effect of social norms on recycling behaviour, with block leader intervention found to have significant effects on social norms.

There have also been norm-based studies testing unique hypotheses not based on pre-existing theory, but using experimental intervention, modelling or observation (Bryce, 1997; Schultz, 1998; Tucker P. , 1999; Shaw P. , 2008). Tucker (1999) used models and observational data to determine the norm effect on a kerbside recycling system. His results indicate that normative effects are seen when there are significant numbers recycling. However, these normative effects may be more related to frequency of bin set-outs rather than weight of material disposed. Shaw (2008) also used modelling and observational data to observe norm effects on kerbside recycling. He found that the type of street had a significant impact on the degree of norm effect on bin set-outs, with households in cul-de-sacs being more influenced by neighbours than households on linear streets. Other studies tested information and block leader intervention impact on bin set-outs. Schultz (1998) collected extensive data, not only on bin set-outs, but also the amount of material being disposed and the level of contamination. He found that feedback on neighbourhood or individual recycling behaviour both had a significant impact on bin set-out and amount of material disposed, however no intervention had an impact on level of contamination. Bryce *et al.* (1997) carried out a similar study in New Zealand but found that no interventions had an impact on bin set-outs.

The main points to be taken from these studies include; community norm effect may influence frequency of bin set-out (participation) but not quality of sorting. Norm effect may be influenced by the layout of a neighbourhood and it may require significant numbers of recyclers for a recycling norm effect to be felt.

Again, the norm based studies are generally limited to measuring participation in recycling systems. This omits the quality of the waste disposal taking place. Additionally, it isn't always clear how participation is defined. Is it number of set-outs per week, fortnight, month or year? This can also depend on the frequency of bin pickup provided by the waste collection. Recycling participation is possibly not the most interesting dependent variable when observing the influence of norms. In Australia, where a household pay mandated council rates for the use of kerbside bins and collection, it is in their best interest to participate in kerbside recycling collection. To not do so, would be ignoring a service they continue to pay for. It then becomes more interesting determining the quality of waste separation that takes place, and this would generally not be affected by the behaviour of surrounding households but the norms within the household. However, it should also be noted that most of the studies reviewed were carried out in the early or late 90's, when kerbside recycling was relatively new and participation was not guaranteed to be high.

2.1.3 MSW recycling economics

The economics of MSW recycling and its connection to plateauing recycling rates can be viewed through the prism of supply and demand. The demand for recyclables controls what is considered recyclable in municipal settings (Porter R. C., 2002). In Australia, this is commonly determined by local government and its recycling contractor. The government body aspires to maximize recycling rates and minimize cost of processing waste, as this waste processing cost must be passed on to householders through annual rates. The Municipal Recycling Facility (MRF) and landfill contractor aim to maximize their profits and ideally follow regulations. Under these conditions, the materials that are considered recyclable are commonly those that can generate a profit for the MRF contractor. Some of the factors determining the profitability include; global commodity prices, ease of transport of the recyclable and government regulations such as Container Deposit Schemes (CDS) or Extended Producer Responsibility (EPR) (Beede, 1995). The common profitable material streams in Australia include; aluminium, steel, paper, paperboard, PET, HDPE, selected mixed plastics, and glass (Blue Environment, 2014).

The supply of these recyclables to a local MRF is predominantly determined by the quality of household waste separation, product or packaging manufacturing trends and household consumption trends. When excluding the recovery of biodegradable waste and assuming incineration is not practiced, the proportion of these recyclable materials in the waste stream determine the full potential of recycling rates. The common proportion of recyclables in MSW in Australia is between 32 to 37 per cent of the waste stream (OEH, 2011; NSW EPA, 2014), proportion that can be susceptible to change. Figure 2.3 shows how waste streams in New York City have evolved over the last century, with the proportion of biodegradable waste decreasing and the proportion of manufactured waste increasing (Walsh, 2002).

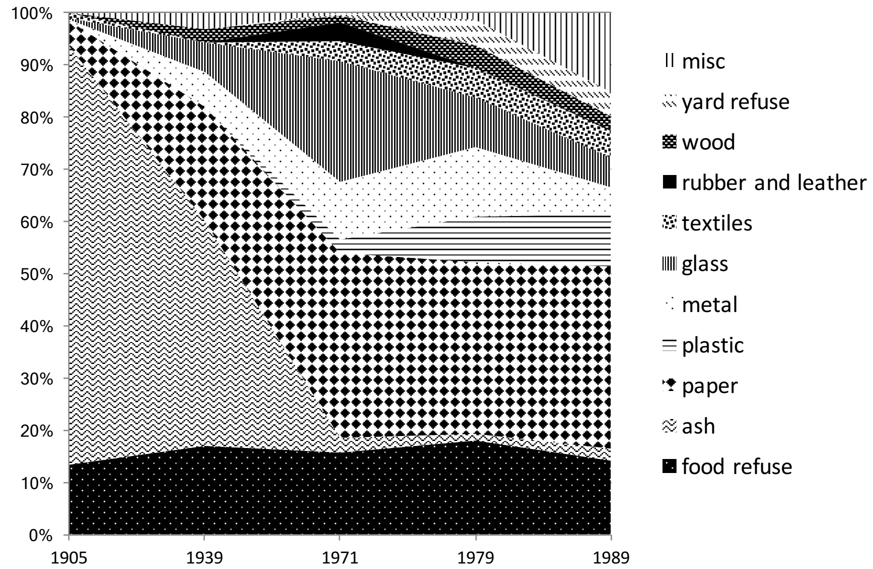


Figure 2.3 New York City, USA MSW stream composition over time (Walsh, 2002)

In addition, manufacturing trends are constantly evolving and in recent years efforts have been made to improve manufacturing efficiency; for example the light weighting of packaging. Light weighting involves decreasing the amount of material used to manufacture each package. From 1992 to 2002, the average weight of glass containers decreased by nearly 50% (Girling, 2003). Aluminium-cans and paperboard have also seen significant improvements in material efficiency through light weighting (EPA, 2004). It is possible these manufacturing changes impact MSW recycling rates.

Technological advancement has also lead to the substitution of tangible products with online services. For example, a trend seen in recent years is decreasing circulation of newspapers due to online journalism. This has reduced the amount of newspapers seen in MSW (Industry Edge, 2013). A similar pattern has been seen with telephone books in Australia, with online classifieds replacing the need for paper versions. Again, these changes have potential impacts on MSW recycling rates.

2.1.4 Context related theories

Some studies have argued that research on recycling behaviour is dependent on the context of the recycling (Derksen, 1993; Guagnano, 1995). This generally means the type of recycling system. The ABC Model proposed by Guagnano *et al.* (1995), suggested that attitude effects behaviour change and this relationship is dependent on external conditions (Figure 2.4). If attitude is extremely positive towards a behaviour and the external conditions are optimal, then behaviour change would be likely. Guagnano *et al.* (1995) compared the level of recycling participation of two groups, one with kerbside recycling access and the other without. He found there was a significantly greater recycling behaviour in those who had access to a kerbside bin even though both had strong pro-recycling attitudes. Derksen *et al.* (1993) found that only when people with high levels of 'concern for environment' had access to a kerbside recycling service, was there a positive effect on recycling behaviour. He also found no significant difference in recycling behaviour between concerned and unconcerned residents when there was access to kerbside recycling. This indicates that 'concern for environment' is possibly a weak influence on recycling behaviour or access to a kerbside service is a very strong influence.

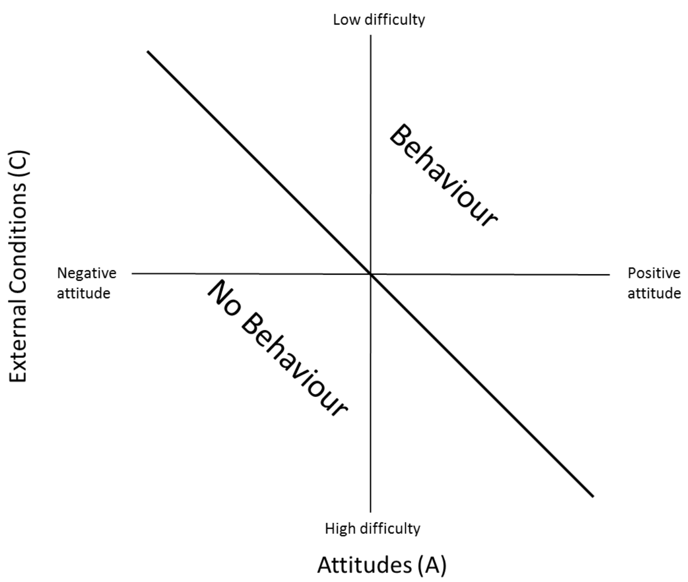


Figure 2.4 ABC model (Guagnano, 1995)

The Low-Cost Hypothesis also relates to behaviour adoption and external conditions (Diekmann, 2003; Andersson, 2010). It predicts that the strength of effects of environmental concern on environmental behaviour diminishes with increasing behavioural costs. In relation to waste disposal, kerbside recycling is defined as a low-cost behaviour (Andersson, 2010). It concurs with the ABC model in suggesting that attitudes have diminishing effects as the behavioural cost increases. However, it goes further in discussing the effect of participating in low-cost behaviour and the possible link with learning and knowledge. Diekmann *et al.* (2003) discusses two knowledge based theories; Rational Choice Theory and Bounded Rationality. Rational Choice Theory proposes that people make rational decisions based upon the information they have while Bounded Rationality treats humans as logically fallible units that often take intellectual short-cuts even when the relevant information is accessible. Diekmann *et al.* (2003) suggests that Rational Choice Theory is relevant for high-cost behaviour, when the potential consequence for errors is high; however the link with highly rational behaviour is weaker for low-cost behaviour. It is inferred that, as kerbside recycling is a low-cost behaviour, is more likely to be related to Bounded Rationality. Meaning that kerbside recyclers are not acting as purely rational units but are taking mental short cuts.

Individual studies have also looked at the impact of dwelling types, recycling time requirements and disposal service quality and their correlation with recycling attitudes and social norms. Shaw (2008) discussed the impact of housing density on recycling, with greater density diminishing the social norm incentive for recycling participation. Mee *et al.* (2004) , Martin *et al.* (2006) and Miafodzveva *et al* (2013) found that a lack of storage space in smaller dwellings was a possible cause for not participating in recycling. This was due to storage space acting as a buffer when bin capacity was exceeded, thus diminishing the impact of service quality issues. Further findings also linked large recycling time requirements and poor service provision as causes of recycling avoidance (Garces, 2002; Martin, 2006). Garces *et al.* (2002) discussed the effect of distance to disposal site on increasing recycling time requirements, thus decreasing recycling participation. Boldero (1995) carried out regression analysis between possible predictors of recycling behaviour and frequency of recycling behaviour, two of the four significant predictors were 'inconvenience' and 'evaluation of council program'. These variables are synonymous with time requirements and council service quality.

2.1.5 Knowledge related theories

There have been various studies focusing upon the relationship between recycling behaviour and knowledge. De Young (1990) found that a lack of information was a major reason for not recycling due to 'not knowing what to do to recycle'. In the Information-Motivation-Behavioural (IMB) Model the importance of access to knowledge is discussed as well as the relevance to recycling (Seacat, 2010). Seacat *et al.* (2010) discusses the importance of knowledge of kerbside recycling schedules, methods of appropriate preparation of recyclable products, knowledge about which products can be recycled, awareness of how collected materials are processed and information about local experts. The IMB Model also discusses the impact of possessing inaccurate information such as; believing that the accidental inclusion of non-recyclable products will result in discarding all products or that products set out for recycling are disposed in landfill.

The relationship between recycling knowledge and recycling behaviour has been tested in multiple studies. The term 'recycling knowledge' has been used to refer to the ability to correctly classify materials during disposal and possessing an understanding of how a recycling scheme works. Most previous studies focused on the link between recycling knowledge and recycling participation (De Young, 1989; Thomas, 2001; Jesson, 2009). Thomas (2001) found that improved understanding of the kerbside recycling system benefited recycling performance. Jesson (2009) indicated that a lack of knowledge about what materials to put in which bin was a major obstacle to recycling and De Young (1989) established that non-recyclers were significantly different from recyclers in understanding how to recycle.

Oskamp *et al.* (1998) carried out one of the few studies to observe the effect of waste classification knowledge on multiple dependent variables; participation, bin contamination and quantity of recyclable material. He found that recycling disposal knowledge was related to quantity of recyclable material per collection but not contamination or participation. This counterintuitive result is possibly explained by his methodology. Knowledge was measured using 12 items on a questionnaire, asking whether they were recyclable (yes, no, don't know). His contamination measurement was based upon a brief bin inspection where it was noted that contamination could be "difficult to notice". A binary measure of 0 for 'no contamination' or 1 for 'contamination' was used. Knowledge assessment could be improved by increasing the number of test items and contamination measurement may be developed by carrying out thorough bin audits.

As discussed earlier in relation to Bounded Rationality, there is evidence that people do not always treat waste disposal as a purely rational behaviour (Moseley, 2013). Moseley *et al.* (2013) proposed that individuals have the necessary information to recycle efficiently but lack the ability to process the entire complex and multiple information sources. He goes on to suggest that peoples' reasoning is based on cognitive short cuts, social processes and logically impure motivations. Some of these cognitive short cuts could be perceived as biases; examples being the stereotype bias or the status quo bias. Stereotype bias refers to a memory distortion towards stereotypes of objects or processes. One study found that an individual's decision to recycle can be determined by the degree the product has been distorted during the consumption process (Trudel, 2013). He determined that distorted products were deemed less useful and therefore less likely to be recyclable. This relates to the stereotype bias in that objects that do not appear identical to images seen in education material may not be identified correctly. The status quo bias is a preference towards the current state of events. Moseley *et al.* (2013) suggests that we don't want to change our waste disposal habits due to limitations on time, resources and intellectual energy.

These knowledge related studies tell us two things; (a) there are different knowledge types relating to recycling, and (b) people may not always act rationally when disposing of waste. The knowledge types discussed in this review refer to recycling procedural awareness (knowing the recycling steps) and disposal knowledge (knowing what to recycle). It is likely that procedural knowledge has a strong link to recycling participation while disposal knowledge is more closely related to bin contamination. As this research is focusing upon the dynamics of waste streams, disposal knowledge is likely to be more applicable than procedural knowledge.

It is also telling that existing research emphasises the limitations in treating humans as purely rational. Whilst knowledge may play a key role in determining waste stream composition, it is likely not the only factor in play, possibly interacting with intangible factors like attitudes and social norms.

2.1.6 Demographics and MSW recycling

Demographics involve the collection of quantifiable data relating to a given population. Common variables seen in literature relating demographics to recycling behaviour include; gender, education, age of head of household, income, race, residential status, household size, and religion (Vining, 1990; Scott D. , 1999; Owens, 2000; Garces, 2002; Martin, 2006; Kurz, 2007). Demographic data is relatively accessible and provides a rough characterization of a given population, however the challenge is drawing a strong link between demographic variables and recycling behaviour. It is possible that demographic variables encompass the direct influences on recycling behaviour.

Different dependent variables were used across the various demographic studies on waste. Owens *et al.* (2000) used 'recycling efficiency' as a measure of recycling behaviour, which represented the proportion of recyclables recovered from the recycling stream. Her research took place in Athens-Clarke County, Georgia, a region with access to kerbside recycling. She found that income, residential status (own/rent) and education level had an impact on recycling efficiency. Gender, age of head of household, and race did not have a significant impact.

Recycling intensity was used as dependent variable in a demographic study of recycling in the Greater Toronto Area in Canada (Scott D. , 1999). Recycling intensity represented the frequency of recycling 12 different materials. Frequency of recycling was determined from a self-report survey. All single dwellings had access to kerbside recycling and multi-unit dwellings had access to a recycling depot. Scott found that age had a positive and significant relationship with recycling intensity however household size, existence of children, education, income and residential status did not.

Participation was a more common measurement of recycling behaviour in demographic related studies (Vining, 1990; Garces, 2002; Martin, 2006; Kurz, 2007). Vining *et al.* (1990) studied the relationship between a selection of demographic variables and recycling participation in Illinois, USA. This region had access to multiple drop-off recycling centres. She found that age and income had an impact on recycling participation but gender, household size, occupation and education level did not. Garces *et al.* (2002) also focused on a region with access to drop-off community paper and glass recycling bins in Zaragoza, Spain. The study found that age and annual family income impacted level of recycling participation, however education level, gender and employment type did not have an impact.

Other research looked at the relationship between demographic variables and recycling participation in regions with access to kerbside recycling (Martin, 2006; Kurz, 2007). In Kurz's *et al.* (2007) study in Northern Ireland he found that higher socio-economic regions more likely to participate. Martin's research also indicated that higher economic status was positively related to recycling participation with residents in detached houses and with higher incomes self-reporting greater levels of recycling behaviour. There was also indication that degree of free time could affect recycling participation, with households with children showing less participation while retirees showing greater participation.

Recycling efficiency was the only dependent variable related to the quality of waste separation and was also the only factor to find a positive correlation with education. A significant education impact was not seen in studies measuring recycling frequency or participation, which appeared to relate more to age, income and socioeconomic status. It is unknown why these factors correlate with higher levels of recycling participation but possibilities include higher levels of free time and higher waste flow making recycling a necessity.

2.1.7 MSW policy

Policy interventions tend to focus more on optimizing purity of waste streams or minimizing landfill rather than maximizing participation or tonnage of waste flow. In this section, four common types of recycling intervention are discussed; education, reward, punishment and system enhancement.

Education policy is commonly used to address contamination problems in waste disposal and to promote correct procedures. There have been few studies focusing upon the success of recycling education campaigns but theory states that education intervention must be applied for a significant period for it to be effective (Adler, 1984). Adler *et al.* (1984) suggests a successful education policy must ensure the public receives and understands the message, agrees with the message and follows the message. This can be challenging for behaviour such as recycling which requires the household to understand when, what, where and how to dispose of their waste. Considering the range of products that can pass through a household it is difficult to ensure there is complete understanding of what material belongs in which bin. There is also little incentive to follow the message when there are no major consequences for not following the correct recycling procedure. When education related policies have been tested there has been evidence of a decreased amount of contamination (Bryce, 1997; Timlett R. &., 2008).

Reward and punishment policy literature also stress the importance in the long-term application of the intervention. Even though the concept of rewards is often a popular option among households there are reports of difficulties in maintaining a desired behaviour once a reward has been terminated (Porter B. L., 1995; Shaw P. &., 2008). Reward intervention was also reported to be more expensive to apply than alternative options such personalized feedback or door-stopping (Timlett R.

&., 2008). A general challenge in policy is finding a method to maintain a behaviour change after the policy has concluded. Reward and punishment are both interventions that generally do not have an enduring influence once concluded.

System enhancement can relate to evolving the physical recycling infrastructure or optimizing the household recycling procedure. Studies have shown that simplifying the recycling process, increasing the range of materials recycled and optimizing the collection frequency can improve the proportion of recyclables recovered (Cole C. Q., 2014). System optimization can also include changing the rules of waste disposal. Examples of rule changes include introducing unit or weight based billing of general waste (Hong S. , 1999; Sterner, 1999; Kinnaman, 2000; Yang, 2007). Studies on these interventions have found that there is a general trend of reduced general waste tonnage and increased recycling weights, however it is necessary to observe levels of contamination to ensure that householder do not place general waste in the recycling stream to avoid charges. Other examples include material bans, such as plastic bag bans (Yang, 2007). Again, it appears that the most effective system enhancement policies are those that are applied permanently and are well regulated.

2.2 Quantitative literature review

A quantitative literature review is being used in this chapter as a method for distilling relevant information from a large amount of literature to create a list of recycling influences. The list of influences will guide research later in the thesis. The review was based upon the question; what are the influences on MSW recycling rates which may lead them to plateau below full potential? Additional information about research methodologies, research location, and research fields was also collected and discussed.

2.2.1 Quantitative review method

The quantitative literature review involved collating English language journal articles on the influences of kerbside recycling behaviour by searching electronic databases of scientific journals. These included Google Scholar, Science Direct and ProQuest from November 2014 to January 2015. Keywords used for the searches were 'recycling', 'curbside', 'kerbside', 'municipal', 'influence', 'determinants', 'separating', 'recovery', 'household', 'waste', 'theory' and 'residential'. This study focused upon kerbside recycling and papers without this focus were excluded.

From each paper analysing the influences on kerbside recycling levels, the relevant information was extracted and recorded in a database. A list of the relevant variables can be seen in Table 1.1. Influences were recorded as direct, indirect or external. The list of papers used for the quantitative literature review can be found in Appendix A.1.

Table 2.1 Data collected from quantitative review journal articles

Data obtained for Quantitative Literature Review
Author
Year of publication
Country of origin
Journal
Possible recycling influences
Sample size
Description of kerbside system
Research field
Dependent variables
Research method

2.2.2 Results

The results of the quantitative literature review indicate the primary influence on kerbside recovery levels. Fifty-one journal articles were reviewed and produced a list of influences in three different categories; direct, intervention and indirect. Other key data includes the geographic locations of past research, the dimensions of recycling that have been focused upon, the research fields that have studied recycling influences, data collection techniques, and the research designs that have been utilized.

As stated, the influences on household recycling rates were divided into three main categories; direct, intervention and indirect (Table 2.1). The 'direct' category encompassed the characteristics of the population or the physical system that was shown to have an immediate impact on household recycling rates. The 'intervention' category included the policies used by government to increase recycling rates. The four categories of intervention were education, system enhancement, reward and punishment. The 'indirect' influence category comprised the demographic characteristics of a population. They are variables that have shown some connection to recycling behaviour but the relationships are likely to be due to underlying direct influences.

Table 2.2 Kerbside recycling influences

Influences on recycling rates	
Direct	Attitude toward recycling Recycling social norms Time required for recycling Available storage space for waste Council pick-up service quality Household consumption trends MRF sorting technology Disposal knowledge
Intervention (Policy)	Education System enhancement Reward Punishment
Indirect (Demographics)	Age Income Education Gender Dwelling type Employment status Religion # of children # in house

A geographic summary of past research indicates that research projects based on kerbside recycling influences are biased towards the United Kingdom and United States, with 20 of the 51 studies based in the UK and thirteen in the US (Table 2.2). Both are developed economies which began introducing kerbside systems in the 1980's and 1990's. There are also sophisticated research institutions in both nations. This bias does suggest that recycling influence research is primarily relevant to North America and Western Europe.

Psychological research has dominated past research into kerbside recycling influences with 14 of 51 past studies in the Psychology field (Table 2.2). Some of the Psychological theories discussed include The Theory of Planned Behaviour, The Altruism Model and the Norm Activation Model. There were twelve studies for which the key research field was engineering related. This was followed by ten economic papers, which often focused on the effect of various economic policies on recycling behaviour. The remaining studies were in the fields of Environmental Science, Policy, Marketing and System Dynamics.

Much of the research carried out on MSW recycling influences used correlational research design, 33 of 52 instances of research design (Table 2.2). Correlational research measures variables of interest and then looks for statistical relationships between them. Twelve studies were relatively superficial, presenting a description of a system using descriptive statistics but offering little analysis. There were five cases of semi-experimental literature, carrying out field experiments on household recycling, using intervention and population blocks to improve the quality of analysis. There were also two papers that carried out a literature review style analysis. No past studies on recycling influences performed experimental or meta-analysis.

Data collection commonly involved the use of qualitative tools such as self-report surveys, interviews and focus groups. There were thirty-one cases of self-report surveys, nine instances of interviews and two examples of focus groups (Table 2.2). There is a clear emphasis on the use of surveys when studying recycling behaviour influences. However, twenty-three papers used quantitative data collection, centred on the common MSW markers; assessing participation via number of bins 'set-out', quantity of material in kerbside bins and amount of contamination in kerbside bins. In some studies, qualitative and quantitative data collection were combined.

Past research on recycling influences has focused upon 'participation' in kerbside systems, with participation used as a dependent variable in forty of the reviewed papers (Table 2.2). This is likely the simplest dependent variable to measure, by counting the bins that have been 'set-out' on collection days. It is a greater challenge to assess the amount of material in kerbside recycling bins and to determine the amount of contamination combined with recyclables. Sixteen of the reviewed papers used amount of material in waste bins as a dependent variable, while only five examined the amount of contamination in bins. This result suggests that a research gap may exist in the understanding of recycling material flow and contamination levels.

Table 2.3 Quantitative review results

Location of research		Research fields		Research design		Data collection technique		Recycling dimension	
United Kingdom	20	Psychology	14	Correlational	33	Self-report survey	31	Participation	40
United States	13	Engineering	12	Descriptive	12	Quantitative measurement	23	Amount of material	16
Sweden	3	Economics	10	Semi-experimental	5	Interview	9	Contamination	5
Australia	2	Environmental Science	5	Review	2	Focus group	2	-	
Norway	2	Policy	4	Experimental	0	-		-	
Switzerland	2	Marketing	3	Meta-analysis	0	-		-	
Portugal	1	System Dynamics	3	-		-		-	
Canada	1	-		-		-		-	
Northern Ireland	1	-		-		-		-	
New Zealand	1	-		-		-		-	
Italy	1	-		-		-		-	
Taiwan	1	-		-		-		-	
Germany	1	-		-		-		-	
South Korea	1	-		-		-		-	
Spain	1	-		-		-		-	

2.2.3 Critique and research contribution

This quantitative review revealed some patterns in previous waste related research worthy of further discussion. For example, a large number of waste research have relied upon the use of surveys and questionnaires. These can be an effective form of data collection in a well-designed study however care must be taken that surveys and questionnaires measure their intended variable. In addition, the validity and reliability of surveys and questionnaires are increased when combined with observational data collection. This was not always seen in past research.

Furthermore, when inspecting the dimensions of recycling behaviour in past work, a strong bias was evident toward 'participation' research. It is likely the simplest variable to measure, by counting recycling bin 'set-out' on collection day. However, there were no longitudinal studies on contamination and limited longitudinal studies on amount of recyclables collected. To improve our understanding of recycling plateaus it is necessary to rectify this situation, as analysis of plateaus will only be possible by carrying out time series analysis of municipal waste streams. This is certainly a possible contribution for this thesis.

In addition, a significant proportion of the reviewed papers did not provide a detailed description of the kerbside systems they were analysing. This weakened the potential to compare between different disposal systems. A suitable requirement for future research would be to describe the following features of a waste disposal system: (a) number and size of recycling bins, (b) number and size of landfill bins, (c) accepted recyclables, (d) frequency of recycling and landfill collection, and (e) age of recycling system. Fortunately, a majority of the studies were sourced from countries with co-mingled kerbside recycling systems. Therefore, some assumptions can be made the recycling system in place.

Although there has been research investigating MSW recycling influences, to probe the problem of plateauing recycling rates it is necessary to understand how these influences may interact to create the plateau dynamic. From the quantitative literature review, it is evident that SD has been applied previously to provide insight into the interaction of MSW disposal influences. SD modelling provides an opportunity to find these interactions and test their influence on recycling plateaus. To gain further insight into the background of SD and waste research, a general review of SD research applied to waste will be carried out. This provides further context for this thesis, assessing how an SD model of recycling plateaus may contribute.

2.3 A review of waste related SD literature

The review of waste related SD literature consists of two major parts; (a) a general summary of SD literature probing waste problems, and (b) a discussion of SD literature relating to plateauing recycling rates. The general review of waste related SD literature provides a summary of all known SD literature related to waste, while the second part of this section focuses upon SD research which may provide insights into plateauing recycling rates.

2.3.1 Waste related SD literature

By implementing a broad review of waste related SD research, an understanding of the research landscape can be gained. This review encompasses the problems and dependent variables being targeted by existing studies and discusses the approaches taken to solve them. Existing SD literature relating to waste were found to fall into three categories; those investigating broad dynamic problems, those testing policy, and those aiming to forecast. A summary of these studies and their dependent variables can be seen in Table 2.3.

Table 2.4 Summary of dependent variables used in waste SD literature

Author	Dependent variables
Chaerul	Hospital waste generated, health risks, life expectancy, treatment cost
Cimren	Number of jobs, GHG emissions, government revenue, recycling rate
Ciplak	Hospital waste generated, number of hospital beds, population
Dace	Landfill capacity, amount of packaging
Dyson	Solid waste generation
Geogiadis	Production capacity
Golroubary	Customer satisfaction, Demand backlog
Hao	C&D recycling total cost, waste to landfill
Karavezyris	Environmental behaviour, MSW recycling rate, illegal disposal, treatment price, regulation
Kollikkathara	Landfill cost, recycling cost
Kum	Informal recycling population, waste generated, unit compost cost, labour force size

Marzouk	Quantity of C&D recycled waste, quantity of landfilled waste, GHG emissions, economic impact
Meadows	State of the World (population, pollution, industrial output, food, resources) Material standard of living (consumer goods/person, food/person, services/person, life expectancy) Human welfare and footprint (human welfare index, human ecological footprint)
Ojoawo	Population, GHG emissions, total waste generated
Randers	Copper recycling rate
Sudhir	Health index, informal sector jobs, material wastage index, per capita future cost
Tam	Quantity of waste generated, quantity of C&D recycled waste, C&D quantity illegally dumped waste, landfill capacity
Ulli-Beer	MSW recycling rate, participation, cost of recycling system, profit from recycling
Zanjani	Solid waste generation, government debt, participation in waste separation
Zhao	C&D recycling cost

Studies using SD modelling to investigate a broad dynamic problem are often those considered the most insightful. For example, Randers *et al.* (1973) and Meadows *et al.* (2005) asked 'how can one slow down the solid waste generation rate' and 'how can one increase the recycled fraction?' They were interested in the impact of material recovery on the long-term life span of resource stocks such as copper or other minerals. Meadow's World 3 model was used to discuss the likely consequences of growing resource consumption on the global system, findings that caused much public debate at the time. Ulli-Beer *et al.* (2004) investigated the problem of motivating households to participate in solid waste reduction and separation, while Georgiadis *et al.* (2013) asked how to carry out strategic capacity planning in the paper recycling industry. Ulli-Beer used variables such as MSW recycling rate, recycling participation and recycling economics to track simulations.

The use of SD models to test specific policies often had a narrower scope, frequently with a specific environment in mind. For instance, Golroudbary *et al.* (2015) observed the effect of introducing an improved recycling system in an electrical manufacturing company, using demand backlog and customer satisfaction as dependent variables. Dace *et al.* (2014) likewise had an interest in using SD modelling in a business environment, aiming to improve the sustainability of packaging design. He settled on a packaging tax as being the best method for improving packaging eco-design and minimising waste.

Several SD studies focused upon Construction and Demolition (C&D) policy testing. Tam's *et al.* (2014) C&D emphasis was upon testing the impact of landfill charges and illegal dumping penalties on C&D recycling rates while Zhao *et al.* (2011) observed the effects of different mobile recycling facilities on C&D recycling rates and overall profitability. Marzouk *et al.* (2014) continued the C&D recycling focus, using a SD model to compare a disposal scenario with a recycling scenario while Hao *et al.* (2008) also carried out a comparison between on-site and off-site waste sorting. Both studies had an interest in the economics of C&D recycling and how this related to material recovery.

Some studies tested waste policy specifically on municipal waste systems. Cimren *et al.* (2010) tested a variety of waste policies for the US state of Ohio. These included the introduction of solid waste recycling, biomass co-firing and By-Product Synergy (BPS). Solid waste recycling was found to reduce air pollution, GHG emissions and energy consumption. Sudhir *et al.* (1997) looked at solid waste management for large Indian cities. He considered the interaction between the formal and informal (wastepickers) waste systems with policy testing focusing upon which of these systems should receive funding priority and the timing of fund allocation. As a final example, Kum *et al.* (2005) looked at possible changes that could be made to urban waste systems in Vietnam. She considered the informal waste sector in the recovery of waste and her conclusions focused upon composting and the informal recycling sector.

Many of the SD studies reviewed did not fall into the categories of modelling a dynamic problem or policy testing, instead they aimed to forecast waste related variables. These were often the simplest models, frequently showing little or no feedback. Forrester, the creator of SD, considered feedback in complex systems one of the foundations of SD (Richardson G. , 2011). Without feedback, it is difficult to consider a model to be a SD model. Kollikkathara had no feedback in his model and influences on waste generation were represented as demographic variables. Key variables being predicted included waste generation and waste budgets. Dyson *et al.* (2005) also lacked feedback in his SD model and again used demographic variables as influences on waste flows to forecast solid waste and recycling quantities.

Some MSW related SD studies neglected recycling, or focused upon recycling economics. Ojoawo *et al.* (2012) and Kollikkathara *et al.* (2010) made no reference to recycling, both simply predicted municipal waste generation. Ojoawo had feedback driving population growth which subsequently increased waste generation in a local government area. He concentrated on predicting solid waste and gas generation. Zanjani *et al.* (2012) also used simple feedback structures and continued the focus on MSW forecasting, determining the pay off period for a government loan to start a municipal recycling program.

Waste produced from healthcare was also of interest by SD forecasters, with Ciplak and Chaerul using SD models to forecast the generation of hospital waste (Chaerul, 2008; Ciplak, 2012). Chaerul was interested in predicting the amount of treated and untreated hospital waste generated while Ciplak aimed to predict the overall amount of hospital waste generated.

Models concentrating on forecasting did at times show mature feedback structures. When Karavezyris modelled MSW recycling rates he considered intangibles such as environmental behaviour and its feedback links to recycling (Karavezyris, 2002). Recycling rates were determined by the combined effect of 'amount of waste collected' and the level of 'environmental behaviour'. Karavezyris tested multiple graphical functions to represent the relationship between 'environmental behaviour' and 'recycling rates'. He noted there was a research gap and this relationship should be investigated in further detail.

It is worth emphasising the scepticism felt about SD models aiming to forecast. Sterman (2000) specifically states that 'the real value in modelling is not to anticipate and react to problems but to eliminate the problem by changing the underlying structure of the system'. This infers that it is the reasonable representation of a problem in SD form that provides value and guidance for policy design, not attempting to predict the future.

2.3.2 SD literature related to plateauing recycling rates

It is worth asking whether any previous SD studies of MSW target the problem being discussed in this thesis; the plateauing of MSW recycling rates below their full potential. Two studies discussed possible causes for MSW plateaus to occur below full potential; Karavezyris and Ulli-Beer (Karavezyris, 2002; Ulli-Beer S. , 2003). Karavezyris *et al.* (2002) suggested that MSW recycling rates are primarily determined by level of 'environmental behaviour'. When environmental behaviour is high, this causes MSW recycling rates to also be high. However, there is not a detailed discussion of the concept environmental behaviour and Karavezyris explicitly states that the relationship between environmental behaviour and recycling rates is not understood.

Ulli-Beer's (2003)work on policy compliance and waste disposal choices also has a close relationship to the present study. She used an SD model to help solve three questions; (a) how do you motivate households to participate in solid waste reduction and separation, (b) how do you recover recyclable material to produce competitive secondary raw material, and (c) how do you finance the recovering and disposal activities of local agents? Although she did not explicitly ask why MSW recycling plateaus are occurring, it is inferred that recycling rates plateau when participation, disposal knowledge and willingness to recycle are maximised.

Her research took place in Switzerland and encompassed household, industry and services waste. Some key characteristics of the Swiss waste system included; (a) GW bag charges to encourage recycling, (b) six common separate recycling streams (glass, aluminium, paper & cardboard, PET, batteries, tin), and (c) material recycling as a combination of kerbside pick-up and drop-off disposal (EEA, 2013).

In light of these waste system characteristics, it is evident that Swiss waste disposal requires more time for disposal than in the Australian system.

Ulli-Beer also carried out policy testing on magnitude of incineration fees and number of recycling streams. She found it was important to both motivate citizens to participate in waste separation and provide infrastructure to simplify disposal (Ulli-Beer S. , 2003). If motivation was purely extrinsic, such as taxing GW disposal, then there was increased likelihood of higher contamination in waste streams. Additionally, there was an upper limit to number of recycling streams because as time cost became too great it caused a community to lose motivation to separate.

The core of Ulli-Beer's stock and flow model, as seen in Figure 2.5, concentrated on the dynamics of participation, describing the flow of individuals between four stocks describing recycling behaviour; inexperienced and unwilling recyclers, inexperienced and willing recyclers, experienced and willing recyclers, and experienced and unwilling recyclers (Ulli-Beer S. , 2003; Ulli-Beer S. R., 2004). Each of these stocks were characterised by fixed attributes, such as 'fraction of appropriately separated material'. Consequently, it was the movement of individuals between the four stocks that determined the resulting waste dynamics, not the flow of material. It is a model structure that emphasises human decision making and suggests that individuals can be categorised as certain types of disposers. There is the possibility of loss of granularity using this approach, as variables such as bin contamination are treated as static for each category of disposer.

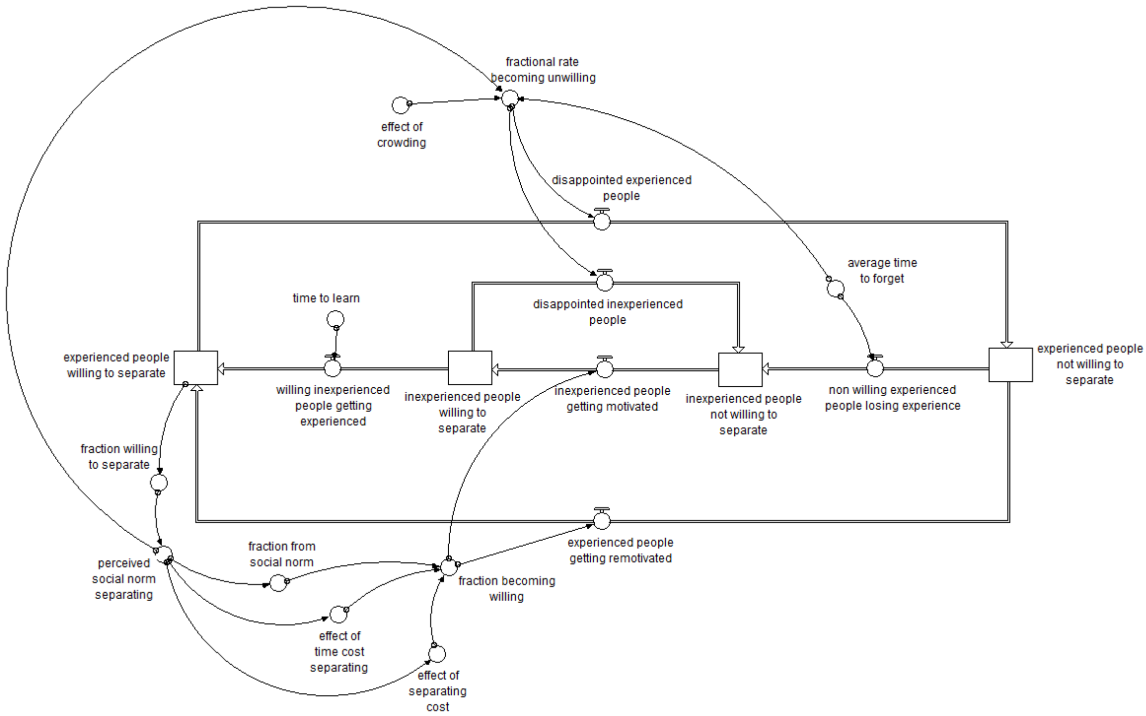


Figure 2.5 Ulli-Beer's recycling dynamics (Ulli-Beer S. R., 2004)

This approach is difficult to apply to Australia as the most recent measure of household recycling participation was close to 100% (ABS, 2010). Australian homeowners are legally required to pay annual rates to their local government, with a portion of these annual rates being used to fund local government waste disposal systems and provide waste bins to all households (Tasmanian Government, 2016). If a household did not participate in kerbside recycling, they would be rejecting a service for which they have already paid. It is possible for households to withdraw from kerbside pickups, however there is then the necessity to personally dispose of waste to local landfill and recycling facilities.

A second point regarding the Ulli-Beer model was the model structure was largely guided by focus groups and discussions with waste disposal experts. This resulted in a SD model consisting of hundreds of parameters, stocks and flows. It would be interesting to investigate a SD model structures that can represent MSW recycling systems in a simpler manner. It would also be useful to investigate alternative means to support model structure using quantitative data. Although qualitative data can be extremely useful in guiding the creation of SD models, it not easy or even possible to replicate.

A third point differentiating Ulli-Beer's work from this thesis is her emphasis on the significance of social norms influencing a community's willingness to spend time separating. As previously noted, Ulli-Beer's research was based in a Swiss municipality where disposal time requirements were high due to greater levels of separation and a necessity to drop-off waste. Ulli-Beer states that observation of others disposal habits and sorted waste plays a significant role in an individuals' own proficiency in waste separation. As waste separation improves, waste stream contamination decreases thus decreasing the gap between full potential and actual recycling rates. However, the use of co-mingled kerbside recycling in Australia limits the opportunity for others to observe waste sorting behaviour outside of a household.

2.4 Literature review summary

Table 2.5 A summary of key findings for significant variables and topics

	Categories of studies	Key findings
Policy	Education	That waste stream contamination decreases due to disposal education, however education must be consistent and long-term.
	Reward	That reward and punishment requires long-term application, however there can be difficulty in maintaining a behaviour once a reward or punishment has been terminated.
	Punishment	
	System Enhancement	Studies have shown that simplifying the recycling process, increasing the range of materials recycled and optimizing the collection frequency can improve the proportion of recyclables recovered.
Physical recycling system	MRF sorting efficiency	That MRF sorting efficiency is positively correlated with recycling rates.
	Ease of use (time)	Large recycling time requirements are likely to lead to recycling avoidance.
	Service quality	Poor recycling service quality may lead to recycling

		avoidance.
	Dwelling storage space	That small amounts of storage may diminish recycling participation levels, as storage space acted as a buffer when bin capacity is exceeded.
Human recycling behaviour	Attitude toward recycling	A significant link was found between a positive attitude toward recycling and recycling participation.
	Disposal knowledge	Disposal knowledge was found to be not related to contamination levels.
	Recycling social norms	Social norms may impact the frequency of bin set-out but not the quality of sorting.
	Consumption trends	That material inputs into the waste stream will have a strong impact on the maximum possible recycling rate.
	Demographics	Waste stream purity was found to be positively correlated with education level.
System Dynamics		Recycling rates plateau when participation, disposal knowledge and willingness to recycle are maximised.

This chapter summarized past literature to isolate potential influences on kerbside recycling rates and why they are plateauing below full potential. The fields of research summarized and critiqued in the qualitative review included MSW recycling economics, attitude based theories, norm based theories, context related theories, knowledge related theories, demographics and MSW recycling, and MSW policy.

Further work on a quantitative literature review found three categories of influences on recycling rates; direct, indirect and policy. Direct influences included attitude toward recycling, recycling social norms, time requirements or convenience of recycling, household storage space, MSW service quality, consumption trends, and MRF sorting technology. Policy influences encompassed education, reward, punishment and System Enhancement. Indirect or demographic influences included age, income, education, gender, dwelling type, employment status, religion, number of children and number in household. A summary of these influences can be seen in Figure 2.6.

Also, a summary of waste related SD literature provided insight into application of the SD methodology and research closely related to this thesis. From this review, some research questions were identified as worth further investigation.

As stated at the beginning of this chapter, three Australian waste flows were reported to be experiencing recycling plateaus; paperboard, ONP and MSW. A question that arose from this, was whether a relationship existed between these plateauing recycling rates. No associations were mentioned in the MSW recycling literature reviewed, except that ONP is a material that passes through MSW. Of interest, is whether a causal relationship exists between these recycling plateaus.

Another key question raised from the review of literature, was what and how causes MSW recycling rates to plateau at a certain level. From the literature review, certain factors can be suggested to be relevant. For instance, when discussing the economics of MSW waste it was observed that the classification of materials as recyclables was based upon demand from commodity markets. It was only the materials that were profitable on the commodities market that were accepted for recovery by local government recycling contractors. This classification combined with the quantity of these materials in the waste stream to determine the full potential recycling rate.

A selection of intangible variables were also observed in relation to MSW recycling rates; attitude toward recycling, recycling social norms, difficulty to recycle, recycling knowledge and population demographics. When studies concentrated on the impact of these variables on recycling participation, it was noted that positive recycling attitudes, recycling being considered a norm, and a convenient recycling system could all increase recycling participation.

The effect of some of these intangibles were also correlated against bin contamination levels. These studies indicated that bin contamination would fall as disposal knowledge improved, or with higher levels of education and income. Bin contamination is an important variable to consider in this thesis as this project is investigating recycling plateaus below their full potential. This state must be being caused by inefficiencies in the recycling system. Bin contamination is an example of inefficiencies in the MSW recycling system, and is a known cause of lost recyclables.

Recycling policy was also a potential factor on recycling rate plateau level, with four main categories of policy discussed; education, reward, punishment and system enhancement. There was evidence of decreased contamination after education campaigns. There were also indications that reward and punishment can be effective at improving participation and recycling quality whilst the program is ongoing but the effect tends to dissipate after program termination. Similarly, System Enhancement was found to be effective at improving recycling rates if it is properly administered.

Two SD researchers, Ulli-Beer and Karavezyris, attempted to combine some of these influences to explain recycling rate dynamics. Karavezyris emphasised the importance of 'environmental behaviour' in determining the upper limit of MSW recycling rates. When environmental behaviour was maximised then so were recycling rates. Ulli-Beer's SD model inferred that recycling plateaus occur when recycling participation, disposal knowledge, and willingness to recycle are maximised. She also considered the proportion of recyclables in the waste stream. However, recycling plateaus were not a focus in either of these models and it would be interesting to probe how plateaus are formed when participation is high at the onset of a recycling system.

A final possible area of contribution related to the dynamics of recycling rates in Australia. There is evidence for both s-shaped and goal-seeking recycling dynamics in global recycling systems. Ulli-Beer modelled these dynamics in an SD model, demonstrating that the s-shaped growth of Swiss recycling rates was largely driven by participation levels. However, this does not explain the dynamics of the Australian kerbside recycling system where participation is high at onset. It would be a noteworthy contribution to propose a feedback structure that can explain the recycling rate dynamics seen in Australia, whether it be s-shaped or goal-seeking behaviour.

2.4.1 Research questions

The literature review has enabled the distillation of key research questions relating to MSW recycling plateaus and SD modelling. The research questions being addressed by this thesis will be:

1. How do MSW recycling plateaus relate to material recycling plateaus?

2. How do direct influences and demographics determine the plateau level of MSW recycling rates when participation is high at recycling onset?

3. How do direct influences and demographics determine the level of MSW bin contamination?

4. Are the forces driving MSW recycling rates exogenous or endogenous to the municipality's waste-control system?

The research questions will be addressed in the order seen in Figure 2.7. Chapter 3 will begin the process of answering Research Question 4 by constructing a dynamic hypothesis using existing literature. This will be set aside while Research Question 1 is addressed by investigating Old Newspaper (ONP) recycling rate plateaus and touching on any links with MSW recycling plateaus. Chapters 5 and 6 use the results of the quantitative literature review as a basis for understanding the influences on MSW recycling plateaus. Chapter 5 focuses upon demographic influences and Chapter 6 the direct influences mentioned in Table 2.1. Chapter 7 then combines the results from previous chapters to construct a SD model upon which testing can be applied, thus answering Research Question 4.

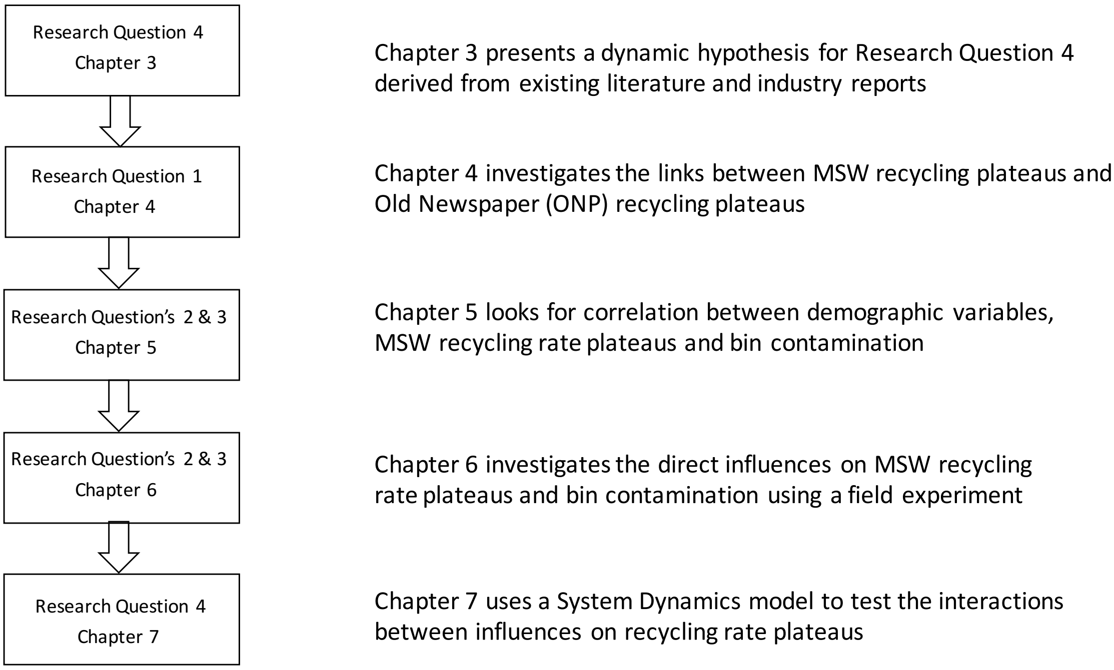


Figure 2.6 Thesis structure in relation to research questions

As a final point, it may be noted that policy is not mentioned in the thesis structure or research questions. Policy was disregarded as a significant influence on recycling rates in the local government case study used in this thesis, after policy history interviews were completed. It was found that the only council waste policy was an annual mail-out of bin collection calendars, a pamphlet also containing updated waste education material. The timing of the mail-out was compared against recycling rate history and no effect was detected.

A dynamic hypothesis concerning recycling plateaus

The approach adopted in this thesis follows Sterman's five-step modelling process; problem articulation, formulation of a dynamic hypothesis, formulation of a simulation model, model testing and policy design (Sterman, 2000). This chapter will describe a dynamic hypothesis for MSW recycling plateaus that will be presented in the form of a Causal Loop Diagram (CLD). The components of the CLD will then be discussed using Stock & Flow (S&F) maps, to provide a detailed explanation for the CLD structure. A similar process was used in Ulli-Beer's work, previously discussed in Section 2.3.2. The work in this chapter provides the foundation for addressing Research Question 4; are the forces driving MSW recycling rates exogenous or endogenous to the municipality's waste-control system?

The chapter is divided into four sections; the dynamic hypothesis is presented in the form of a CLD, there is then an explanation of the hypothesis using a stock and flow map representing the physical system and a stock and flow model representing learning and knowledge, and finally a discussion relating decision making under uncertainty to the dynamic hypothesis.

3.1 Causal Loop Diagram representing the Dynamic Hypothesis

In this section, the Dynamic Hypothesis of this thesis is presented in the form of a CLD. It is a summary of existing theory and a prediction of interactions. The hypothesis proposes that the cause-effect structure of a MSW system contains four principal feedback loops (seen in Figure 3.2); a social learning loop, a learning time limit loop, a council education impact loop and a council education effectiveness loop. Further details of these loops and variables can be found in Table 3.1 and Table 3.2. The reference mode the Dynamic Hypothesis is attempting to simulate is seen in Figure 3.1.

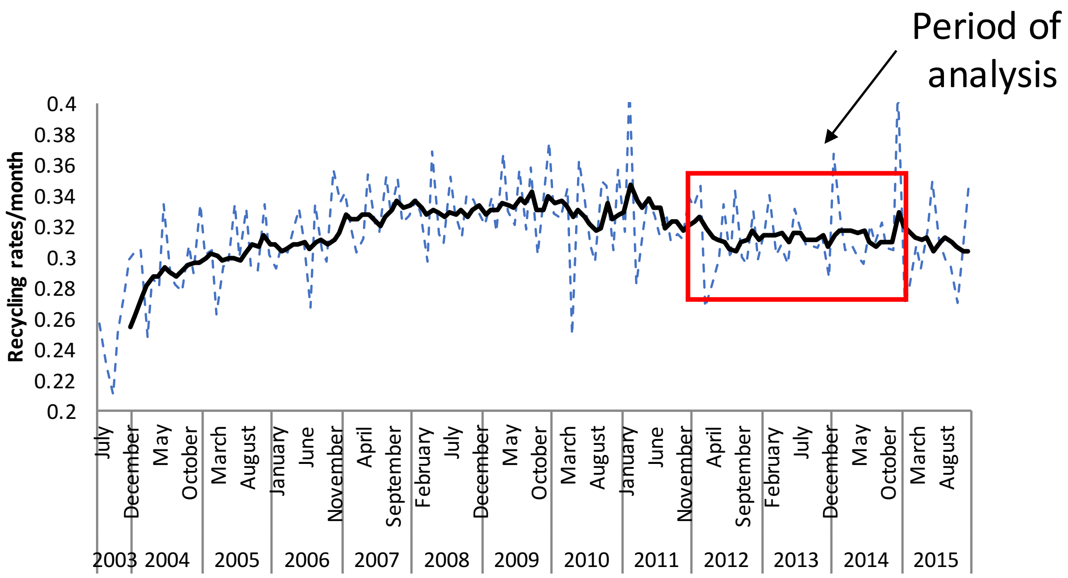


Figure 3.1 Dynamic Hypothesis reference mode

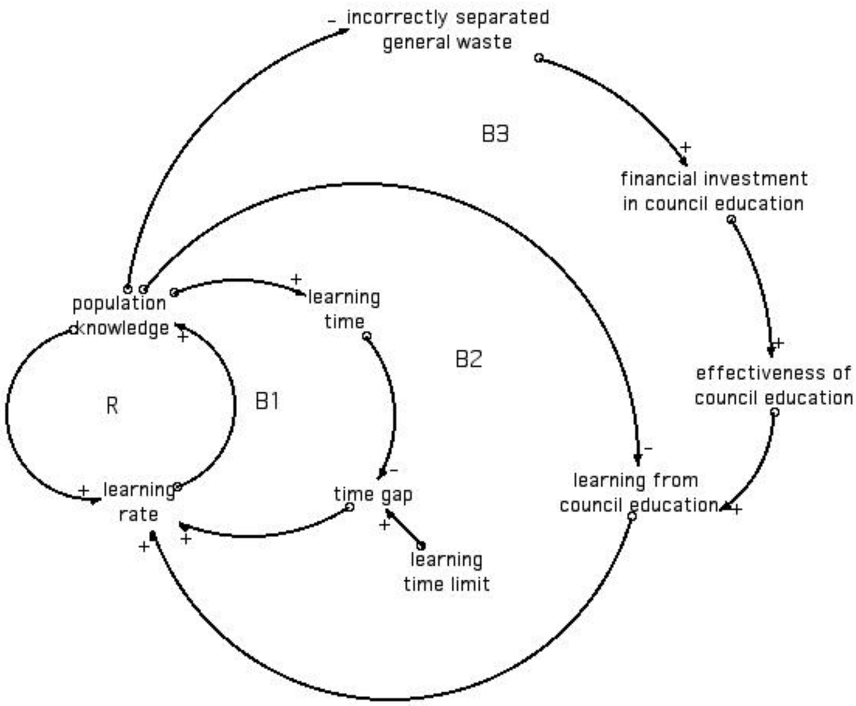


Figure 3.2 Dynamic Hypothesis (R = Social learning loop, B1 = learning time limitations loop, B2 = operant conditioning loop, B3 = council reaction to contamination loop)

Table 3.1 Dynamic Hypothesis Feedback Loop

Loop	Name	Type	Explanation
R	Social Learning Loop	Reinforcing	The greater the amount of waste separation knowledge in the community, the greater the sharing of knowledge. The more sharing the more knowledge.
B1	Learning Time Limit Loop	Balancing	When a community begins learning disposal rules, the elementary rules are absorbed early and quickly. These rules can be applied to much of waste. However, for the waste that is not explained by the major disposal rules it is necessary for greater research and time investment for correct disposal. This creates a case of diminishing returns; the closer to complete knowledge, the more difficult the learning process becomes.
B2	Council Education Impact Loop	Balancing	The less waste separation knowledge in a community the greater the impact of council education. Once community knowledge of waste separation becomes more extensive the impact of council education diminishes.
B3	Council Education Effectiveness Loop	Balancing	As recycling bin contamination increases pressure is placed upon the council by the MRF contractor to minimize contamination. The council will either increase frequency of education campaigns or aim to increase its effectiveness (by targeting specific materials or a population subset). There is a delay in this feedback loop due to the time taken to detect contamination levels and subsequently for the council to prepare an education campaign.

Table 3.2 Dynamic Hypothesis Variable Definitions

Variable	Definition	Units
Population knowledge	The average proportion of waste and recycling that is correctly disposed by the case study population.	Knowledge units
Learning rate	The rate of spread of new disposal knowledge throughout the case study population. This is driven by council education or observation of peers.	Unit knowledge/ month
Learning time	The amount of time required to learn a 'unit' of disposal knowledge.	Minutes
Time gap	The difference between the amount of time committed to learning disposal rules per month, and the learning time required to possess perfect disposal knowledge.	Dimensionless
Learning time limit	The amount of time committed to learning disposal rules.	Minutes
Incorrectly separated general waste	The proportion of contamination in the kerbside recycling bin.	Dimensionless
Financial investment in council education	The amount of financial investment a council commits to waste disposal education.	Dollars
Effectiveness of council education	The degree to which council messages regarding disposal rules are absorbed by the target population.	1/month
Learning from council education	The level of learning occurring due to inputs from council disposal education	Knowledge unit/month

To further understand the proposed feedback loops, in subsequent sections of this chapter there are discussions using existing theory and S&F maps. This begins in the next section with a review of the physical MSW systems in use in Australia. This encompasses MSW material flows and some of the procedures in place to collect and sort waste.

3.2 The Physical System

In Australia MSW disposal is under the purview of local government. Householders pay for MSW disposal through their annual council rates, the council then provide a kerbside waste disposal service. The two generic kerbside bins are ‘Landfill’ (also known as ‘General Waste’) and ‘Co-mingled Recycling’, with a ‘Garden Waste’ bin also often occurring (DECC, 2007). Recycling and Garden Waste bins are generally 240L and General Waste 120L (ACT Government, 2016). ‘Landfill’ bins are commonly collected weekly, while ‘Recycling’ and ‘Garden Waste’ are more likely to be collected fortnightly (DECC, 2007; ACT Government, 2017). Garden Waste does not fall within the scope of this thesis and is therefore not included in the modelling process. Figure 3.3 provides an outline of MSW material flow.

The collection is commonly carried out by a council contractor using dedicated vehicles (ACT Government, 2016). Management rights are also usually given to contractors for Municipal Recycling Facilities (MRFs) and Landfill, which often serve many council regions to achieve economies of scale (Porter R. C., 2002; NSW EPA, 2015).

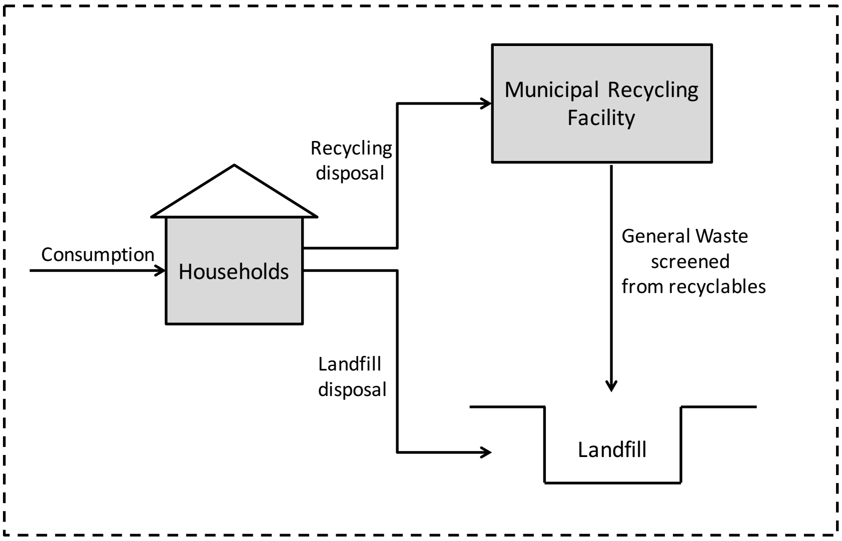


Figure 3.3 Scope of research: from material flow into households to waste disposal

There are common procedures for material once it arrives at a MRF. The procedures mentioned here are considered the industry standard and represent the procedures and technologies in place at the time of this research (Pressley, 2015). A first sorting step involves manually extracting obvious contaminants such as objects that are too large or too long for mechanical sorting, and can become entangled in the equipment (Cimpan, 2015; Pressley, 2015). An inclined Disc-Screen is used to separate paper and cardboard from the recycling waste stream (Pressley, 2015). Disc-Screens are designed to allow heavy objects to fall through but propel paper and cardboard upwards. Light refraction is also used to determine three varieties of plastic; PET, HDPE and other firm plastics (Pressley, 2015). Steel cans are separated from the recycling stream using magnets and aluminium is diverted using eddy current generators (Cimpan, 2015; Pressley, 2015).

MRF's in Australia using this procedure have relatively high recovery efficiencies (Table 3.3). There is 100% efficiency for recovery of 'Old Corrugated Containers' and 99% recovery efficiency for other types of paper (Pressley, 2015). Metals, glass and plastics all have recovery efficiencies above 90%. Approximately 10% of material passing through a MRF will be categorized as residual or non-recoverable and diverted to landfill.

Table 3.3 MRF sorting efficiency (Pressley, 2015)

MRF type	OCC	Non-OCC fibre	Al	Fe	Film	HDPE	PET	Glass	Residual rate
Single stream	100%	99%	97%	98%	90%	98%	98%	95%	10%

Material not diverted to a MRF is sent to landfill, which come in three varieties: MSW, Codisposed and Monofills (Scott J. B., 2005). MSW landfills reject any form of hazardous waste, receiving waste from households and commercial entities. Codisposed landfills accept both MSW and industrial waste and can contain hazardous wastes, while Monofills are landfills containing only hazardous wastes which often go through some pre-treatment before disposal (Scott J. B., 2005).

A stock and flow diagram (Figure 3.4) summarizing MSW material flow was derived using industry reports, discussions with local government and personal observation of Australian waste infrastructure and processes (DECC, 2007; DECC, 2008; Blue Environment, 2014). It encompasses material flow within municipalities, from household consumption to landfill disposal and recyclables recovery. The stock 'household material' represents all products or materials entering a household, being either recyclable or general waste

From the 'household material' stock, material flow splits into two paths; recyclables and general waste. The 'recyclables' and 'general waste' stocks represent the absolute amount of these materials in household material flow. These stocks are either correctly or incorrectly disposed; the proportions being influenced by the contamination index and bin bias. Correctly disposed recycling and incorrectly disposed GW are placed in kerbside recycling bins, named here as the 'recycling bin' stock. These are the materials and products that are transported to the MRF and sorted into a variety of recyclable categories. The incorrectly disposed GW is screened and diverted to landfill. The correctly disposed GW and incorrectly disposed recycling are placed in the kerbside general waste bin, seen in the model as the 'GW bin' stock. These materials are transported to the local landfill for disposal.

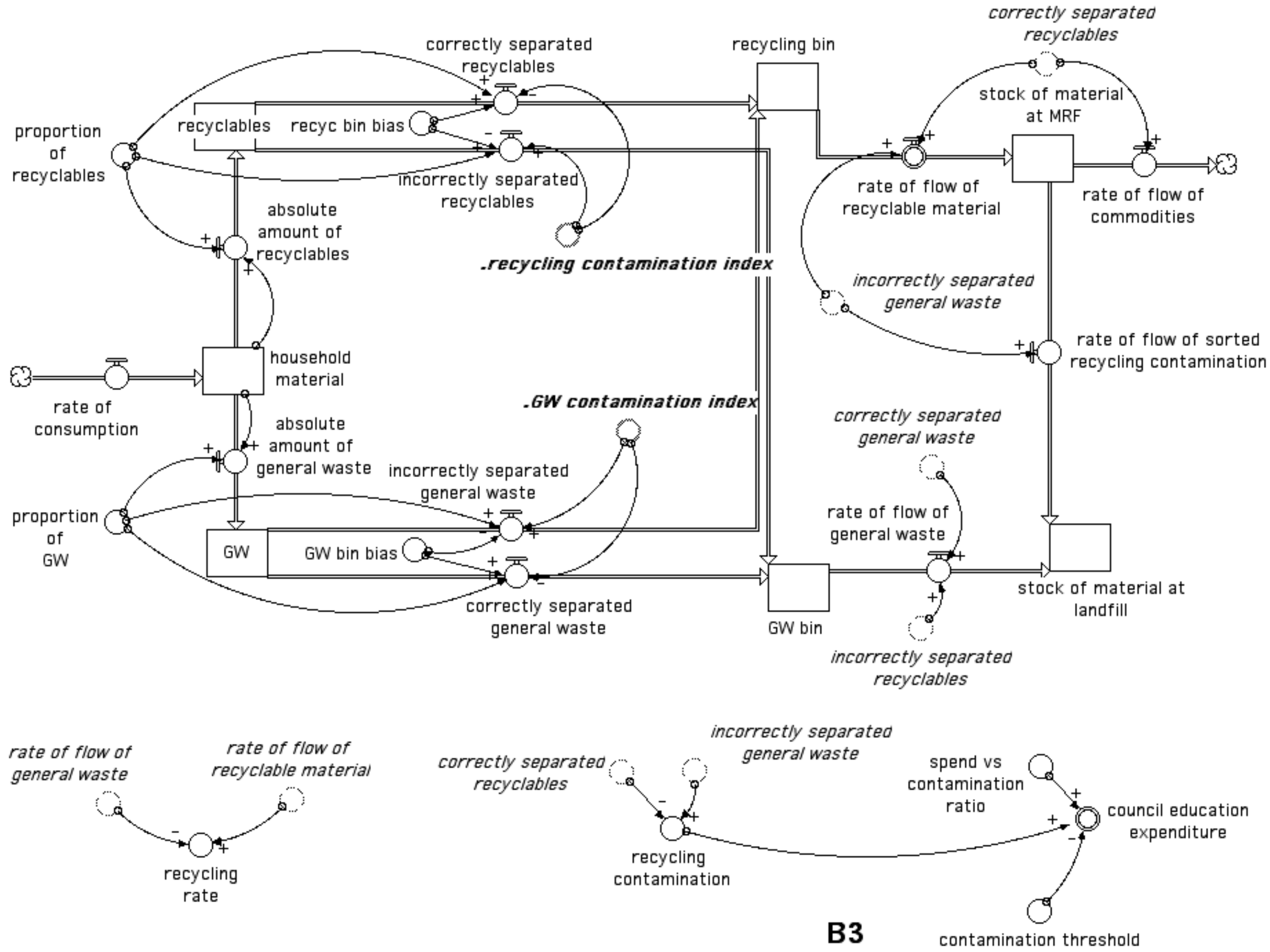


Figure 3.4 MSW material flow (stock = square box representing accumulation of state variable, flows= double lined arrows represent changes in the amount accumulated, parameters = circles, thin arrows = influence links)

To answer the research question, the model combines tangible and intangible variables. The tangible, such as the material flow seen in Figure 3.4, can be observed and measured using metrics such as weight or volume. However, there are intangible variables that are more difficult to observe. Examples seen in this thesis include learning and knowledge, and decision making under uncertainty. Disposal knowledge is represented in Figure 3.4 by the contamination index, a concept that will be elaborated upon in Section 3.3. Population disposal knowledge is also impacted by balancing loop B3, which is also discussed in Section 3.3. Bin bias refers to decision making under uncertainty and is elaborated upon in Section 3.4. Before discussing these sections, it is important to know how the tangible and intangible parts of the model are connected.

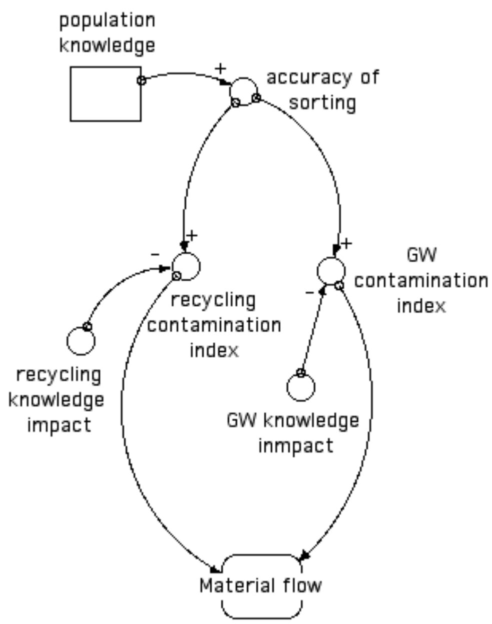


Figure 3.5 Model component determining the relationship between 'population knowledge' and 'purity' of waste streams

In the SD model presented in this thesis, the relationship between knowledge level and the proportion of contamination in waste streams is controlled by the structure seen in Figure 3.5. Knowledge level is taken to be the proportion of the waste stream that can be correctly identified. A representation of this knowledge is made for both the recycling and GW streams and these parameters go on to influence the material flow seen in Figure 3.4. The contamination indexes influence the proportion of waste that is correctly or incorrectly disposed. In addition, a knowledge impact parameter links to both GW and recycling contamination indices. This allows for population knowledge to have differing impact on recycling and GW contamination. Further detail of the learning and knowledge portion of the model can be found in the next section.

3.3 Population learning and knowledge

Learning is defined in this section as a change in the nervous system produced by experience and resulting in a change of behaviour (Hill, 1981). Knowledge is a consequence of learning and described as beliefs that are correct and justified (Hunt, 2003). Three types of learning are often discussed: (a) Classical conditioning (learning through association), (b) Operant conditioning (learning through consequences), and (c) Observational learning (learning through observation) (Mazur, 1998). This thesis will argue that operant conditioning and observational learning are connected to municipal waste disposal and will relate them to a SD model. No evidence was found to link classical conditioning with household recycling or waste disposal. Therefore, it will not be considered in the SD model relating MSW disposal to population learning and knowledge. The proposed learning feedback structure can be seen in Figure 3.6. The remainder of this section will explain the rationale behind this configuration.

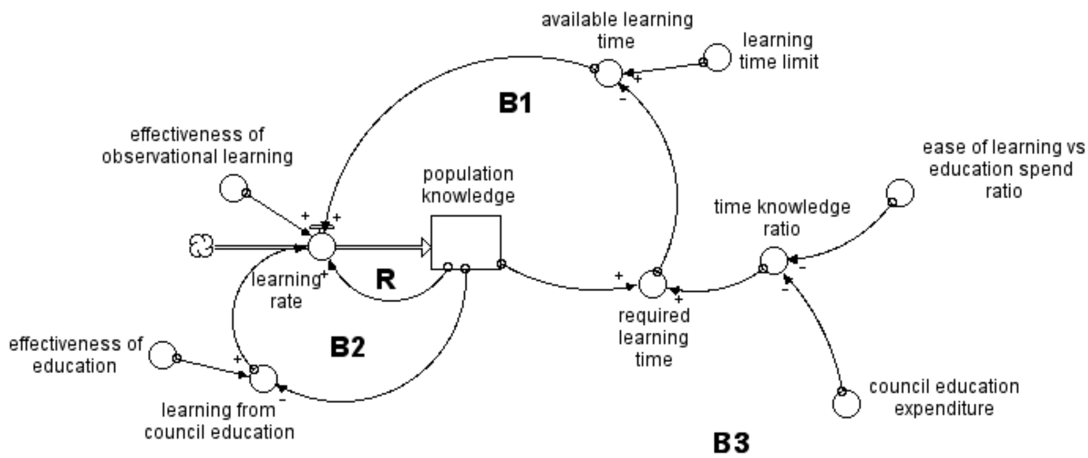


Figure 3.6 Population knowledge dynamics: consisting of a reinforcing social learning loop (R), a balancing operant conditioning loop (B2) and a balancing learning time limitation loop (B1)

3.3.1 Operant Conditioning

Operant Conditioning corresponds to balancing loop B2 in Figure 3.6 and represents learning via a response to behavioural consequences (Hill, 1981). If the behaviour is followed by a pleasant or satisfying consequence, the likelihood of repeating the behaviour increases (Mazur, 1998). If behaviour is followed by an unpleasant or negative consequence, the likelihood of repeating the behaviour decreases. It is often related to voluntary behaviours and occurs in situations containing many stimuli. The four possible types of operant conditioning include (a) positive reinforcement (a pleasant stimulus is presented to increase behaviour), (b) negative reinforcement (an unpleasant stimulus is removed to increase behaviour), (c) punishment (an unpleasant stimulus is presented to reduce a behaviour), and (d) extinction (a pleasant stimulus is removed to decrease a behaviour) (Mazur, 1998).

The evolution of the learning process can be expressed graphically as a learning curve (Hill, 1981). The horizontal axis representing the number of learning trials an individual has undergone while the vertical axis represents the associated knowledge level. The idealized learning curve from operant conditioning is an asymptote (Hill, 1981). Operant conditioning results in a decelerating diffusion curve because the number of naïve or ignorant individuals decreases over time (Franz, 2009). From time to time, due to the stochastic nature of partly learning through trial and error, s-shaped learning curves may occur yet this can be considered uncommon (Franz, 2009). Based upon this evidence, it appears reasonable to represent Operant Conditioning as a balancing loop in Figure 3.6.

Previous studies have found links between operant conditioning and municipal recycling behaviour. Thyer (1998) found that operant conditioning had been applied to promoting community recycling efforts while Coon (2005) discussed the possibility of families, work groups, factories, and dormitories using operant conditioning by setting up a periodic feedback system to meet recycling goals.

Australian councils also provide waste disposal feedback to households. Many Australian councils request that their waste collection contractor refuse to collect bins that are highly contaminated (DSEWPC, 2012). This can be considered a form of 'extinction', the removal of a positive stimulus to decrease contamination. Contaminated bins are identified using a video camera attached to the mechanical bin-lifting arm (DSEWPC, 2012). As the bin's contents are tipped into the truck's body the driver has a moment to determine level of contamination. If contamination is identified the bin is returned to the kerbside unemptied. There is no feedback about specific contaminating materials.

Another example of councils using operant conditioning is the use of bin labels. When bins have low levels of contamination, some councils place stickers upon bins to indicate high quality separation (DSEWPC, 2012). There have also been regions where prizes have been awarded for consistent good quality waste separation.

Operant conditioning that occurs from direct experience with the consequences of an action is called contingency shaped, meaning learning transpiring purely from trial and error. It is also possible for operant conditioning to be rule-governed (Mazur, 1998). This happens when verbal instructions or written rules are given to the learner, with a correct or incorrect response being judged against the associated rules. Councils define the disposal rules to which feedback is provided (Table 3.4). Instead of providing correct disposal choices for individual materials and products, councils publicise broad recycling rules (ACT Government, 2016; ACT Government, 2017). At times these rules are defined by material type (paper, paperboard, polystyrene, food items), and at times by product type (steel cans, aluminium cans, aluminium trays, aluminium foil, glass bottles or jars, plastic bags, disposable nappies, light globes, bubble wrap) (ACT Government, 2016). There are also categories that encompass multiple products and materials (rigid plastic containers, clothing, and crockery). It is assumed by local government that these rules will encompass most of the waste flow. They are made accessible to the community and intentionally kept simple to maximise recycling participation. However, due to their simplicity there is room for interpretation, resulting in waste categorisation errors. This raises the question of whether additional detailed knowledge can be developed by alternative learning methods.

Table 3.4 Council disposal rules (used in educational material either graphical or in text) (ACT Government, 2017)

Recycling	*General waste*
Rigid plastics containers	***Plastic bags***
Steel cans	***Crockery***
Aluminium cans, trays and foil	***Disposable nappies***
Paper and paperboard	***Windows/drinking glasses***
Glass bottles and jars	***Food items***
	Light globes
	Bubble wrap
	Clothing
	Polystyrene

3.3.2 Observational Learning/Imitation

Observational learning or imitation involves the patterning of behaviour after someone else by imitating or choosing not to imitate and is represented in Figure 3.6 as feedback loops R and B1 (Hill, 1981). Three types of observational learning are proposed by Thorpe (1963); (a) social facilitation (the behaviour of one individual inspires a similar behaviour of another individual, but the behaviour is one that is already in the repertoire of the imitator), (b) local enhancement (the behaviour of a model directs the attention of the learner to an object or place in the environment, meaning that the response that might otherwise have been learned from trial and error is acquired much more rapidly), and (c) true imitation (the imitation of a behaviour pattern that is very unusual or improbable, so that it would seldom be learned through trial and error).

Social learning commonly follows a sigmoid diffusion curve as there are increasing number of skilled individuals from which to learn (Franz, 2009). Although the sigmoid (s-shaped) dynamic is considered typical, it may not always occur because of the differing types of social networks and early adopters. For example, if the first adopter belonged to a subgroup of very strongly connected individuals, but these individuals have weak links with the remaining population, then it is possible for there to be a fast diffusion followed by a slower subsequent spread (like decelerating curves/asymptote). However, there are no obvious examples of highly integrated sub-groups in council populations and therefore the assumption will be made that social learning will follow a sigmoid diffusion curve. It therefore appears reasonable to represent observational learning as a combination of a balancing and reinforcing loop in Figure 3.6.

Observational learning has been mentioned to be a key influence on pro-environmental behaviour such as recycling (Thyer, 1998; Haldeman, 2009). Previous studies have also shown that household relationships have an impact on recycling effectiveness, with some family members influencing the behaviours of others (Meneses, 2005).

3.3.3 Learning and Time Cost

The time required to learn correct disposal practice can be considered a major cost of the waste disposal learning process (Guagnano, 1995; Perrin, 2001; Thomas, 2001; Wilson, 2007; Nixon, 2009). As previously stated, education campaigns have been designed to minimise this cost using broad disposal rules. However, there are waste items that can be difficult to classify. In such situations, it may be necessary to perform additional research to make a correct disposal decision. Diekmann (2003) states that people place limitations on the amount of time they are willing to devote to correct waste disposal, particularly when there is no clear benefit or significant negative consequences when incorrect decisions are made.

3.3.4 Use of SD theory to support model structure

A SD construct that has been related to learning is the Limits to Growth (or Limits to Success) archetype (Kim, 2000). This archetype is often linked to the Law of Diminishing Returns. Diminishing Returns occurs when a system experiences increasing resistance after a period of effort and growth. In previous work, it has been discussed in relation to learning a second language (Senge, 2006). A behaviour that has been repeatedly linked to operant and observational learning (Hill, 1981). In this thesis, Figure 3.6 has been adapted from a Limits to Growth S&F template (Bourguet-Diaz, 2003). In its simplest form, the Limits to Growth archetype consists of a reinforcing loop and a balancing loop. The reinforcing loop (R) in Figure 3.5 demonstrates that as knowledge increases within a community there is a greater amount of knowledge sharing. This correlates with imitation or observational learning.

The balancing loop (B1) represents the average time limitation that householders place on the learning process. They may be willing to quickly check an information source, but not to devote extensive time researching the correct disposal choice for an unfamiliar waste item. A consequence of the broad disposal rules is that not all products that pass-through households are defined. To always dispose correctly, additional research is necessary.

The Limits to Growth archetype does not account for the initial incentive for learning (Kim, 2000). For this, the concept of an external source of knowledge, representing council education, was taken from the Bass Diffusion model (Sterman, 2000). In the Bass Diffusion model, the Market Saturation loop refers to the adoption of a product or idea due to advertising (Sterman, 2000). This has been adapted for the municipal waste disposal learning process, replacing advertising with council education and the flow of adopters with the accrual of knowledge. The council education learning loop correlates with operant conditioning. The balancing loop (B2) represents the impact of operant conditioning upon community disposal knowledge.

Also visible in both Figure 3.4 and Figure 3.6 is balancing loop B3, which refers to the link between recycling bin contamination, council education expenditure and population knowledge levels. The loop is active when two conditions are met; (a) when a contract exists between the council and their recycling contractor placing limits on recycling bin contamination, and (b) when this contamination limit is exceeded. In this situation, a council is obligated to invest in a waste education campaign to decrease recycling bin contamination.

3.4 Decisions under uncertainty

Even though not appearing in the Dynamic Hypothesis, decision making under uncertainty is directly related to disposal knowledge levels. As disposal knowledge amongst the population is never absolute, there are always some uncertain disposal decisions made. The application of these concepts can partly be seen in Figure 3.4, and are described as bin bias. This section provides some explanation of why these parameters are present in the model and how they were derived.

As disposal rules are kept purposely broad, there are some materials/products that do not clearly align with any disposal category (e.g. soiled paper products, composite materials). As previously stated, in this position people have the option of investing time to acquire new knowledge about waste disposal (via research or communication with peers). However, it is also possible that people who are not willing to devote time to additional learning will choose to guess the correct disposal choice. To improve the modelling process, it is necessary to consider how disposal decisions are made, whether uncertainty may be relevant to waste disposal, and if so how can it be measured.

3.4.1 Influences on decisions under uncertainty

Subjective Expected Utility Theory provides a construct for understanding uncertain decisions (Mongin, 1997). It states that a decision maker chooses between uncertain choices by comparing their respective utilities and their respective probabilities (Mongin, 1997). If an individual was attempting to dispose an unknown glass object and the choices were the household recycling bin or the general waste bin, this could be represented as follows: Let P_1 be the probability that the glass object was recyclable and u_1 the utility of disposing the glass object in the recycling bin. Let P_2 be the probability that the glass object was general waste and u_2 be the utility of disposing the glass object in the general waste bin. Figure 3.7 provides a visual representation of this uncertain decision.

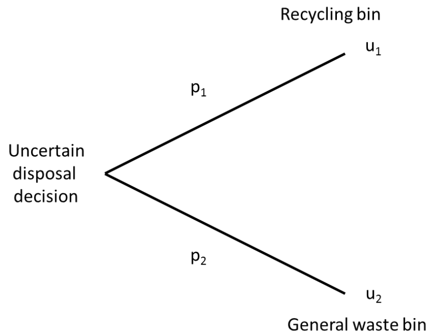


Figure 3.7 Waste disposal decision tree for uncertain decisions

When comparing the terms in Figure 3.7, and assuming no outside influences (equal utility and no knowledge influencing probability), there would be a 50% probability of making the correct choice. However, if there are differing utilities for each choice or there is related knowledge affecting each likelihood, then the choices will not have an equal chance of occurring.

When considering the utility of municipal waste disposal in the Australian context, the key gain is the removal of waste from a property. This utility is equal for the recycling bin and the general waste bin. Additionally, there is no economic advantage or material gain for choosing either bin. Research on the impact of recycling on self-image and wellbeing does propose some effect. Abbott (2013) discusses the relationship between adherence to social and moral norms and a consequent 'warm glow'. 'Warm-glow' is closely related to attitude and social norms, both discussed in Chapter 2. His analysis failed to find a significant relationship between 'warm glow' and recycling. In contrast, Halvorsen found that the most important variable increasing household recycling efforts is finding the act itself pleasant (Halvorsen, 2004). Due to the intangible nature of 'warm glow', any difference in utility between recycling bin disposal and general waste bin disposal is likely minimal.

When assessing the probability of a choice, it is assumed this is based upon existing knowledge. When incomplete knowledge is applied to decision making there is often reference to heuristics (Shah, 2008). A heuristic is an approach to problem solving that 'employs a practical method not guaranteed to be optimal or perfect but sufficient for purpose' (OED online, 2016). A relevant heuristic to waste disposal is the 'representative bias' (Tversky, 1974). The representative bias asks the question; what is the probability that object A belongs to class B? For example, what is the probability that an unrecognised glass object is recyclable? To answer such a question, a person would generally rely on the representative heuristic in which probabilities are evaluated by the degree to which A is representative of B. When A is like B then the probability that A originates from B is judged to be high. If A is not like B, the probability of that A originates from B is judged to be low.

This research is not attempting to untangle the specific relationships within an uncertain bin choice; it only notes its presence and measures its magnitude (see next section). This information will indicate a bias toward the general waste or recycling bin when making an uncertain decision. It is necessary to determine how to identify uncertain decisions (guesses) and how to measure outcomes.

3.4.2 How to identify uncertain decisions

Knowledge can be described as beliefs that are correct and justified (Hunt, 2003). Exams and tests are a long-established method for assessing knowledge. For example, measuring the proportion of correct responses in a multiple-choice test addresses whether the response matches the teacher's reality. However, proportion does not indicate whether the response is a belief or a guess. One method used to distinguish between a guess and a belief is the use of certainty scales.

The use of certainty scales based on self-report, gives some insight into the strength of the belief. Link (1982) performed a dichotomous choice test using a confidence scale. Low responses on the confidence scale were assumed to signal uninformed guesses. Hunt (2003) found that the use of certainty scales were useful in determining a 'signal of knowing'. The 'signal of knowing' being an indicator of the current state of a brain. When certainty scales were used after the subject made a test response, they were largely accurate in distinguishing between correct and incorrect responses (Hunt, 2003).

Confidence Based Marking (CBM) schemes have also gained recognition as a legitimate means for achieving greater insight in knowledge assessment (Hench, 2014). CBM assumes a linear relationship between confidence (or certainty) and the mark expected by students. It involves a marking scheme where a responder will receive a mark of 3, 2 or 1 for a correct response and 0, -2, or -6 for incorrect responses, dependent upon level of certainty of being correct (Table 3.5). This system has been used in university testing of medical students (Schoendorfer, 2012).

Table 3.5 CBM marking scheme

Certainty scale	Low	Mid	High	No reply
Mark if correct	1	2	3	0
Mark if incorrect	0	-2	-6	0

Methods for detecting the presence of low-certainty decisions will be discussed in greater detail in Chapter 6.

3.4.3 Uncertain decisions and bin bias

As stated, reference to low-certainty decisions has been represented in the SD model as a bin bias parameter. This parameter measures the probability of a community choosing the general waste bin or the recycling bin when disposing an unfamiliar waste item. In the SD model, bin bias is represented as a static parameter during a given simulation run.

There are two options to determine the value of the bin bias parameters. The first involves the detection and measurement of disposal guesses. When disposal guesses are detected using methods discussed in the previous section, it is possible to count guesses going to the recycling bin (A) and guesses going to the GW bin (B). Bin biases can then be calculated using equations 3.1 and 3.2.

$$GW\ bin\ bias = \frac{B}{A} \qquad [3.1]$$

$$Recycling\ bin\ bias = \frac{A}{B} \quad [3.2]$$

An alternative is to 'reverse engineer' bin bias values using waste audit data. If waste audit data can be used to constrain waste stream proportions, then intangible parameters such as bin bias can be used to match the contamination levels measured during the audit. These processes will be discussed further in Chapters 6 and 7.

Before going on to further investigate MSW recycling rate plateaus, an examination of Old Newspaper (ONP) recycling plateaus is carried out in the next chapter. The purpose of this slight detour is to understand how a material's recycling plateau may relate to MSW recycling plateaus. The use of the term 'recycling rate' differs slightly between ONP and MSW. While ONP recycling rates refer to the proportion of ONP recovered for recycling, MSW recycling rates describe both the proportion of recyclables recovered and the proportion of recyclables in the waste stream. This results in ONP recycling rates being significantly higher than MSW recycling rates.

Australian Newspaper Recycling Plateaus

Chapter 4 addresses Research Question 1; how do MSW recycling plateaus relate to material recycling plateaus? To answer this question, an examination of Old Newspaper (ONP) has been carried out.

The term ONP refers to post consumer discarded newspapers. In Australia, newsprint has in the past achieved recycling rates of approximately 78%. However, recycling rate growth has slowed since the early 2000's (Figure 4.1) (Industry Edge, 2013).

In this chapter, analysis of ONP recycling rates will take place within the prism of ONP supply and demand. A System Dynamic (SD) model will be used to determine the major influences on ONP supply. A combination of market trends and price comparisons will be used to better understand the influences on ONP demand. However, before beginning this analysis it is useful to have a better understanding of the Australian newspaper industry.

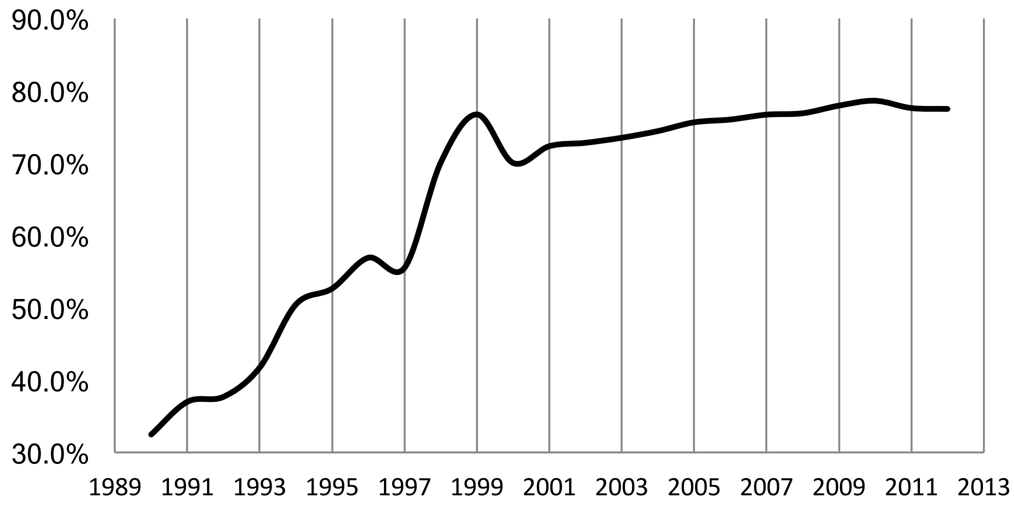


Figure 4.1 Percentage of newspaper recycled in Australia (% recycled = ONP reused/newspaper circulation) (Industry Edge, 2013).

4.1 Background of newspaper recycling

The Australian newspaper industry is amongst the most concentrated globally, with three major owners of metropolitan or national newspapers; News Corp Australia, Fairfax, and Seven West Media (Papandrea, 2013). They control twelve titles; encompassing two national titles, two published in both Sydney and Melbourne and one in each of the remaining states and territories. Regional Australia is served by 37 daily newspapers, largely held by News Corp, Fairfax Media and by APN News & Media Limited.

The newspaper sector in Australia has experienced economic pressures in recent years, with newspaper revenue being squeezed by free online news sources and highly competitive internet advertising (Papandrea, 2013). Since the 1980's, newspaper circulation in Australia has been experiencing gradual decline. This circulation decline has accelerated since 2006 and can be observed in Figure 4.2 and Figure 4.12.

As of 2010, 70 per cent of newsprint used in Australia was produced locally by the Albury Paper Mill in NSW and the Boyer Paper Mill in Tasmania (PNEB, 2010). The Tasmanian Boyer Mill has been in operation since 1941, producing newsprint from local Eucalypt species until 2008 (Bradshaw, 2001). In 1981, a second newsprint paper mill was introduced in Albury NSW to take advantage of local maturing pine plantations. The Albury Mill had the added advantage of proximity to Sydney and Brisbane. An Albury de-inking plant was commissioned in 1993 and made active in 1995 (PNEB, 2010). This made the Albury paper mill capable of recycling old newspaper into newsprint. Approximately 43000 tons of de-inked, de-watered recycled fibre was annually sent to the Boyer Mill from the Albury Mill, to also give its newsprint some recycled content (Bradshaw, 2001). Before the use of old newspaper in milling newsprint, the only domestic demand was from the paperboard industry (Industry Commission, 1990).

There has traditionally been a close relationship between Australian newspaper publishers and newsprint mills. Up until 1997, Australia's two newsprint paper mills were fully or partly owned by newspaper publishers (Bradshaw, 2001). This close relationship was reaffirmed by the 1990 formation of the Publishers National Environment Bureau (PNEB) (PNEB, 2010). This brought together Australia's major newspaper publishers in an agreement to commit to long term contracts for newsprint containing recycled fibre. A component of the commitment to recycling included the introduction of a newspaper recycling quota. The first recycling target was set in 1992 with the aim to reach 40% by 1995, and in 1996 this was increased to 60% by 2000. This was augmented again in 2000, to reach 74% by 2005 and in 2005 the goal was increased to 76% by 2010. The combination of guaranteed demand for newsprint containing recycled fibre, plus the upgrade of the Albury Mill in 1995, has been thought to have provided a boost to newspaper recycling rates.

The incentive for newspaper publishers and newsprint mills to recover ONP was generated by environmentalists, government bodies and market competitors. Mill technology had evolved, with recycled fibre newsprint mills appearing overseas (Bradshaw, 2001). If similar technology was not developed in Australia, there was risk for domestic publishers and mills to appear antiquated and thus susceptible to international competition. Further competition came from the Australian paperboard industry, which was threatening to expand their business by developing a recycled fibre newsprint mill (Industry Commission, 1990).

Consequently, upgrading mill capabilities was partly related to maintaining international and domestic competitiveness. Additionally, the amount of newspapers in landfill started to become a community concern, brought to light by environmentalists (Bradshaw, 2001). Environmentalists and subsequently government began to ask why there was no recycled content in newsprint.

Since the mid 90's most ONP has been recycled by domestic paperboard, domestic newsprint and the export market (Industry Edge, 2013). The domestic newsprint market had a peak in demand in 1998 and has been declining ever since. The domestic paperboard market has shown consistent growth until 2010, after which was a drop-in demand. The export market has grown consistently since the 1990's.

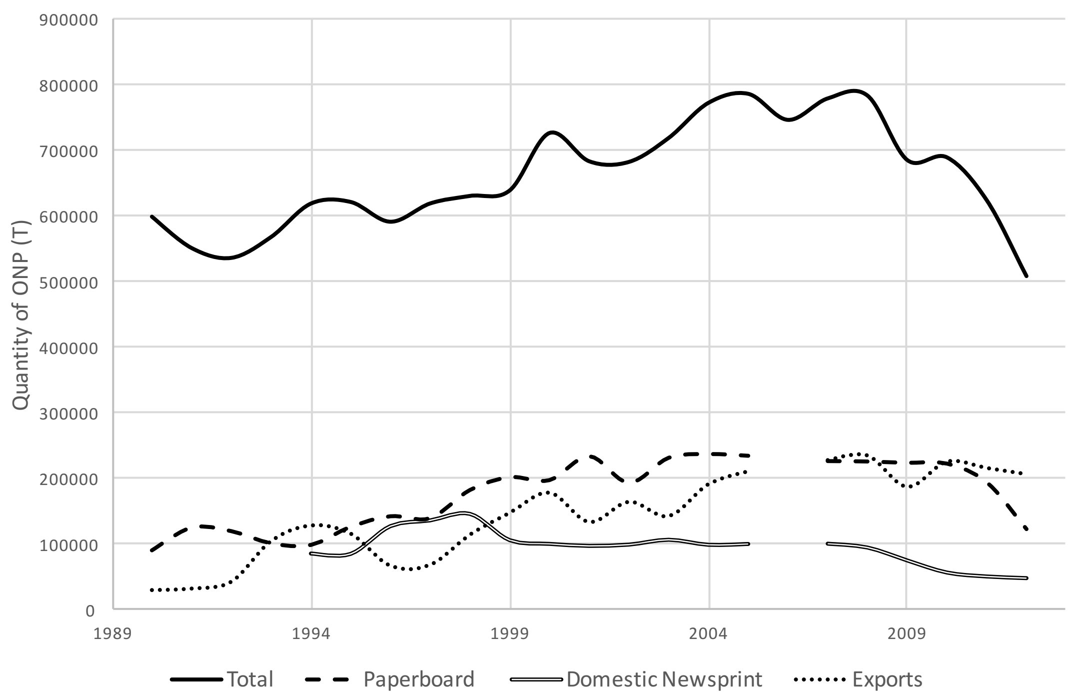


Figure 4.2 Australian newspaper circulation in tonnes per annum and destination of ONP (Industry Edge, 2013)

The goal of this chapter is to determine the reason for newspaper recycling plateaus by analysing the trends of ONP supply and demand. As ONP is sourced from household waste and from Commercial (enterprise) & Industry (C&I), these waste flows will be investigated. The three key sectors consuming ONP to be analysed are domestic newsprint, domestic paperboard, and the export market. The export market refers to the export of ONP out of Australia into international markets. Any conclusions made from analysis of ONP recovery will be related to plateauing MSW recycling rates.

4.2 Methodology for investigating ONP plateaus

Data was collected from secondary sources to inform this research. This section summarises the data collection and analysis methods used for ONP supply and demand.

4.2.1 ONP supply

A key consideration when analysing ONP supply, is the origin of ONP. Approximately 85% of postconsumer ONP is sourced from MSW, with the remaining 15% obtained from C&I (Integrated Waste Management Board, 1996). As stated in Section 2.1.4, the type of recycling system in place can have a powerful effect on recycling behaviour (Derksen, 1993; Guagnano, 1995). So, when analysing ONP supply from MSW it is important to understand how collection takes place and the characteristics of the collection system. As kerbside collection is currently the dominant form of MSW collection in Australia with 91% of households having access in 2009 (ABS, 2009), it is necessary to dissect its characteristics to gain insight into ONP supply and how it relates to recycling plateaus.

An SD model was used to understand the impact of ONP supply on ONP recycling rate dynamics. To create an ONP recycling simulation, it was determined that four queries needed to be resolved; (a) the rate of adoption of kerbside recycling, (b) whether different types of council exist, (c) if there are different council types, do they have different average populations, and (d) how much ONP could be recovered from the average council with kerbside recycling? The premise of this modelling action was, that an ONP simulation with a close fit with historical data would suggest that ONP supply is the key influence on ONP recycling plateaus. If the fit was not good, then the cause of recycling plateaus likely comes from elsewhere.

To determine the rate of adoption, the year of kerbside recycling onset was determined for a sample of 59 Australian councils. Kerbside recycling time series were generated from newspaper archives, council records and information communicated in response to an article published by the Australian Local Government Association (ALGA). Concomitant to kerbside recycling onset, information was collected about council classifications and populations. A summary of council classifications can be seen in Table 4.1. These are based upon council population, population density, level of urbanity, and location (DIRD, 2013).

Table 4.1 Australian Local Government classifications (DIRD, 2013)

Metropolitan		Regional Centre		Regional	
UCC	Urban Capital City	URM	Urban Regional Medium	RAL	Regional Agricultural Large
UDL	Urban Development Large	URS	Urban Regional Small	RAM	Regional Agricultural Medium
UDM	Urban Development Medium	URV	Urban Regional Very Large	RAS	Regional Agricultural Small
UDS	Urban Development Small			RAV	Regional Agricultural Very Large
UDV	Urban Development Very Large			RSG	Rural Significant Growth
UFL	Urban Fringe Large			RTM	Rural Remote Medium
UFM	Urban Fringe Medium			RTS	Rural Remote Small
UFS	Urban Fringe Small				
UFV	Urban Fringe Very Large				

To determine the different types of councils, council classifications were used to create three groups of councils; metropolitan, regional centres and regional. Council classifications seen in Table 4.1 were used to create these three council groups. Metropolitan councils encompassed the following classifications from Table 4.1: 'urban capital (UC)', 'urban development (UD)', and 'urban fringe (UF)' classifications. Regional centre councils encompassed the following classifications from Table 4.1: 'urban regional (UR)'. Councils identified as 'rural remote (RR)', 'regional agricultural (RA)', or 'rural significant growth (RTG)' were used to create a regional council grouping. Due to the geographic remoteness of City of Karratha, City of Kalgoorlie-Boulder, and Bathurst Regional Council they were changed from the regional centre to regional category.

To gain further insight into the character of these council categories, the average population per council was determined for regional areas and urban centres (metropolitan and regional centres combined). Local government population data from June 2006 was sourced from the Australian Bureau of Statistics (ABS). The current number of councils with kerbside recycling was determined using the Planet Ark website 'recycling near you' (Planet Ark, 2016).

4.2.2 ONP Demand

Demand for ONP in the domestic newsprint sector was assessed by collating the price history of its constituents; ONP and pinus radiata pulp log. The mill door price for pinus radiata pulp log was determined from academic, government and industrial sources (ANU Forestry, 2000; ANU Forestry, 2000; ANU Forestry, 2001; ANU Forestry, 2002; ANU Forestry, 2002; New Zealand Ministry for Primary Industries, 2017). The New Zealand Ministry for Primary Industries provides quarterly prices for pinus radiata pulp log from 1992 to present day. There is not a publicly accessible source of Australian pinus radiata pulp log prices. An intermittent Australian price history was gathered from academic and industrial sources.

Two data sets were used to summarise Australian ONP price history; irregular Australian ONP prices and the US ONP Producer Price Index (PPI). Due to the global nature of the scrap paper market it was hypothesised there would be similar price dynamics between US and Australian ONP markets (Porter R. C., 2002). A linear regression analysis was performed between Australian ONP price history and US ONP PPI to determine correlation. The regression model results were used to scale the US ONP PPI to represent Australian ONP price history.

The US PPI measures "the average change over time in the selling prices received by domestic producers for their output" (BLS, 2015). It is a dimensionless ratio calculated using Q_0 as the quantity of the commodity shipped during the base period, P_0 as the price of the commodity in the base period, and P_i as the price of the commodity in the current period (BLS, 2015). The PPI formula can be seen in Equation 4.1:

$$I_i = \left[\frac{\sum Q_0 P_0 \left(\frac{P_i}{P_0}\right)}{\sum Q_0 P_0}\right] \times 100 \qquad [4.1]$$

$\frac{P_i}{P_0}$ represents the price ratio and $Q_0 P_0$ represents the weights in value form (BLS, 2015). The index can be described as 'a weighted average of price relatives'.

4.3 Results of ONP plateau analysis

In this section, data and analysis results are presented in four parts; ONP supply data, ONP supply model, newsprint sector demand and domestic paperboard and export demand. Section 4.3.1 discusses the data being used for the SD model in Section 4.3.2, with the goal of analysing ONP supply. The data relating to ONP supply concentrates on MSW waste collection, the key source of ONP. As kerbside recycling is the dominant form of household recycling, there is a focus on the evolution of kerbside collection. Section 4.3.3 carries out a price ratio analysis of the two raw ingredients in Australian newsprint; ONP and pinus radiata pulplog. A discussion of the relationship between Australian newspaper circulation and the paperboard and export markets is found in Section 4.3.4.

4.3.1 ONP Supply data

The data discussed in this section is used to characterise the SD model, which is subsequently used to simulate ONP recycling rates. The data will encompass kerbside recycling onset, types of councils and their recycling systems, populations of councils, the dynamics of kerbside recycling participation and the average amount of ONP recovered from kerbside collection.

A sample of Australian councils were surveyed to determine the trends of kerbside recycling onset. Figure 4.3 shows the data for 59 Australian councils, (representing 10.37% of the 569 Australian councils) showing the year they adopted kerbside recycling and their LGA category (DIRD, 2016). Further detail of this data can be seen in Appendix B.1.

When these data were graphed, it became apparent that there were two major categories of councils; the early adopters and the late adopters of kerbside recycling. Metropolitan and regional centres commonly being the early adopters and regional councils being the late adopters. Two possible reasons for this divide include the necessity of economies of scale and the need to minimise transport requirements. It has been reported that capital cost per ton and operating cost per ton declines the larger the MRF size (Porter R. C., 2002). In the 1990's, a MRF required a population of at least 300000 to be financially sustainable (Porter R. C., 2002). It has also been stated that recycling facilities should not be too far from points of waste generation because of associated transport costs (Farhan, 2006; Partick Engineering, 2010). On the demand side of MRF location, it is recommended to choose locations where the need for recovered resources is greatest (Neeley, 2017). A component of this involves choosing a location close to transport corridors to facilitate the movement of sorted materials to market (Partick Engineering, 2010).

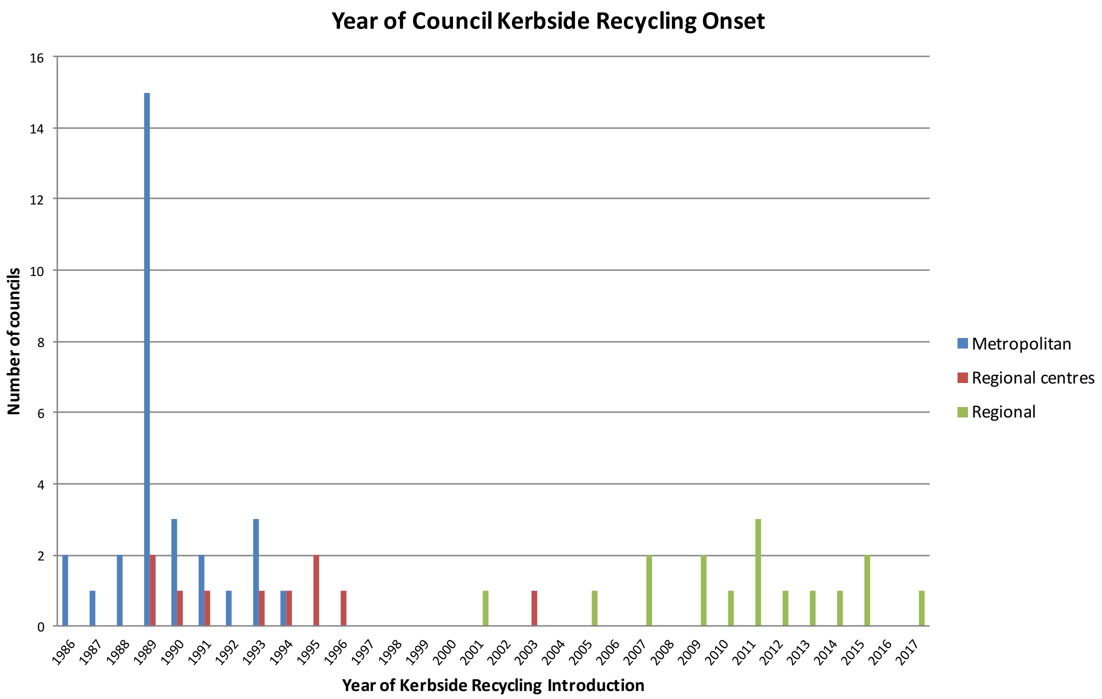


Figure 4.3 Council's kerbside recycling onset

Taking note of the status of local government waste disposal, kerbside recycling is now the dominant disposal method (DIRD, 2016; Planet Ark, 2016). The Planet Ark 'Recycling Near You' website provides the most comprehensive data regarding the current recycling facilities being offered by Australian councils. Planet Ark representatives request annual updates from councils. Table 4.2 showed that 85.24% of councils have some access to recycling, with 73.46% of councils using kerbside recycling. It is also apparent that the councils that have no recycling or only drop-off recycling, are predominantly regional. As regional councils generally have smaller populations, it is hypothesised that a large majority of the population have access to recycling. A topic discussed further in Table 4.3.

Table 4.2 Status of Australian council recycling systems in 2016 (Planet Ark, 2016)

	Kerbside recycling	Drop-off recycling	No recycling facilities	Unknown	Total
Metropolitan and regional centres	235	12	2	0	249
Regional	183	55	69	13	320
Total	418	67	71	13	569

A summary of council populations and the associated waste disposal options reveals some interesting attributes (DIRD, 2016; Planet Ark, 2016). As shown in Table 4.3, 98.95% of Australian population have some access to some form of recycling, and 96.63% of the population have access to kerbside recycling. As kerbside participation is near saturation, this does not appear to be the limiting factor on recycling rates.

Table 4.3 2015 populations in Australian councils with access to different recycling systems (Planet Ark, 2016; DIRP, 2017)

	Kerbside recycling	Drop-off recycling	No recycling facilities	Unknown	Total
Metropolitan and regional centres	20,601,067	266,480	48,686	0	20,916,233
Regional	1,348,171	260,484	178,685	15,263	1,802,603
Total	21,952,643	526,964	227,371	15,263	22,718,836

The quality of waste separation has also been found to have an impact on ONP recycling rates. Two kerbside bins are the norm in Australia; one for comingled recycling and one for general waste. There is generally some contamination in both bins, recyclables in general waste and general waste in recycling. Appendix B.4 shows the evolution of kerbside bin contamination in a selection of 15 Sydney councils (APrince Consulting, 2008; APrince Consulting, 2011; APrince Consulting, 2016). The data indicates a progressive decrease in general waste contamination while there is a gradual increase in recycling bin contamination. As of 2015, the recycling bin contamination sat at 13% and the general waste bin contamination at 11.4%. A summary of New South Wales (NSW) council 2011 waste audits showed

22.1% of general waste was potentially recyclable (NSW EPA, 2014). A summary of South Australia (SA) council kerbside systems found 18% of general waste was recyclable (Nolan-ITU, 2002). Again, as a conservative measure, the contamination figures from the Sydney councils will be used as a guide when modelling kerbside adoption.

As stated in Section 4.2, postconsumer ONP is sourced from MSW and C&I. The proportions from each need to be known as they experience different influences. Industry reports from the US indicated that the MSW is the principal postconsumer ONP waste flow with 85% of the market, while 15% of postconsumer ONP is sourced from C&I (Integrated Waste Management Board, 1996).

As a final point, not all postconsumer ONP enters the municipal waste system. Some ONP is reused, with examples of reuse including for cleaning and gardening purposes. Research has shown that about 7% of newsprint consumed is destroyed, or ruined beyond re-use, leaving a maximum of 93% available for recovery (PNEB, 2010).

4.3.2 ONP supply model

To simulate ONP recycling rates, an SD model was formed from the data in the previous section and a construct known as the logistic model. This is a construct often used to model the diffusion and adoption of new ideas or products (Sterman, 2000). It consists of two major feedback loops; a reinforcing feedback loop and a balancing feedback loop. The reinforcing feedback loop represents the 'infection' of councils who have not adopted kerbside recycling by councils that have. This is a simplification of the process which would include economic and political considerations. The balancing feedback loop represents the diminishing adoption effect due to decreasing numbers of councils that have yet to adopt kerbside recycling. Two logistic models of innovation diffusion were applied to represent two periods of kerbside adoption; metropolitan and regional centres (urban) during the 1980s and 1990s and regional councils during the 2000s (Figure 4.4).

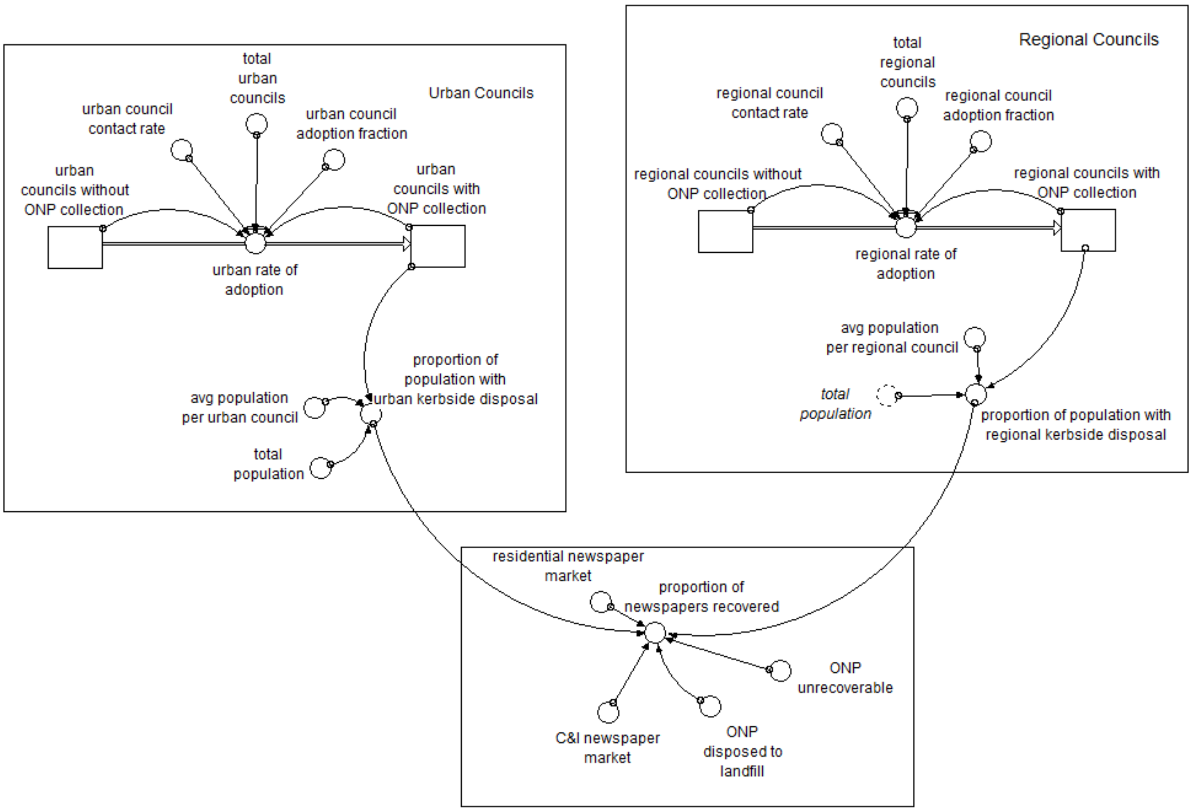


Figure 4.4 Stock and flow model of ONP supply (Sterman, 2000)

The values and formulas used in the model relate to the data discussed in Section 4.1. The parameter 'Total councils' represent the number of councils currently with kerbside recycling. Council numbers and council population figures have been previously explained in Tables 4.2 and 4.3. The rate of adoption equation is defined by the Logistic model of innovation diffusion (Sterman, 2000). The proportion of ONP lost to landfill was input as 11.4% and the proportion of ONP considered unrecoverable was 7% (PNEB, 2010). Further detail of this information can be found in Appendix B.3.

The Logistic Models of Innovation Diffusion were constrained using data collected on kerbside recycling adoption (Figure 4.5a and Figure 4.5b). This determined the values of contact rate and adoption fraction. Adoption fraction is the probability of adopting kerbside recycling after having a meaningful contact with another council currently with kerbside recycling. Contact rate is the frequency of waste related contacts between councils per year.

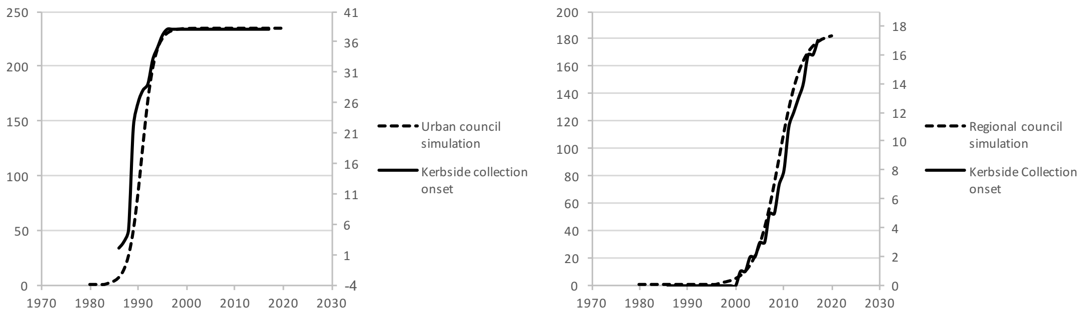


Figure 4.5 Rate of adoption, constrained by (a) urban council onset of kerbside recycling, and (b) regional council onset of kerbside recycling

Model output (Figure 4.6) indicated that the simulated maximum level of ONP recovered is like the real-world recovery level. However, the gradient of the initial growth was greater in the simulation than what occurred historically. Possible reasons for this include assuming 100% participation from onset of kerbside recycling, or presuming a consistent amount of ONP lost to incorrect disposal or other uses.

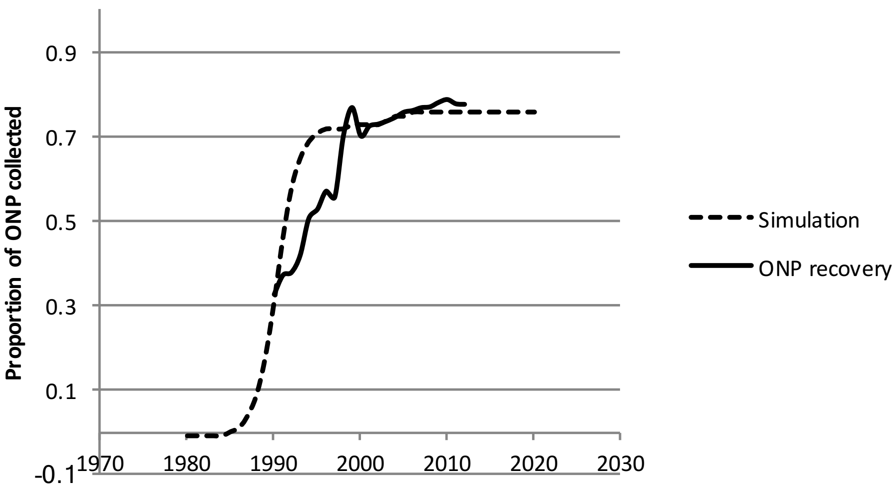


Figure 4.6 Output of stock and flow model: Proportion of ONP recovered

To test the 100% participation supposition, an investigation of kerbside recycling participation revealed household participation takes approximately five years to peak (Figure 4.7 and Appendix B.2) (Sudol, 1991; US EPA, 1993; US EPA, 1993; US EPA, 1993). Participation was measured in monthly intervals, requiring at least one bin set-out in that month to be considered a participant. While it should be noted that these case studies were international and occurred in the 1990's, it does suggest that frequent recycling participation may be subject to some evolution. If consideration of a learning process around participation and bin contamination is made for future versions of this model, this may account for the gradient discrepancy.

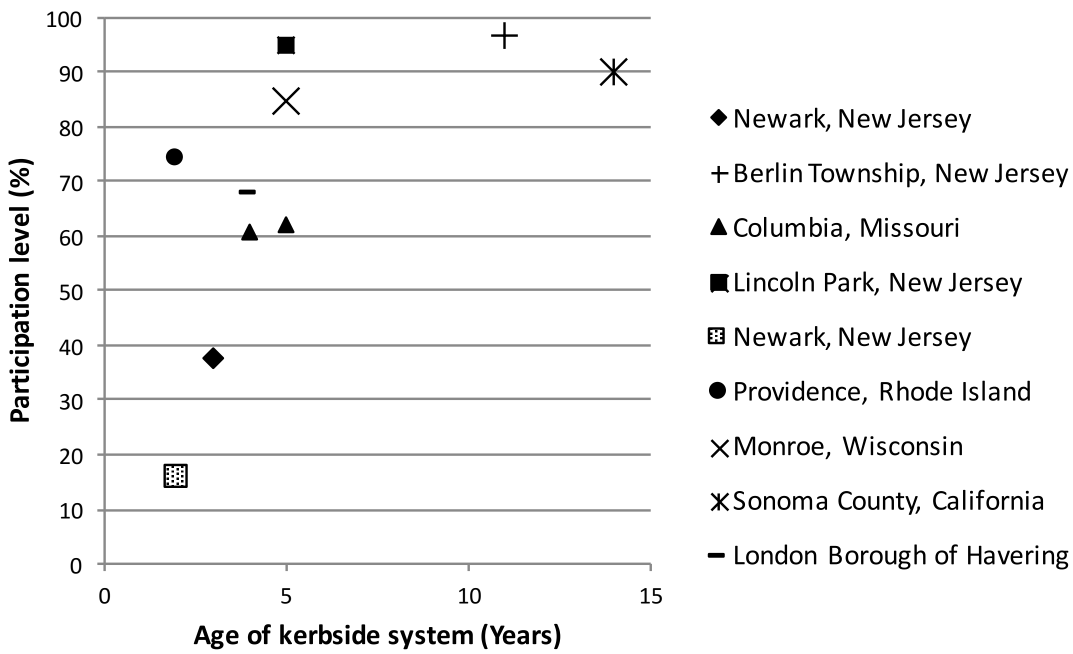


Figure 4.7 Relationship between age of kerbside recycling system and participation (US EPA, 1993; US EPA, 1993; US EPA, 1993)

When considering simulation results and possible explanations for the discrepancies, there is significant inference that ONP recycling plateaus are due to the inefficiencies in recovering disposed newspaper. These inefficiencies include households having no access to recycling facilities, destroyed or ruined newspaper, and newspaper incorrectly disposed to landfill.

4.3.3 Newsprint sector demand

ONP demand also exerts influence on ONP recycling rates. As stated previously, one demand being the use of ONP in the manufacture of newsprint. There are two sources of raw material for newsprint containing recycled fibre; pinus radiata pulp log at mill-door prices and ONP (PNEB, 2010). This section presents a price ratio analysis to determine the incentives to use either raw material. Comprehensive price history is not publically available for either material in Australia. Ten Australian pinus radiata pulp log mill-door price data points were collected and compared to a comprehensive price history available for New Zealand pinus radiata pulp log at mill-door prices (New Zealand Ministry for Primary Industries, 2017). This price comparison can be seen in Figure 4.8. The average Australian price was 37.52 AUD and the average New Zealand price was 37.73 AUD. The average for New Zealand prices encompassing the same time as the sample of Australian prices (November 1999 to July 2004) was 34.62 AUD. Based on similarity of means, the New Zealand price history was used as a surrogate for Australian price history.

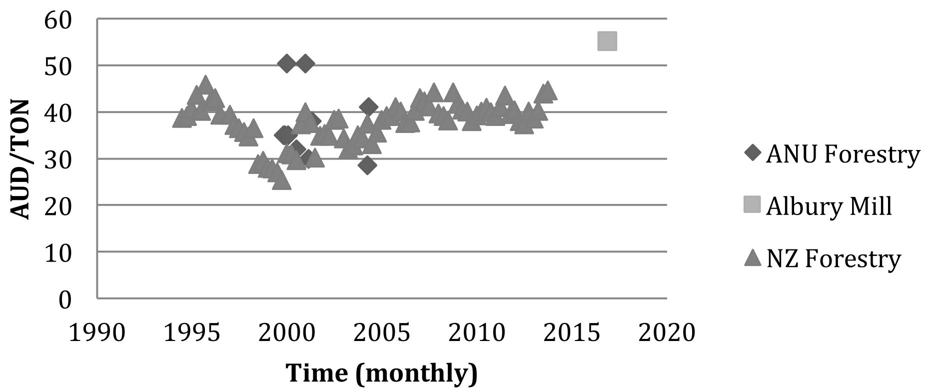


Figure 4.8 New Zealand and Australian pinus radiata pulp log at mill door prices AUD

Intermittent price data was also gathered for Australian ONP price history (AS6 grade). AS6 grade "consists of baled newspapers as typically generated from news drives and kerbside collections" (PapertoPaper, 2007). Corresponding to this, US news waste paper PPI was gathered from the US Bureau of Labor Statistics (BLS, 2015). As the US PPI is an accurate indicator of price dynamics of an international market, it was hypothesised there would be similar price dynamics in Australia. A linear regression analysis was carried out to determine degree of correlation with Australian ONP prices (Table 4.4). A high degree of similarity between the two data sets was found (p=3.4e-05). Based on this analysis and the regression results (intercept of 81.62 and estimate of 1.3092) the US PPI was adjusted to represent Australian ONP prices. Figure 4.9 presents the intermittent Australian ONP prices and adjusted US PPI for news wastepaper.

Table 4.4 Linear regression analysis of US news waste paper PPI and Australian ONP prices

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	81.6227	32.1536	2.539	0.015 *
AS_6.AUD	1.3092	0.2814	4.653	3.4e-05 ***

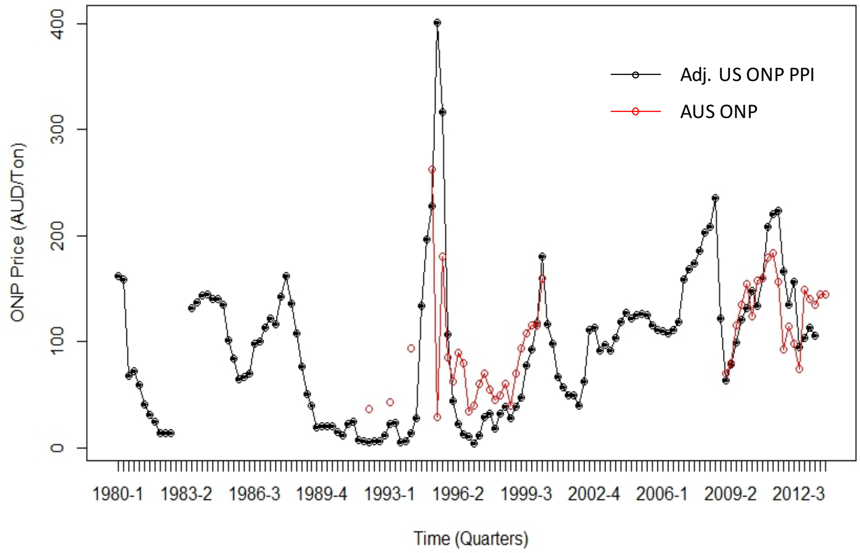


Figure 4.9 Australian ONP prices AUD and adjusted US news waste paper PPI (BLS, 2015)

The price-ratio simulation indicated a similarity with the actual proportion of ONP used in newsprint production (see Figure 4.10). The price-ratio calculation was constrained by the technical limits of Australian newsprint being able to contain up to 40% recycled fibre, shown in Equation 4.2 (PNEB, 2010). This analysis suggests that newsprint manufacturing in Australia was guided predominantly by economic concerns. This is supported by the following PNEB statements; “by 2000, competition from exporters and other users of recovered newspapers dropped newsprint’s share of the kerbside paper market” and “producers and publishers faced growing competition from cardboard manufacturers and exporters” in ONP recovery throughout the 2000s (PNEB, 2010). There is future potential for refining the simulation by considering PNEB’s ONP recycling quota.

$$Price\ ratio = \frac{radiata\ pine\ pulplog\ AUD/ton}{ONP\ AUD/ton} \times Maximum\ ONP\ limit \qquad [4.2]$$

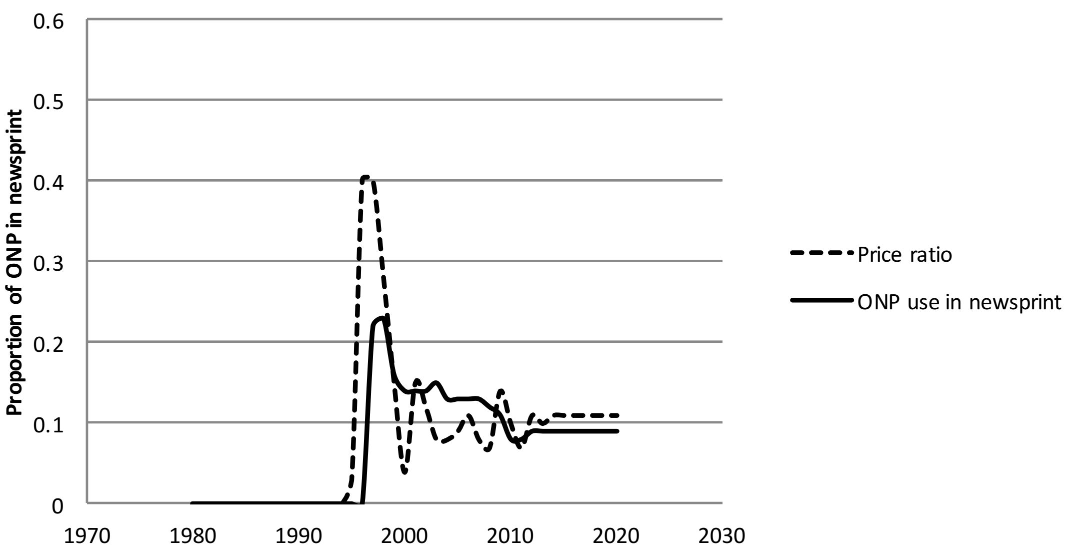


Figure 4.10 Price ratio simulation and actual ONP use in domestic newsprint

4.3.4 Domestic paperboard and export demand

As previously stated in Section 4.2, the domestic paperboard and export market came to dominate ONP consumption in the late 1990s and 2000s. This section will be used to discuss the relationship between the paperboard and export markets, and their association with ONP recycling rates.

Visy and Amcor controlled 97% of the Australian paperboard market in 2004, with Visy independently having a 55% market share in 2007 (Cooke, 2007; Lewis, 2009). Both companies are vertically integrated; providing services such as collection, sorting and recycling of waste from industry, supermarkets and households (Murphy, 2003; Amcor, 2010; Centre for International Economics , 2011).

When waste paper supply exceeded domestic demand in the newsprint or paperboard industry, the excess was exported by Visy and Amcor (Visy Industries, 2006; Centre for International Economics , 2011; Moore, 2012). Official data indicates that 10 to 20 per cent of scrap paper collected in NSW was exported, 93% of which was sent to China in 2010 (Centre for International Economics , 2011). Additional information relating to paperboard production capacity and export markets can be found in Appendices B.5, B.6 and B.7.

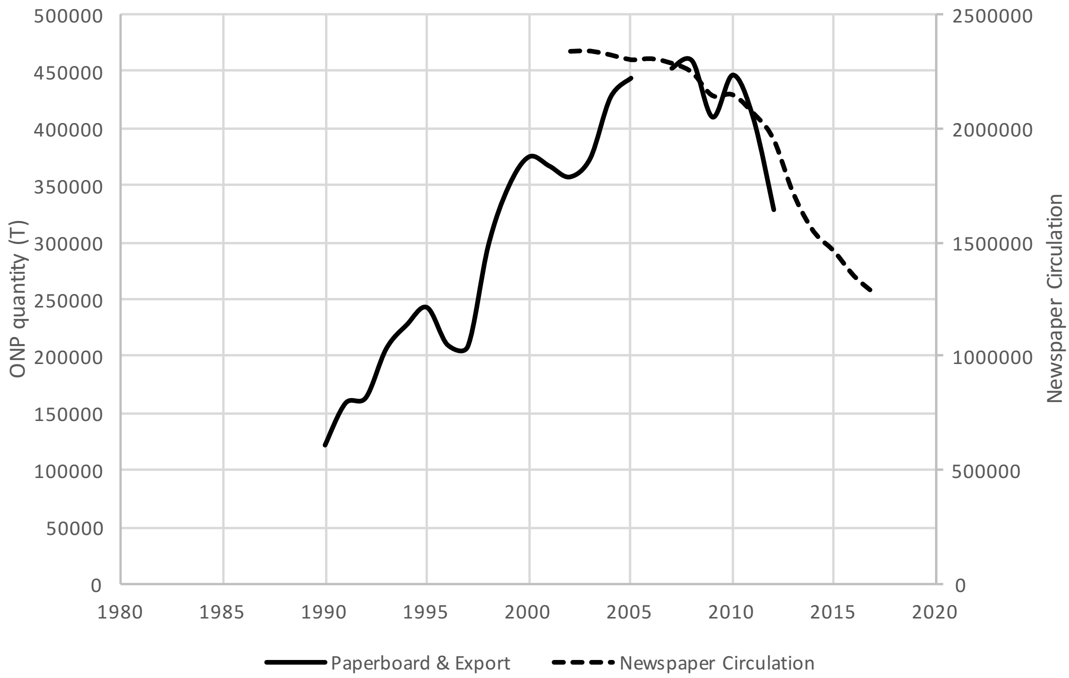


Figure 4.11 A comparison of ONP use in the paperboard & export markets, and circulation of Australia's 12 largest daily newspapers (APC, 2008; Industry Edge, 2013)

As the paperboard and export markets are connected, they have been treated as single category in Figure 4.11. The figure shows growth during the 1990s and early 2000s, followed by a significant drop in 2010. When compared to the total circulation of Australia's 12 largest daily newspapers, it is evident a drop-in print readership also occurs around 2010 (APC, 2008). Newspaper circulation in Australia, as discussed in Section 4.1.1, has experienced economic pressures in recent years, with newspaper revenue being squeezed by free online news sources and highly competitive internet advertising (Papandrea, 2013). Figure 4.11 indicates correlation between newspaper circulation and level of ONP used in the paperboard or export markets. The possible explanation for this correlation, is diminishing ONP supply forced the paperboard industry to source alternative raw materials for production. This reaffirms the findings of Section 4.3.2, that ONP demand is limited by ONP supply.

4.4 Discussion of ONP plateau research results

This study concluded that MSW ONP supply was the primary limiting factor on ONP recycling rates plateauing below full potential. The three influences on ONP supply were kerbside recycling coverage, ONP lost via incorrect disposal and ONP deemed unrecoverable due to alternative use. The model of ONP supply can be seen in Figure 4.4 and the model output is presented in Figures 4.5 and 4.6. Data analysis indicated that ONP supply is diminished by lack of access to recycling facilities. It was found that as kerbside recycling coverage increased there was a subsequent increase in ONP collected. This occurred predominantly in the 1980s and 1990s, however there was a second uptick in the 2000s coinciding with regional adoption of kerbside recycling.

Unfortunately, there is little improvement possible in expanding kerbside recycling. All metropolitan or regional centre councils had access to kerbside facilities while 20.38% of regional councils had unknown or no access to recycling facilities (Planet Ark, 2016). As the proportion of the national population in these councils was around 1.57%, further regional kerbside recycling expansion is unlikely to have a great impact.

Ruined ONP and ONP incorrectly disposed to landfill were the other inefficiencies in recovery. Further investigation into human disposal behaviour may be an interesting area of investigation to determine whether ONP recovery can be improved.

Based upon the price ratio analysis in Section 4.3.3, ONP demand from the domestic newsprint market is dependent on the prices of ONP and pinus radiata pulp log. Recent trends indicate that although there is the capacity to increase the proportion of ONP in newsprint, it is being removed from the production due to the unfavourable price comparison with pine pulp log. Even though the newsprint industry has been involved in creating a recycling quota system, the domestic paperboard industry and the export market dominate ONP recovery. This means there is little need for them to increase intake as quotas are currently being met by the paperboard and export markets.

Although in depth analysis of influences was not carried out for ONP recovery in the paperboard and export markets, trends were observed. As noted when defining the scope of this thesis, Australia is the geographic focus of recycling analysis. This is a key reason for not delving deeply into the recycling export market. These markets are connected, as the main stakeholders in the paperboard market can divert ONP for export if expedient. A decrease in ONP use is evident since 2010 and appears to correlate with a declining newspaper circulation. This sector of ONP recycling dominates demand and still appears to surpass supply.

These results provide insight into the Research Question 1: how do MSW recycling plateaus relate to material recycling plateaus? Industrial reports showed that 85% of ONP was estimated to originate from MSW and 15% from C&I (Integrated Waste Management Board, 1996). It should be noted that the C&I recycling rate was kept constant during model simulation. The following statements could be used to describe the manner in which MSW recycling plateaus relate to material recycling plateaus:

- If a recycling plateau is not occurring in MSW and C&I, then a material recycling rate plateau would not occur.
- If a recycling plateau is only occurring in MSW yet there is change in the C&I recycling rate, there may be minor change to the material recycling rate.
- If a recycling plateau is only occurring in C&I but not in MSW, it is likely that significant change would be evident in the material recycling rate.
- If a recycling plateau is occurring in both MSW and C&I, then a material recycling rate plateau would occur.

It therefore appears that MSW recycling rates have a dominant impact on material recycling rates but not total control, as C&I recycling rates also player a lesser role in determining whether a plateau takes place. This conclusion is only accurate if the material being recycled in only sourced through MSW or C&I.

Impact of demographics on MSW recycling rate plateaus

Chapter 5 investigates both Research Question 2 and 3; asking how do direct influences and demographics determine the plateau level of MSW recycling rates and bin contamination levels? This chapter concentrates on the demographic influences on MSW recycling rate plateaus.

Demographic variables were discussed in Chapter 2 and identified as a category of variables that have shown correlation with recycling behaviour in the past. As demographics are measured cyclically they are an important indicator of societal trends. If they co-vary with features of MSW recycling, it is possible to use them as markers for desired or undesired behaviour. This is useful as they are easier to measure than other variables influencing human behaviour, such as attitude or social norms. Research on the relationship between demographics and recycling has shown contradictory results in the past. This chapter aims to clarify some of this confusion by investigating the relationship between demographic variables, gathered from the Australian census, and the influences on MSW recycling rates plateauing below their full potential.

5.1 Background of MSW recycling and demographics

Previous literature linking demographic variables with recycling has focused upon a limited selection of demographic variables (see Table 5.1). They included education level, income, age, number in household, residential status, dwelling type, ethnicity, presence of children, gender, and socioeconomic status.

There has also been a range of recycling-related dependent variables tested in previous work (Table 5.1). Ranging from diversion rate, recycling efficiency, recycling intensity and recycling participation. Some of these variables were based upon quantitative data, for example diversion rate was defined as the amount of recyclables collected divided by the total amount of collected waste (Clarke, 2006). Recycling efficiency was defined as the weight of recyclables correctly disposed in the recycling bin divided by the total weight of recyclables summed over both bins (Owens, 2000). This indicator represents the proportion of recyclables recovered.

Other dependent variables were based upon qualitative self-report. Recycling intensity used a self-report scale indicating the frequency of recycling a range of materials (Scott D. , 1999). This metric encompassed commonly recycled materials and was measured on a 4-point scale that ranged from 'recycle always' to 'never recycle'. Several previous studies used recycling participation as the dependent variable and also used self-report scales (Vining, 1990; Berger, 1997; Martin, 2006; Nixon, 2009).

The dependent variables chosen for this project needed to assist in answering the research aim; to investigate the influences on MSW recycling rates to plateau below their full potential. Recycling rates were a necessary dependent variable, as they are the key metric being researched. Knowing consumption levels was also useful for understanding how and why recycling rates were changing. It was also necessary to measure bin contamination, for both recycling and general waste (GW), as this provided insight into the quality of waste separation.

Some of the dependent variables used in previous studies were not used for this research. For example, the studies measuring recycling participation were often older, occurring in the 1990s or early 2000s. Participation was tested because recycling systems were still novel and participation levels were variable. In recent years, household recycling has become a social norm and recycling systems have been simplified to maximise participation. Studies in Australia have indicated that household recycling participation is close to saturation (98%) in areas with kerbside recycling facilities (ABS, 2010). Consequently, measures of participation were not included in this study. Additionally, self-report techniques were excluded as they can be susceptible to bias (Tonglet, 2004; Paulhus, 2007).

Previous studies found some strong correlations between demographic and recycling variables. Diversion rates were positively associated with socioeconomic status (Clarke, 2006). The higher the socioeconomic status the more material was diverted for recovery. It was not apparent whether this was due to consumption trends or high quality waste separation. Bin contamination was negatively associated with income, education level and residential status (own, rent) (Owens, 2000). Consumption levels were not tested in the referenced studies.

Another lesson learned from previous studies was the importance of testing only one recycling system for each study. Some studies tested communities with access to kerbside recycling while other communities only had access to drop-off recycling (Vining, 1990; Scott D. , 1999; Owens, 2000; Clarke, 2006; Martin, 2006). Some research, particularly projects with large sample sizes, encompassed multiple types of waste disposal methods (Berger, 1997; Nixon, 2009). It is highly likely that these contextual factors impact the relationship between demographic and recycling variables. To minimise confounding effects from varied recycling systems, analysis will be applied to a region with access to only one type of recycling system.

It was also necessary to collect reliable and valid data to carry out this analysis. Demographic data from previous studies had two origins; surveys or census. Surveys tended to have smaller sample sizes while census data encompassed entire populations. Of these data options, census data were deemed preferable to surveys as the resulting data was deemed a more accurate representation of the population.

Table 5.1 Summary of previous studies focusing upon the relationship between demographics and MSW recycling

Source/ waste disposal type	Data collection	Dependent variable	Explanatory variables	Impact on DV	Analysis technique
(Clarke, 2006) Kerbside disposal	Census	Diversion rate (recyclables/total collected waste)	• % below poverty line • % of household headed by female with children • % of adults without high school diploma • % minority population	• - • - • - • -	Linear regression GIS
(Owens, 2000) Kerbside disposal	Survey	Recycling Efficiency (recyclables/recyclables + recyclables in GW)	• Income • Age • Gender • Education level • Race • Residential status • # in household • Age of household head	• + • No impact • No impact • + • No impact • + • No impact • No impact	Generalised linear model Wilcoxon Test
(Scott D. , 1999) Kerbside disposal	Survey	Recycling intensity (self-report: recycle always, regularly, only sometimes, never)	• Age • # in household • Children • Education • Income • Residential status	• + • No impact • No impact • No impact • No impact • No impact	Stepwise multiple regression analysis
(Nixon, 2009) Mixed (kerbside recycling + drop-off disposal)	Survey	Probability of recycling participation (self-report)	• Age • Urban • Ethnicity • Education level • Household income • Residential status • Dwelling type • # in household	• + • No impact • Mixed • No impact • No impact • + • No impact • +	Logistic regression
(Vining, 1990) Drop-off disposal	Survey	Recycling participation (self-report)	• Age • Education level • Gender • # in household • Occupation • Income	• + • No impact • No impact • No impact • No impact • +	T-test Chi-squared
(Berger, 1997) Mixed	Census	Recycling participation (self-report)	• Education • Income • Size of residence • Apartment	• + • + • - • -	Hierarchical regression
(Martin, 2006) Kerbside disposal	Survey	Recycling participation (self-report: non-recyclers, casual recyclers, full recyclers)	• Age • Young children • Income • Detached housing	• + • - • + • +	Chi-squared

In this study census data are used as a source of demographic information for the case study region. From this data, 130 demographic variables were collected and were tested for correlation with recycling variables (see Appendix C.1). Five recycling variables will be tested to give insight into plateauing recycling rates. These are: (a) recycling rate plateau (b) recycling bin contamination, (c) GW bin contamination, (d) recycling consumption, and (e) GW consumption.

5.2 Methodology for analysing MSW plateau's relationship with demographics

This investigation took place in an Australian council region in the state of New South Wales (NSW). The council region has had a kerbside recycling system since 2003 and its recycling history can be seen in Figure 5.1. A kerbside general waste (GW) was in existence before then and is ongoing.

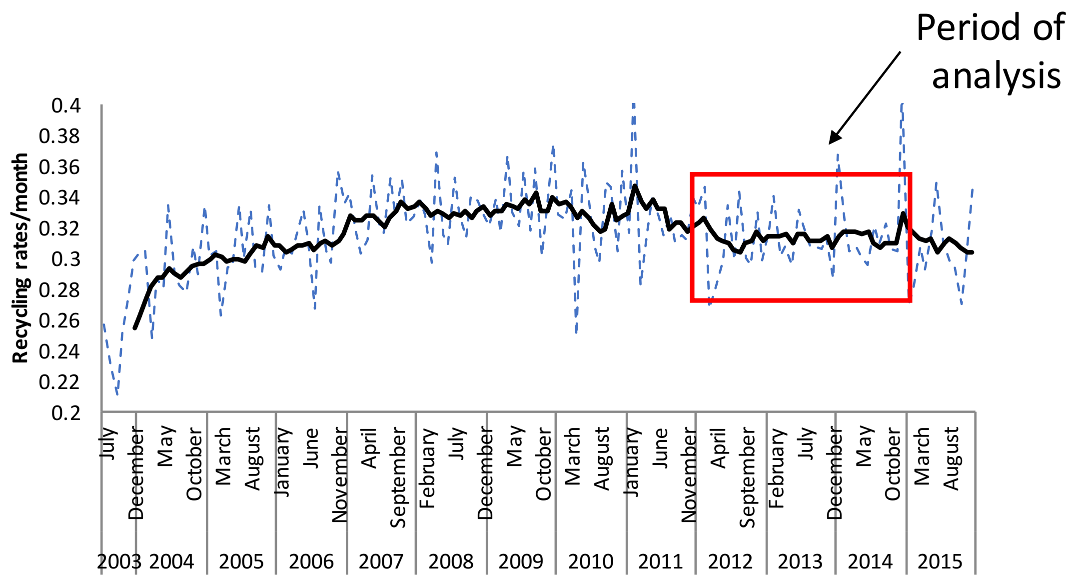


Figure 5.1 Council recycling rate history (smoothed using a 6-period moving average)

The waste collection system of the case study region can be considered typical of Australia. There exists a 120l GW bin collected weekly and a 240l recycling bin collected fortnightly. In recent years, a 240l garden waste bin was introduced but this waste flow will not be considered in this study as garden waste recycling levels respondent to different influences than processed waste. For example, garden waste recovery surges in Spring and Summer due to faster vegetation growth rates.

The council region is sub-divided into 10 recycling zones and 5 general waste collection zones (CZ). The difference is due to a fortnightly collection for recycling and a weekly collection for general waste. The recycling collection zones are labelled Monday A, Tuesday A, Wednesday A, Thursday A, Friday A, Monday B, Tuesday B, Wednesday B, Thursday B and Friday B while GW collection zones include Monday, Tuesday, Wednesday, Thursday and Friday. The GW collection zones are formed from the combination of A and B recycling collection zones (see Figure 5.2).

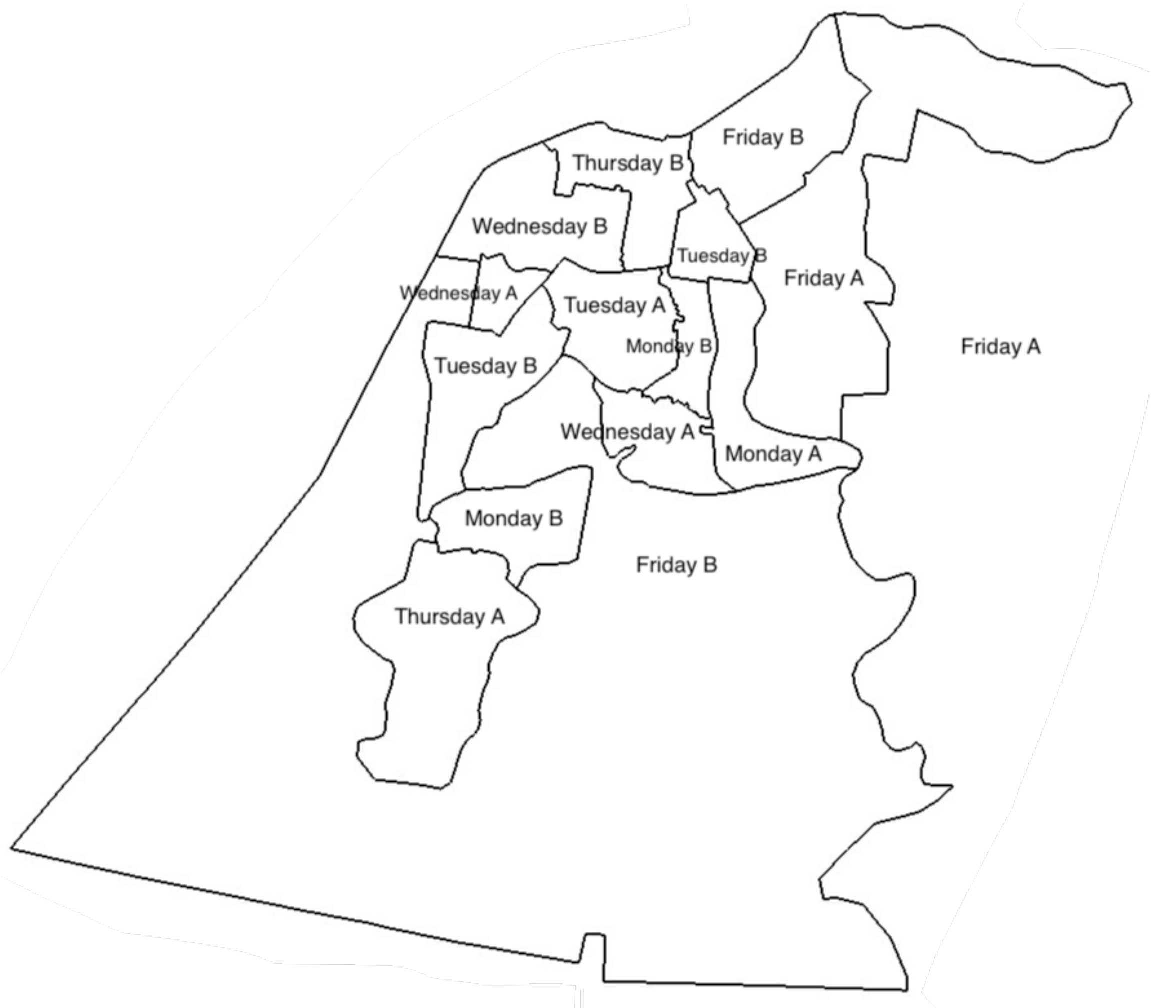


Figure 5.2 Council collection zone map

Waste flow history was collated using council invoices administered by the local landfill operation and the local MRF. The invoices provided a description of each truck load of waste that deposited GW at landfill or recyclables at the MRF. The description included a truck identifier, the date and time of deposit, the origin of the waste, the weight deposited and the associated charge. Only loads originating from the case study region were included in this research. As council collection zones were defined by day of collection, it was possible to connect waste flows to collection zones. On this basis, it was feasible to calculate the weekly tonnage of general waste collected from each zone, and the fortnightly tonnage from each recycling zone. The data ranged from June 2011 to October 2014, and consisted of 88 measures. The gross tonnage of material from each zone was divided by the number of households, giving a weight per household for each zone. The equations for recycling and GW are displayed in Equations 5.1 and 5.2.

$$Recycling\ produced\ per\ dwelling = \frac{fortnight.recycling\ tons * 1000kg/ton}{\#\ of\ dwellings\ (CZ.A\ or\ B)} \quad [5.1]$$

$$GW\ produced\ per\ dwelling = \frac{(GW\ tonnage.wk1 + GW\ tonnage.wk2) * 1000kg/ton}{\#\ of\ dwellings\ CZ.A + \#\ of\ dwellings\ CZ.B} \quad [5.2]$$

Recycling rates were subsequently calculated using Equation 5.3. Graphs presented the recycling rates for each collection zone can be seen in Appendix C.2.

$$CZ\ Recycling\ rates = \frac{recycling\ produced\ per\ dwelling}{recycling\ produced\ per\ dwelling + GW\ produced\ per\ dwelling} \quad [5.3]$$

A waste audit was carried out in the case study region over a two-week period in October 2015. On each week day, the GW and recycling bins were collected from 50 randomly selected households. The proportion of separate and multi-unit dwellings seen in the collection zone was represented in the sample. It should be noted that a smaller number of bin samples were taken on Friday A and Friday B due to low kerbside bin set-out, closer to 40 instead of 50 bins. As the waste audit data were used for contamination proportions and average household quantities, it was deemed sufficient for analysis.

Waste from the selected households was transported to a nearby council facility for auditing to take place. GW was separated into 23 different categories and recycling was separated into nine different categories. The waste audit was organised by the principle researcher and carried out with the support of six engineering student volunteers. Bin contamination was investigated in detail during the waste audit. This involved isolating bin contamination and weighing sub-categories of materials.

Census data was obtained from the 2011 Australian census (ABS, 2011). The Australian Bureau of Statistics (ABS) provides GIS data packs associating demographic variables with geographic zones. The smallest geographic unit used in these data packs is named the Statistical Area 1 (SA1). SA1s forming the local government case study region can be seen in Figure 5.3a. Ninety-seven SA1s were used to characterise the case study region. As SA1s closely aligned with council collection zone boundaries it was possible to use these to provide a demographic summary of each collection zone. The resulting regions can be seen in Figure 5.3b. Six SA1s were excluded from the analysis due to poor fit with collection zone boundaries, leaving 91 SA1s in the study.

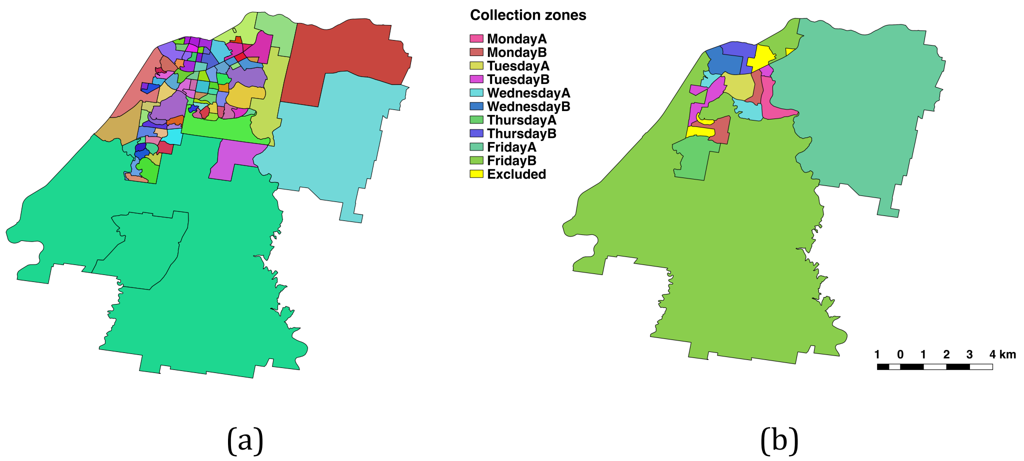


Figure 5.3 (a) A GIS summary of SA1 zones, and (b) their relationship with council collection zones

5.3 Results of MSW plateaus and demographics analysis

5.3.1 Recycling Variables

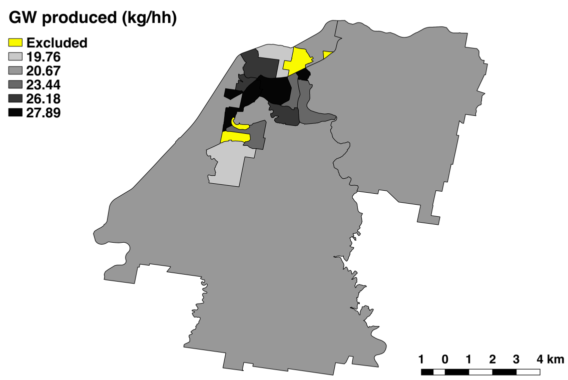
The dependent variables in this study include recycling rates, recycling consumption, GW consumption, recycling bin contamination and GW bin contamination (Table 5.2). As GW and recycling had different collection frequencies it was necessary to normalise the time periods. The weekly collections of GW were converted to fortnightly and as there were only 5 GW collection zones the average GW consumption figures for A and B zones remained the same. GW consumption figures ranged from 19.76kg/fortnight/household to 27.89kg/fortnight/household, while recycling consumption figures ranged from 7.35kg/fortnight/household to 14.19kg/fortnight/household. Recycling rates were derived from consumption figures using Equation 5.3. A geographic summary of recycling rates, recycling consumption and GW consumption can be seen in Figure 5.4.

The data for the five dependent variables were collected from two separate sources; truck weighbridges and a waste audit. The weighbridges were used to measure waste flow entering the Municipal Recycling Facility (MRF) and the landfill. This metric provided the data for recycling consumption, GW consumption and recycling rate plateaus. Recycling consumption consisted of recyclables plus incorrectly disposed GW. GW consumption included GW plus incorrectly disposed recyclables. Recycling rates were calculated from these consumption figures and are an accurate representation of the methodology used by government bodies in Australia for computing recycling rates. Contamination data was collected during a waste audit of the case study region.

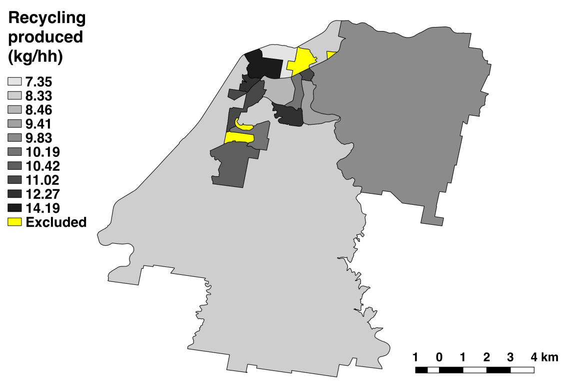
Table 5.2 Collection zone's recycling rate plateaus, and recycling consumption and GW consumption per fortnight

Collection zones	Recycling rates (%)	Recycling consumption (kg/fortnight/household)	GW consumption (kg/fortnight/household)
Monday A	28.56	9.41	23.44
Monday B	30.24	10.19	23.44
Tuesday A	23.38	8.46	27.89
Tuesday B	28.35	11.02	27.89
Wednesday A	32.05	12.27	26.18
Wednesday B	35.31	14.19	26.18
Thursday A	34.52	10.42	19.76
Thursday B	27.13	7.35	19.76
Friday A	32.21	9.83	20.67
Friday B	28.49	8.33	20.67

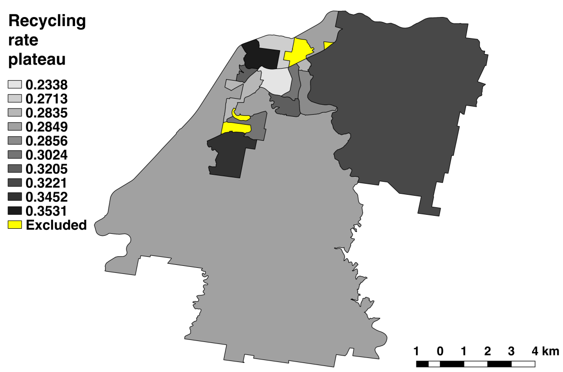
Collection zone waste audit results provided insight into the level of contamination in recycling bins and GW bins (Table 5.3). The figures in Table 5.3 are given as a percentage of the total sample weight. GW bin contamination ranged from a minimum of 7.73% to 18.55% of general waste being recyclable. Recycling bin contamination ranged from a minimum of 8.01% to 24.14% of recycling consisting of GW. A geographic representation of bin contamination can be seen in Figure 5.5.



(a)



(b)

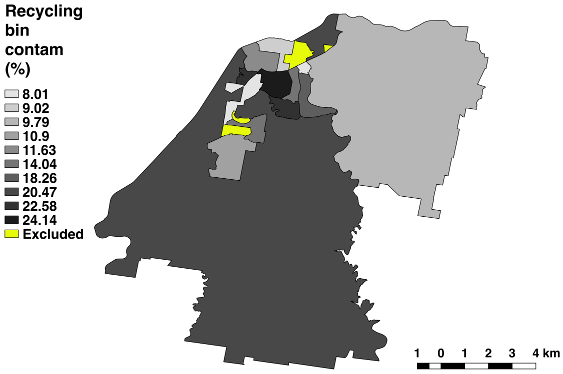


(c)

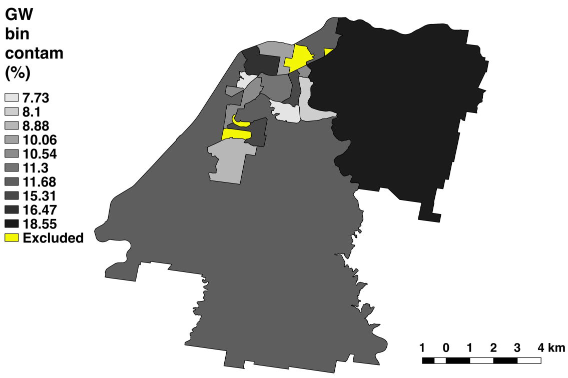
Figure 5.4 A GIS representation of (a) GW consumption per household, (b) recycling consumption per household, and (c) average recycling rate plateaus for the case study region waste collection zones

Table 5.3 Collection zone bin contamination

Collection zones	Recycling bin contamination (%)	GW bin contamination (%)
Monday A	18.26	8.1
Monday B	14.04	15.31
Tuesday A	24.14	11.3
Tuesday B	8.01	10.54
Wednesday A	22.58	7.73
Wednesday B	11.63	16.47
Thursday A	10.9	8.88
Thursday B	9.02	10.06
Friday A	9.79	18.55
Friday B	20.47	11.68



(a)



(b)

Figure 5.5 A GIS representation of (a) average recycling and (b) GW bin contamination for case study waste collection zones

5.3.2 Demonstrating recycling plateaus

Recycling rates were calculated for each of the 10 collection zones within the council region. The figures given in Table 5.2 represent an average of time series data over a plateau period. Evidence that recycling rates are experiencing a plateau include: inspection of collection zone recycling rates (Appendix C2) and a Fourier Analysis, in the form of a periodogram, identifying any cycles within the time series data.

The periodogram was carried out on monthly recycling rate history for the case study region (Figure 5.6) (Hernandez, 1999). The results of the periodogram indicated a spike at a frequency of around 0.01. Using the formula F = 1/T (F = frequency, T = Period) a period of 100 months or 8.33 years was found to represent this time series. As the entire data set runs for approximately 12 years it is likely that the periodogram is detecting the growth of the early 2000s and the slight drop over 2011 and 2012. As these changes are minimal, it was determined that a plateau could be assumed during the period of analysis.

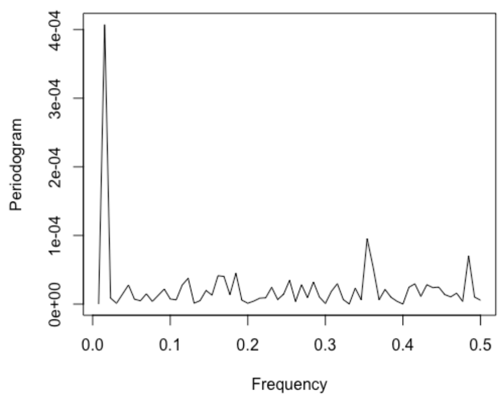


Figure 5.6 Periodogram of recycling rate history

5.3.3 Principal Component Analysis (PCA)

As 130 demographic variables were available for correlational analysis, it was decided that PCA would be an appropriate technique to highlight the dominant dimensions within the data set. A m-by-n data matrix represented the demographic data analysed in this chapter (Equation 5.4). With m being the number of rows in the matrix, signifying the 10 collection zones within the local government region. The number of columns, n, indicated the 130 demographic variables tested.

$$X = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \qquad [5.4]$$

A condition number test indicated a high level of multicollinearity between the 130 demographic variables (Kappa = 904.11). The condition number was calculated multiplying the norm of matrix X by the norm of the inverse of matrix X, as seen in Equation 5.5.

$$cond(X) = \|X\| \times \|X^{-1}\| \qquad [5.5]$$

As a rule of thumb a condition number greater than or equal to 30 represents severe collinearity (Williams, 2015). Because of this high condition number, a PCA was applied to the 130 demographic variables.

The first steps of PCA involved centring and scaling matrix X. The vectors of matrix X were centred by the subtraction of the vector mean and scaling by the division of the vector standard deviation. The centred and scaled data matrix (X_{cs}) was then used to calculate the covariance matrix (D) using Equation 5.6, with X_{cs}^T being the transpose of X_{cs} and m the number of observations in each vector.

Eigenvalues were derived from the covariance matrix for each of the 130 demographic variables (Equation 5.7). λ represented a Lagrange multiplier and I_n an Identity Matrix of size n. 'Det' signified finding the determination of a 130*130 data matrix resulting from ($D-\lambda I_n$). The resulting equation was solved for λ, also known as the eigenvalue or the maximal nontrivial Lagrange multiplier.

The eigenvalues found from Equation 5.7 were then used to derive eigenvectors using Equation 5.8. $\vec{0}$ represented a zero vector and $\vec{v}$ the eigenvector. To calculate the eigenvectors corresponding to eigenvalues, the vectors equal to the null space of $D - \lambda I_n$ were calculated.

The PCA scores (Y) were derived from the matrix multiplication of eigenvectors ($\vec{v}$) and scaled and centred demographic data (X_{cs}), as seen in Equation 5.9.

$$D = X_{cs}^{T} X_{cs} \frac{1}{m} \quad [5.6]$$

$$Det(D - \lambda I_n) = 0 \quad [5.7]$$

$$\vec{0} = (D - \lambda I_n)\vec{v} \quad [5.8]$$

$$Y = \vec{v} X_{cs} \quad [5.9]$$

Once PCA was complete two techniques were applied to choose the number of principal components to retain; the Scree Test and Proportion of Variance Explained. Cangelosi (2007) discussed the use of Cattell's Scree test to determine the number of components to retain from PCA. This involves finding the first inflection point on a plot with eigenvalues on the y axis and component number on the x axis. The inflection point was identified at component 5 and can be seen in Figure 5.7.

When applying the Proportion of Variance Explained, it is common to choose levels between 70% to 95% of proportion of variance (Jolliffe, 2002). The first five components represented 90.69% of cumulative variance (Table 5.4). Both of these tests indicated that five principal components were a reasonable number to retain.

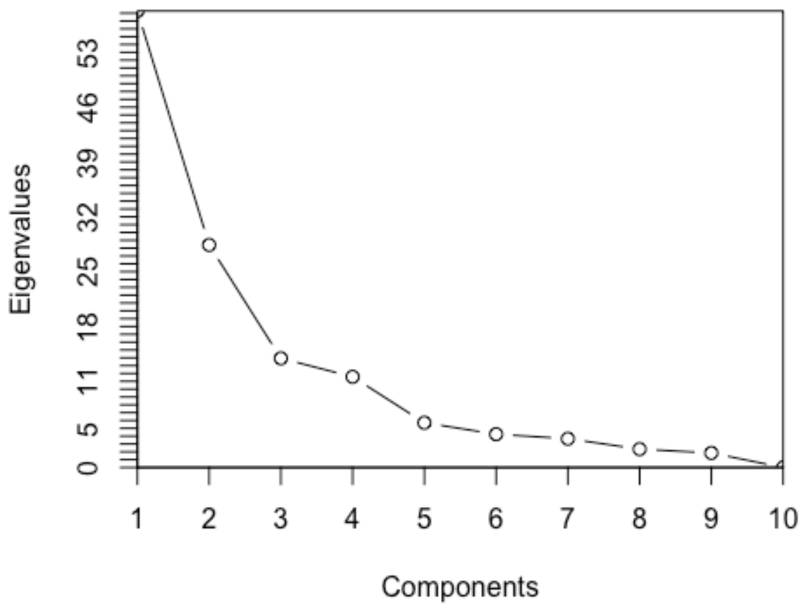


Figure 5.7 A Scree Plot presenting the eigenvalues of 10 Principal Components

Table 5.4 Principal Component (PC) proportions of variance

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Standard deviation	7.6338	5.3298	3.7324	3.4020	2.3891	2.0603	1.9155	1.5303	1.3600	4.4e-15
Proportion of Variance	0.4483	0.2185	0.1072	0.0890	0.0439	0.0327	0.0282	0.0180	0.01423	0.0e-00
Cumulative Proportion	0.4483	0.6668	0.7739	0.8631	0.9069	0.9395	0.9678	0.9858	1	1

Variable loadings or eigenvectors of PC1, PC2, PC3, PC4 and PC5 indicated the characteristics of the principal components. The negative loadings represent one end of a continuum for the principal component and the positive loadings the other end of the continuum. (Figure 5.8). Variable loading data can be seen in Appendix C.3.

Using variable loadings, PC1 was found to be related to household size and household income. The underlying theme of the positive spectrum was large household size and high household income. Examples include couple families with children, female 35 to 49, mothers in the workforce and high income households. The common theme of the negative spectrum was small household size; showing a high loading from the 25 to 34 age group, few bedrooms, a low household income and people living in a lone household without a car. PC1 was responsible for 44.83% of variance, making it the dominant principal component.

PC2 showed a strong relationship with level of education. The positive spectrum of variable loadings showed a strong link with high levels of education; included people with or in the process of receiving university qualifications and those working as managers or professionals. There was also mention of those that had moved address recently, had no religion and had Scottish ancestry. The common theme of the negative spectrum was low levels of education; referring to people with no qualifications, people without a high school diploma and with trade qualifications. There was also some association with certain ethnic groups. PC2 was responsible for 21.85% of variance.

Judging by the variable loadings on PC3, there was an association with financial security. On the positive spectrum, there was heavy loading from demographic variables indicating an older population, higher levels of white collar workers and a greater proportion of home owners. On the negative spectrum, there was suggestion of greater loadings from variables signifying youth and financial stress. The youth influence was particularly apparent in variables like 'disengaged youth 15 to 25 not in work or school' and 'one parent families with kids under 15'. There was indication of financial stress through variables like 'rent social housing', 'one parent families with kids under 15' and 'households in housing stress'. PC3 was responsible for 10.72% of variance.

PC4 showed an association with time spent at home and mobility. On the positive spectrum, there was reference to the 65 to 85 plus and 0 to 4 age ranges. The positive spectrum also showed association with people in need of assistance due to disability. The negative spectrum referenced the 50 to 59 age range, school age children, and couples without children. PC4 was responsible for 8.9% of variance.

PC5 displayed signs of being related to age of family. The positive spectrum correlated with older families with references to the 18 to 24 and 50 to 59 age ranges. There was also mention of university attendance, households with 4 or more bedrooms, unpaid carers and disengaged youth 15 to 25 not in work or school. The negative spectrum represented younger families with reference to the 25 to 49 and 0 to 4 age ranges and unpaid child carers. PC5 was responsible for 4.39% of variance.

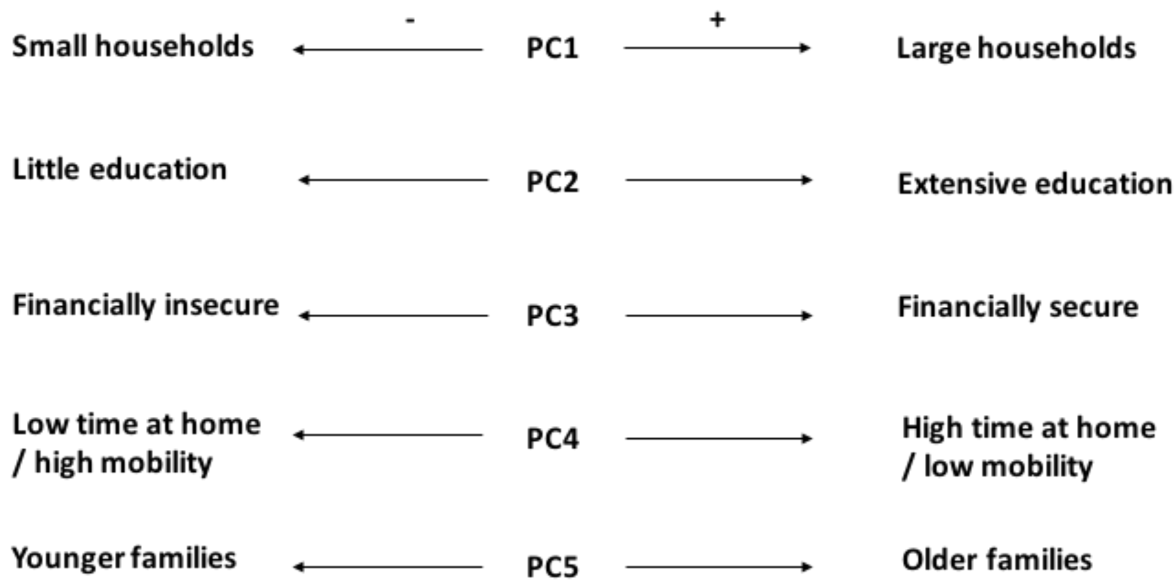


Figure 5.8 Principal component spectrums

5.3.4 Correlation

Pearson Correlation tests were carried out to assess the relationship between the five principal components and the recycling dependent variables. The principal component scores for each collection zones were correlated with the associated recycling rate plateau, recycling bin contamination, GW bin contamination, recycling consumption, and GW consumption. The formula for Pearson's Correlation can be seen in Equation 5.10.

$$r = \frac{\sum_m (x_m - \bar{x})(y_m - \bar{y})}{\sqrt{\sum_m (x_m - \bar{x})^2 \sum_m (y_m - \bar{y})^2}} \qquad [5.10]$$

Correlation results were presented in Table 5.5 and were interpreted using the following categories; (a) 0 – 0.10 was considered No Correlation, (b) 0.10 – 0.30 was considered a Weak Correlation, (c) 0.30 - 0.50 was considered a Medium Correlation, (d) 0.50 - 0.70 was considered a High Correlation and (e) 0.70 - 1 was considered a Very High correlation (Cowan, 1998).

Table 5.5 Results from a Pearson's Correlation between principal component predictor variables and dependent variables

	Recycling rate plateau		RB contamination		GW contamination		Recycling consumption		GW consumption	
PC1	0.513	High	-0.065	No	-0.239	Weak	0.474	Med	0.102	Weak
PC2	-0.029	No	-0.529	High	0.087	No	-0.580	High	-0.781	Very High
PC3	0.468	Med	-0.577	High	0.403	Med	0.381	Med	-0.075	No
PC4	-0.003	No	-0.304	Med	-0.088	No	0.152	Weak	0.250	Weak
PC5	0.296	Weak	-0.096	No	-0.032	No	0.292	Weak	0.106	Weak

Recycling rate plateaus were highly correlated with PC1 (number of people in household) and moderately with PC3 (financial security). As number of people in household and financial security increased, so did the recycling rate plateau. This is supported by the correlation results between PC1, PC3 and consumption. Recycling consumption had a stronger positive correlation with PC1 and PC3 than GW consumption. This infers that as households grow and become more financially secure, the proportional growth in recyclables consumption is greater than the proportional growth of GW consumption. This has the effect of increasing the recycling rate plateau.

Both recycling and GW consumption had a strong negative correlation with PC2, level of education. As education level increased, the amount consumed fell. The cause of this was not clear, but possibilities include (a) the highly educated purchasing less packaging, (b) the highly educated composting food scraps at home, (c) the highly educated having smaller families, and (d) the highly educated doing less home cooking.

A strong correlation was found between recycling bin contamination and PC2 (level of education) and PC3 (level of financial security). As level of education and financial security increased, recycling bin contamination decreased. This was combined with a moderate negative correlation with PC4, level of time at home. It is possible that educational institutional culture and curriculum result in a greater emphasis on environmental behaviour. Financial security would also lessen time pressures, allowing more time for environmentally minded behaviour like recycling. PC4 could also relate to available opportunity to recycle, the more time in the home the greater the likelihood of taking time to separate well.

GW bin contamination only showed a mild correlation with PC3 (financial security). As financial security increased, so did GW contamination.

5.4 Discussion of the relationship between MSW plateaus and demographics

A strength of this research was the use of PCA to determine the most influential demographics categories, derived from many demographic variables. This analysis provided an empirical process for selection of predictor variables and provided insight into their level of significance. It could be considered an assessment of previous studies, asking whether previous demographic variables chosen as predictor variables of waste disposal behaviour were the most appropriate.

For some principal components, there was clear overlap with previously tested predictor variables. The most influential component, representing household size and income, had clear overlap with variables described in Table 5.1; income, number in household, dwelling type, size of residence, young children, and detached housing. This was also the case for the second most influential component, level of education, which had links with Table 5.1 variables such as percentage of adults without a high school diploma, education level, ethnicity or race, and % minority population. The third principal component, financial security, showed commonality with percentage below the poverty line, occupation, and residential status.

Other principal components were not represented in previous studies. At the positive spectrum for principal component four, time at home/mobility, there was a strong relationship with the very young and the very old age groups. On the negative spectrum, were the ages between the very young and very old. Principal component five, age of family, showed a similar pattern. With the positive spectrum showing an association with people over 50 and teenagers or people in the twenties, while the negative spectrum related to people in their 30's or 40's and children under 10. Previous studies treated age as a continuous numerical variable. However, the results from the PCA indicate there may be age groups that are more influential on recycling behaviour than others, particularly concentrations of the very young and very old.

After the principal component predictor variables were finalised, the question remained how they influenced recycling rate plateaus. The correlation analysis indicated that recycling rate plateaus were highly influenced by household size and income, and moderately influenced by financial security. As household size and income increased, a subsequent increase was seen in recyclable but not GW consumption. This resulted in a small rise in recycling rate plateau.

Financial security demonstrated a similar correlation with consumption; as it increased there was an increase in recyclable consumption and no significant impact on GW consumption. Again, this resulted in an increase in recycling rate plateau.

It was also interesting to observe the correlation between financial security and bin contamination. While financial security was associated with decreased recycling bin contamination, there was also an increase in GW bin contamination. It is difficult to explain why this is occurring, however it may relate to the emphasis of education campaigns on recycling disposal.

Level of education had very little association with recycling rate plateau. Although education pushed consumption levels lower, this occurred for both recyclables and GW. Meaning that the ratio between the two waste streams stayed near constant. This corroborates previous studies which have found that lower levels of education were correlated with larger amounts of waste (Sterner, 1999). It is likely that education level has a soft downward pressure on recycling rate plateaus, as it strongly decreases recycling bin contamination but has little impact on GW bin contamination. Again, this is partly supported by earlier research which found that correct waste disposal increases with education level (Owens, 2000). These results do indicate that higher levels of education and financial security are associated with improved disposal knowledge for the recycling bin. One possible reason for this is environmentally minded inclinations and improved time availability.

It was immediately apparent from these results that PC4 (time at home/mobility) and PC5 (age of family) had no significant relationship with recycling rate plateaus or bin contamination. This suggests that the recycling predictor variables used in previous studies (Table 5.1) are still the most appropriate demographic variables to use when attempting to understand recycling behaviour.

As stated at the beginning of this chapter, both Research Questions 2 and 3 were the focus of this study. Three conclusions can be made from this chapter regarding recycling rate plateau levels and bin contamination: (a) consumption trends are the dominant influence on MSW recycling rate plateau levels, (b) a high recycling rate plateau region is characterised by large families, high household income, and good financial security, and (c) a low recycling bin contamination region is characterised by high education levels and good financial security.

It should also be noted that the strength of the relationship between demographic principal components and the recycling variables was not particularly strong, especially for recycling rates and GW bin contamination. This suggests that while demographics may be able to explain some facets of recycling behaviour, it does not capture the full picture. It will be necessary to investigate other potential influences on recycling rate plateaus.

A Field Experiment

6.1 Introduction of the field experiment

As with Chapter 5, Chapter 6 also addresses Research Questions 2 and 3; asking how do direct influences and demographics determine the plateau level of MSW recycling rates and bin contamination levels? However, instead of focusing upon demographics there is a focus upon potential direct influences.

The relationship between six potential recycling influences on recycling rate plateaus and bin contamination were tested. These tests were carried out in the form of a field experiment of an Australian local government municipal waste system. Three waste collection zones in this area were selected from ten collection zones. One to represent high achieving recyclers, a second to signify moderate achieving recyclers, and another to characterise low achieving recyclers. The high achieving recycling zone (Thursday A) had high recycling rates and low bin contamination, while the low achieving recycling zone (Tuesday A) had low recycling rates and high bin contamination. The moderate achieving recycling zone (Monday A) had recycling rates and bin contamination that fell between these extremes. For households with access to kerbside recycling in the case study region, participation was close to 100%. This concurs with Australian Bureau of Statistics data, which indicates that 91% of Australian households in 2009 were reported to have access and use kerbside recycling (ABS, 2009). A household survey was distributed to measure the impact of 6 potential direct influences on recycling behaviour and allow comparison between the three collection zones.

The potential direct influences were collated from existing recycling literature and were discussed in detail in Chapter 2. These influences on recycling behaviour include (a) waste disposal knowledge, (b) attitude toward recycling, (c) recycling social norms, (d) dwelling types, (e) time devoted to waste disposal, and (f) kerbside recycling service quality. Waste disposal classification knowledge refers to the ability to correctly identify a waste object as recyclable or general waste. An individual's attitude toward recycling denotes their inclination to view recycling from a positive, neutral or negative perspective. Recycling social norms relates to an individual's view of their neighbours' recycling beliefs. Dwelling types included standalone housing, townhouses and apartments. Time devoted to waste disposal refers to the amount of time required each week by households to separate and dispose of their waste. Kerbside waste disposal service quality indicates the quality of the waste pick-up service supplied by waste contractors and the local government in Australia. As bin capacity issues were the only common service quality complaint for the case study region, the frequency of bin overflows for both recycling and general waste services was used to represent service quality. A summary of these recycling influences was provided in Chapter 2 and a visual summary can be seen in Figure 6.1.

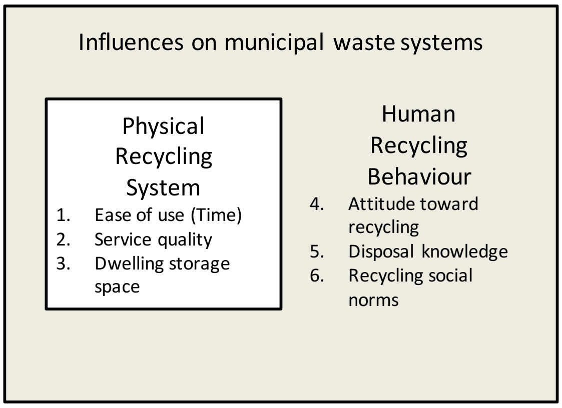


Figure 6.1 The six variables being tested in field experiment

6.1.1 The bin bias concept

A novel concept introduced in this chapter is that of bin bias. Bin bias is defined as the probability of choosing the GW bin or the recycling bin when making uncertain disposal decisions. It is a relevant idea, as disposal knowledge is not flawless and at times citizens make disposal guesses. It is also observable, if guesses can be identified.

A common structure to determine guessing is the combination of a knowledge test with a certainty scale. Link (1982) used a dichotomous choice test and certainty scales to detect guessing. The certainty scales provided three choices; low confidence, medium confidence, high confidence. Hunt (2003) discussed the usefulness of certainty scales in determining true knowledge. He applied a 5-point certainty scale consisting of; extremely sure, very sure, somewhat sure, very unsure, not sure at all. A correct response with a low certainty rating was labelled a guess or partially informed. Hench (2014) used Confidence Based Marking (CBM) to identify over and under-confidence. Again, this combined a knowledge test with a three-point certainty scale. Michailova *et al.* (2013) used a multiple-choice knowledge test combined with a confidence scale to identify overconfidence. The certainty scale was defined using percentages between 33% to 100%. Extremely low ratings of confidence represented guessing.

The goal for this study is to use a similar method to detect guessing for a disposal knowledge test. Using this data, it will be possible to calculate the probability of disposing guessed recyclables or guessed general waste in the recycling bin or general waste. This data can be used to determine whether bin bias significantly impacts recycling rates.

6.1.2 Proposed causal relationship between six potential recycling influences

When existing theory and previous findings are reviewed, a possible causal relationship can be proposed (Figure 6.2). The TPB and the IMB model provided a template for interactions between the six variables being tested, while several studies provided insight into the specific causal links of Figure 6.2 (Ajzen, 1986; Seacat, 2010). Beginning with dwelling size, Martin *et al.* (2006) and Garces *et al.* (2002) found that dwelling types impact recycling time requirements and recycling service quality, which subsequently impact attitude toward recycling (Links 1, 2, 4 & 5). Shaw (2008) established that dwelling types also impact the strength of recycling social norms (Link 3). The TPB and the IMB models, as well as providing a template for the interactions, also emphasised a strong relationship between recycling norms and attitudes (Link 6). Finally, a number of studies have found a relationship between recycling attitudes and norms, and enthusiasm for recycling (Links 7 & 8) (Boldero, 1995; Schultz, 1998; Tonglet, 2004; Oom Do Valle, 2005; Nigbur, 2010).

Some assumptions were made when creating Figure 6.2. When recycling participation levels are saturated, recycling motivation is posited to affect recycling rates and bin contamination in two ways: (a) motivation to learn disposal rules and (b) level of bias towards recycling bin (Links 9 &10). It is also assumed that an increased motivation to learn disposal rules will result in a greater disposal knowledge (Link 11). Additional discussion of these links can be seen in sections 2.1.2, 2.1.3, 2.1.4, and 2.1.5 of this thesis.

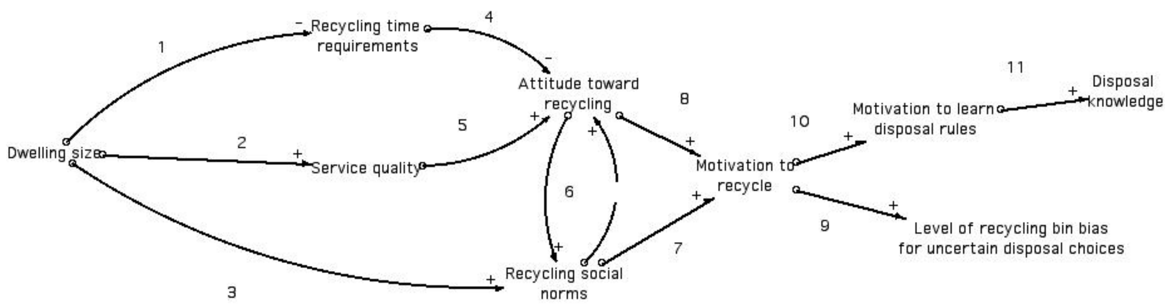


Figure 6.2 Influence diagram showing potential interaction between the 6 recycling rate plateau stimuli

6.1.3 The 3 hypotheses of this study

Hypothesis 1: A causal pathway will become apparent from Figure 6.2.

Hypothesis 2: Improved waste disposal knowledge will result in lower bin contamination due to greater proficiency in waste separation.

Hypothesis 3: High achieving recycling collection zones will have greater biases towards the recycling bin when making uncertain decisions.

6.2 Field experiment methodology

In this section, the methodology for the field experiment is explained. This encompasses three subsections; collection zone selection, calculation of required sample size, and survey design. The selection of collection zones section describes the use of recycling and bin contamination data to choose three collection zones representing high, moderate and low recycling achievers. Section 6.2.2 presents the calculations used to predict the number of completed surveys required from each collection zone to get valid results. Section 6.2.3 outlines the design of the survey, to obtain data on the six recycling influences.

6.2.1 Collection zone selection for field experiment

Three collection zones were chosen for this field experiment based upon waste audit and recycling history data. The waste audit took place in October 2015 over a two-week period using the method presented in the previous chapter. The method for calculating recycling rate history has also been discussed in Chapter 5, using weighbridges at the local landfill and Municipal Recycling Facility (MRF). As previously presented, recycling production was calculated using Equation 6.1 and GW production was calculated using Equation 6.2. Collection zone recycling rates were determined from Equations 6.1 and 6.2 and can be seen in Equation 6.3. In these equations, the symbol 'CZ' refers to 'Collection Zone'.

$$Recycling\ produced\ per\ dwelling = \frac{fortnight.recycling\ tons * 1000kg/ton}{\#\ of\ dwellings\ (CZ.A\ or\ B)} \quad [6.1]$$

$$GW\ produced\ per\ dwelling = \frac{(GW\ tonnage.wk1 + GW\ tonnage.wk2) * 1000kg/ton}{\#\ of\ dwellngs\ CZ.A + \#\ of dwellings\ CZ.B} \quad [6.2]$$

$$CZ\ Recycling\ rates = \frac{recycling\ produced\ per\ dwelling}{recycling\ produced\ per\ dwelling + GW\ produced\ per\ dwelling} \quad [6.3]$$

Results from the waste audit and recycling history analysis were used to determine the ideal collection zones to use for a field experiment comparing recycling characteristics. It was determined that three collection zones would be an appropriate number to include, to represent a high achieving recycling area, a moderately good recycling area, and a low achieving recycling area. Collection zone Thursday A possessed the highest recycling rate of 33.65% and Tuesday A the lowest at 23.39%. Monday A fell in between at 27.73% of waste recovered. Thursday A had the lowest recycling bin contamination at 10.9%, followed by Monday A at 18.26% and Tuesday A at 24.14%. Monday A had the lowest GW bin contamination at 8.1%, followed by Thursday A with 8.88% and Tuesday A at 11.3%. These results are presented in Table 6.1 and the selected collection zones can be seen in Figure 6.3.

Table 6.1 Summary of recycling characteristics for selected collection zones

Collection zones	Recycling rate plateau (%)	Recycling bin contamination (%)	GW bin contamination (%)	Recycling consumption (kg/fortnight/hh)	GW consumption (kg/fortnight /hh)
Thurs A	34.52	10.9	8.88	10.42	19.76
Monday A	28.56	18.26	8.1	9.41	23.44
Tuesday A	23.38	24.14	11.3	8.46	27.89

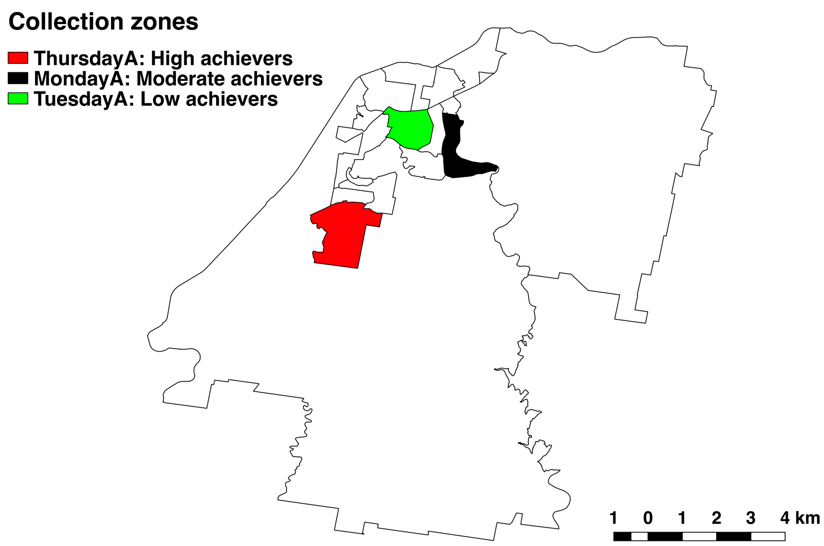


Figure 6.3 Collection zones selected for field experiment

6.2.2 Household survey sample size and distribution method

The approximate sample size required for each collection zone was calculated using Equation 6.4; the method for calculating sample size when population standard deviation is known. Population standard deviation was calculated using a survey pilot run and found to be $\sigma = 3.21$. A 95% confidence interval (Z =1.96) was chosen and a margin of error of ± 0.5 (E = ± 0.5) to the nearest knowledge score. It was found that at least 159 surveys per collection zone were required to meet these conditions.

$$sample\ size = \frac{Z^2 \times \sigma^2}{E^2} \qquad [6.4]$$

The number of dwellings in each collection zone influenced the number of surveys that were distributed. Tuesday A consisted of 1701 dwellings, Monday A 1315 dwellings and Thursday A 1576 dwellings. In the three collection zones, there was a total of 4592 dwellings. Survey response rates have shown large variation (Nulty, 2008). To err on the side of caution, a low response rate of approximately 15% was assumed. This resulted in 1000 surveys being distributed for each collection zone with the aim of achieving at least 159 survey returns per collection zone.

Surveys were distributed via post and internet with each postal survey pack consisting of a participant information sheet, a cover letter introducing the research, the survey and a reply-paid envelope. The information sheet provided contact details in case of queries about research and human ethics information. A reminder notice was sent two weeks after the survey pack was distributed. Documents from the survey pack can be seen in Appendix D.4.

Of the three collection zones; 157 surveys were received from Tuesday A, 215 from Monday A and 236 from Thursday A. A total of 608 surveys were returned. As Tuesday A returned slightly under the required number of surveys, the conditions set in Equation 6.4 were mildly exceeded.

6.2.3 Survey design

The survey was divided into three sections; a knowledge test, summary of demographic details and a summary of household recycling behaviour and perceptions. The knowledge test focused upon correctly assessing products as recyclable or GW. Pictures of 36 products were included in this section, combined with a disposal choice scale and a 4-point certainty scale (Figure 6.4). Participants were asked to choose in which kerbside bin they would dispose the product (landfill bin or recycling bin) and the level of certainty in their decision. Low certainty correlated with a low number and a high certainty with a high number.

Figure 6.4 Format of knowledge assessment in household survey

18 glass and 18 plastic objects were used in the knowledge portion of the survey. Only two material types were chosen to provide sufficient power for contrast. Plastic and glass were the chosen materials for the survey as the waste audit had indicated they had significantly different waste stream profiles. Approximately 50% of plastic was found to be treated as GW and 50% as recyclable. In contrast, nearly 100% of glass was found to be treated as recyclable. A goal of the study was to determine whether the prevalence of recyclable and GW for each material influenced disposal choices when guessing.

Products were also divided into three categories of difficulty; easy, moderate and hard (Michailova, 2013). Categories were formed using pilot runs and council education material. The survey pilot runs consisted of testing the survey on two small groups, of 20 to 30 people. 'Easy' products were those that matched council education material, 'moderate' products were those that were like council education material but not exact, 'difficult' products were those that bore no similarity to council education material. Pilot runs were used to determine if categories were accurate portrayals of difficulty. Additionally, 18 of the products were recyclable and the other 18 were GW.

The second part of the survey analysed the demographic characteristics of responders. The demographic variables collected included; age, gender, income, household size, number of cars, number of children under 15, dwelling type, homeowner status, occupation, education level. These variables were chosen based on the results of Chapter 5 and findings in previous studies.

The final portion of the survey investigated household recycling behaviour, specifically; attitude toward recycling, recycling social norms, waste disposal time requirements and waste disposal service quality. Participants responded to the following statements:

- "I believe that kerbside waste separation is a worthwhile activity"
- "I believe that my local community think kerbside waste separation is a worthwhile activity"
- "Frequency of recycling bin overflow in the past month"
- "Frequency of GW bin overflow in the past month"
- "Time required per week for sorting and disposing recycling waste in kerbside bin"
- "Time required per week for sorting and disposing general waste in kerbside bin"

Levels of agreement were used to respond to attitude and social norm statements (Strongly disagree, disagree, neutral, agree, and strongly agree). When responding to frequency of bin overflows, survey participants could choose 0, 1 or 2 for recycling bins and 0, 1, 2, 3, 4 for GW bins. Response choices for weekly disposal time requirements included < 5 minutes, 5 – 10 minutes, 10 – 15 minutes, 15 – 20 minutes and > 20 minutes. A copy of the survey can be seen in Appendix D.4.

Bin bias was measured by collating all disposal decisions with a certainty level of 1. These disposal decisions represented disposal 'guesses'. The 'guesses' were subsequently separated by collection zone and probability was calculated using counts of landfill disposal versus counts of recycling bin disposal.

Two recycling influences that were not analysed in detail were recycling policy and MRF sorting efficiency. Policy interviews were carried out with staff of the local government, involving queries about education, rewards, punishment and system enhancement. The findings of these interviews were that little policy action was ongoing. The exception was an annual distribution of new disposal calendars with updated disposal rules. This was thought to have minimal impact on recycling levels and did not occur during the waste audit or household survey data collection. The recycling rate history showed no change during distribution of disposal calendars (Figure 5.1).

MRF sorting efficiency was also mentioned as a potential influence on recycling rate plateaus. Using existing literature and interviews with MRF staff, it was found that a MRF's sorting efficiency was commonly above 90% (Pressley, 2015).

6.3 Field experiment results

Section 6.3 summaries the results from the field experiment. Section 6.3.1 summarises the collinearity between the six recycling influences while Section 6.3.2 focuses upon the comparison between the three collection zones using descriptive and analytical statistics. Section 6.3.3 looks at bin bias results across the three collection zones and Section 6.3.4 compares 2011 census data with survey demographic data, providing insight into the profile of the survey sample.

6.3.1 Correlation between the 6 direct influences on recycling

A correlation analysis was performed between potential direct influences on recycling rate plateaus. This was completed to assess the relationships proposed in Figure 6.2. Heterogeneous correlation was applied to disposal knowledge, attitude toward recycling, recycling social norms, service quality (bin overflows) and disposal time requirements. A heterogeneous correlation was necessary as the survey data was a combination of numerical and ordinal data (Bamattre, 2017). Polychoric correlation occurred between ordinal variables, polyserial between numeric and ordinal, and Pearson's correlation between numerical variables. Correlation results were interpreted using the following categories; (a) 0 – 0.10 was considered No Correlation, (b) 0.10 – 0.30 was considered a Weak Correlation, (c) 0.30 - 0.50 was considered a Medium Correlation, (d) 0.50 - 0.70 was considered a High Correlation and (e) 0.70 - 1 was considered a Very High correlation (Cowan, 1998).

The correlation tests shown in Table 6.2 did not support the hypothesis of dwelling size impacting recycling time requirements and service quality. It is also apparent that service quality (r_{rec} = 0.009, r_{gw} = -0.092) and time requirements (r_{rec} = 0.041, r_{gw} = 0.05)) do not affect attitude toward recycling. There is indication of a weak correlation between dwelling size and recycling social norms (r = 0.184). The strongest correlations were seen between variables with similar scales. Recycling bin overflows were found to be moderately correlated with GW bin overflows (r = 0.401). Meaning that if recycling consumption was high, then it was moderately likely that GW consumption was too. A similar pattern was seen for disposal time; if greater time was devoted to recycling disposal then it was highly likely a similar amount of time was spent on GW disposal (r = 0.791). A high correlation was seen between recycling social norms and attitudes towards recycling (r = 0.586). The insight being that if an individual had a positive opinion of recycling they were more likely to think that their community had similar positive beliefs.

Table 6.2 Heterogeneous correlation matrix

	Disposal knowledge	Recycling bin overflow	GW bin overflow	Time devoted to recycling	Time devoted to GW	Attitude toward recycling	Recycling social norms	Dwelling size
Disposal knowledge	1							
Recycling bin overflow	0.06	1						
GW bin overflow	-0.034	0.401	1					
Time devoted to recycling	0.064	0.063	0.03	1				
Time devoted to GW	0.032	-0.013	0.067	0.791	1			
Attitude toward recycling	0.118	0.009	-0.092	0.041	0.05	1		
Recycling social norms	0.04	0.03	0.021	-0.011	0	0.586	1	
Dwelling size	0.042	0.041	-0.014	0.075	0.059	0.055	0.184	1

6.3.2 Chi-squared and regression analysis of collection zones

Table 6.3 presents a summary of the disposal knowledge scores, indicating that Thursday A had the highest average of 75.26% correct, followed by Monday A (74.5%) and Tuesday A (73.94%). It was predicted that this pattern would occur, as Thursday A had the lowest bin contamination followed by Monday A and Tuesday A. However, the similarity between disposal knowledge scores was greater than expected. It must be acknowledged that the survey may have some difficulty in detecting differences in intangible variables such as disposal knowledge, recycling attitudes or social norms.

Table 6.3 Summary of disposal knowledge assessment for collection zones

	Thursday A	Monday A	Tuesday A
% correct	0.7526	0.7450	0.7394
Average correct (Total 36)	27.09	26.82	26.62
Standard Deviation	3.99	4.29	3.98
Material % correct	Plastic: 0.8232 Glass: 0.6919	Plastic: 0.7817 Glass: 0.7047	Plastic: 0.8132 Glass: 0.5011
End use status % correct	Recyclable: 0.8192 GW: 0.6839	Recyclable: 0.8056 GW: 0.6810	Recyclable: 0.8167 GW: 0.6621
Classification difficulty % correct	Easy: 0.8669 Moderate: 0.7112 Hard: 0.6797	Easy: 0.8620 Moderate: 0.6953 Hard: 0.6771	Easy: 0.8568 Moderate: 0.6971 Hard: 0.6603
Average certainty	3.16	3.23	3.14

Chi-square tests of independence were performed to examine the relationship between attitude, social norms, GW bin overflow, recycling bin overflow, time for disposal, disposal knowledge, and dwelling types with collection zones (Figure 6.5). The relationship between recycling attitudes, time for disposal and disposal knowledge were found to not be significantly associated with collection zones. This infers that there was not significant difference of disposal knowledge, recycling attitudes and time for disposal between the collection zones.

Significant difference was found between collection zones for both GW bin overflows (X^2 (8) = 23.68, p = 0.0026) and recycling bin overflows (X^2 (8) = 14.94, p = 0.0048). Thursday A was most likely to experience GW and recycling bin overflows, followed by Monday A and Tuesday A. This pattern is likely explained by average household size which can be seen in Table 6.5 (Thursday A = 3.24, Monday A = 2.56, Tuesday A = 2.35). However, the frequency of bin overflow did not appear to impact enthusiasm for recycling, with the high achieving recycling zone possessing the greatest number of overflows.

A significant relationship was also found between social norms and collection zones (X^2 (8) = 16.84, p = 0.032). The survey participants from Tuesday A had a worse perception of their neighbours recycling beliefs than Monday A and Thursday A. This may be partially explained by dwelling type trends seen over the three collection zones, with Tuesday A have a significantly greater proportion of higher density dwellings than Monday A and Thursday A (X^2 (4) = 71.04, p = < 0.01).

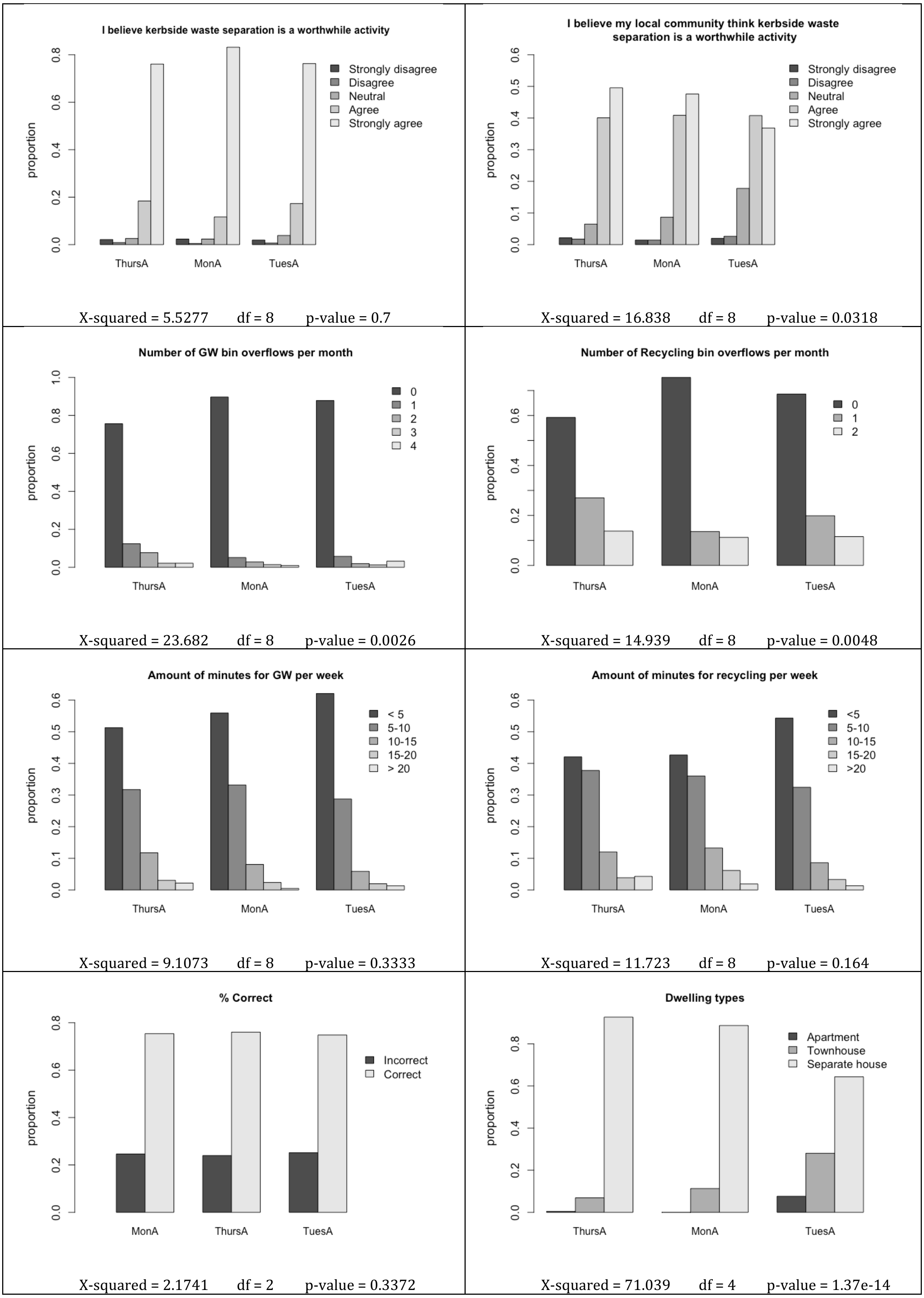


Figure 6.5 Summary of chi-square tests of independence over collection zones

The lack of significant disposal knowledge difference over the three collection zones contradicts hypothesis 2 of this study; that collection zones with lower bin contamination should have significantly higher disposal knowledge. Linear regression tests were applied to further investigate knowledge trends (Figure 6.6). Each test consisted of three data points, representing each collection zone used in the field experiment. Knowledge scores were compared against recycling rate plateaus, GW bin contamination and recycling bin contamination. Mean knowledge ($p = 0.5405$, Adj $R^2 = -0.1268$) did not have a significant relationship with GW bin contamination but did have a significant relationship with recycling bin contamination ($p= 0.0159$, Adj $R^2 = 0.9988$) and recycling rate plateaus ($p = 0.0419$, Adj $R^2 = 0.9914$).

It is insightful that although significant difference in knowledge scores was not seen between collection zones, correlations with recycling rates and recycling contamination were evident. It is possible the methodology for knowledge measurement was insensitive but was still able to detect the trends between the collection zones.

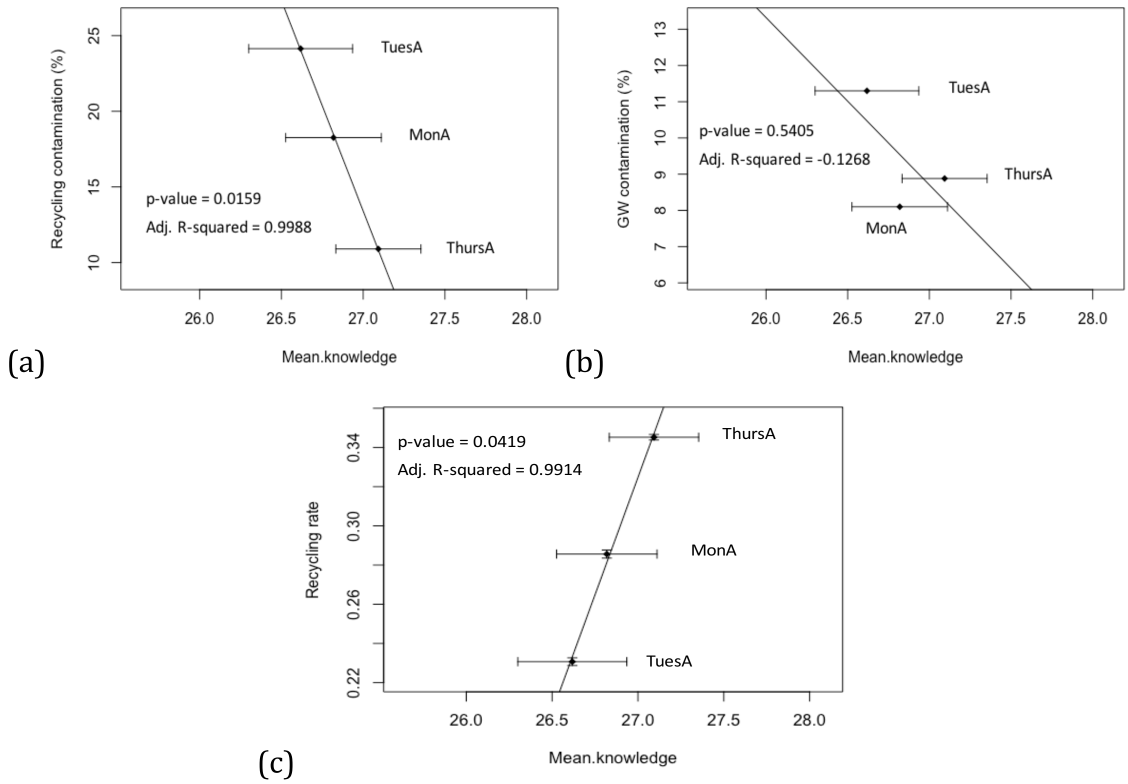


Figure 6.6 Summary of linear regression analysis comparing disposal knowledge against (a)Recycling contamination, (b) GW contamination, and (c) recycling rate plateaus. Error bars represent standard error of the mean (standard $error = \pm\frac{s}{\sqrt{N}}$).

6.3.3 Bin bias

As already stated, bin bias is defined as the probability of choosing the GW bin or the recycling bin when making uncertain disposal decisions. It is apparent from Chi-squared tests of independence there were significant differences (Figure 6.7 and Table 6.4). When looking at uncertain recyclables disposal, Tuesday A had a greater bias towards landfill disposal (X^2 (2) = 4.96, p = 0.084) than Thursday A and Monday A. Tuesday A had the lowest recycling rates and the highest bin contamination. GW also showed a bias towards the GW bin for all collection zones, showing significant difference between Monday A and Thursday A (X^2 (2) = 6.2, p = 0.045). Overall, about 80% of guessed GW was disposed in the GW bin in all collection zones.

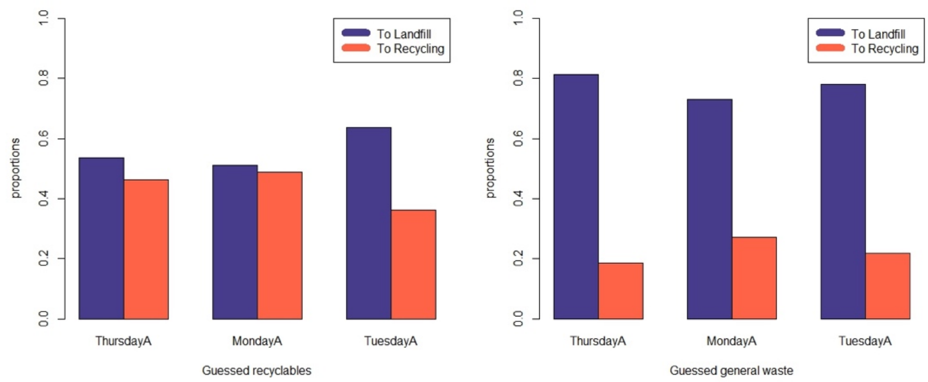


Figure 6.7 Bin bias results for three collection zone; guessed recyclables and guessed GW

Table 6.4 Contingency table for bin bias (Units = number of guesses)

	Thursday A	Monday A	Tuesday A		Thursday A	Monday A	Tuesday A
Guessed recycling to landfill	79	68	88	Guessed GW to landfill	257	216	228
Guessed recyclables to recycling	68	65	50	Guessed GW to recycling	59	80	64

6.3.4 A comparison of demographic data between census and survey

Demographic data collected from the household survey was compared to 2011 census demographic data to determine the representativeness of the survey. Most the demographic variables seen in the census and survey showed similarity, however some discrepancies were apparent. Regarding the dwelling type of survey responders, there is a similarity with census trends. Both Thursday A and Monday A show most survey responders lived in standalone houses, closely matching census figures. Tuesday A survey data showed greater representation of apartment dwellers compared to census data. This may be due to misnaming townhouses as apartments.

The average age of the survey responder was considerably older than census data average age. As the census encompasses the entire population it is understandable the average age was lower than the survey, which only considered the age of the responder. Survey responders were often likely to be the head of the household and thus older than the average population age.

Three demographic variables did show some difference between census and survey figures that was more difficult to explain. Census data indicated that there were near equal proportions of males and females in all three collection zones, however the survey response showed a clear female bias for Tuesday A. Some discrepancy was also seen between census and survey data for ownership status, with both Monday A and Tuesday A showed lower than expected proportions of renters. Renters may possess a weaker association to their residence, or a diffusion of responsibility in shared housing, thus reducing survey participation. Thursday A also showed household income was significantly lower than the census figure. This may be due to those with high paying employment being time poor. A summary of demographic data can be seen in Table 6.5.

Table 6.5 A summary of collection zone demographics for 2011 Australian census and household survey

			Thursday A	Monday A	Tuesday A
Age	Census		35	36	35.5
	Survey		50	56	49
Gender	Census	Male	49.5%	49.8%^Δ	48.8%^Δ
		Female	50.5%	51%^Δ	49.9%^Δ
	Survey	Male	45.85%	40.78%	28.1%
		Female	54.15%	59.22%	71.9%
% of dwelling type	Census	Separate House	85.4%	87.3%^◊	53.9%^◊
		Townhouse	14.6%	10.8%^◊	42.4%^◊
		Apartment	0%	0%^◊	0.04%^◊
	Survey	Separate House	92.67%	88.68%	64.33%
		Townhouse	6.9%	11.32%	28.03%
		Apartment	0.5%	0%	7.64%
# of people per household	Census		3.2	2.66	2.26
	Survey		3.24	2.56	2.35
% of hh with kids under 15	Census		43.37%	29.45%	20.2%
	Survey		45.74%	23.67%	25.68%
Median income	Census		2650 AUD	1705 AUD	1270 AUD
	Survey		2000 AUD	1625 AUD	1025 AUD
Homeowner status	Census	Owner	21.3%*	28.9%*	21.2%*
		Mortgage	53%*	42.9%*	28.9%*
		Rent	18.3%*	20.07%*	36%*
	Survey	Owner	36.24%	60%	42.11%
		Mortgage	55%	34.63%	41.45%
		Rent	8.7%	5.37%	16.45%

*Figures do not add to 100% due to vacant dwellings

^Δ Figures do not add to 100% due to census data sorting methods (ABS, 2017)

^◊ Figures do not add to 100% due to exclusion of 'other dwellings'

6.4 Discussion of field experiment results

The key findings from this study related to highlighting the major influences on municipal recycling rates plateauing below their full potential. Six potential influences on recycling rate plateaus and bin contamination were tested. These included; a) waste disposal classification knowledge, (b) attitude toward recycling,

(c) recycling social norms, (d) dwelling types, (e) time devoted to waste disposal, and (f) kerbside recycling service quality.

Section 6.3.4 discussed the validity of the survey. Most of the demographic variables showed similarity between census and survey, however some differences were noted. The average age of survey responder was older than the average population age but followed a similar pattern between collection zones. As discussed in Section 6.3.1, this was likely due to heads of households responding to the survey rather than children.

Some of the demographic comparisons between survey and census data were significantly different. The gender response for Tuesday A was skewed toward females, Thursday A's household income was lower than expected and homeowner status of Monday A and Tuesday A survey responders was biased against rental residents. The discrepancy in Thursday A household income was thought to be due high paying employment requiring long working hours, thus providing little time to reply to surveys. The low number of rental responders was thought to be caused by a weak association to their residence, and diffusion of responsibility in shared housing.

Hypothesis 1 of this chapter predicted that a causal pathway would be apparent in Figure 6.2. For both Dwelling size and Social norms, significant difference was seen between the collection zones. Recycling high achievers possessed larger dwellings and had more positive perceptions of their neighbour's recycling efforts. There was conflicting evidence for recycling attitudes impacting recycling rate plateaus, with correlation and tests of independence showing different results. As previously stated, there are indications that both disposal knowledge and bin bias have some impact on recycling rate plateaus. A visual representation of this pathway can be seen in Figure 6.8.

The impact of dwelling type on this causal pathway is worth further discussion. Shaw stated that greater housing density diminished the social norm incentive for recycling participation (Shaw P. , 2008). This has been supported by the results of this analysis, that suggest that dwelling type may relate to strength of community. Results indicated that higher density communities having more negative views of their neighbours recycling habits.

There is conflicting evidence that recycling social norms go on to influence personal attitudes towards recycling. Although there is a high correlation between the two, no significant difference in recycling attitudes was found between the collection zones. As discussed in Section 2.1.2, the general positive picture of recycling may bias responses to recycling attitude questions.

It was apparent that recycling time requirements and waste service quality did not diminish enthusiasm for recycling. The key evidence for this was the time requirements were greatest, and service quality was lowest in the high achieving recycling zone. If onerous time requirements and poor service quality did diminish recycling zeal, it would be expected to see highest time input and poorest service quality in the low achieving recycling zone.

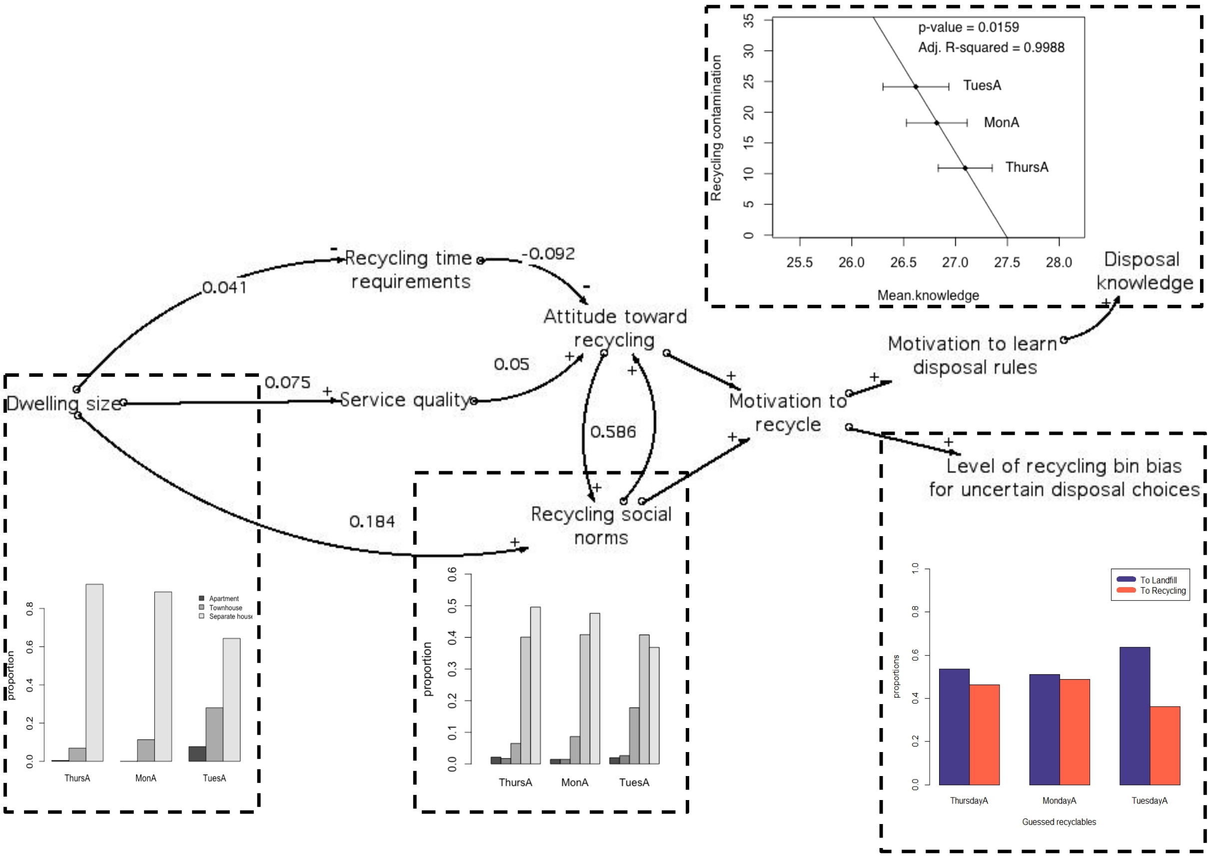


Figure 6.8 Results of correlation and chi-squared tests for the proposed causal pathway of 6 potential influences on recycling rate plateaus

Hypothesis 2 predicted that improved waste disposal knowledge would result in lower bin contamination due to greater proficiency in waste separation. This statement was largely based upon the waste audit results which showed large differences in bin contamination over the three collection zones. Linear regression results indicated that improved disposal knowledge decreased recycling contamination but was less influential on GW contamination. The change in bin contamination subsequently impacted recycling rate plateaus. However, chi-squared results showed that the knowledge difference between the collection zones was not significant. There could be multiple reasons for this: (a) participants may be putting additional effort into the survey knowledge test, but be more casual when disposing waste, (b) only enthusiastic recyclers took part in the survey, or (c) lack of measurement of incorrect disposal procedure. An example of incorrect disposal procedure includes disposing of recycling in the correct bin but placing it in a plastic bag, thus making it impossible to process in the recycling facility.

Considering the regression analysis results in Figure 6.6 and the relationship seen between education level and bin contamination seen in Chapter 5, it is extremely likely disposal knowledge is negatively correlated to bin contamination. However, it must be concluded that the knowledge test carried out in this chapter was an insensitive measure. It is recommended that future attempts to measure intangibles such as disposal knowledge or recycling attitudes should be designed as a 'blind' experiment. This should diminish the effects of response bias and would prevent participants attempting to maximise correct disposal scores.

Hypothesis 3 predicted that high achieving recycling collection zones would have greater biases towards the recycling bin when making uncertain decisions. The results indicated that uncertain decisions were always biased towards the GW bin. For recyclables, this GW bias was generally small with near equal probability that unrecognised waste could go in either bin for the high and moderate achieving collection zones. Unrecognised recyclables in the low achieving collection zone had about a 60% chance of being placed in the GW bin. For GW, all collection zones were heavily biased towards the GW bin. This allows the conclusion that rather than biases towards the recycling bin in high achieving zones, there are signs of greater biases towards the GW bin in low achieving recycling zones.

This brings us back to the research questions; asking how direct influences impact MSW recycling rate plateaus and bin contamination. This chapter finds that a causal pathway is apparent that influences both disposal knowledge and bin bias. There is evidence that these variables subsequently impact bin contamination and recycling rate plateaus. Although there are conflicting results, they suggest that as disposal knowledge improves bin contamination decreases. This improvement in bin contamination is likely to be proportionally greater for recycling than for GW. However, as the GW stream accounts for approximately 2/3 of the waste stream the smaller reductions in GW bin contamination may still push recycling rates higher. This was supported by the regression analysis, which showed disposal knowledge levels positively correlated with higher recycling rate plateaus.

Consistent bin bias is also likely to have an impact on recycling rate plateau. Biases towards the recycling bin increase the recycling rate plateau and may increase or decrease bin contamination. In contrast, biases towards the GW bin would decrease the recycling rate plateau and may also increase or decrease bin contamination. Results indicated that low achieving recycling regions are more likely to dispose an unknown recyclable into a GW bin than moderate and high achieving regions. This would result in a decreased recycling rate. If disposal knowledge levels are lower, as they appear to be in low achieving recycling zones, the bin bias effect would be enhanced.

The key conclusions from this chapter were the relevance of both disposal knowledge and bin bias on MSW recycling rates. Chapter 7 will carry out SD modelling, and will incorporate disposal knowledge and bin bias.

A Modelling Experiment

7.1 Introduction

The fourth research question of this thesis asked 'are the forces driving MSW recycling rates exogenous or endogenous to the municipality's waste-control system?' Part of this question has already been addressed in Chapter 3 with the presentation of the dynamic hypothesis. The hypothesis was based upon existing literature, however in this chapter an experiment is run to determine the implications of the hypothesis. This is done by building a stock and flow model that has the structure of the dynamic hypothesis, and that uses the data gathered during the project – in particular, the waste facility weighbridge data and the waste audit data. In addition, the conclusions arrived at in Chapters 5 and 6 are used to build confidence in the model structure.

As emphasized in Table 7.1, a key goal of this model should be to seek an endogenous explanation for the plateauing of MSW recycling rates (Richardson G. , 2011). The seeking of an endogenous influence in a human driven system is a potentially empowering approach. If endogenous leverage points are discovered, this provides a possible human driven solution to the problem being investigated. If an exogenous perspective is applied, the best that can be hoped for is accurate prediction of influences outside of our control. This explains why this thesis is focused upon finding an endogenous explanation for plateauing recycling rates. If this can be found, then a solution within our control can be proposed to lift recycling rates.

The possibilities of this modelling experiment include the successful capture of an endogenous explanation for plateauing MSW recycling rates or a model with exogenous drivers of dynamics. This may be due to the lack of endogenous drivers or because the model boundaries have not captured these drivers.

Table 7.1 A summary of modelling perspectives

Mode of analysis	True state of affairs: Exogenous	True state of affairs: Endogenous
Endogenous	Striving for understanding & leverage, but failing ✓	Achieving understanding & leverage ✓✓✓
Exogenous	Accepting fate or predicting ×	Confused & misguided ×××

7.2 Stock and Flow Model

An SD model provides a way to explore the dynamical implications of the dynamic hypothesis. It thus provides a way to test the hypothesis and to experiment with alternative hypotheses. The approach adopted here follows Sterman's five-step modelling process; problem articulation, formulation of a dynamic hypothesis, formulation of a simulation model, model testing and policy design. As previously stated, the problem being investigated is the plateau of recycling rates below their full potential, although the dynamics of recycling rate growth will also be discussed. The SD model is this chapter addresses the level at which recycling rates plateau and the dynamics of recycling rate growth.

Part of problem articulation is the proposal of a reference mode. Common reference modes seen in complex systems include exponential growth, goal seeking behaviour, s-shaped growth, oscillation, growth with overshoot, and overshoot and collapse (Sterman, 2000). Using recycling rate data from the case study region (Figure 7.1), the dynamics bear closest resemblance to goal seeking behaviour. Figure 7.1 also indicates that a time horizon of around 10 to 20 years is sufficient to demonstrate recycling rate dynamics.

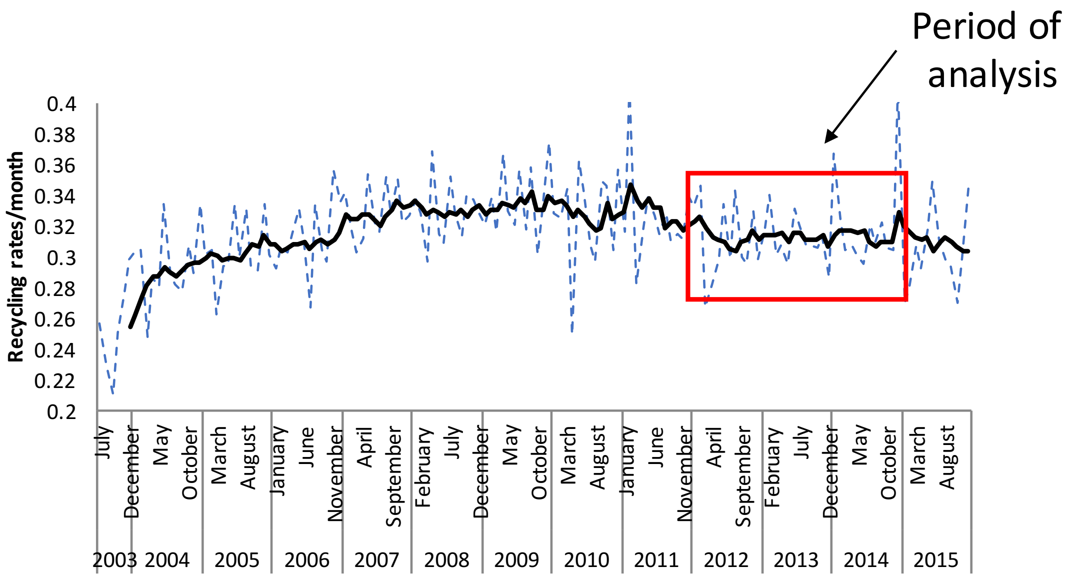


Figure 7.1 Recycling rate history of case study region with the dashed line showing raw recycling rate and the black line showing a 6-point moving average (also seen as Figure 5.1)

The Stock and Flow Model is an important component of SD, as it provides an opportunity to test and experiment with proposed feedback structures. The Stock and Flow Model for this thesis has already been discussed in Chapter 3. The three major components of the Stock and Flow Model that are presented in this section include; (a) learning and disposal knowledge, (b) material flows, and (c) links between disposal knowledge and material flows.

Data and results from previous chapters have been used as a guide for the model structure. The initial foundation for the SD model included the material flow pathways seen in the council case study and results from previous chapters that indicated that the major influences on MSW recycling rates were; (a) disposal knowledge, (b) bin bias, and (c) waste stream proportions.

7.2.1 Learning and Population Knowledge

As discussed in Chapter 3, two types of learning styles are presented in the Stock and Flow Model; (a) Operant Conditioning (learning through consequences), and (b) Observational Learning (Mazur, 1998).

In Figure 7.2, Observational Learning is represented by the reinforcing loop (R) and the learning time limitations as balancing loop B1. In addition, the learning curve dynamic of Operant Conditioning is represented by the council education balancing loop (B2) and a portion of balancing loop B3 is presented. Balancing loop B3 demonstrates the link between recycling bin contamination and council education expenditure. The interaction between the learning loops and time limitations is seen in the learning rate. All feedback loops link to this rate of change and is characterised by Equation 7.1. A detailed explanation of each stock, flow and parameter can be found in Appendix E13, 14 and 15.

$$learning\ rate = (time\ gap\ fraction \times effectiveness\ of\ observational\ learning \times population\ knowledge) + (learning\ from\ council\ education \times time\ gap\ fraction) \quad [7.1]$$

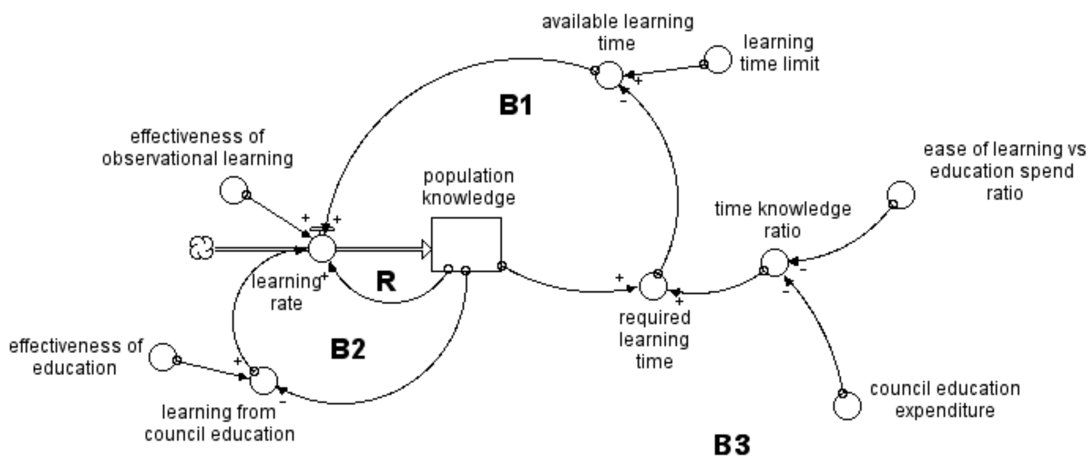


Figure 7.2 Learning and Population Knowledge portion of SD model

7.2.2 Relationship between disposal knowledge and material flows

It is necessary to connect the intangible disposal knowledge (Figure 7.2) with the tangible material flow (Figure 7.5). A simplified form of this relationship can be seen in Equation 7.2, with 'accuracy of sorting' representing 'population knowledge', 'knowledge impact' weighting the influence of 'population knowledge' on contamination levels, 'idw' representing incorrectly disposed waste and 'cdw' representing correctly disposed waste. The 'Material flow' term represented the material flow portion of the model seen in Figure 7.5.

$$contamination\ index = \frac{idw}{cdw} = 1 - Accuracy\ of\ sorting^{knowledge\ impact} \qquad [7.2]$$

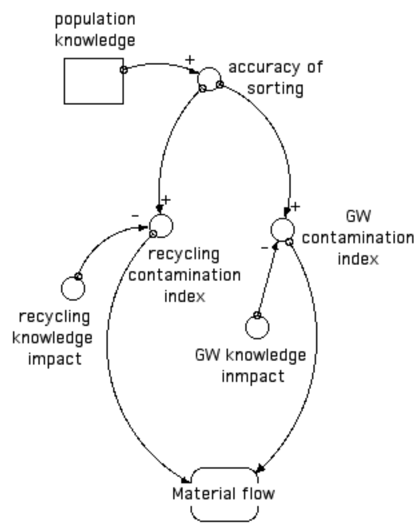


Figure 7.3 Model component determining the relationship between 'population knowledge' and 'purity' of waste streams ('Material flow' = Figure 7.5)

With regards to the relationship between population knowledge and waste stream contamination, no literature could be found to explain this dynamic. Instead, a graphical function was created to vary the impact of population disposal knowledge on waste stream contamination (Figure 7.4). This provided the ability to have a flexible relationship between population knowledge and contamination levels. When 'knowledge impact' is equal to 1, the relationship can be considered linear. A 'knowledge impact' less than 1 indicates that population disposal knowledge has shown a greater improvement in bin contamination than expected.

This may be due to a population placing greater emphasis on one waste stream when learning disposal rules. A value greater than 1 indicates a higher level of bin contamination than expected, a sign that a waste stream's disposal rules have been neglected.

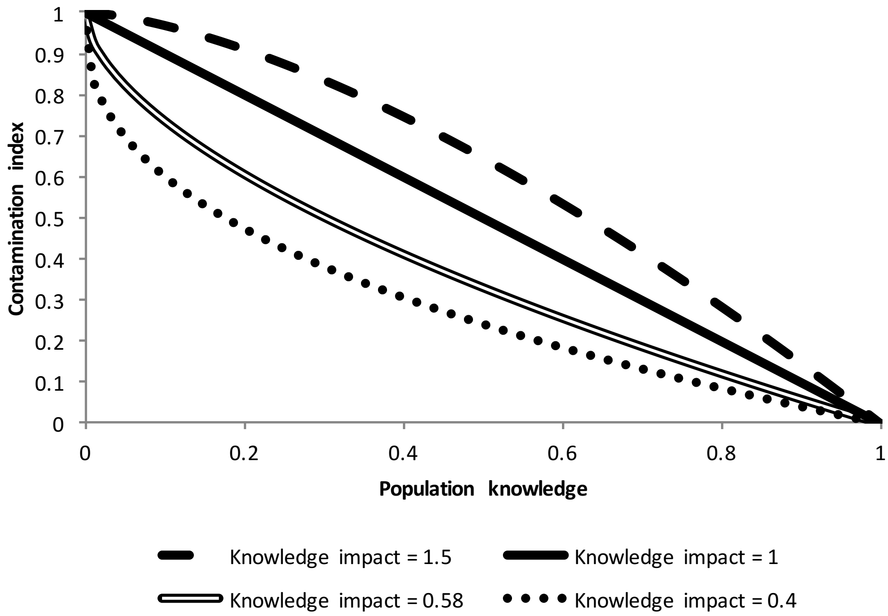


Figure 7.4 The graphical function determining the relationship between population knowledge and the contamination index

Equation 7.2 was refined by adding a bin bias variable. Results from previous chapters emphasised bin bias as being a significant factor in MSW dynamics. As discussed in previous chapters, there are intangibles such as attitudes and social norms that influence disposal decisions. Using bin bias to represent these intangibles it is possible to represent its impact. Equation 7.3 includes bin bias, represented as 'bb' and characterises the relationship used in the model.

$$contamination\ index = \frac{bb \times idw}{cdw} = 1 - Accuracy\ of\ sorting^{knowledge\ impact} \quad [7.3]$$

A 'bb' equal to 1 represented no bin bias. If 'bb' was greater than 1 then there was a bias towards the incorrect bin. If the 'bb' was less than 1 then there was bias towards the correct bin.

7.2.3 Material flows

The final portion of the SD model outlined the waste flows from entry into a household to their arrival at a MRF or landfill. Materials passing through a household were separated into two categories; (a) recyclables, (b) and GW. Recyclable material includes paper, paperboard, aluminium, steel, glass, and liquid paperboard. GW represented materials going to landfill and included organic waste, plastic film, unrecyclable glass and composites.

The main material flow parameters and pathways can also be seen in the model, Figure 7.5. The proportion of GW and recyclables in the waste stream are key parameters, and were determined by waste audit data. The GW proportion of the waste stream was split into correctly and incorrectly disposed GW. Correctly disposed GW was that placed in the GW bin and incorrectly disposed GW was that placed in the recycling bin. The recyclable proportion of the waste stream divided into correctly and incorrectly disposed recycling. Correctly disposed recycling was that placed in the recycling bin and incorrectly disposed recycling was that placed in the GW bin.

The two algorithms that helped determine the rate of flow of correctly and incorrectly disposed waste are Equations 7.4 and 7.5. Equation 7.4 represent the relationship between disposal knowledge and material flows while Equation 7.5 signifies the 'waste stream proportion' of recyclables or GW. 'Wsp' represents 'waste stream proportion', 'idw' represents incorrectly disposed waste and 'cdw' represents correctly disposed waste.

$$contamination\ index\ (ci) = \frac{bb \times idw}{cdw} \qquad [7.4$$

$$wsp\ = idw + cdw \qquad [7.5]$$

To determine the formula for correctly disposed and incorrectly disposed waste a simultaneous equation was solved using Equations 7.4 and 7.5 as the basis (see Equations 7.6 to 7.11). Equations 7.6 and 7.9 were used to control flow to the correct or incorrect bins. The equations were applied to both the recycling and GW streams seen in Figure 7.5.

Solving for 'correctly disposed waste' (cdw):

$$\frac{cdw \times ci}{bb} + cdw = wsp \quad [7.6]$$

$$cdw\left(\frac{ci}{bb} + 1\right) = wsp \quad [7.7]$$

$$cdw = \frac{wsp}{(\frac{ci}{bb}+1)} \quad [7.8]$$

Solving for 'incorrectly disposed waste' (idw):

$$\frac{bb \times idw}{ci} + idw = wsp \quad [7.9]$$

$$idw\left(\frac{bb}{ci} + 1\right) = wsp \quad [7.10]$$

$$idw = \frac{wsp}{(\frac{bb}{ci}+1)} \quad [7.11]$$

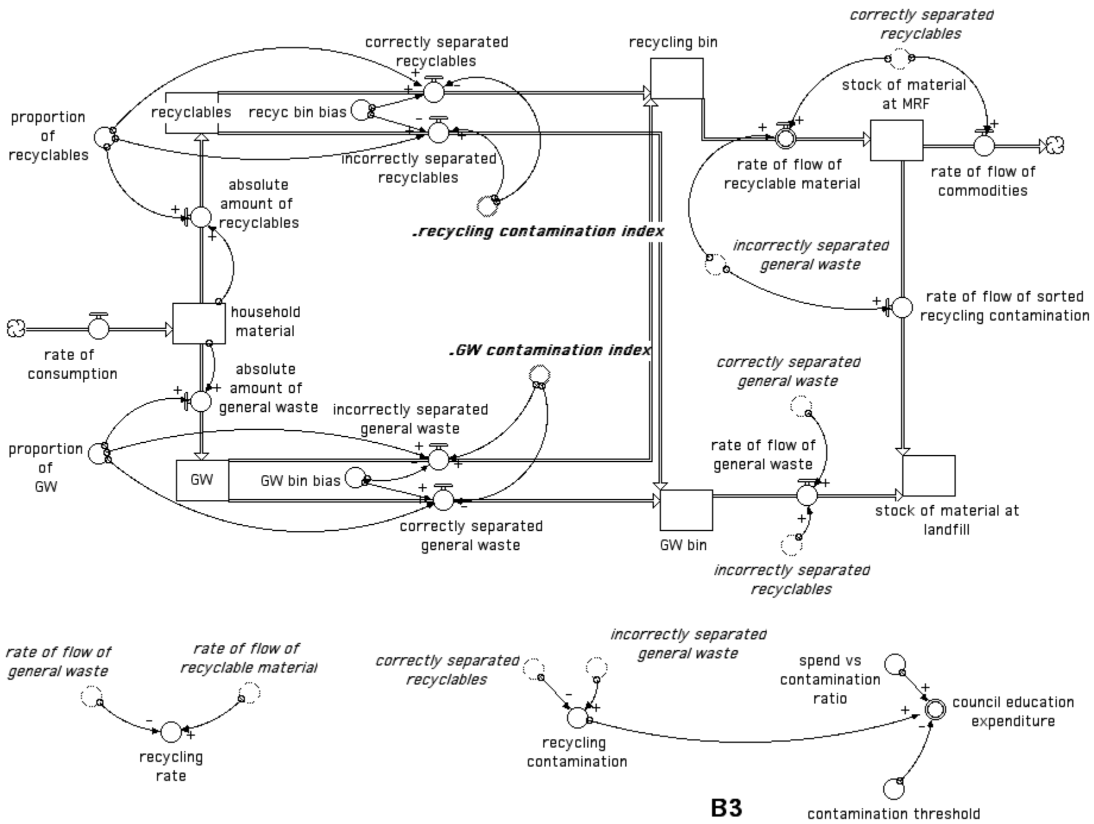


Figure 7.5 Material flow portion of SD model (also see Figure 3.2)

The key dependent variables observed via model simulations were recycling rate, recycling bin contamination and GW bin contamination. These variables were compared against waste audit data and weighbridge records. These were highly significant variables during model testing and policy simulations. In these equations, it is assumed that after disposal recycling bin contents were sent to a MRF for sorting and contaminants in the recycling bin (i.e. incorrectly disposed GW) were diverted to landfill. All GW bin contents were sent to landfill. Recycling rates and bin contamination were calculated using Equations 7.12, 7.13 and 7.14:

$$Recycling\ rate = \frac{rate\ of\ flow\ of\ recyclable\ material}{rate\ of\ flow\ of\ recyclable\ material + rate\ of\ flow\ of\ GW} \quad [7.12]$$

$$Recyc.\ bin\ contam.(\%) = \frac{incorrectly\ separated\ GW}{incorrectly\ separated\ GW + correctly\ separated\ recyc.} \times 100 \quad [7.13]$$

$$GW\ bin\ contam.(\%) = \frac{incorrectly\ separated\ recyc.}{incorrectly\ separated\ recyc + correctly\ separated\ GW} \times 100 \quad [7.14]$$

7.3 Methods for constraining and testing SD model

In this section there is a discussion of the methods used to constrain the model when comparing against historical recycling rates. Two key processes are discussed; the process taken to constrain the model when simulating recycling rate growth and recycling rate plateau, and the method used to calculate historical recycling plateaus to compare against simulated recycling plateaus. With regards to recycling plateau simulations, the model was constrained using waste audit data; specifically waste stream proportions of GW and recyclables. The model was also constrained by matching model bin contamination to waste audit bin contamination. A similar process was used for simulating recycling growth. Although, in the case of recycling growth, waste proportion data was averaged over the whole council region rather than by collection zone.

However, to start with it is worth examining the method for calculating historical recycling rate plateaus. These are the calculations that were used to check the accuracy of model plateau simulations.

7.3.1 Method for calculating historical recycling rate plateaus

Historical recycling rate plateaus were calculated using two sources of data; (a) weighbridge data from landfill and recycling facilities, and (b) collection zone dwelling counts. Dwelling counts were used to normalise waste flows by council collection zone.

Weighbridge data was obtained from the case study council's waste invoices. Monthly billings were received from their waste transport contractor for the tonnage of waste and recycling transported to the local landfill and Municipal Recycling Facility (MRF). The invoices recorded the time of drop-off, weight of waste deposited, truck registration, and origin of waste. Weighbridge data from June 2011 to October 2014 was used for this analysis.

Dwelling count data was gathered from two main sources; (a) council housing lists, and (b) manual checks using Google Earth and site visits. Correlation checks using population figures was also applied.

It was observed that the council housing list did not include all kerbside bins being put out for collection. Using Google Earth and site visits, it was apparent that some unregistered addresses were using council bins. These were predominantly Multi-Unit Dwellings (MUD).

Google Earth was again used to count the number of kerbside bins accompanying these unregistered addresses. This manual check focused upon addresses that were not private businesses, and possessed council bins. This final manual check were the figures used when calculating historical recycling rates and the results of these measures can be seen in Table 7.2.

Table 7.2 Collection zone dwelling counts

	Council housing list (2014)	Manual check (2015)	Collection zone population
Monday A	1315	1315 ◊	3087
Tuesday A	1558	1701 *	3974
Wednesday A	1339	1339 ◊	3798
Thursday A	1518	1576 *	4849
Friday A	1231	1411 *	4200
Monday B	1620	1620 ◊	4400
Tuesday B	1091	1139 *	3237
Wednesday B	960	977 *	2453
Thursday B	1594	1783 *	5007
Friday B	478	1009 #	2442

*Multi-Unit Dwelling bins were not counted in council figures

#New development not included in council figures

◊Council figure matched manual count

As a further check on the reliability of dwelling counts, correlation and linear regression analyses were made with collection zone population figures derived from census data (Figure 7.6). It was hypothesised that an accurate dwelling count should have a strong positive correlation with collection zone population. A strong positive correlation was found between dwelling numbers and population (r = 0.912) and a significant linear regression result (p = 2.35e-4, Adj R^2 = 0.8109).

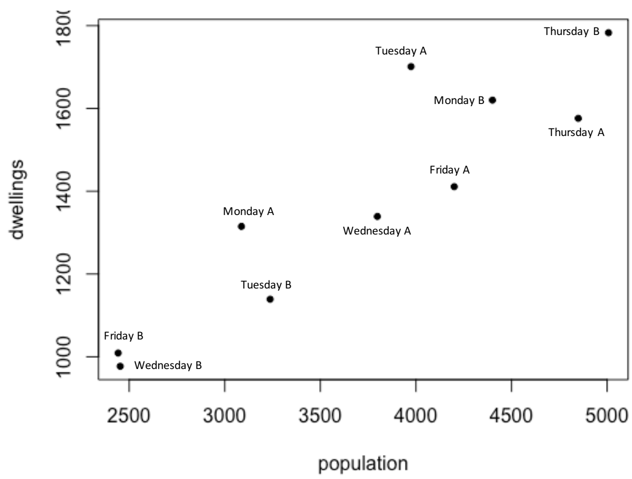


Figure 7.6 Scatterplot of council collection zone dwelling count and population

As outlined in Chapter 5, and seen again in Equations 7.15, 7.16 and 7.17, the weighbridge data and dwelling counts were used to calculate collection zone recycling rates. These formulas reflect the weekly GW collection and fortnightly recycling collection. There is also consideration of collection zone boundaries, with the weekly GW collection containing collection zones A and B, while fortnightly recycling collections rotated between A and B zones.

$$Recycling\ produced\ per\ dwelling = \frac{fortnight.recycling\ tons * 1000kg/ton}{\#\ of\ dwellings\ (CZ.A\ or\ B)} \quad [7.15]$$

$$GW\ produced\ per\ dwelling = \frac{(GW\ tonnage.wk1 + GW\ tonnage.wk2) * 1000kg/ton}{\#\ of\ dwellings\ CZ.A + \#\ of\ dwellings\ CZ.B} \quad [7.16]$$

$$CZ\ Recycling\ rates = \frac{recycling\ produced\ per\ dwelling}{recycling\ produced\ per\ dwelling + GW\ produced\ per\ dwelling} \quad [7.17]$$

7.3.2 Method for simulating recycling rate plateaus

MSW recycling rates simulated via the SD model used data sourced from waste audits. A 2015 waste audit provided the core data, however some additional bin contamination figures were taken from a 2013 waste audit of the same region. The 2015 waste audit followed best practice, using the NSW guide to waste audits (DECC, 2008). All bin contamination data can be seen in Table 7.3.

Two key figures for each collection zone were taken from the waste audit results to constrain the model's recycling rate simulation; (a) bin contamination, and (b) waste stream proportions. Bin contamination represented the proportion of GW in the recycling bin or recycling in the GW bin, and was calculated using Equation 7.18:

$$contamination = \frac{incorrectly\ disposed\ waste}{incorrectly\ disposed\ waste + correctly\ disposed\ waste} \quad [7.18]$$

Due to the expense and time required to carry out an audit, only one audit could be performed during this research project. This resulted in bin contamination measures for each council collection zone relying on one, or at most, two data points. This is evident in Table 7.3.

Table 7.3 Collection zone bin contamination calculations

	Mon A	Mon B	Tues A	Tues B	Wed A	Wed B	Thurs A	Thurs B	Fri A	Fri B
2013 Recycling contamination	23.4%	-	20.4%	-	29.3%	-	11%	-	14.9%	-
2013 GW contamination	-	-	-	-	-	-	-	-	-	-
2015 Recycling contamination	13.13%	14.04 %	27.87%	8.01%	15.87%	11.63 %	10.8%	9.02%	4.67%	20.47 %
2015 GW contamination	8.10%	15.31 %	11.30%	10.54 %	7.73%	16.47 %	8.88%	10.06 %	18.55 %	11.68 %
Final Recycling contamination	18.27% *	14.04 %	24.14% *	8.01%	22.59% *	11.63 %	10.9% *	9.02%	9.79%*	20.47 %
Final GW contamination	8.10%	15.31 %	11.30%	10.54 %	7.73%	16.47 %	8.88%	10.06 %	18.55 %	11.68 %

*Average of 2013 and 2015 waste audit results

The 2015 waste audit was also the source of waste proportion data, and in this case each collection zone was characterised by a single data point. To calculate proportions, it was necessary to use waste audit data (Table 7.4) and Equations 7.19 and 7.20. As recycling was collected fortnightly and GW weekly, correctly disposed GW and GW contamination (incorrectly disposed recyclables) were doubled to represent fortnightly collection.

$$Recycling\ proportion = \frac{Recycling + 2 \times GW\ contamination}{Recycling + Recycling\ contamination + 2 \times (GW + GW\ contamination)} \quad [7.19]$$

$$GW\ proportion = 1 - recycling\ proportion \quad [7.20]$$

Table 7.4 Waste audit weights and proportions for each collection zone

	MonA	MonB	TuesA	TuesB	WedA	WedB	ThursA	ThursB	FriA	FriB
Recyc (kg)	463.62	372.25	433.43	499.77	398.81	448.3	496.5	511.82	412.74	248.8#
GW contam (kg)	36.7	84.88	63.08	62.84	43.51	82.5	46.43	51.59	65.72	63.25
GW (kg)	416.62	469.46	495.38	533.25	519.24	418.47	476.7	461.29	288.55#	478.11
Rec contam (kg)	70.07	60.78	167.51	43.54	75.21	58.98	60.12	50.75	20.22	64.04
Total (kg)	1440.33	1541.7	1717.86	1735.49	1599.52	1509.22	1602.88	1588.33	1141.5	1395.56
Recycling proportion	0.3728	0.3516	0.3257	0.3604	0.3037	0.4064	0.3677	0.3872	0.4767	0.2689
GW proportion	0.6272	0.6484	0.6743	0.6396	0.6963	0.5936	0.6323	0.6128	0.5233	0.7311

Waste contractor picked up smaller sample (< 50) due to shortage of bins

The data in Tables 7.3 and 7.4 were the key constraints on the SD model. The proportion figures were used to numerate the 'proportion of recyclables' and 'proportion of GW' parameters, seen in Figure 7.5. The level of bin contamination was predominantly controlled via the learning time limit parameter and the bin bias parameter. Changes were also made to knowledge impact parameters, the time knowledge ratio parameter and the learning effectiveness parameters to alter the shape of recycling rate growth. When bin contamination matched waste audit contamination, recycling rates were observed to check they were within historical bounds. The bin contamination model outputs can be seen in Figure 7.7. Equations 7.12, 7.13 and 7.14 indicate how the MSW recycling rate was then calculated within the model, after being constrained by waste stream proportions and bin contamination.

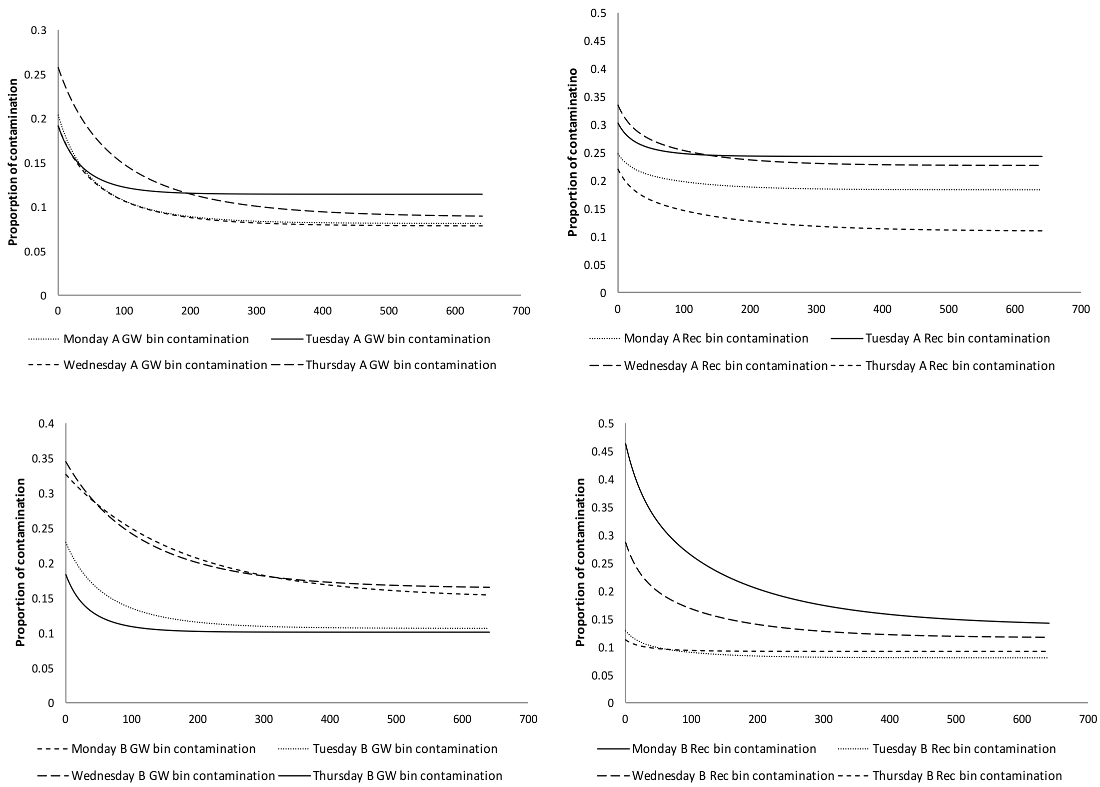


Figure 7.7 SD model simulations of bin contamination (time scale = model time steps)

7.4 System Dynamics model tests

The tests carried out to determine the accuracy of the model involved comparing historical recycling rate patterns with simulated recycling rates. Section 7.4.1 presents a check of recycling rate growth while Section 7.4.2 discusses the simulated recycling rate plateaus, comparing them against historical averages. Section 7.4.3 examines the key endogenous feedback loop found in the model. Sensitivity tests were also carried out on the model parameters and can be found in Appendix E.

Friday A and Friday B collection zones were excluded from the study due to irregularities in the waste audit sampling procedure; less than 50 GW bins were collected on Friday A and less than 50 recycling bins were collected on Friday B. This shortfall was due to smaller than expected bin numbers in the sampling region. The irregular number of bins collected in these two zones meant it was not possible to obtain an accurate picture of recycling and GW proportion in the waste stream.

7.4.1 Recycling rate growth dynamics

The replication of recycling rate growth seen in the whole case study region was guided using waste audit data and results from Chapter 6. The model was constrained using waste stream proportions and bin contamination data from the waste audit seen in Table 7.3 and Table 7.4. The recycling stream formed 35.94% of the waste stream and GW 64.06%. Recycling bin contamination was constrained at 14.89% and GW bin contamination at 11.86%. Other parameters such as learning time limit, effectiveness of observational learning, effectiveness of council education, GW knowledge impact, recycling knowledge impact, GW bin bias and recycling bin bias were modified to optimise a historical fit. The output of the simulation can be seen in Figure 7.6 and a summary of parameter values in Appendix E.12.

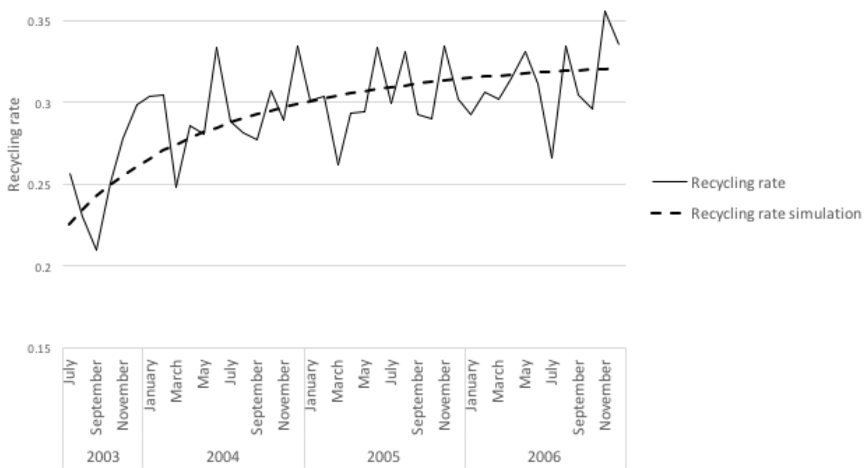


Figure 7.8 A fitting of SD simulation over historical recycling rates

Three factors were critical in shaping the recycling growth dynamic; bin bias, knowledge impact on contamination, and the interaction between learning loops. A summary of their impact on model dynamics can be seen in Figure 7.9. Bin bias influences the vertical alignment of recycling rates, knowledge impact on contamination the curve of recycling rates, and the interaction between learning loops the shape of the recycling rate growth.

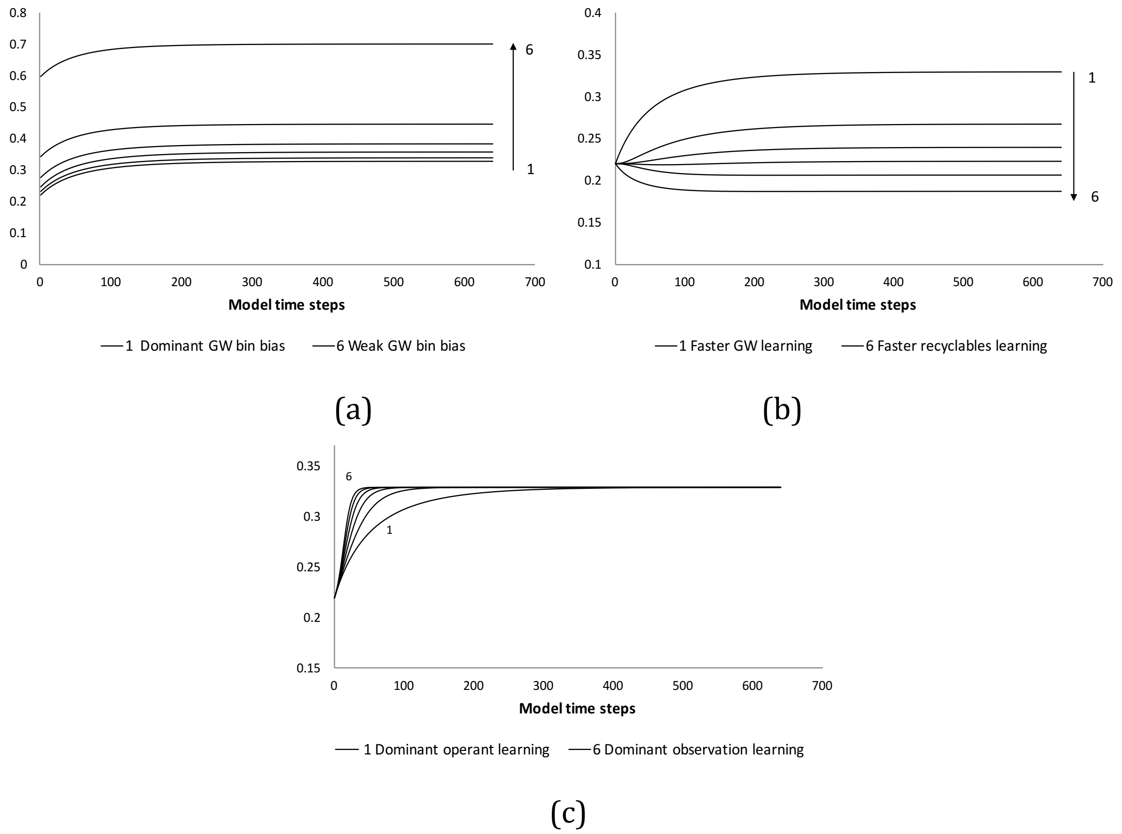


Figure 7.9 Impact of (a) bin bias, (b) knowledge impact on contamination, and (c) the interaction between learning loops.

After simulating the constrained model, parameters such as GW bias and Recycling bias were compared to results in Chapter 6. The GW bias was strongly towards landfill, a result that was also seen in Chapter 6. There was also a slight bias towards landfill when regarding recycling, again a result supported by the results in Chapter 6.

It is necessary to recognise that the acting influences are all exogenous. Even though feedback loops are active, the recycling rate parameter is not contained within them. This suggests that recycling rate growth is exogenous to a municipality's waste control system. Further testing of the model was continued in the next section, focusing on simulations of MSW recycling plateau level.

7.4.2 Recycling rate plateau simulations

As stated in Section 7.3, the ability of the model to simulate recycling rate plateaus was determined by comparing plateau simulations with historical trends. This takes place in Figure 7.10, with historical trends being represented by three dashed lines showing; a historical average, an upper limit, and a lower limit. These values are also seen in Table 7.5. When the simulated recycling plateau fell within these bounds, this supported the structure of the model. It should also be noted that apart from varying waste stream proportions and bin contamination levels, all simulations used the same starting conditions as the simulation seen in the previous section.

After simulations were run it was evident that five of the recycling rate simulations fell within the historical bounds, while three did not (Table 7.5 and Figure 7.10). The simulated recycling rate of Wednesday A, Thursday A, Monday B, Tuesday B and Wednesday B fell within the expected bounds. The simulated recycling rate of Monday A, Tuesday A, Thursday B fell outside of the expected bounds.

Table 7.5 A summary of model parameter values and output

	MonA	TuesA	WedA	ThursA	MonB	TuesB	WedB	ThursB
Recyc rate simulation	0.3961	0.3291	0.3248	0.3479	0.2809	0.3131	0.3367	0.3540
Historical average	0.2856	0.2307	0.3221	0.3452	0.3024	0.2886	0.3508	0.2713
+ 1 Stan. Deviation	0.3159	0.2553	0.3491	0.367	0.325	0.318	0.376	0.2893
- 1 Stan. Deviation	0.2553	0.2061	0.2951	0.3234	0.2798	0.2592	0.3256	0.2533

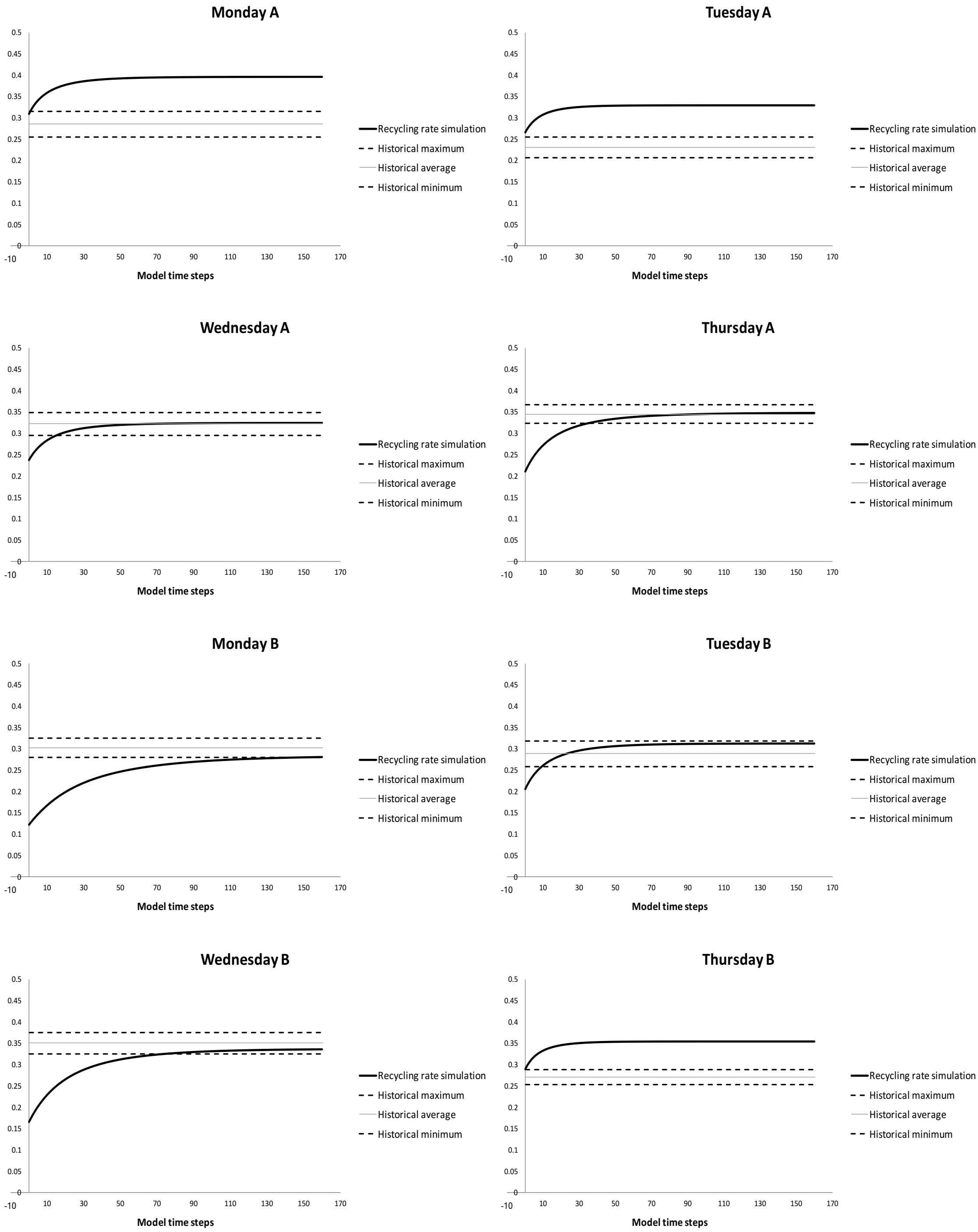


Figure 7.10 Model test results; comparison of recycling rate simulation with range of real world recycling rate plateau

Figure 7.10 informs us that the SD model does not always accurately replicate historical recycling rate benchmarks. It is worth discussing possible reasons for the poor results of Monday A, Tuesday A and Thursday B simulations.

Assuming the model structure is appropriate, the two possible causes for the model discrepancy include: (a) sampling error, and (b) measurement random error. Sampling error is the difference between the population and sample values (Bethea, 1991). The sampling method used for the waste audit involved collecting waste and recycling from 50 dwellings in each collection zone, with dwellings classified as separate houses or Multi-Unit Dwellings (MUDs). Council housing lists were used to determine the proportion of separate houses versus MUDs in each collection zone. When randomly choosing dwellings for the waste audit, these proportions of separate housing and MUDs were replicated for the sample. After the waste audit, upon investigating the results it became apparent that treating MUD's as a single category may have been in error. Tuesday A and Thursday B contained MUD's that were significantly larger than multi-unit housing in other collection zones. They appeared to have different characteristics than smaller MUD's. These differences included a greater amount of bin sharing and longer distances between dwellings and bins. It is possible that poor capture of large MUD's waste profile lead to a higher simulated recycling rate. Chapter 5 results indicate that high density dwellings generally have lower recycling rates.

When t-tests are carried out, comparing the demographics of Monday A, Tuesday A and Thursday B against the rest of the collection zones, eleven of 130 variables had p-values below 0.1 (Table 7.6). From these results, it can be inferred that the three outlying collection zones have a smaller dwelling size, with fewer occupants and a lower income. These findings reinforce the hypothesis that pockets of high density MUD's may need to be considered in future sampling actions.

Table 7.6 T-tests results to determine characteristics of collection zone outliers

	t-test (MonA, TuesA, ThursB vs other)			
	t-statistic	df	p-value	MonA, TuesA, ThursB vs other
High mortgage repayments 2600 plus	-3.75	6.45	0.0083	Lower proportion
Older lone persons households	3.66	4.41	0.0182	Higher proportion
Female 65 plus	2.53	7.46	0.0375	Higher proportion
4 or more bedroom households	-2.91	4.39	0.0391	Lower proportion
Young couples aged 14 to 44 without children	2.57	6.04	0.0423	Higher proportion
High income households more than 2500 week	-2.46	6.15	0.0484	Lower proportion
Employed part time total	-2.90	3.40	0.0534	Lower proportion
Median household income	-2.41	5.82	0.0535	Lower level
Female 70 to 84	2.16	7.45	0.0652	Higher proportion
Total 65 plus	2.01	7.98	0.0798	Higher proportion
Female 35 to 49	-2.12	4.42	0.0950	Lower proportion

The existence of measurement random error of the waste audit is also necessary to consider. This refers to the statistical variation in the measured waste audit data due to precision limitations of the measurement device (Bethea, 1991). For example, Tuesday A recycling bin contamination was considerably larger due to large pieces of concrete being placed in the bin. This demonstrates that waste audit data was susceptible to random fluctuations in disposal behaviour, a problem that can be minimised by averaging over many observations. As mentioned previously, due to the time and expense of waste audits there was difficultly in running multiple audits during this research project. It is possible that random error also played a role in the large recycling rate seen in the Monday A simulation. A combination of high recycling and low GW bin contamination, with high proportions of recycling and low proportions of GW, resulted in the highest simulated recycling rate. It would be worthwhile to see how these figures average over multiple waste audits.

Taking into consideration that plateau levels were controlled by waste stream proportions and bin contamination, and if the accuracy of the model could be improved via additional and refined waste audit data, then at least one of these key influences are exogenous to MSW recycling rates. In this case it is waste stream proportions, as no obvious feedback was observed during this case study between MSW recycling rates and waste stream proportions. Bin contamination however did show evidence of endogenous feedback and will be discussed in greater detail in the next section.

7.4.3 A learning loop

Bin contamination, and by consequence recycling rates, were found to be endogenously impacted by balancing loop B3. This balancing loop connects recycling bin contamination to increases in population disposal knowledge via council education campaigns. It is essentially a link between material flow and human behaviour.

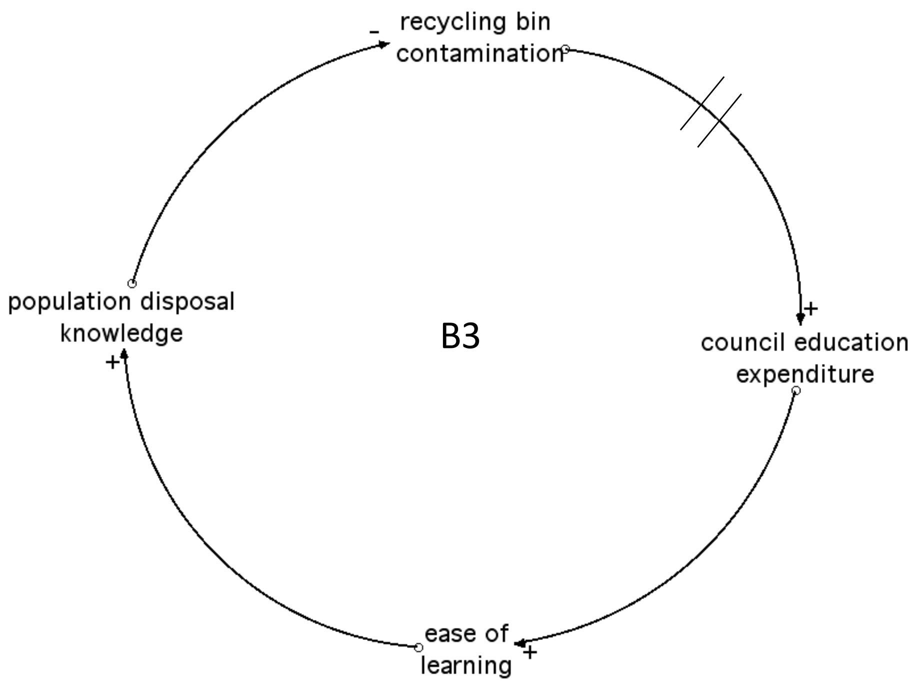
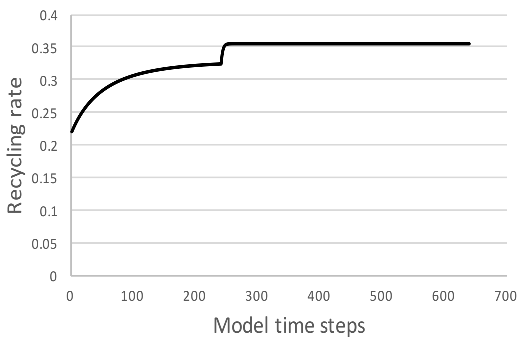


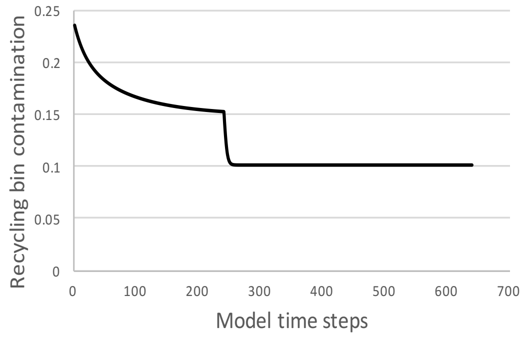
Figure 7.11 Balancing loop B3

However, the feedback loop is active only under two conditions; (a) when there exists a contractual obligation for the council to maintain recycling bin contamination below a certain limit, and (b) when recycling bin contamination exceeds this limit. In this situation, the council is obligated to decrease recycling bin contamination for the benefit of their recycling contractor. Bin contamination is generally decreased by implementing waste education campaigns, an action that often requires considerable preparation time. Consequently, there is commonly a delay between detection of excess bin contamination and onset of an education campaign,

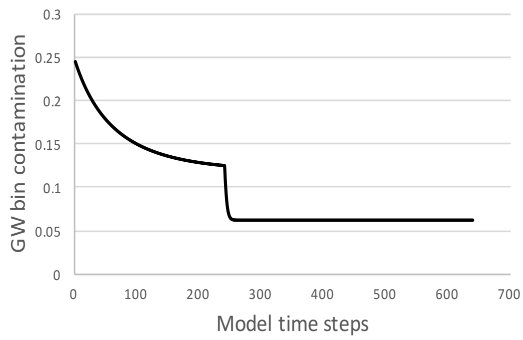
When this loop is activated within the model it is possible to see its impact on bin contamination and recycling rate plateaus (Figure 7.12). In the scenario seen below, a response is forced by instigating a recycling bin contamination threshold of 10%. If recycling bin contamination exceeds this level, there is an increase in council waste education expenditure. A waste education campaign reduces the time requirements of learning disposal rules, thus resulting in improved disposal knowledge. This reduces both recycling and GW bin contamination and subsequently increases the recycling rate plateau.



(a)



(b)



(c)

Figure 7.12 The impact of implementing a recycling bin contamination threshold on (a) recycling rate, (b) recycling bin contamination, and (c) GW bin contamination

Balancing loop B3 represents the key endogenous insight from this model. However, it must be acknowledged it is weak and only occurs under certain conditions. The term 'weak' is applied because any impact on the level of recycling plateau is mild.

This is an interesting finding, because despite local government managing daily waste operations and often setting recycling targets, it appears they have limited ability to affect recycling rates. This is reinforced by Figure 7.9, which demonstrates that the model parameters with the most influence on MSW recycling rates are all exogenous. It may be argued that councils can invest in new recycling streams, such as organics collection and composting. However, this generally requires significant upfront costs, years of preparation and may not be an option for smaller municipal areas. The question remains whether there are alternative methods for local government to impact recycling rates, and perhaps create additional endogenous feedback loops.

7.5 Discussion of modelling results

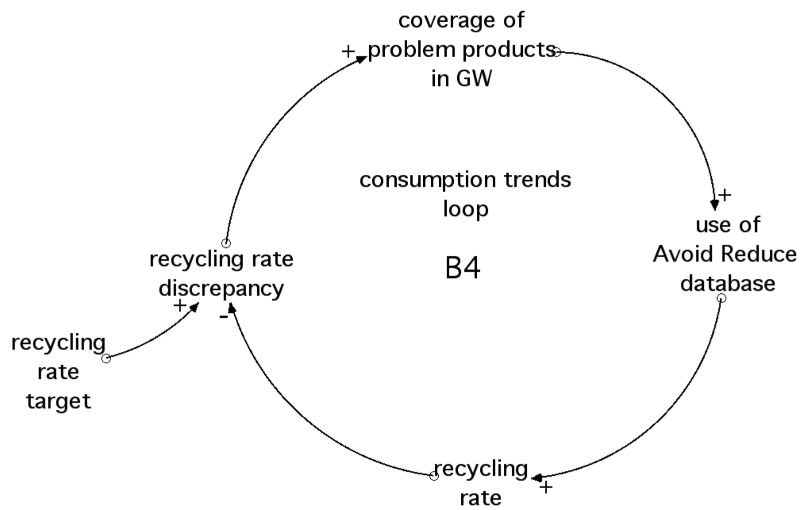
When considering the results from model testing, a response is possible to Research Question 4, which asked; 'are the forces driving MSW recycling rates exogenous or endogenous to the municipality's waste-control system?'

Before answering this, it is necessary to determine whether the SD model was a reasonable representation of the dynamic hypothesis. Firstly, the structure of the model aligns with existing literature and the model algorithms show unit consistency. Secondly, with regards to model simulations, the historical checks generally showed reasonable output. Historical recycling growth could be replicated by the model with realistic parameter values. Although plateau level simulations did not perfectly replicate all historical plateaus, a possible explanation for the discrepancies was offered and a means to resolve the issue. With these results in mind, it is likely the model is a reasonable representation of the dynamic hypothesis and can be used to draw insight into the recycling plateau issue.

Returning to the research question; while the SD model had an endogenous (feedback) mechanism that influenced recycling plateaus, it was only mild. It was apparent that plateaus were largely determined by waste stream proportions, a factor exogenous to the municipality's waste control system. Influences on recycling growth were also primarily exogenous, being determined by exogenous learning feedback loops, bin bias and knowledge weighting.

These findings suggest that currently; local government has limited options if attempting to resist plateauing MSW recycling rates. This is a state that is undesirable as they are the day-to-day managers of Australian waste systems.

To rectify this, it is necessary to find means for local government to improve stagnant residential recycling rates. If infrastructure development is excluded from consideration, the likely remaining options to increase the proportion of recyclables in the municipal waste stream include 'Avoid and Reduce' education campaigns or liaising with local business to reduce wasteful packaging. If effective, these options could create endogenous feedback loops that would place upward pressure on municipal recycling rates. The 'Avoid and Reduce' education policy is represented as loop B4 in Figure 7.7 and influencing packaging types as loop B5.



(a)

(b)

Figure 7.13 Proposed endogenous feedback loops: (a) B4 and (b) B5

With regards to 'Avoid and Reduce' education campaigns, although Australian local government attempt this it generally exists in a very rudimentary manner. Examples include 'buy in bulk', 'buy good quality', and 'take your own shopping bag' (Cardinia Shire, 2013). Based upon the stagnant nature of MSW recycling rates, it is also evident they have not been very effective. It appears that current 'education' programs undertaken by Australian Local Government are insufficient to significantly affect recycling rates. There is a potential for research into how to optimise this type of education campaign. Some interesting questions to resolve include; what types of information should appear in this type of waste education campaign, how can effective performance feedback be created, how should it be delivered, and how can potential impact be measured.

Regarding types of information to include in this type of education campaign, an interesting first question to ask is; what do people need to know when attempting to minimise waste through strategic purchasing? This is an important first step as different approaches to distilling this information will have different challenges. For example, one option is to offer highly granular information about products to avoid to minimise waste.

If the disposal status of a product is known before purchase, a more informed purchasing decision can be made. However, there are some clear challenges to this approach. The first is a municipality's need to remain neutral when dealing with the market place. Local government cannot be seen to be biasing one business over another. The question remains whether council can direct residents away from certain products, while keeping market neutral. The second challenge is potential data copyright breaches if linking products with a retail outlet. Although potentially useful to offer detailed information about the disposal status of products residents encounter daily, any reproduction of a business stock list can represent a copyright breach (Coles Group, 2017). The third problem is the potential scope of the project, dealing with multiple businesses and potentially hundreds of thousands of products. When also considering that various markers needing to be attached to each product, such as disposal status or price, the size of the project becomes considerable.

Another challenge relates to creating an effective feedback system between local government and households. As the primary goal is to improve municipal recycling rates, a key metric to communicate with residents is the current recycling rate. From this they can assess their status, and with the assistance of local government, set reasonable recycling targets. However, it is also necessary to provide some guidance as to how these targets can be met. One option is to design waste audits to identify the products and packaging types in the GW stream. These 'problem' products can then be linked to the 'Avoid and Reduce' product database, which will ideally provide ideas about how to avoid or reduce consumption of this waste. As new audits take place, these 'problem' product lists can be updated. However, a challenge to consider here, is how the effectiveness of this feedback can be increased when recycling targets are not being met. Is this simply a matter of these 'avoid and reduce' messages receiving more coverage or other there are means to persuade residents to change consumption habits?

Other points of interest are finding the ideal method for delivery of this 'Avoid and Reduce' information and how the subsequent impact might be measured. For instance, should delivery be done online via websites and mobile apps, or is it best to engage personally through workshops, events or focus groups. If there is an impact, could this be best detected through MSW recycling rates or is it best to track consumption habits. In addition, at what geographic scope might these measurements take place; a household caste study or perhaps observation of a whole council region. These are all questions that need to be investigated.

With regards to the second potential feedback loop B5, council influencing retail packaging, action may be more difficult. A relationship between local government and retail regarding their packaging is currently relatively minimal. However, there is some progress at the federal and state level in the form of the Australian Packaging Covenant Organisation (APCO) and the National Environment Protection Measure (NEPM) for used packaging (APCO, 2017). APCO is an industry led group while the NEPM is a government program that captures those businesses that have not signed on to APCO. The clear majority of brands and companies that fall under these programs are signatories to APCO. All 986 APCO signatories provide public annual reporting to give insight into their progression in meeting their packaging sustainability goals. For instance, in their 2017-2022 Strategic Plan two of their goals are: (a) APCO will have developed proven viable approaches to remove 50% of current problem packaging types or materials from the waste stream, and (b) APCO will have delivered a packaging Labelling Scheme in market covering 85% of packaging.

If APCO and the NEPM achieve their goals, then it may not be necessary for council to become involved in retail packaging. However, it is still worth considering including the signatories rate of progress in waste education campaigns to residents. This fulfils two functions; (a) by publicising business progress on sustainable packaging this increases pressure on business to meet goals, and (b) provides additional information to households when choosing locations for shopping. While option 'a' represents the council influencing retail packaging feedback loop, option 'b' relates back to the council influencing consumption trends feedback loop.

Conclusion

This thesis has focused upon the problem of inefficient use of resources within the human economy. Recycling has been used as an example of a potential avenue to improve the efficiency resource use. However, some materials and waste types that are currently being recycling are showing plateauing recycling rates.

The aim of this thesis has been to find the specific set of factors that are influencing recycling rates to plateau below full potential and to use this information to determine if and how recycling rates can be raised. The research questions being addressed by this thesis are:

1. How do MSW recycling plateaus relate to material recycling plateaus?
2. How do direct influences and demographics determine the plateau level of MSW recycling rates when participation is high at recycling onset?
3. How do direct influences and demographics determine the level of MSW bin contamination?
4. Are the forces driving MSW recycling rates exogenous or endogenous to the municipality’s waste-control system?

Section 8.1 of this chapter will summarise the findings of research question 1, looking at the links between MSW plateaus and ONP plateaus. The conclusions of research questions 2 and 3 will be discussed in sections 8.2 and 8.3, with a focus on how direct influences and demographics impacted the dependent variables. The results relating to the final research question is summarised in section 8.4 and section 8.5 raises potential ideas for future research.

8.1 How do MSW recycling plateaus relate to material recycling plateaus?

In response to Research Question 1, an investigation was carried out on plateauing ONP recycling rates. As discussed in Chapter 1 and 2, ONP has also been showing signs of recycling rate plateau in Australia. The major influence on ONP recycling rate plateau was found to be the supply of ONP to the recycling market. There were inefficiencies in the collection of ONP such as incorrect disposal or being used for alternative purposes (e.g. gardening, cleaning). The main supply of ONP was found to be from MSW and thus the improvement in ONP supply were driven by the adoption of kerbside recycling by local government and participation of industry groups like PNEB in creating recycling quotas. These improvements largely occurred in the 1980's, 1990's and early 2000's. When collection of ONP could be improved no further, demand began to exceed supply, thus leading to a plateau in ONP recycling rates below full potential. This led to the major portion of this thesis, understanding the recycling rate plateaus that were also appearing in MSW systems.

8.2 How do direct influences and demographics determine the plateau level of MSW recycling rates when participation is high at recycling onset?

The MSW recycling rate plateau level was predominantly determined by proportion of waste and recyclables in the waste stream. In Chapter 5, regression analysis showed recycling rate plateaus were most influenced by consumption trends. As number of people in a dwelling rose, there was a proportionally larger rise in recycling than GW. This lead to higher recycling rate plateaus in these larger households. It was not completely clear why consumption trends changed for these larger households, but possibilities include: (a) families with kids purchase products that are more likely to be recyclable, and (b) larger households also had higher incomes, therefore there may be a correlation with higher education levels.

In Chapter 7 sensitivity tests of the SD model, seen in Appendix E, indicated that changes in waste proportions had the greatest impact on the level of recycling rate plateau. As the proportion of recyclables in the waste stream increased, so did the recycling rate plateau.

SD model tests also indicated that under certain conditions, GW bin bias had a significant impact on the plateau level. If disposal knowledge levels were low and GW was diverted to the recycling bin, this had a significant impact on recycling rate, however it also led to extremely high recycling bin contamination. Other parameters, like recycling bin bias and disposal knowledge levels had some impact on level of recycling rate plateau but played a lesser role.

8.3 How do direct influences and demographics determine the level of MSW bin contamination?

Chapter 5 results from correlation and multiple linear regression show bin contamination was most affected by level of education and financial security. Variables such as household size, time at home and family age were also considered however no correlation was found. As level of education rose there was a strong negative correlation with recycling bin contamination, while no correlation was found between education level and GW contamination. A strong negative correlation was also found between level of financial security and recycling bin contamination, and a weaker positive correlation between level of financial security and GW bin contamination. It was thought that demographic variables encompass the specific influences on recycling rates and bin contamination, which were discussed in Chapter 6 and 7.

Further linear regression analysis in Chapter 6 indicated a significant relationship between disposal knowledge and recycling bin contamination. This analysis was applied to survey and waste audit data, and showed that as disposal knowledge increased, recycling bin contamination decreased. Again, this relationship did not translate to GW bin contamination. These results imply that improvement in disposal knowledge is concentrated on recycling bin rules, while the GW bin is neglected. This pattern of learning would result in a persistent proportion of recyclables going to landfill.

The testing of the SD model in Chapter 7 also supported the link between bin contamination and disposal knowledge. Furthermore, there was evidence of a relationship between bin contamination and bin bias. Model testing showed that as disposal knowledge rose, bin contamination would fall with the dynamics of bin contamination follow a decay pattern.

The relationship between bin contamination and bin bias was less clear and depended greatly on the proportion of recyclables or GW in the waste stream. The current Australian MSW stream is generally about two thirds GW and one third recycling, as presented in Chapter 6, Table 6.3. This meant that when there was a general disposal bias towards landfill, disposal guesses resulted in less bin contamination as nearly two thirds of the waste stream were classified as GW. However, when the disposal bias was towards recycling, then higher levels of bin contamination were more likely.

8.4 Are the forces driving MSW recycling rates exogenous or endogenous to the municipality's waste-control system?

The key goal of the SD model was to ascertain whether an endogenous explanation for plateauing recycling rates existed. However, a purely endogenous explanation could not be found using existing model boundaries.

Plateau levels were found to be determined primarily by exogenous parameters; waste stream proportions and bin bias. Recycling growth was also determined predominantly by exogenous factors; exogenous learning feedback loops, bin bias, and knowledge impact on waste streams.

The little endogenous feedback detected only occurred under certain conditions; (a) when there existed a contractual obligation for the council to maintain recycling bin contamination below a certain limit, and (b) when recycling bin contamination exceeded this limit. It did have an impact on recycling rate plateau, but only by decreasing bin contamination. It was still the proportion of recyclables in the waste stream determining the upper limits of recycling rates.

These findings led to the key conclusion of the thesis; that although local government in Australia is the primary manager of residential waste systems, they have limited tools available to them when attempting to increase recycling rates. This plays a key role in the current stagnation of MSW recycling rates in Australia. To gain further understanding of recycling plateau levels, it would be necessary to investigate whether different model boundaries would uncover additional endogenous feedback loops.

8.5 Limitations of the study

While this thesis has aimed to meet high research standards, there are areas for improvement. These range from the large scale; such as the scope of the thesis, to the small scale, such as the way the model was designed and data collected. This section will discuss some of the limitations of this work.

There are examples of possible sample error, due to samples being an imperfect representation of the population of interest. For example, relying on a single waste audit possibly increased the risk of sampling error. The waste audit was used to assess the composition of the waste stream and to determine contamination figures. As residential consumption habits can vary over time, it would be highly beneficial to have data from multiple waste audits. However, this was difficult to achieve due to the expense and the time requirements of a waste audit.

There was also some evidence of sampling error during the household survey sample, with some female gender bias, even though the census data demonstrated that there should be close to an even split between genders. This was difficult to overcome, and appeared to be related to socioeconomic status. The lower the socioeconomic status, the greater the bias towards female response. In chapter 6, the low socioeconomic zone also had significantly lower response rates. It is possible that greater resources may need to be expended in low socioeconomic zones to achieve accurate results.

There was also a potential response bias in the survey in the form of insignificant difference in disposal knowledge. Response bias occurs when there is a systematic measurement error, creating a value different from the true value of the population of interest. Due to an obvious knowledge test being implemented through the survey, it is possible there was a misrepresentation of real-world disposal knowledge. It is possible that the test lead to additional effort being made by residents, or only those residents that were already motivated to take part.

The SD model created in this thesis was limited in scope as this study emphasised the collection of quantitative data to support the model structure and model output. While this lead to a greater level of confidence in the model structure, by necessity, the model and its boundaries remained small. This is a possible reason for a model that contained only a single endogenous feedback loop. It appears that other endogenous feedback loops that drive residential recycling rates occur beyond the model boundaries used in this thesis. Therefore, the model structure can be used to better our understanding of local government recycling rates, however it doesn't provide a largely endogenous explanation for residential recycling dynamics. This is certainly a limitation in the field of System Dynamics.

As a final comment on thesis limitations, policy testing was not carried out on the SD model. Therefore, while a model was extensively tested there is uncertainty about its level of usefulness. Again, additional work would need to be completed before ready for policy testing.

8.6 Future research

From the discussion at the end of Chapter 7, two opportunities for future research are apparent. These opportunities represent the two potential feedback loops discussed at the end of Chapter 7; council influencing consumption trends (via 'Avoid and Reduce' campaigns) and council influencing retail packaging types. They can make recycling rates endogenous to the SD model, via feedback loops that can increase the proportion of recyclables in the waste stream.

Research into 'Avoid and Reduce' education campaigns offers an interesting avenue for investigation. Although, avoid and reduce messages are currently used by local government, they are rudimentary in nature. A fact possibly explained by legal and technical constraints. The question to be asked is how these legal and technical constraints can be overcome to create an effective approach to influence consumption habits.

An alternative potential endogenous feedback loop worthy of examination is one that aims to limit supply of non-recyclables packaging and products. As stated in Chapter 7, there are already programs currently in place in Australia, such as the Australian Packaging Covenant, with the goal of reducing problem packaging. If the council can measure retails' progress and publicise this progress, again this may be a useful feedback. Again, there remains uncertainty regarding how this may be implemented and is worth additional investigation.

To formalise both these feedback loops, it is recommended that public recycling rate targets are applied. From an SD perspective, this solidifies the feedback loop by providing indication when additional effort is required. Therefore, council expenditure can be increased when progress is lagging and decreased when goals are being met. This is somewhat like the contractual limits set on bin contamination discussed in Section 7.3. However, questions remain regarding what metrics should be included in this type of feedback and to deliver the information.

Apart from future investigation of endogenous feedback loops it is also possible to refine the data collection processes for the model in this thesis. The key example of this is the use of waste audit data. In Chapter 7 when testing the SD model, the susceptibility of waste audit data to random error and sampling error was revealed. To minimise the chance of random error, it was recommended that additional waste audits be used to average bin contamination and waste proportion data. This would also provide an opportunity to vary sampling techniques, providing an opportunity to accurately sample all dwelling types.

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Appendix A

A.1 List of articles used in Quantitative Literature Review

1	(Andersson, 2010)	38	(Seacat, 2010)
2	(Barr S. , 2007)	39	(Shaw P. , 2008)
3	(Barr S. F., 2003)	40	(Shaw P. &., 2008)
4	(Barr S. &., 2005)	41	(Sterner, 1999)
5	(Barr S. G., 2001)	42	(Thomas, 2001)
6	(Berglund, 2006)	43	(Timlett R. &., 2011)
7	(Boldero, 1995)	44	(Timlett R. &., 2008)
8	(Bruvoll, 2002)	45	(Tucker P. , 1999)
9	(Bryce, 1997)	46	(Tucker P. S., 2000)
10	(Callan, 1997)	47	(Ulli-Beer S. , 2003)
11	(Chan, 2013)	48	(Ulli-Beer S. R., 2004)
12	(Cole C. Q., 2014)	49	(Van Houtven, 1999)
13	(De Young, 1989)	50	(Wilson, 2007)
14	(Everett, 1993)	51	(Yang, 2007)
15	(Fornara, 2011)		
16	(Garces, 2002)		
17	(Guagnano, 1995)		
18	(Halvorsen, 2004)		
19	(Hong S. , 1999)		
20	(Hong S. &., 1999)		
21	(Hopper, 1991)		
22	(Jesson, 2009)		
23	(Karavezyris, 2002)		
24	(Kurz, 2007)		
25	(Martin, 2006)		
26	(McDonald, 2003)		
27	(Mee, 2004)		
28	(Nigbur, 2010)		
29	(Nixon, 2009)		
30	(Noehammer, 1997)		
31	(Oom Do Valle, 2005)		
32	(Oskamp, 1998)		
33	(Owens, 2000)		
34	(Perrin, 2001)		
35	(Pressley, 2015)		
36	(Robinson, 2005)		
37	(Schultz, 1998)		

Appendix B

B1. List of councils and the year of kerbside recycling onset

Year of onset	LGA category	Council Nam	State	Source
2010	RAL	Western Plains Regional Council (Dubbo)	NSW	(Dubbo City Council)
2009	RAL	Circular Head Council	TAS	(Circular Head Council, n.d.)
2011	RAM	Shire of Moora	WA	(Shire of Moora, 2010)
2009	RAM	Weddin Shire Council	NSW	(Weddin Shire Council, n.d.)
2011	RAM	Bogan Shire Council	NSW	(Bogan Shire Council)
2014	RAM	Shire of Chittering	WA	(Shire of Chittering, 2016)
2013	RAM	Shire of Northam	WA	(Shire of Northam, 2013)
2005	RAS	City of Onkaparinga	SA	(City of Onkaparinga, 2008)
2001	RAV	Rural City of Murray Bridge	SA	
1991	UDM	City of Victor Harbor	SA	(VH, 1991)
2012	RAV	Huon Valley Council	TAS	(Huon Valley Council, 2012)
2011	RAV	District Council of Mount Remarkable	SA	
2015	RSG	Shire of Augusta-Margaret River	WA	(PerthWaste, 2015)
2005	RTM	Alexandrina Council	SA	(Alexandrina Council, 2004)
2015	RTS	East Arnhem Regional Council	NT	(East Arnhem Regional Council, 2015)
1990	UCC	Council of the City of Sydney	NSW	(Casimir, 1990)
2007	UCC	City of Hobart	TAS	
1986	UCC	Brisbane City Council	QLD	
1994	UCC	Australian Capital Territory	ACT	(Department for Environment, Food & Rural Affairs, 2001)
1975	UDL	Rockdale City Council	NSW	(Bita, 1990)
1993	UDL	Georges River Council	NSW	(Hurstville City Council, 1992)
1989	UDL	Ku-ring-gai Council	NSW	(Browne, 1989)
2004	UDL	Hobsons Bay City Council	VIC	(Hobson Bay City Council, 2012)
1989	UDM	*Lane Cove Municipal Council	NSW	(Large, 1989)
1990	UDM	City of Canada Bay Council	NSW	(Bita, 1990)
1988	UDM	North Sydney Council	NSW	(Chater, 1988)
1989	UDM	Woollahra Municipal Council	NSW	(Large, 1989)
1987	UDM	The Council of the City of Botany Bay	NSW	(SMH, 1987)
1988	UDM	Waverley Council	NSW	(Chater, 1988)
1989	UDM	Inner West Council	NSW	(Large, 1989)
1989	UDM	*Burwood Council	NSW	(Bita, 1989)
1989	UDM	Willoughby City Council	NSW	(SMH, 1993)
1989	UDS	*Strathfield Municipal Council	NSW	(Bita, 1989)
1989	UDS	*Mosman Municipal Council	NSW	(Bita, 1989)
1989	UDV	*Blacktown City Council	NSW	(Bita, 1989)
1989	UDV	*Canterbury-Bankstown Council	NSW	(Bita, 1989)
1989	UDV	*Sutherland Shire Council	NSW	(Bita, 1989)
1989	UFL	*Blue Mountains City Council	NSW	(Bita, 1989)
1992	UFL	City of Wanneroo	WA	(City of Wanneroo, 1992)
2016	UFM	Shire of Kalamunda	WA	
1989	UFM	*Wollondilly Shire Council	NSW	(Bita, 1989)
1991	UFM	Cardinia Shire Council	VIC	(The Bottle Depot, 1991)
1993	UFS	Town of Gawler	SA	(Northern Adelaide Waste Management Authority)
1993	UFV	*Casey City Council	VIC	
1989	UFV	*The Council of the Shire of Hornsby	NSW	(Bita, 1989)
1990	UFV	Campbelltown City Council	NSW	(Bita, 1989)
1989	UFV	Central Coast Council	NSW	(Gosford City Council)
1994	URM	Meander Valley Council	TAS	(WT, 1996)
2007	URM	Bathurst Regional Council	NSW	(Bathurst Regional Council, n.d.)
1995	URM	Cessnock City Council	NSW	(SMH, 1995)
1995	URM	Maitland City Council	NSW	(SMH, 1995)
2003	URM	Queanbeyan-Palerang Regional Council	NSW	
2017	URS	City of Karratha	WA	(Allingham, 2016)

2007	URS	City of Kalgoorlie-Boulder	WA	(City of Kalgoorlie-Boulder, 2016)
1993	URS	Kingborough Council	TAS	(Local Government Board, 2002)
1989	URV	Wollongong City Council	NSW	(Bita, 1989)
1990	URV	Gold Coast City Council	QLD	(City of Gold Coast, n.d.)
1989	URV	Newcastle City Council	NSW	(Bita, 1989)
1996	URV	Lake Macquarie City Council	NSW	(Fitzhenry, 1998)

*Councils listed with kerbside paper recycling onset as 1989. There was some uncertainty about exact starting date, but these councils were listed as possessing kerbside paper recycling in 1989.

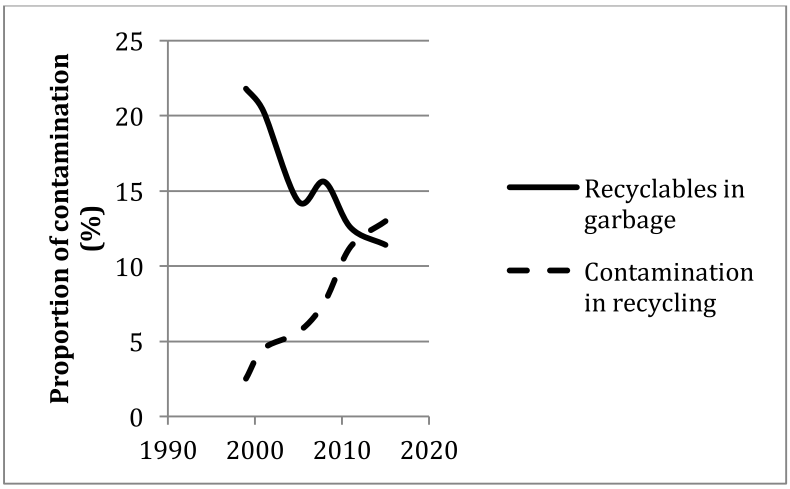
B2. MSW participation and age of kerbside recycling system

Area	**Participation rate**	**Pick-up frequency**	**Kerbside recycling onset**	**Mandatory recycling**	**Number of recycling streams**	**Region type**	**Year of participation measure**	**Source**
Sanoma County California	90%	Weekly	1978	No	3 (plastics & metals,glass, newspaper)	Rural	1991	(US EPA, 1993)
Berlin Township, New Jersey	97%	Weekly	1980	Yes	3 (comingled, paper, card)	Suburbs	1990	(US EPA, 1993)
Lincoln Park, New Jersey	95%	Monthly	1987	Yes	1 (just newspaper)	Suburbs	1991	(US EPA, 1993)
Newark, New Jersey	16%	Weekly	1988	Yes	2 (comingled & newspaper)	Urban	1989	(US EPA, 1993)
Columbia, Missouri	61%,62%	Monthly	1986	No	4 (news, glass,card,alum)	Suburbs	1989,1990	(US EPA, 1993)
Providence, Rhode Island	74%	Weekly	1989	Yes	2 (comingles & newspaper)	Urban	1990	(US EPA, 1993)
Monroe, Wisconsin	85%	Weekly	1986	Yes	2 (comingled & paper)	Rural	1990	(US EPA, 1993)
London Borough of Havering	70%	Weekly	2000	-	1 (comingled)	Urban	2002	(Lyas, 2005)
Newark, New Jersey	37.7%	Weekly	1988	Yes	2 (comingled & newspaper)	Urban	1990	(Sudol, Newark's curbside recycling program: A participation rate study, 1991)

B3. Parameters and formulas for stock and flow model

	Value/formula	Units	Source
Urban councils with ONP	*235*	*councils*	*(Table 4)*
Urban council	*1*	*1/year*	*(Figure 8)*
Urban council adoption	*0.8*	*fraction*	*(Figure 8)*
Total urban	*235*	*councils*	*(Table 4)*
Avg population per	*84001 (20916233* people/249 councils)	*people/council*	(Table 4 & 5)
Rate of adoption	*(councils with kerbside recycling/total councils) * (contact rate * adoption fraction * councils without kerbside recycling)*	*councils/year*	
Total	22718836	*people*	*(Table 5)*
Regional councils with	*183*	*councils*	*(Table 4)*
Regional council	*1*	*1/year*	*(Figure 8)*
Regional council	*0.36*	*fraction*	*(Figure 8)*
Total regional	*183*	*councils*	*(Table 4)*
Avg population per	*5633 (*1802603 people/320 councils)	*people/council*	(Table 4 & 5)
	$\frac{regional\ councils\ with\ ONP\ collection \times avg\ population\ per\ council}{total\ population}$	*fraction*	
Proportion of population	$\frac{urban\ councils\ with\ ONP\ collection \times avg\ population\ per\ council}{total\ population}$	*fraction*	
Residential ONP market	*0.85*	*fraction*	(Integrated Waste
C&I ONP	*0.15*	*fraction*	(Integrated
ONP	*0.07*	*fraction*	(PNEB, 2010)
ONP disposed	*0.114*	*fraction*	(APrince
Proportion of newspapers	*residential ONP market * (proportion of population with kerbside recycling – ONP landfilled – ONP unrecoverable) + C&I ONP market*	*fraction*	

B4. Australian MSW contamination rates over time

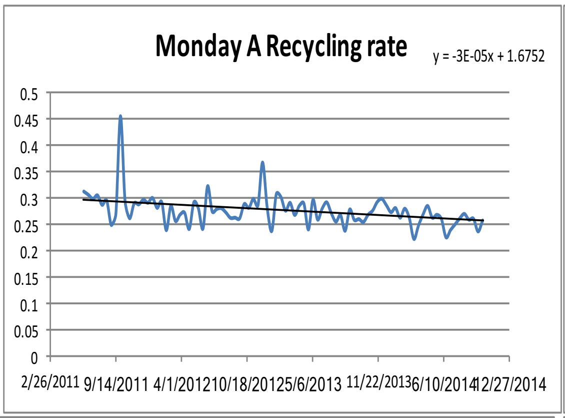


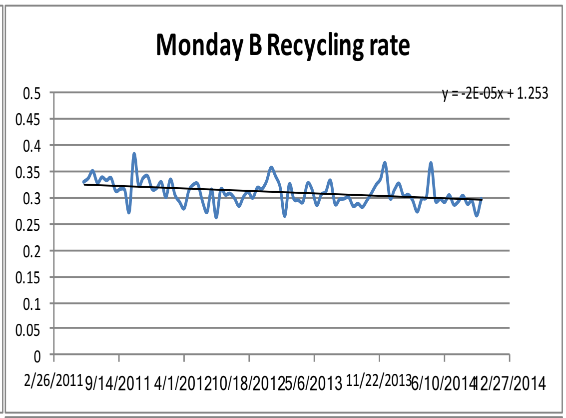
Appendix C

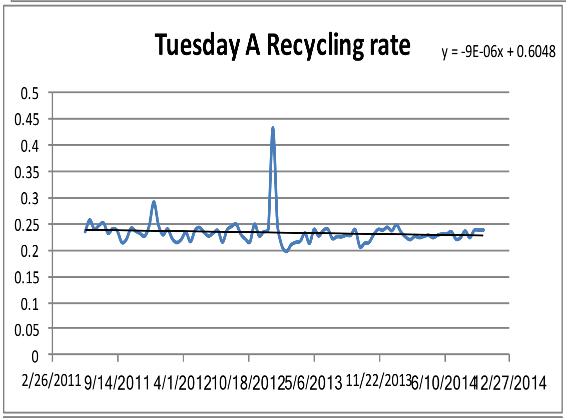
C1. List of demographics variables used in PCA analysis

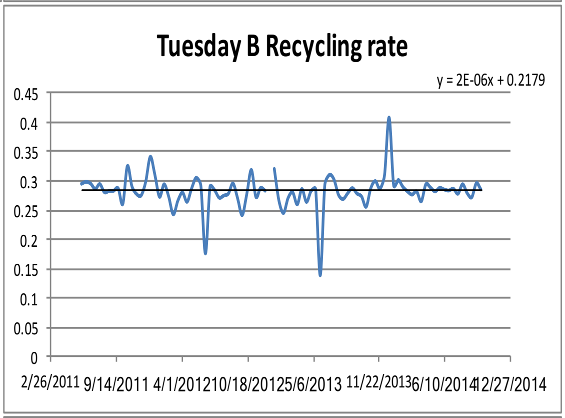
Median age	People with a Christian religion	Young lone persons households
Population density	People with a non-Christian religion	Older lone persons households
Total households	People with no religion	Group households
Total 0 to 4	Households without broadband	Average household size
Female 0 to 4	Low income households less than 600 week	People of Aboriginal or Torres Strait
Male 0 to 4	High income households more than 2500 week	People born overseas
Total 5 to 11	Median household income	Recent arrivals
Female 5 to 11	People in need assistance due to disability	People of non-English speaking
Male 5 to 11	SEIFA index of disadvantage	People not fluent in English
total.12.to.17	SEIFA index of disadvantage advantage	People born in Former Yugoslavia republic
Female 12 to 17	People with university qualifications total	People born in India
Male 12 to 17	People with university qualifications female	People speaking Italian at home
Total 18 to 24	People with university qualifications male	People speaking Macedonia at home
Female 18 to 24	People with trade qualifications total	People with Irish ancestry
Male 18 to 24	People with trade qualifications female	People with Scottish ancestry
Total 25 to 34	People with trade qualifications male	4 or more bedrooms
Female 25 to 34	People with no qualifications total	Vacant dwellings
Male 25 to 34	People with no qualifications female	People in non-private dwellings
Total 35 to 49	People with no qualifications male	Lone persons households
Female 35 to 49	People with below year 11 schooling	People moved address in 5 years
Male 35 to 49	People attending university total	Mortgage holders
Total 50 to 59	People attending university female	Rent privately
Female 50 to 59	People attending university male	Rent social housing
Male 50 to 59	People attending Tafe	Median monthly mortgage repayments
Total 60 to 69	Unemployment rate	High mortgage repayments 2600 plus
Female 60 to 69	Youth unemployment rate	Median weekly rental
Male 60 to 69	Labour force participation	High rental payments 400 plus
Total 70 to 84	Mothers in the workforce	Households in housing stress
Female 70 to 84	Disengaged youth 15 to 25 not in work or school	Households in mortgage stress
Male 70 to 84	Employed part time total	Households in rental stress
Total 85 plus	Employed part time female	2 bedrooms or less
Female 85 plus	Employed part time male	Separate homes
Male 85 plus	Technician trade workers	Couple families with children
Under 18 total	Managers or professionals	Total dwellings
Under 18 female	Couples without children	
Under 18 male	Young couples aged 14 to 44 without children	
Total 65 plus	Older couples 65 without children	
Female 65 plus	One parent families with kids under 15	
Male 65 plus	People who travelled to work by car	
Total population	People who travelled to work by public transport	
Total population female	People who cycled to work	
Total population male	People who walked to work	
Labourers	People who worked at home in a home based	
Volunteers	Households without a car	
Unpaid carers	Households with 2 or more cars	
Unpaid child carers	Couple families with children under 15	
High density	One parent families with children	
Home owners	Medium density	

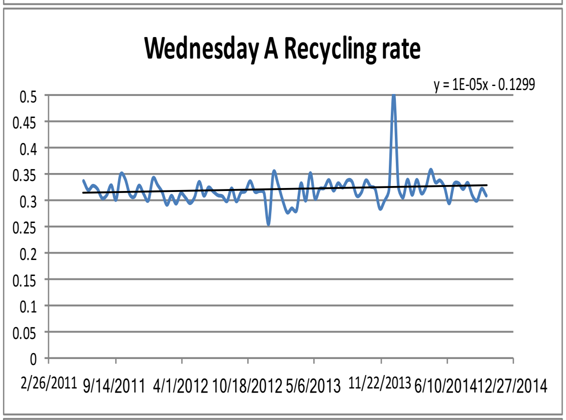
C2. Collection zone recycling rates

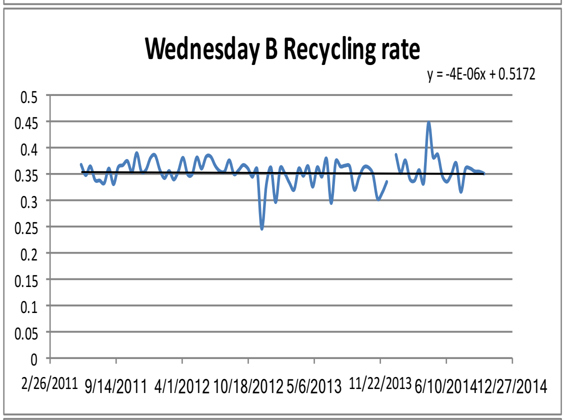


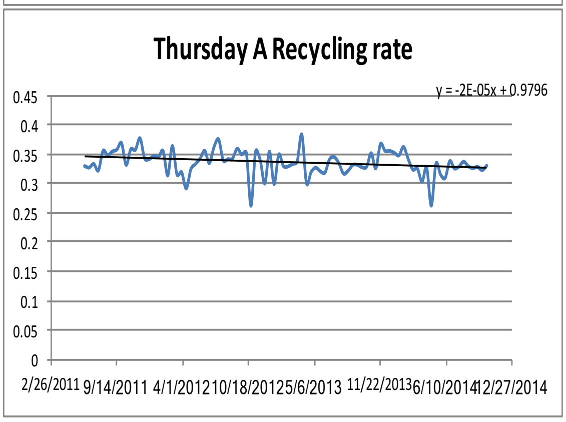


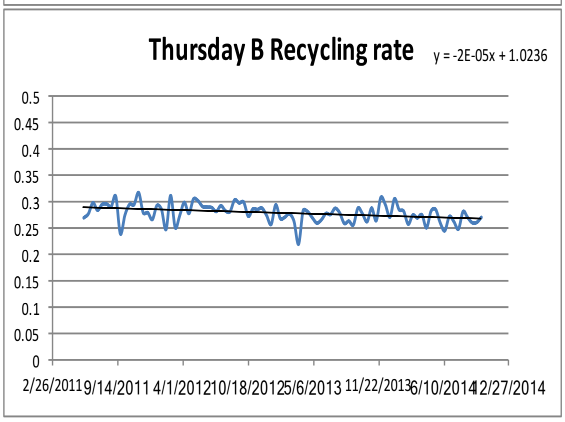












C3. Variable loadings on Principal Components (Loadings = Eigenvectors)

PC1		PC2		PC3		PC4		PC5	
couple families with children	0.1286	people with uni qualifications total	0.1775	people with Irish ancestry	0.2228	population density	0.2142	total 18 to 24	0.3070
couple families with children under 15	0.1283	people with uni qualifications female	0.1771	median age	0.2141	total population female	0.2028	female 18 to 24	0.3051
female 35 to 49	0.1278	people with uni qualifications male	0.1739	couples without children	0.2055	male 85 plus	0.2016	male 18 to 24	0.2748
employed part time female	0.1273	people attending university male	0.1710	older couples 65 without children	0.2049	total population	0.1906	total population male	0.2029
total 5 to 11	0.1273	managers or professionals	0.1578	home owners	0.1988	total population male	0.1775	people attending university female	0.2022
households with 2 or more cars	0.1266	people moved address in 5 years	0.1534	male 70 to 84	0.1713	total households	0.1613	median household income	0.1829
mothers in the workforce	0.1260	people attending university total	0.1531	median weekly rental	0.1657	total 85 plus	0.1561	total population	0.1822
female 5 to 11	0.1257	people with no religion	0.1392	male 65 plus	0.1615	total dwellings	0.1454	total population female	0.1628
under 18 total	0.1248	male 35 to 49	0.1390	female 60 to 69	0.1537	people attending university female	0.1403	people speaking Macedonia at home	0.1553
avg household size	0.1243	people with Scottish ancestry	0.1296	youth unemployment rate	0.1467	female 70 to 84	0.1346	male 50 to 59	0.1442
4 or more bedrooms	0.1232	people attending university female	0.1234	total 70 to 84	0.1442	people speaking Macedonia at home	0.1339	people born in F Yugoslavia republic	0.1415
under 18 female	0.1225	vacant dwellings	0.1224	total 60 to 69	0.1435	people in need assistance due to disability	0.1288	total dwellings	0.1372
households without broadband	0.1225	SEIFA index of disadvantage	0.1131	people speaking Italian at home	0.1372	female 85 plus	0.1288	people attending university total	0.1339
mortgage holders	0.1222	rent privately	0.1087	total 65 plus	0.1364	people born in F Yugoslavia republic	0.1282	male 12 to 17	0.1211
under 18 male	0.1216	SEIFA index of disadvantage advantage	0.1086	volunteers	0.1352	female 65 plus	0.1236	total households	0.1182

C3. Variable loadings on Principal Components (Loadings = Eigenvectors)

high income households more than 2500 week	0.1213	people with a non christian religion	0.1041	female 70 to 84	0.1211	total 0 to 4	0.1232	people with no qualifications male	0.1045
total 12 to 17	0.1210	high density	0.1039	high rental payments 400 plus	0.1207	total 70 to 84	0.1225	total 50 to 59	0.1022
male 5 to 11	0.1199	people who cycled to work	0.1023	managers or professionals	0.1195	median weekly rental	0.1192	labour force participation	0.0997
female 12 to 17	0.1182	volunteers	0.0992	female 65 plus	0.1133	female 0 to 4	0.1109	technician trade workers	0.0961
median monthly mortgage repayments	0.1168	total population male	0.0991	male 50 to 59	0.1103	people not fluent in english	0.1037	unpaid carers	0.0948
employed part time total	0.1162	recent arrivals	0.0940	male 85 plus	0.1021	male 70 to 84	0.1005	high density	0.0945
total 35 to 49	0.1154	total population	0.0916	SEIFA index of disadvantage	0.0960	group households	0.1002	rent social housing	0.0858
people who worked at home in a home based business	0.1144	total dwellings	0.0907	male 60 to 69	0.0960	total 65 plus	0.0936	labourers	0.0795
high mortgage repayments 2600 plus	0.1143	young couples aged 14 to 44 without children	0.0852	SEIFA index of disadvantage advantage	0.0834	male 0 to 4	0.0898	male 60 to 69	0.0663
male 12 to 17	0.1126	2 bedrooms or less	0.0841	people with Scottish ancestry	0.0821	people attending university total	0.0858	employed part time total	0.0658
median household income	0.1113	total households	0.0838	people with trade qualifications male	0.0812	people who travelled to work by public transport	0.0782	disengaged youth 15 to 25 not in work or school	0.0636
people who travelled to work by car	0.1096	people in non-private dwellings	0.0837	total 50 to 59	0.0801	people who cycled to work	0.0679	avg household size	0.0628
unpaid child carers	0.1062	total population female	0.0825	people with uni qualifications female	0.0796	separate homes	0.0669	employed part time female	0.0602
people with a christian religion	0.1062	people born in India	0.0822	people with uni qualifications total	0.0712	older lone persons households	0.0604	female 50 to 59	0.0578
separate homes	0.1044	labour force participation	0.0815	median monthly mortgage repayments	0.0696	people who travelled to work by car	0.0573	people with Irish ancestry	0.0542
high rental payments 400 plus	0.1016	young lone persons household	0.0798	people with uni qualifications male	0.0654	youth unemployment rate	0.0572	total 60 to 69	0.0411

C3. Variable loadings on Principal Components (Loadings = Eigenvectors)

		s							
total 0 to 4	0.0968	medium density	0.0742	unpaid carers	0.0619	one parent families with children	0.0537	youth unemploy ment rate	0.0388
SEIFA index of disadvant age advantage	0.0895	people attending tafe	0.0717	labour force participati on	0.0574	labour force participati on	0.0512	total 12 to 17	0.0378
labour force participati on	0.0860	total 35 to 49	0.0676	people with below year 11 schooling	0.0565	unpaid child carers	0.0511	4 or more bedrooms	0.0369
SEIFA index of disadvant age	0.0837	high income household s more than 2500 week	0.0576	people attending university male	0.0563	managers or profession als	0.0506	under 18 male	0.0367
female 0 to 4	0.0831	employed part time male	0.0530	people with trade qualificati ons total	0.0560	male 35 to 49	0.0454	people with no qualificati ons total	0.0364
male 0 to 4	0.0827	lone persons household s	0.0497	people attending tafe	0.0555	mothers in the workforce	0.0445	people attending university male	0.0359
people with Scottish ancestry	0.0658	male 18 to 24	0.0481	people not fluent in english	0.0537	high density	0.0433	people in need assistance due to disability	0.0358
median weekly rental	0.0657	high mortgage repayment s 2600 plus	0.0468	female 50 to 59	0.0477	male 65 plus	0.0422	people of aboriginal torress strait islander origin	0.0348
male 35 to 49	0.0651	household s without broadban d	0.0452	people attending university total	0.0470	high rental payments 400 plus	0.0417	high income household s more than 2500 week	0.0348
volunteers	0.0610	female 25 to 34	0.0448	high mortgage repayment s 2600 plus	0.0458	female 60 to 69	0.0412	SEIFA index of disadvant age advantage	0.0260
youth unemploy ment rate	0.0379	people born overseas	0.0437	mortgage holders	0.0431	female 5 to 11	0.0403	people attending tafe	0.0226
people with Irish ancestry	0.0352	employed part time total	0.0382	people with a christian religion	0.0398	under 18 female	0.0402	people who worked at home in a home based business	0.0212
household s in mortgage stress	0.0282	people who walked to work	0.0369	older lone persons household s	0.0367	median household income	0.0387	volunteers	0.0195
one parent families with children	0.0252	total 25 to 34	0.0368	4 or more bedrooms	0.0364	disengage d youth 15 to 25 not in work or school	0.0347	SEIFA index of disadvant age	0.0183
people with trade qualificati	0.0217	median household income	0.0364	separate homes	0.0354	mortgage holders	0.0346	household s with 2 or more cars	0.0142

ons female									
managers or professionals	0.0216	male 0 to 4	0.0342	vacant dwellings	0.0304	people of non english speaking background	0.0334	female 60 to 69	0.0140
couples without children	0.0190	total 85 plus	0.0339	people with no qualifications female	0.0301	total 35 to 49	0.0309	separate homes	0.0136
home owners	0.0147	median weekly rental	0.0337	median household income	0.0301	avg household size	0.0293	people with Scottish ancestry	0.0118
people with uni qualifications male	0.0118	female 85 plus	0.0331	total 85 plus	0.0286	home owners	0.0274	couples without children	0.0104
people with uni qualifications total	0.0079	group households	0.0323	households with 2 or more cars	0.0277	couple families with children under 15	0.0248	young lone persons households	0.0091
one parent families with kids under 15	0.0046	male 85 plus	0.0315	high income households more than 2500 week	0.0254	older couples 65 without children	0.0216	female 85 plus	0.0070
people with uni qualifications female	0.0035	mortgage holders	0.0310	female 18 to 24	0.0252	people speaking Italian at home	0.0213	people born in India	0.0003
older couples 65 without children	0.0020	total 18 to 24	0.0298	group households	0.0235	people with no religion	0.0189	one parent families with children	0.0000
rent social housing	-0.0011	female 12 to 17	0.0271	employed part time female	0.0218	people attending university male	0.0158	households without broadband	-0.0003
people of aboriginal torress strait islander origin	-0.0028	male 25 to 34	0.0258	couple families with children	0.0216	high income households more than 2500 week	0.0154	households without a car	-0.0005
total population female	-0.0041	people who travelled to work by public transport	0.0251	households without broadband	0.0216	female 35 to 49	0.0153	one parent families with kids under 15	-0.0011
people speaking Macedonia at home	-0.0048	people with Irish ancestry	0.0220	people attending university female	0.0211	under 18 total	0.0103	home owners	-0.0027
male 50 to 59	-0.0053	couple families with children under 15	0.0197	people who travelled to work by public transport	0.0117	people with no qualifications female	0.0096	female 70 to 84	-0.0036
people attending university total	-0.0067	households without a car	0.0156	total 18 to 24	0.0115	median monthly mortgage repayments	0.0090	people with uni qualifications male	-0.0042
people attending university male	-0.0081	female 5 to 11	0.0151	couple families with children	0.0112	high mortgage repayments 2600	0.0079	people with trade qualifications male	-0.0054

C3. Variable loadings on Principal Components (Loadings = Eigenvectors)

				under 15		plus			
people speaking Italian at home	-0.0116	employed part time female	0.0101	people born overseas	0.0105	lone persons households	0.0053	people with below year 11 schooling	-0.0069
people born in F Yugoslavia republic	-0.0117	mothers in the workforce	0.0095	high density	0.0104	people moved address in 5 years	0.0047	older couples 65 without children	-0.0080
total 50 to 59	-0.0145	high rental payments 400 plus	0.0054	lone persons households	0.0085	people of aboriginal torress strait islander origin	0.0045	people with uni qualifications total	-0.0084
total population	-0.0148	4 or more bedrooms	0.0047	people with no qualifications total	0.0080	rent social housing	0.0037	people with a christian religion	-0.0103
people attending university female	-0.0157	female 35 to 49	0.0039	people who walked to work	0.0062	people with a christian religion	0.0028	managers or professionals	-0.0105
female 50 to 59	-0.0217	female 18 to 24	0.0004	people of non english speaking background	0.0059	people born overseas	0.0009	couple families with children	-0.0110
total population male	-0.0224	under 18 female	-0.0001	people with trade qualifications female	-0.0011	people with trade qualifications female	0.0000	people who travelled to work by car	-0.0113
median age	-0.0285	total 5 to 11	-0.0007	male 18 to 24	-0.0035	people with uni qualifications female	-0.0004	people with a non christian religion	-0.0115
people with no qualifications female	-0.0314	people of non english speaking background	-0.0063	people with no religion	-0.0044	people with below year 11 schooling	-0.0007	people with uni qualifications female	-0.0128
unpaid carers	-0.0346	people who worked at home in a home based business	-0.0071	young couples aged 14 to 44 without children	-0.0056	couple families with children	-0.0015	employed part time male	-0.0129
people with no religion	-0.0370	households in rental stress	-0.0086	young lone persons households	-0.0086	female 25 to 34	-0.0030	under 18 total	-0.0156
people with trade qualifications total	-0.0441	couple families with children	-0.0087	2 bedrooms or less	-0.0093	total 60 to 69	-0.0030	2 bedrooms or less	-0.0178
people with below year 11 schooling	-0.0450	median monthly mortgage repayments	-0.0101	male 35 to 49	-0.0096	one parent families with kids under 15	-0.0034	people with no qualifications female	-0.0182
people with no qualifications total	-0.0499	under 18 total	-0.0102	female 85 plus	-0.0105	low income households less than 600 week	-0.0045	high mortgage repayments 2600 plus	-0.0198
people who	-0.0507	total 12 to 17	-0.0113	unpaid child	-0.0121	people with uni	-0.0047	vacant dwellings	-0.0217

C3. Variable loadings on Principal Components (Loadings = Eigenvectors)

cycled to work				carers		qualifications total			
people moved address in 5 years	-0.0511	older lone persons households	-0.0121	total 35 to 49	-0.0123	young lone persons households	-0.0056	female 65 plus	-0.0222
population density	-0.0564	male 5 to 11	-0.0124	mothers in the workforce	-0.0132	rent privately	-0.0071	mortgage holders	-0.0225
people in need assistance due to disability	-0.0575	male 50 to 59	-0.0138	female 35 to 49	-0.0149	4 or more bedrooms	-0.0074	people with trade qualifications total	-0.0237
female 60 to 69	-0.0597	households with 2 or more cars	-0.0163	people with a non christian religion	-0.0160	labourers	-0.0076	female 5 to 11	-0.0253
male 85 plus	-0.0626	under 18 male	-0.0189	avg household size	-0.0185	unpaid carers	-0.0087	households in rental stress	-0.0262
female 18 to 24	-0.0633	total 0 to 4	-0.0243	people speaking Macedonia at home	-0.0217	people with no qualifications total	-0.0092	total 5 to 11	-0.0265
people with no qualifications male	-0.0685	population density	-0.0256	people with no qualifications male	-0.0224	male 25 to 34	-0.0094	people of non english speaking background	-0.0268
male 70 to 84	-0.0694	total 50 to 59	-0.0275	employed part time total	-0.0237	total 25 to 34	-0.0094	total 85 plus	-0.0268
total dwellings	-0.0741	avg household size	-0.0339	recent arrivals	-0.0255	people with uni qualifications male	-0.0111	people not fluent in english	-0.0268
people with trade qualifications male	-0.0768	households in housing stress	-0.0367	low income households less than 600 week	-0.0259	people with Irish ancestry	-0.0124	recent arrivals	-0.0292
total households	-0.0769	female 50 to 59	-0.0378	people born in F Yugoslavia republic	-0.0284	total 5 to 11	-0.0126	people who walked to work	-0.0320
people born in India	-0.0770	male 12 to 17	-0.0400	female 5 to 11	-0.0305	2 bedrooms or less	-0.0166	total 70 to 84	-0.0334
total 18 to 24	-0.0772	people in need assistance due to disability	-0.0435	people who worked at home in a home based business	-0.0311	male 18 to 24	-0.0171	population density	-0.0338
people attending tafe	-0.0787	male 60 to 69	-0.0462	total dwellings	-0.0333	households without a car	-0.0192	male 0 to 4	-0.0341
disengaged youth 15 to 25 not in work or school	-0.0803	female 0 to 4	-0.0493	total households	-0.0369	under 18 male	-0.0228	male 25 to 34	-0.0363
technician trade workers	-0.0807	people who travelled to work by car	-0.0497	male 0 to 4	-0.0376	male 12 to 17	-0.0244	male 5 to 11	-0.0392
male 18 to 24	-0.0825	people not fluent in	-0.0622	people who	-0.0386	total 12 to 17	-0.0257	people in non-	-0.0427

C3. Variable loadings on Principal Components (Loadings = Eigenvectors)

		english		travelled to work by car				private dwellings	
total 70 to 84	-0.0825	female 70 to 84	-0.0625	male 25 to 34	-0.0397	people with Scottish ancestry	-0.0267	people who travelled to work by public transport	-0.0433
male 65 plus	-0.0834	female 65 plus	-0.0636	people in non-private dwellings	-0.0413	employed part time female	-0.0271	lone persons households	-0.0451
labourers	-0.0839	unpaid child carers	-0.0642	people born in India	-0.0427	female 12 to 17	-0.0323	couple families with children under 15	-0.0458
total 60 to 69	-0.0841	total 70 to 84	-0.0646	total population male	-0.0441	total 18 to 24	-0.0329	people with trade qualifications female	-0.0463
households in housing stress	-0.0852	low income households less than 600 week	-0.0648	people who cycled to work	-0.0481	people with no qualifications male	-0.0334	median monthly mortgage repayments	-0.0473
unemployment rate	-0.0860	male 70 to 84	-0.0678	total population	-0.0525	households in mortgage stress	-0.0342	households in housing stress	-0.0480
female 70 to 84	-0.0883	total 65 plus	-0.0686	total 5 to 11	-0.0568	people who worked at home in a home based business	-0.0384	total 65 plus	-0.0485
employed part time male	-0.0890	median age	-0.0693	unemployment rate	-0.0574	households with 2 or more cars	-0.0390	female 35 to 49	-0.0496
people in non-private dwellings	-0.0901	male 65 plus	-0.0717	technician trade workers	-0.0578	vacant dwellings	-0.0428	mothers in the workforce	-0.0566
total 65 plus	-0.0917	youth unemployment rate	-0.0762	people moved address in 5 years	-0.0580	female 18 to 24	-0.0483	median age	-0.0645
vacant dwellings	-0.0926	unemployment rate	-0.0815	medium density	-0.0590	unemployment rate	-0.0512	under 18 female	-0.0649
female 65 plus	-0.0947	total 60 to 69	-0.0826	total population female	-0.0593	households without broadband	-0.0557	people speaking Italian at home	-0.0650
rent privately	-0.0955	couples without children	-0.0843	people in need assistance due to disability	-0.0604	people with a non christian religion	-0.0583	people born overseas	-0.0650
medium density	-0.0955	separate homes	-0.0987	rent privately	-0.0613	male 5 to 11	-0.0622	male 70 to 84	-0.0672
young couples aged 14 to 44 without children	-0.0962	people with trade qualifications male	-0.0996	total 25 to 34	-0.0685	median age	-0.0640	female 12 to 17	-0.0684
high density	-0.0968	disengaged youth 15 to 25 not in work or school	-0.1026	under 18 female	-0.0729	male 60 to 69	-0.0677	young couples aged 14 to 44 without	-0.0756

C3. Variable loadings on Principal Components (Loadings = Eigenvectors)

								children	
households in rental stress	-0.0986	female 60 to 69	-0.1034	male 5 to 11	-0.0750	people with trade qualifications total	-0.0680	group households	-0.0761
total 85 plus	-0.0989	people with a christian religion	-0.1060	female 12 to 17	-0.0765	households in rental stress	-0.0756	low income households less than 600 week	-0.0774
people with a non christian religion	-0.0999	technician trade workers	-0.1079	under 18 total	-0.0772	households in housing stress	-0.0770	male 65 plus	-0.0787
people not fluent in english	-0.1012	labourers	-0.1088	under 18 male	-0.0800	recent arrivals	-0.0870	total 35 to 49	-0.0803
group households	-0.1024	older couples 65 without children	-0.1089	total 12 to 17	-0.0819	young couples aged 14 to 44 without children	-0.0880	people who cycled to work	-0.0815
recent arrivals	-0.1043	one parent families with kids under 15	-0.1189	male 12 to 17	-0.0846	SEIFA index of disadvantage advantage	-0.0882	total 25 to 34	-0.0837
female 85 plus	-0.1052	home owners	-0.1223	total 0 to 4	-0.0895	SEIFA index of disadvantage	-0.0887	households in mortgage stress	-0.0909
female 25 to 34	-0.1061	people speaking Macedonia at home	-0.1261	households without a car	-0.0939	people who walked to work	-0.0904	total 0 to 4	-0.0941
male 60 to 69	-0.1061	one parent families with children	-0.1267	population density	-0.0967	medium density	-0.0909	median weekly rental	-0.0951
older lone persons households	-0.1085	rent social housing	-0.1273	female 25 to 34	-0.1011	employed part time total	-0.0933	female 0 to 4	-0.0968
people who travelled to work by public transport	-0.1096	households in mortgage stress	-0.1279	labourers	-0.1030	people with trade qualifications male	-0.0977	male 35 to 49	-0.0990
young lone persons households	-0.1163	people born in F Yugoslavia republic	-0.1306	female 0 to 4	-0.1044	volunteers	-0.0991	unemployment rate	-0.0997
people who walked to work	-0.1163	people speaking Italian at home	-0.1340	employed part time male	-0.1080	technician trade workers	-0.1020	rent privately	-0.0998
2 bedrooms or less	-0.1163	unpaid carers	-0.1372	people of aboriginal torress strait islander origin	-0.1222	couples without children	-0.1132	people moved address in 5 years	-0.1027
low income households less than 600 week	-0.1175	people with trade qualifications total	-0.1375	households in mortgage stress	-0.1224	people attending tafe	-0.1180	medium density	-0.1038
people born overseas	-0.1190	people with no qualificati	-0.1434	disengaged youth 15 to 25 not	-0.1318	employed part time male	-0.1249	high rental payments 400 plus	-0.1123

		ons male		in work or school					
total 25 to 34	-0.1193	people of aboriginal torress strait islander origin	-0.1536	one parent families with children	-0.1576	people in non-private dwellings	-0.1461	male 85 plus	-0.1225
households without a car	-0.1198	people with trade qualifications female	-0.1587	households in rental stress	-0.1589	people born in India	-0.1847	female 25 to 34	-0.1386
lone persons households	-0.1221	people with below year 11 schooling	-0.1683	households in housing stress	-0.1758	male 50 to 59	-0.2382	people with no religion	-0.1529
people of non english speaking background	-0.1241	people with no qualifications total	-0.1695	one parent families with kids under 15	-0.1812	total 50 to 59	-0.2656	unpaid child carers	-0.1565

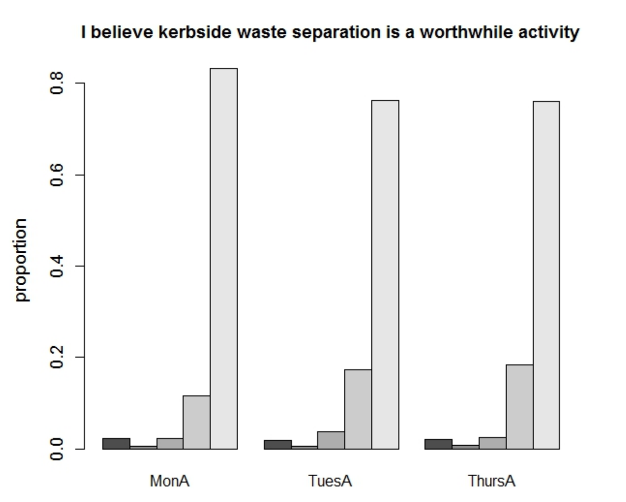
Appendix D

D.1. Heterogeneous correlation of survey direct influences on recycling with demographic variables

	Disposal knowledge	Attitude toward recycling	Recycling social norms	Recycling bin overflows	GW bin overflows	Time for recycling disposal	Time for GW disposal
Number in household	0.119	-0.018	0.078	0.383	0.206	0.104	0.081
Number of kids	0.098	0.036	0.055	0.268	0.109	0.077	0.049
Education level	0.107	0.088	0.022	0.056	-0.052	0.046	0.013
Household income	0.206	0.04	0.059	0.179	0.057	0.05	-0.001
Number of cars	0.125	-0.02	0.056	0.224	0.189	0.012	-0.014
Age	-0.17	-0.044	0.095	-0.304	-0.156	0.023	0.066

D2. Comparing direct recycling influences across collection zones

D.2.1. Attitude proportions across collection zones



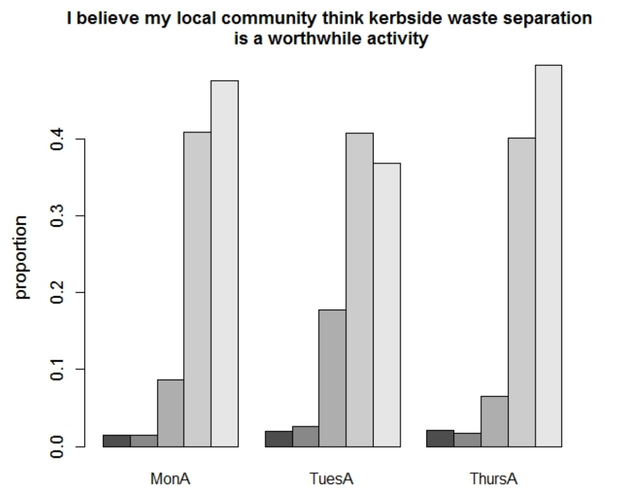
	MonA	ThursA	TuesA
Strongly disagree	5	5	3
Disagree	1	2	1
Neutral	5	6	6
Agree	25	43	27
Strongly agree	178	178	119

Pearson's Chi-squared test

data: Attitude

X-squared = 5.5277	df = 8	p-value = 0.7

D.2.2. Social norm proportions across collection zones



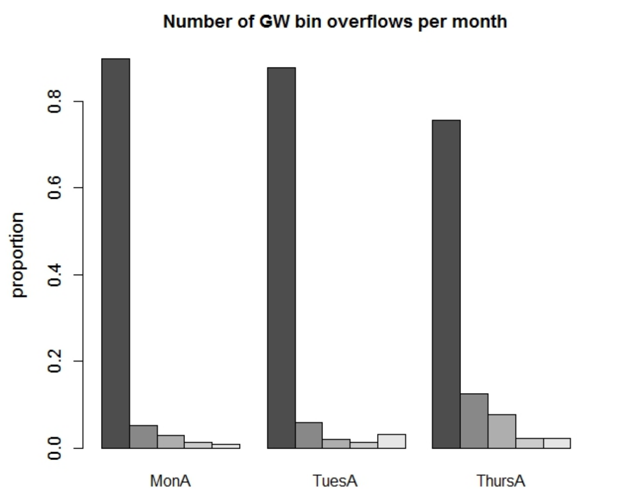
	MonA	ThursA	TuesA
Strongly disagree	3	5	3
Disagree	3	4	4
Neutral	18	15	27
Agree	85	93	62
Strongly agree	99	115	56

Pearson's Chi-squared test

data: Social norms

X-squared = 16.838	df = 8	p-value = 0.03184

D.2.3. Frequency of GW bin overflow per month across collection zones



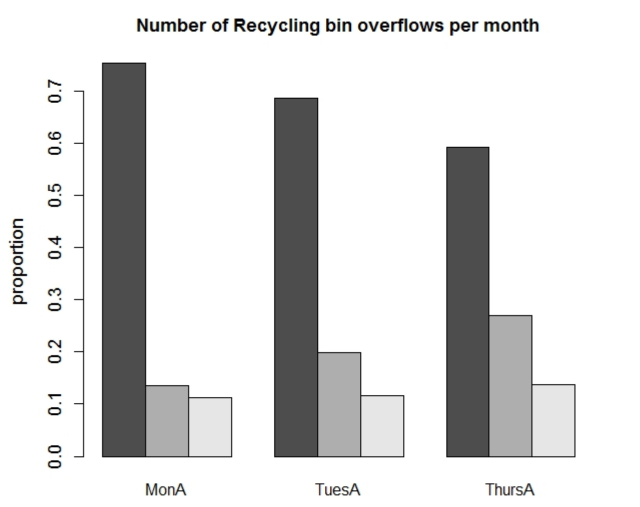
	MonA	ThursA	TuesA
0	192	177	137
1	11	29	9
2	6	18	3
3	3	5	2
4	2	5	5

Pearson's Chi-squared test		
data: GW bin overflow		
X-squared = 23.682	df = 8	p-value = 0.002591

Chi-square post hoc test

	comparison	Raw.p	Adj.p
1	MondayA vs. ThursdayA	0.0023	0.0069
2	MondayA vs. TuesdayA	0.6022	0.6022
3	ThursdayA vs. TuesdayA	0.0093	0.014

D.2.4 Frequency of Recycling bin overflow per month across collection zones



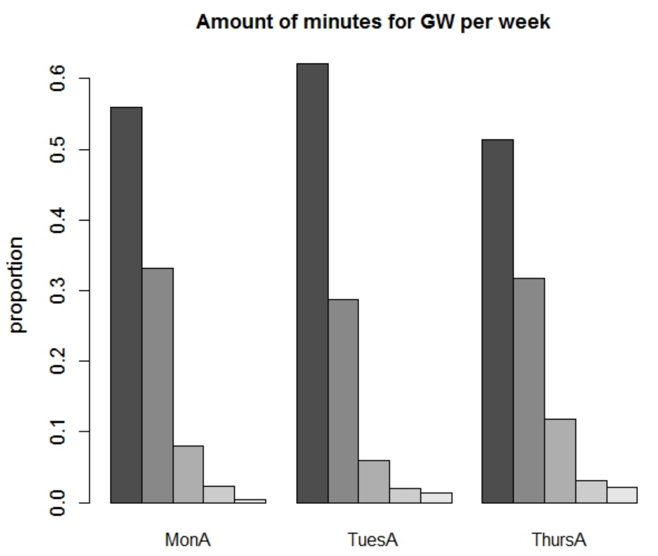
	MonA	ThursA	TuesA
0	161	138	107
1	29	63	31
2	24	32	18

Pearson's Chi-squared test		
data: Recycling bin overflow		
X-squared = 14.939	df = 8	p-value = 0.004829

Chi-square post hoc test

	comparison	Raw.p	Adj.p
1	MondayA vs. ThursdayA	0.0006	0.0017
2	MondayA vs. TuesdayA	0.2471	0.2471
3	ThursdayA vs. TuesdayA	0.1622	0.2433

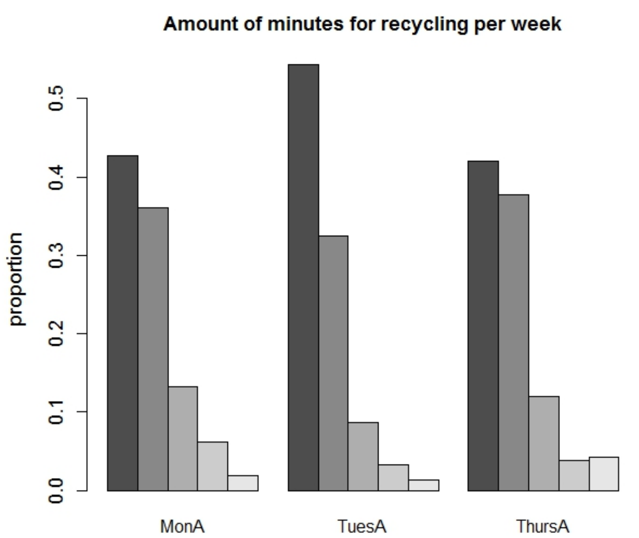
D.2.5 Amount of time (minutes) devoted to GW each week across collection zones



	Mon A	Thurs A	Tues A
<5	118	118	95
5-10.	70	73	44
10-15.	17	27	9
15-20.	5	7	3
>20	1	5	2

Pearson's Chi-squared test		
data: Weekly GW time		
X-squared = 9.1073	df = 8	p-value = 0.3333

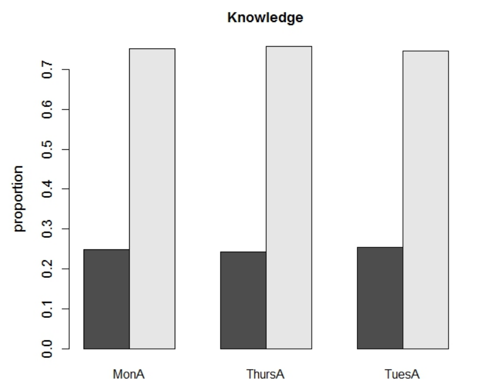
D.2.6 Amount of time (minutes) devoted to recycling each week across collection zones



	MonA	ThursA	TuesA
<5	90	98	82
5-10.	76	88	49
10-15.	28	28	13
15-20.	13	9	5
>20	4	10	2

Pearson's Chi-squared test		
data: Weekly recycling time		
X-squared = 11.723	df = 8	p-value = 0.164

D.2.7 Knowledge scores across collection zones



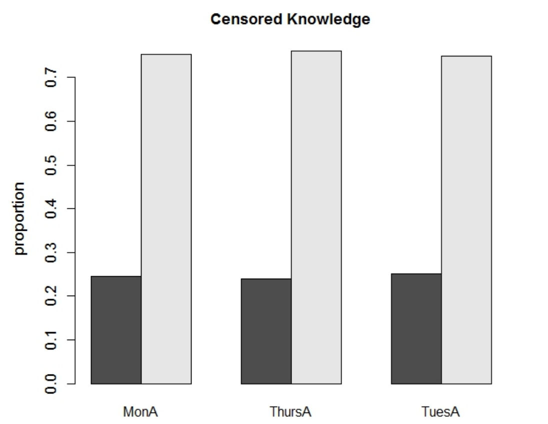
	Mon A	Thurs A	Tues A
Incorrect	1899	2049	1420
Correct	5766	6394	4179

Pearson's Chi-squared test		
data: Knowledge		
X-squared = 2.1741	df = 2	p-value = 0.3372

Chi-square post hoc test

	comparison	Raw.p	Adj.p
1	MondayA vs. ThursdayA	0.4632	0.4632
2	MondayA vs. TuesdayA	0.4407	0.4632
3	ThursdayA vs. TuesdayA	0.1447	0.4341

D.2.8 Censored knowledge scores across collection zones



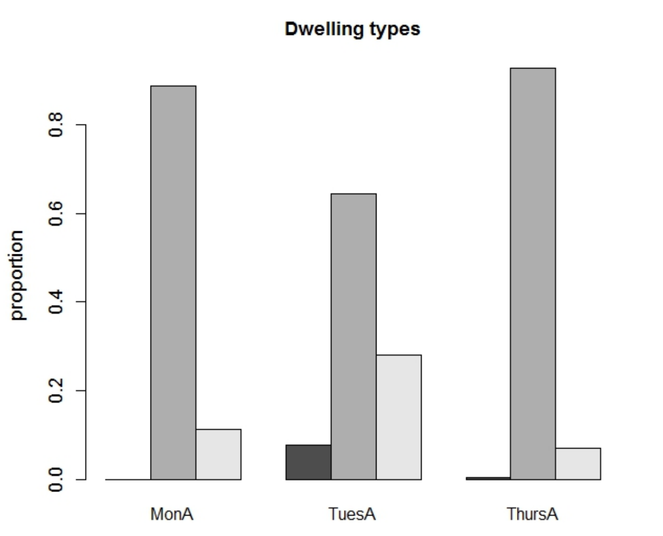
	Mon A	Thurs A	Tues A
Incorrect	1752	1885	1314
Correct	5293	5867	3825

Pearson's Chi-squared test		
data: Censored Knowledge		
X-squared = 2.6055	df = 2	p-value = 0.2718

Chi-square post hoc test

	comparison	Raw.p	Adj.p
1	MondayA vs. ThursdayA	0.3512	0.4706
2	MondayA vs. TuesdayA	0.4706	0.4706
3	ThursdayA vs. TuesdayA	0.1084	0.3253

D.2.9 Dwelling types across collection zones

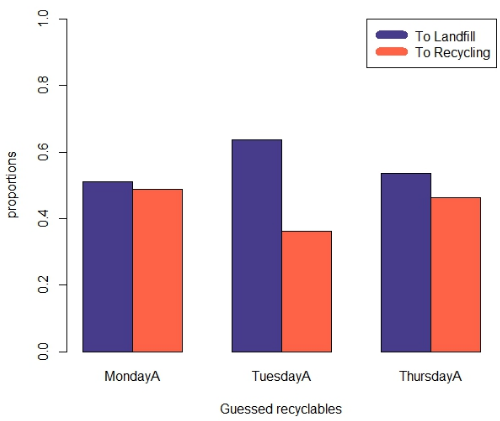


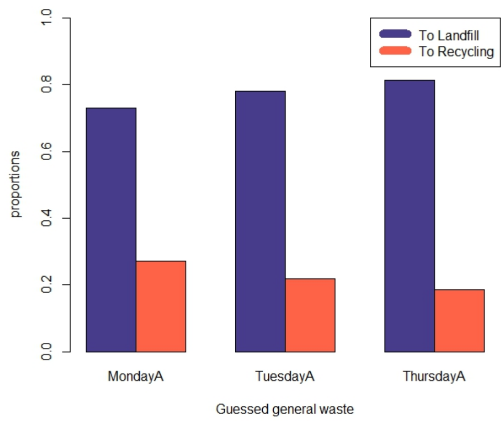
	Mon A	Thurs A	Tues A
Apartment	0	1	12
Separate house	188	215	101
Townhouse	24	16	44

Pearson's Chi-squared test		
data: Recycling bin overflow		
X-squared = 71.039	df = 4	p-value = 1.37e-14

D.3. Comparing bin biases across collection zones

D.3.1. Recycling and GW bin bias across collection zones





Guessed recyclables

	MondayA	TuesdayA	ThursdayA
Guessed.recycling.to.GW	68	88	79
Guessed.recycling.to.RB	65	50	68

Pearson's Chi-squared test		
data: Recyc		
X-squared = 4.9625	df = 2	p-value = 0.08364

	comparison	raw.p	adj.p
1	MondayA.vs.TuesdayA	0.0375	0.1126
2	MondayA.vs.ThursdayA	0.7196	0.7196
3	TuesdayA.vs.ThursdayA	0.0931	0.1397

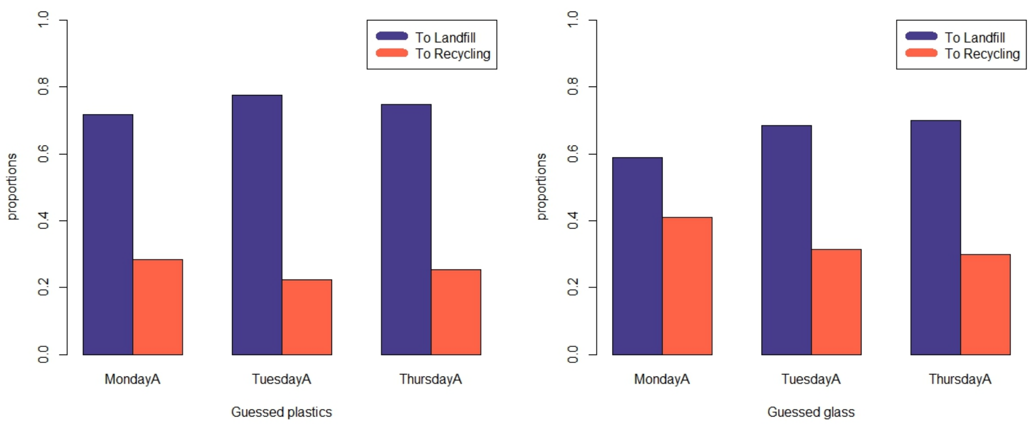
Guessed GW

	MondayA	TuesdayA	ThursdayA
Guessed.GW.to.GW	216	228	257
Guessed.GW.to.RB	80	64	59

Pearson's Chi-squared test		
data: Recyc		
X-squared = 6.2003	df = 2	p-value = 0.04504

	comparison	raw.p	adj.p
1	MondayA.vs.TuesdayA	0.1519	0.2279
2	MondayA.vs.ThursdayA	0.0157	0.0472
3	TuesdayA.vs.ThursdayA	0.3633	0.3633

D.3.2. Plastics and Glass bin bias across collection zones



Guessed plastics

	MondayA	TuesdayA	ThursdayA
Guessed.plastic.to.GW	175	183	189
Guessed.plastic.to.RB	69	53	64

Pearson's Chi-squared test		
data: Recyc		
X-squared = 2.148	df = 2	p-value = 0.3416

	comparison	raw.p	adj.p
1	MondayA.vs.TuesdayA	0.1727	0.5182
2	MondayA.vs.ThursdayA	0.4789	0.5247
3	TuesdayA.vs.ThursdayA	0.5247	0.5247

Guessed glass

	MondayA	TuesdayA	ThursdayA
Guessed.GW.to.GW	109	133	147
Guessed.GW.to.RB	76	61	63

Pearson's Chi-squared test		
data: Recyc		
X-squared = 6.1996	df = 2	p-value = 0.04506

	comparison	raw.p	adj.p
1	MondayA.vs.TuesdayA	0.0548	0.0822
2	MondayA.vs.ThursdayA	0.0265	0.0795
3	TuesdayA.vs.ThursdayA	0.8291	0.8291

D.4. Household survey pack

Household Recycling Survey

To the resident
23 Smith Street
QUEANBEYAN NSW 2620

Dear Queanbeyan resident,

I invite you to participate in a survey on household recycling.

My name is Brendan Moloney and I am the primary investigator of a PhD project based in the Research School of Engineering of The Australian National University.

In recent years recycling rates in Australia have begun to plateau below their full potential, meaning that some recyclables are being lost to landfill or are polluting our environment. My project focuses upon household recycling, looking at the main influences on recycling rates with the aim of improving material recovery. My PhD case study is with the Queanbeyan-Palerang Regional Council. Part of the case study involves a household survey.

The survey will take about 5 to 7 minutes to complete. You have the option of returning your survey by post (using the reply paid envelope found in the survey pack) or to complete the survey online. The online survey link is http://householdrecycling.poll.anu.edu.au/XXXX. The main part of the survey asks how you choose to sort common household items between your landfill and recycling kerbside bin. I also inquire about the degree of certainty in your decision. I ask that you refrain from checking council waste education material and make your choices based on your normal waste disposal behaviour.

If you decide to participate I would appreciate it if you return the survey **within two weeks** upon receipt. For any additional questions my contact details are in the participant information sheet or at the bottom of this letter.

Many thanks for your time,

Brendan Moloney

Primary Investigator
Research School of Engineering, The Australian National University
Email: brendan.moloney@anu.edu.au

Participant Information Sheet

Researcher:

My name is Brendan Moloney and I am a PhD candidate from the Australian National University in Canberra. I am based in the Research School of Engineering and I am the primary researcher involved in a study of the major influences of kerbside waste recycling rates.

Project Title: Discovering the major influences on the plateau of kerbside recovery rates.

General Outline of the Project:

Description and Methodology:

The main goal of this household survey is to understand how household behaviour has affected kerbside recovery rates over time. A case study is being carried out on Queanbeyan-Palerang Regional Council with the aim to understand how motivation to recycle and recycling knowledge affects recycling rates.

Data will be gathered through surveys of households in Queanbeyan. This will take place during the months of June and July, 2016. Households are chosen randomly during this period of data collection.

Participants: Participants will include Queanbeyan-Palerang Regional Council households who agree to take part in a short survey, either online or reply posting the completed survey sheet.

Use of Data and Feedback:

Data gathered from this process will contribute to journal publications and an Australian National University doctoral thesis. Results of the survey and the correct answers to the waste disposal portion of the survey will be made available for all participants via the below website. Results will be available after September 21st 2016.

http://householdrecyclingsurvey.wordpress.com

Participant Involvement:

Voluntary Participation & Withdrawal:

Participation in this project is **voluntary** and any participants may, without any penalty, decline to take part or withdraw from the research at any time until the work is prepared for publication. If this occurs the participants survey data will be destroyed.

What will participants have to do?

Participants will be asked to take part in an estimated 5 to 10 minute survey; the topic being household recycling attitude and knowledge. The survey can be completed online or using the hardcopy in this pack. The online survey link is found in your cover letter. There is a reply-paid addressed envelope to return the survey.

Participant Limitation: To participate in the study households will need to be currently using the council kerbside recycling service and to have some knowledge of waste separation in their residence.

Confidentiality:

Confidentiality will be provided to all householder participants, no identifying data will be gathered and all recycling related data will be aggregated. The information provided by households will only be sighted by myself, and my supervisors Dr Matthew Doolan and Dr Barry Newell. Any publications will not name the source of the data provided and confidentiality will be protected as far as the law allows.

Privacy Notice:

The ANU Privacy Policy can be found at https://policies.anu.edu.au/ppl/document/ANUP_010007 and contains information about how you can:

- Have access or seek correction to your personal information,
- Complain about a breach of an Australian Privacy Principle (APP) by ANU and how ANU will handle the complaint.

Data Storage:

Where: Data will be stored on password protected ANU secure servers, of the College of Engineering and Computer Science Home Drive.

How long: Data will be stored by me for a period of five years from thesis publication. After this period the data will be retained by my supervisor; Dr Matthew Doolan.

Queries and Concerns:

If you would like additional information or would like to raise queries in relation to the project you can contact me or my primary supervisor:

Primary researcher
Brendan Moloney
brendan.moloney@anu.edu.au
0405 955 798

Primary supervisor
Dr Matthew Doolan
matthew.doolan@anu.edu.au

Ethics Committee Clearance:

The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee. If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
Telephone: +61 2 6125 3427
Email: Human.Ethics.Officer@anu.edu.au

Please start on this page For each object, choose the kerbside bin and mark your level of certainty. Please make your choices based on your usual disposal behaviour

Plastic shampoo bottle  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Cracked wine glass  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Plastic bag  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Glass jar  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Flat plastic bottle  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Glass jar (sealed)  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Polyester rag  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Cracked drinking glass  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Plastic coat hanger  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)
Balloon  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Plastic bottle lid  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Cracked glass bowl  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Plastic bottle  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Glass wine bottle  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Styrofoam  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Cracked ceramic mug  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Firm plastic pieces  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Broken glass bottle  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)
Broken PC mouse  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Glass pot lid  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Plastic garden pot  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Glass cologne bottle  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Plastic figurine  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Light globe  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Plastic yoghurt tub  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Glass beer bottle  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Bubble wrap  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)
Glass nailpolish bottle  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Bagged recyclables  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Glass storage jar  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Plastic bike reflector  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Broken drinking glass  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Broken milk crate  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Glass vitamin bottle  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Cracked glass jug  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)	Glass mirror  ❑ Landfill ❑ Recycle ❑1 ❑2 ❑3 ❑4 (Lo) Certainty (Hi)

X
X
X
X

Please turn over

Your Household					
1. Do you have access to kerbside recycling?	❑ Yes		❑ No		
2. Gender	❑ Male	❑ Female	❑ Other		
3. Dwelling type	❑ Separate house	❑ Townhouse	❑ Apartment		
4. Year of birth	______________				
5. Number of people in household	❑ 1	❑ 2	❑ 3	❑ 4	
	❑ 5	❑ 6	❑ 7	Other ________	
6. Number of people in household below the age of 15	❑ 0	❑ 1	❑ 2	❑ 3	
	❑ 4	❑ 5	❑ 6	Other ________	
7. Occupation *Please give full title. For example: Childcare Aide, Maths Teacher, Pastry Cook	________________________________				
8. Level of education completed	❑ No qualifications	❑ Tafe	❑ Bachelor		
	❑ High School	❑ Trade	❑ Postgraduate		
9. Weekly household income (before tax)	❑ < $199	❑ $400 - $799	❑ $1250 - $1999		
	❑ $200 - $399	❑ $800 - $1249	❑ > $2000		
10. Homeowner status	❑ Home owner	❑ Rent	❑ Mortgage holder		
11. Number of cars in household	❑ 0	❑ 1	❑ 2	❑ 3	Other _______
Experiences and Beliefs					
1. Frequency of **recycling bin** overflow in the past month	❑ No overflow	❑ Once	❑ Twice		
2. Frequency of **general waste bin** overflow in the past month	❑ No overflow	❑ Once	❑ Twice	❑ Three times	❑ Four times
3. Time required per week for sorting and disposing **recycling waste** in kerbside bin	❑ < 5 minutes	❑ 5- 10 minutes	❑ 10-15 minutes	❑ 15-20 minutes	❑ > 20 minutes
4. Time required per week for sorting and disposing **general waste** in kerbside bin	❑ < 5 minutes	❑ 5- 10 minutes	❑ 10-15 minutes	❑ 15-20 minutes	❑ > 20 minutes
5. I believe kerbside waste separation is a worthwhile activity	❑ Strongly disagree	❑ Disagree	❑ Neutral	❑ Agree	❑ Strongly agree
6. I believe that my local community think kerbside waste separation is a worthwhile activity	❑ Strongly disagree	❑ Disagree	❑ Neutral	❑ Agree	❑ Strongly agree
7. When unable to identify waste as recycling or landfill I put it in …	❑ The Recycling bin		❑ The Landfill bin		
Thank you for participating					

Appendix E

E.1. System Dynamics model sensitivity tests

A sensitivity analysis was carried out on the model to determine which parameters had a detectable impact. This process overlapped with Extreme Value Checks on parameters. The parameters tested included the 'time knowledge ratio', the 'learning time limit', 'recycling bin bias', 'GW bin bias', 'knowledge impact' and waste stream proportions. The time knowledge ratio referred to the relationship between the population disposal knowledge level and the required time to learn additional units of knowledge. The learning time limit denoted the average amount of time an individual was willing to devote to learning about waste disposal per month. The recycling bin bias signified the recycling disposal bias, a low bias number representing a bias towards the GW bin and a high bias number indicating a bias towards the recycling bin. The GW bin bias followed a similar pattern, with a low bias number indicating a bias towards the GW bin and a high bias number a bias towards the recycling bin. Knowledge impact varied the weighting of population knowledge on recycling and GW bin contamination. Variation of waste steam proportions changed the percentage of GW and recyclables in the waste stream.

The results of sensitivity testing proved informative in determining influential parameters and can be seen in TableE1.1. The Time Knowledge Ratio was shown to have minimal impact on recycling rate plateau levels (Δ = 0.1523) but a large effect on bin contamination levels (ΔGW =0.3207, ΔRec = 0.6485). A similar effect was seen by the Learning Time Limit, with a small impact on recycling rate plateau (Δ=0.164) but a significant effect on bin contamination (ΔGW =0.3358, ΔRec = 0.6641). The Recycling bin bias had a moderate impact on recycling rate plateau (Δ=0.3232) and GW bin contamination (Δ=0.3198) but no influence on recycling bin contamination (Δ=0). A larger effect on recycling rate plateau (Δ=0.6341) was seen by GW bin bias, which also had a large impact on recycling bin contamination (Δ=0.5784) but no influence on GW bin contamination (Δ=0). Knowledge impact was found to have no impact on recycling rate plateau (Δ=0), or bin contamination (Δ=0). Variation of waste stream proportions had a large impact on recycling rate plateau (Δ=1) but no impact on bin contamination (Δ=0). Sensitivity analysis graphs can be seen in Appendix E.2 to E.13..

Table E1.0.1Results of sensitivity analysis of SD model parameters

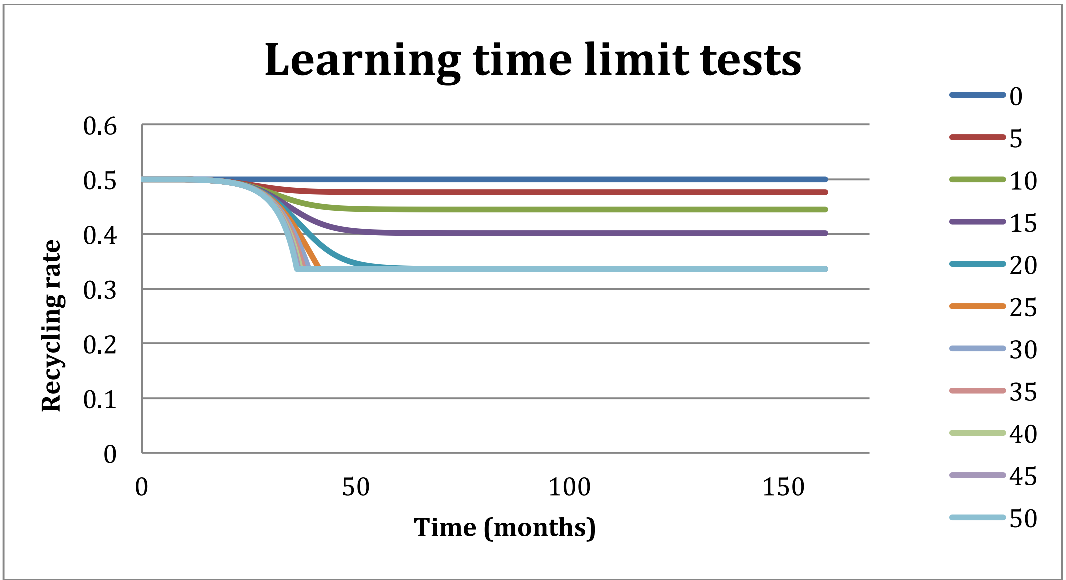
	Time Knowledge ratio	**Learning time limit**	**Recycling bin bias**	**GW bin bias**	**Proportion of waste stream GW**	**Proportion of waste stream recyclables**	**Knowledge impact**
High	0.5	0.5	0.3232	1	1	1	0.3359
Low	0.3359	0.3359	0	0.3658	0	0	0.3359
Δ Recycling rate plateau	0.1523	0.164	0.3232	0.6341	1	1	0
High	0.6485	0.6640	0	0.6648	0	0	0
Low	0	0	0	0.0864	0	0	0
Δ Recycling bin contamination	0.6485	0.6641	0	0.5784	0	0	0
High	0.3207	0.3358	0.3358	0	0	0	0
Low	0	0	0.0160	0	0	0	0
Δ GW contamination	0.3207	0.3358	0.3198	0	0	0	0

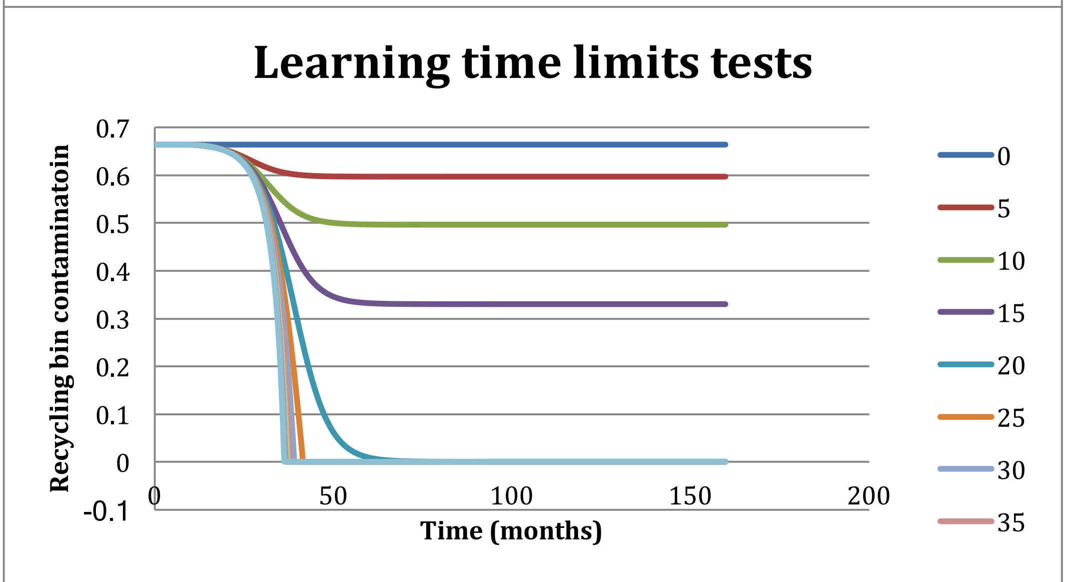
Further tests were run on the model to determine the change in recycling rate plateau when bin contamination was removed. The results from the simulation tests show that the removal of bin contamination may increase or decrease recycling rate plateaus (Table E1.2). This reveals that recycling rate plateaus are sometimes inflated above the actual proportion of recyclables in the waste stream due to GW mixing with recycling. If the weight of recycling contamination was greater than GW contamination, then the recycling rate was more than the full potential recycling rate. Meaning if waste streams were purified by improving disposal knowledge than recycling rates will drop. However, if the weight of GW contamination was greater than recycling contamination, then the actual recycling rate was below the full potential recycling rate. This would result in a recycling rate increase if waste streams were purified by improving disposal knowledge.

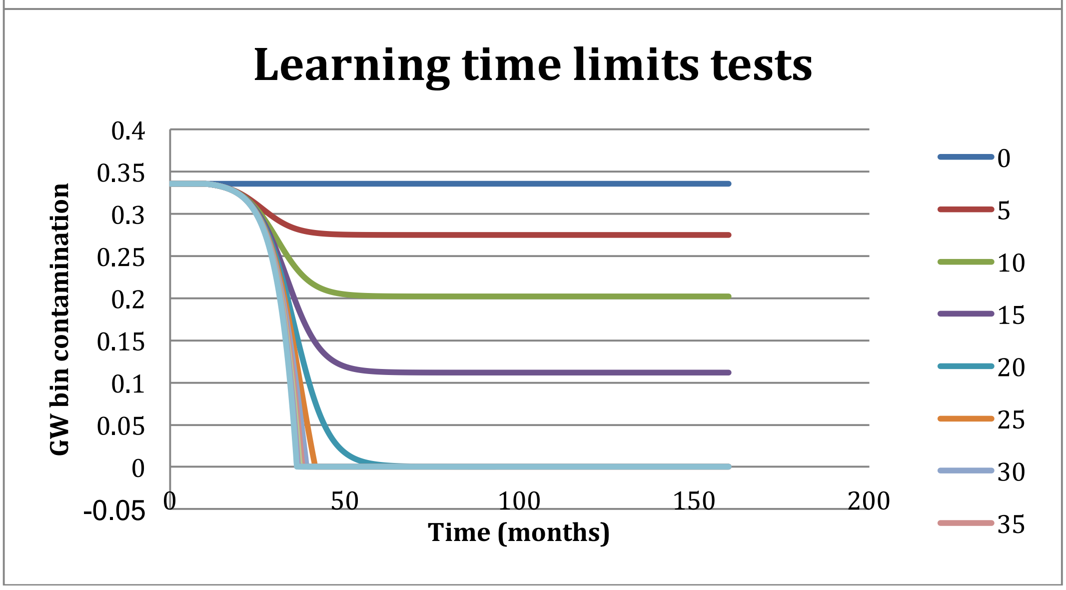
Table E1.0.2 Percentage change in recycling rates when bin contamination is removed

Collection zone	Recycling rates with bin contamination	Recycling rates without bin contamination	% change
Monday A	0.3961	0.3728	- 5.88%
Monday B	0.2809	0.3516	+ 25.17%
Tuesday A	0.3291	0.3257	- 1.03%
Tuesday B	0.3131	0.3604	+ 15.11%
Wednesday A	0.3248	0.3037	- 6.5%
Wednesday B	0.3367	0.4064	+ 20.7%
Thursday A	0.3479	0.3677	+ 5.69%
Thursday B	0.3540	0.3872	+ 9.38%

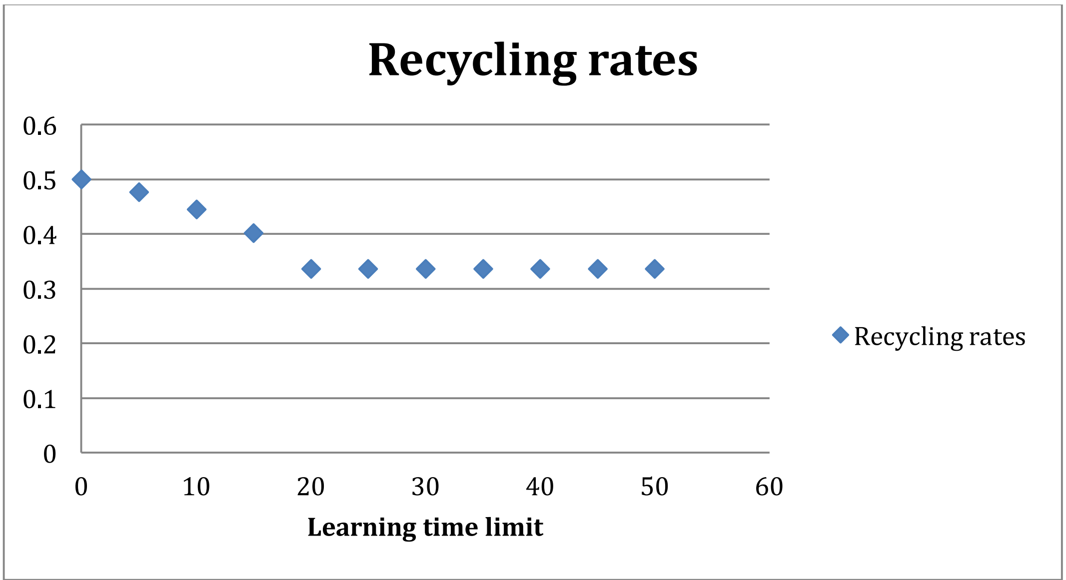
E.2. Sensitivity test of learning time limit parameter

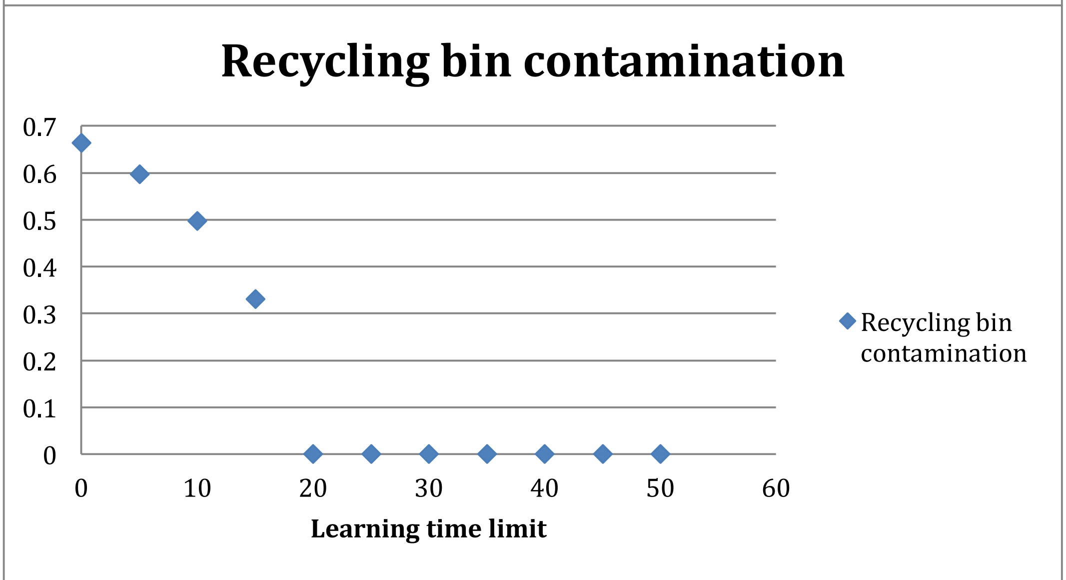


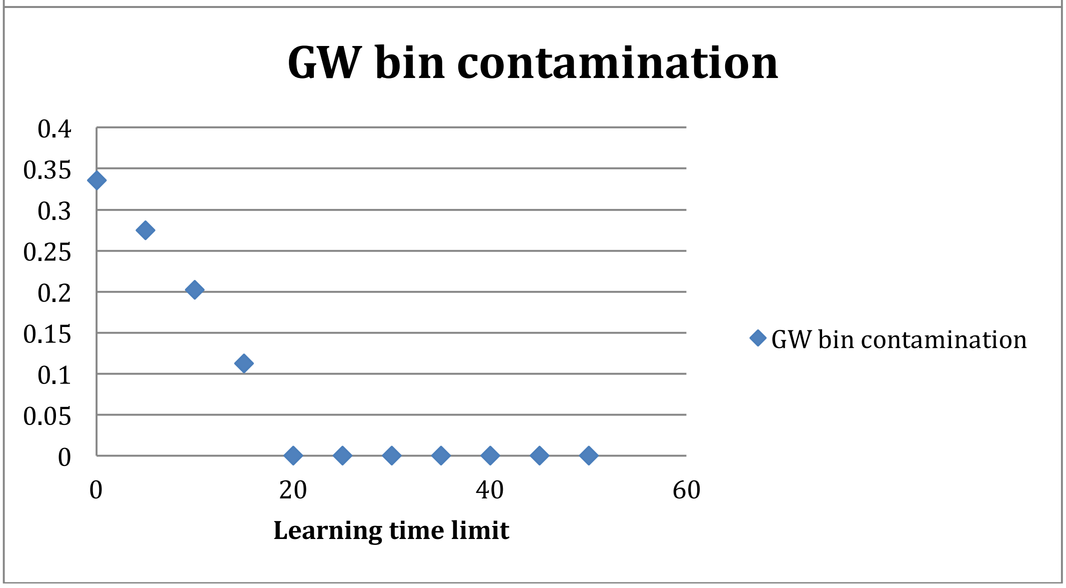




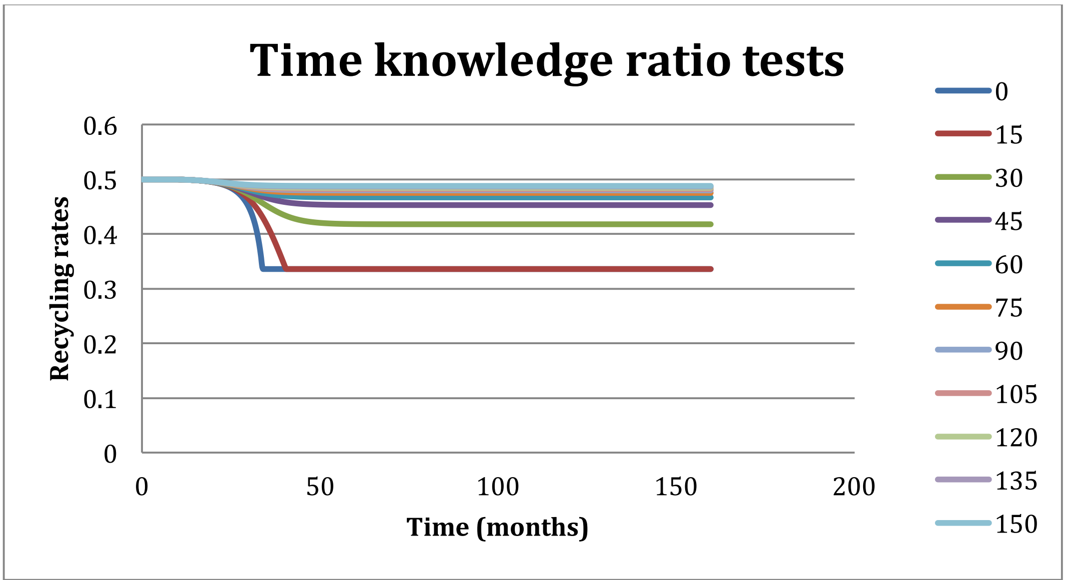
E.3. Sensitivity test of learning time limit parameter

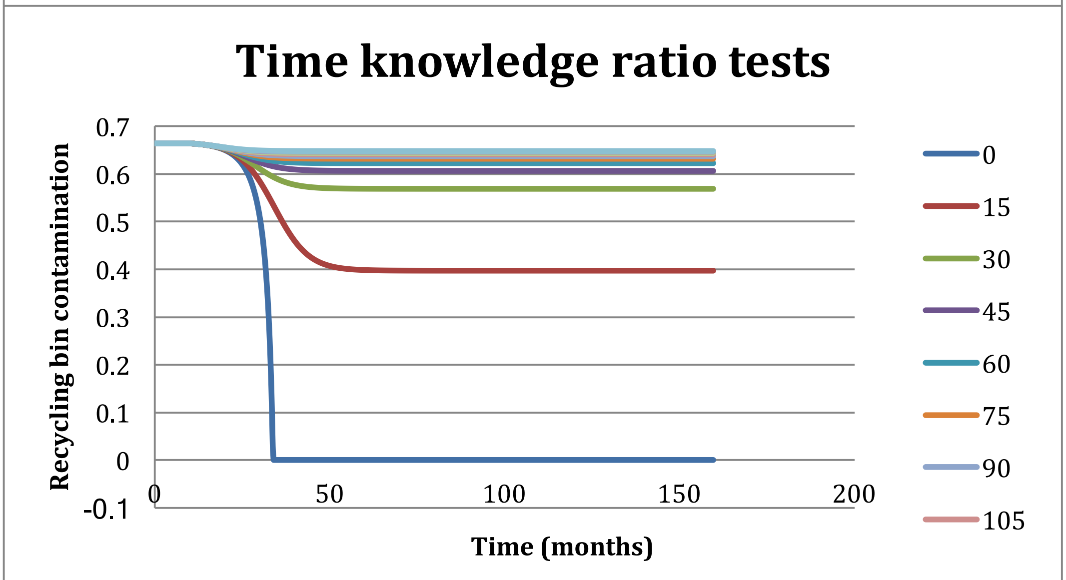


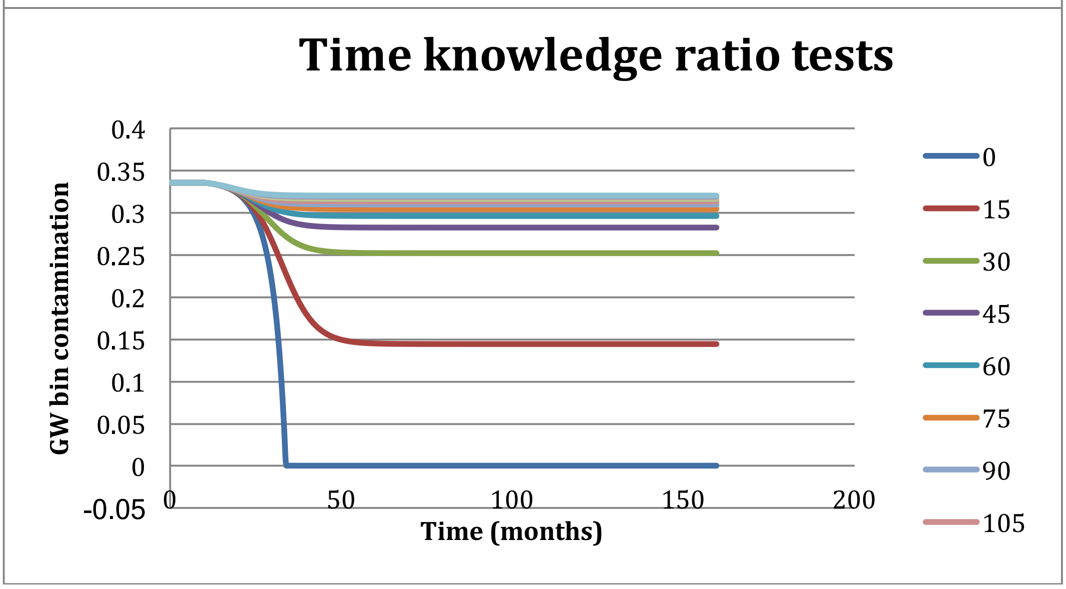




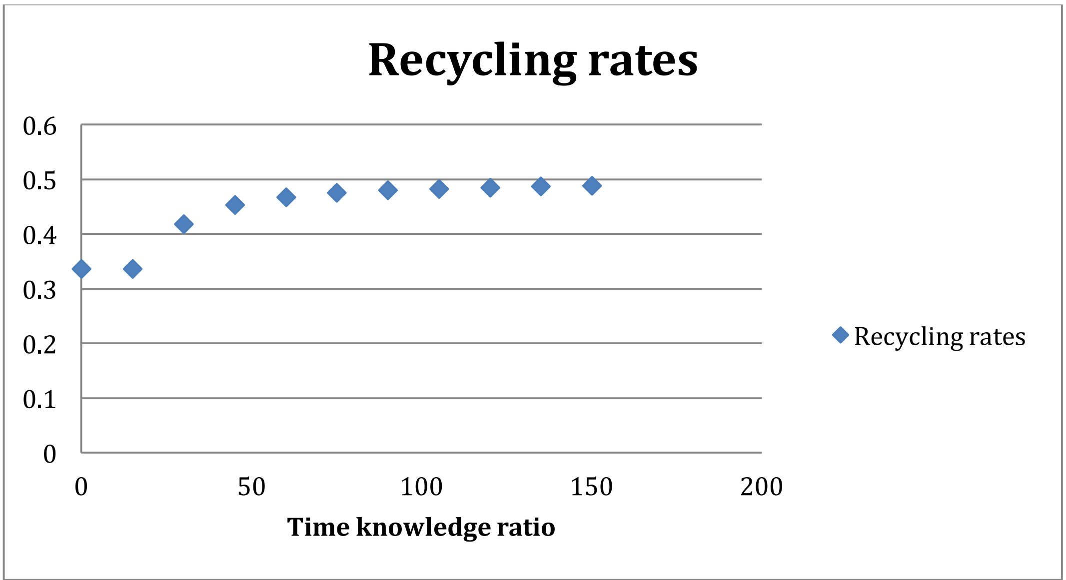
E.4. Sensitivity test of time knowledge ratio parameter

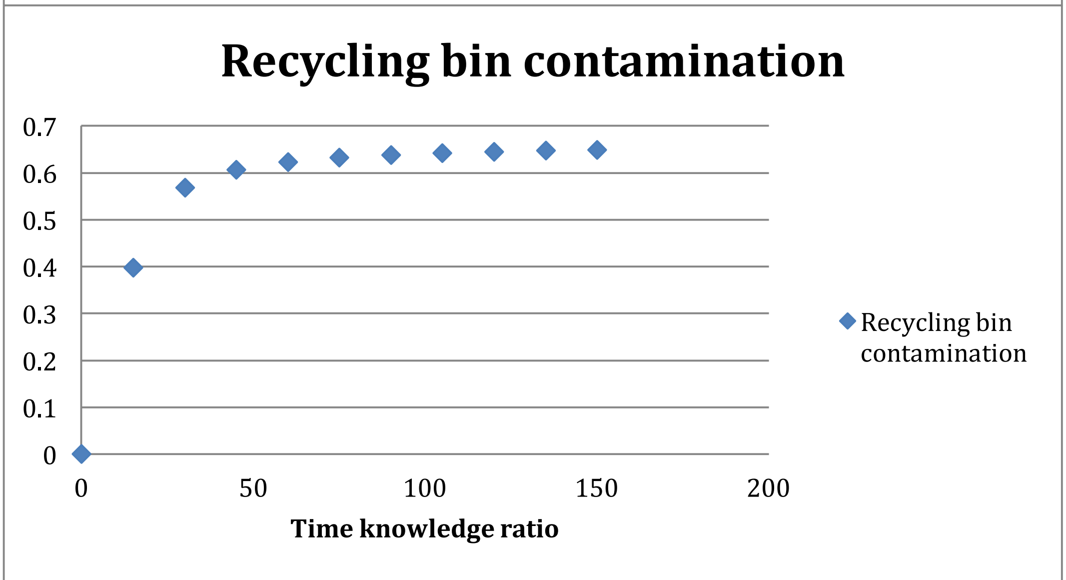


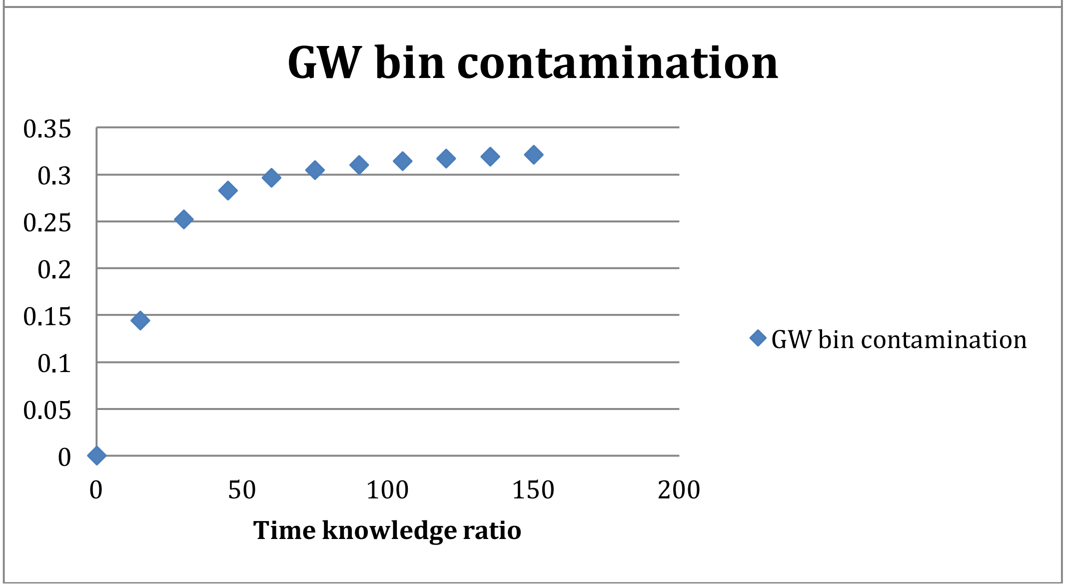




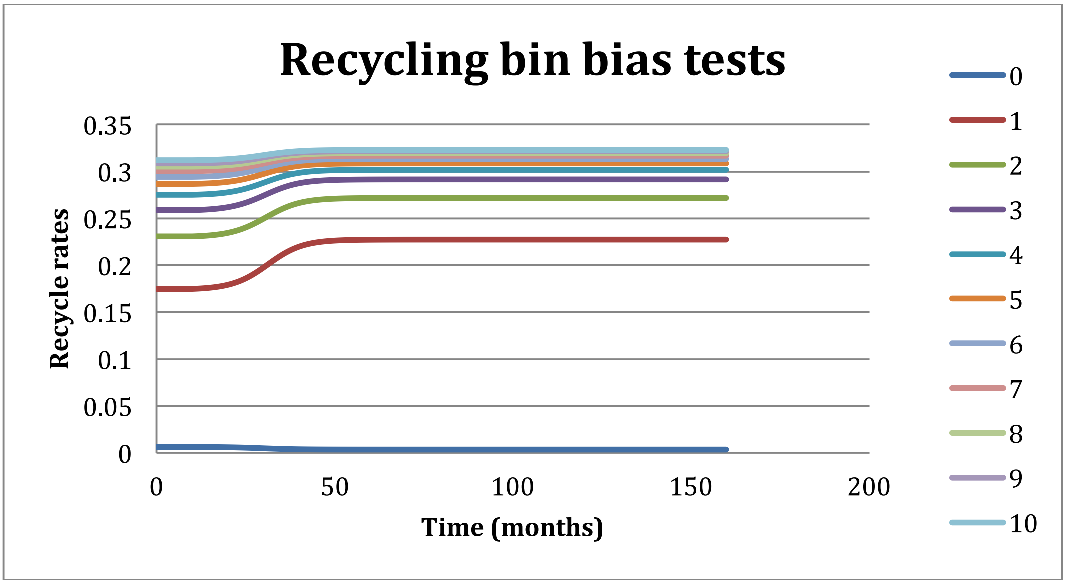
E.5. Sensitivity test of time knowledge ratio parameter

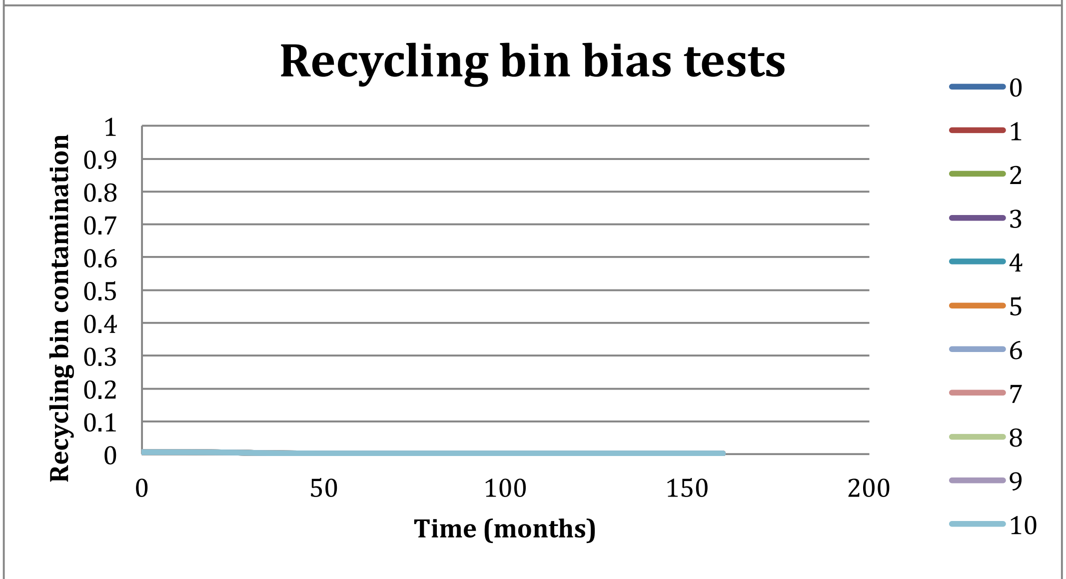


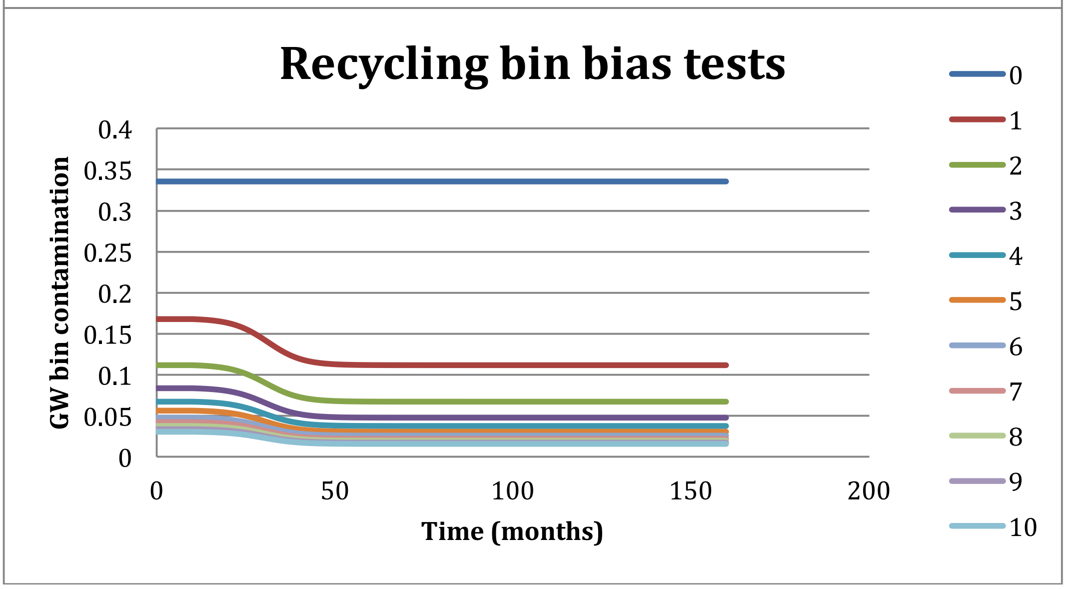




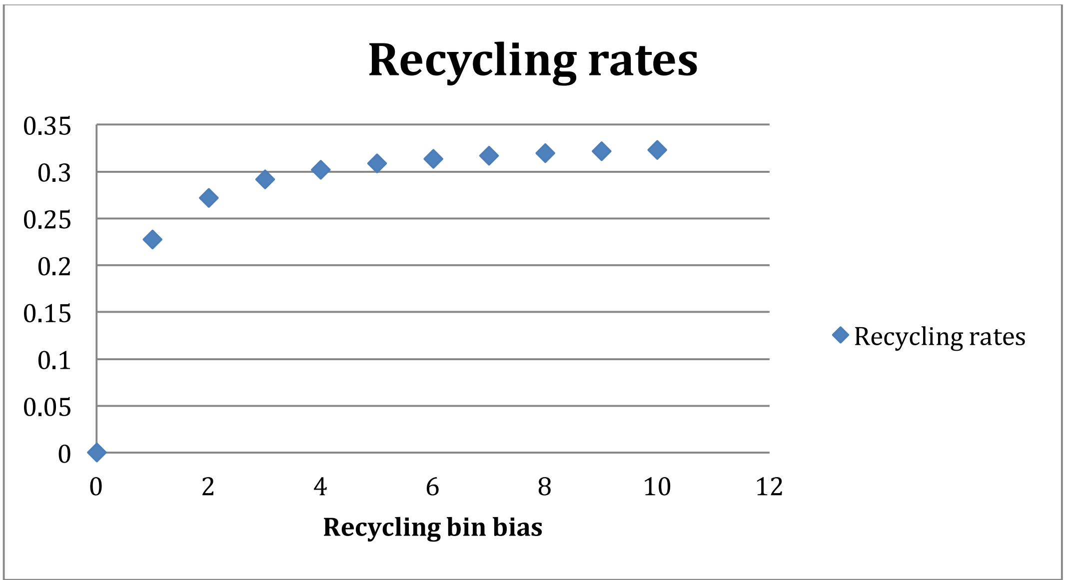
E.6. Sensitivity test of recycling bin bias parameter

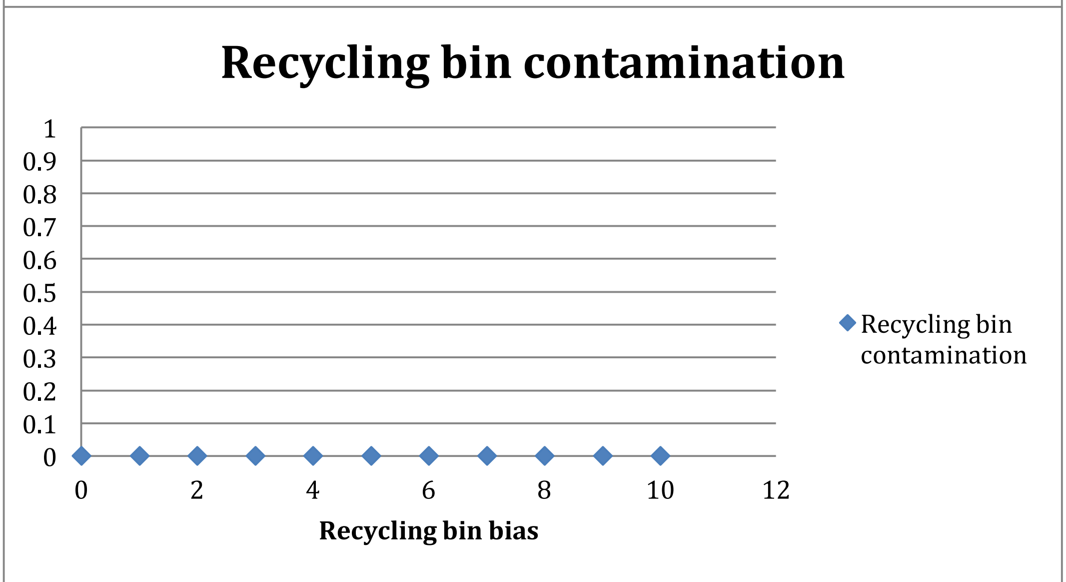


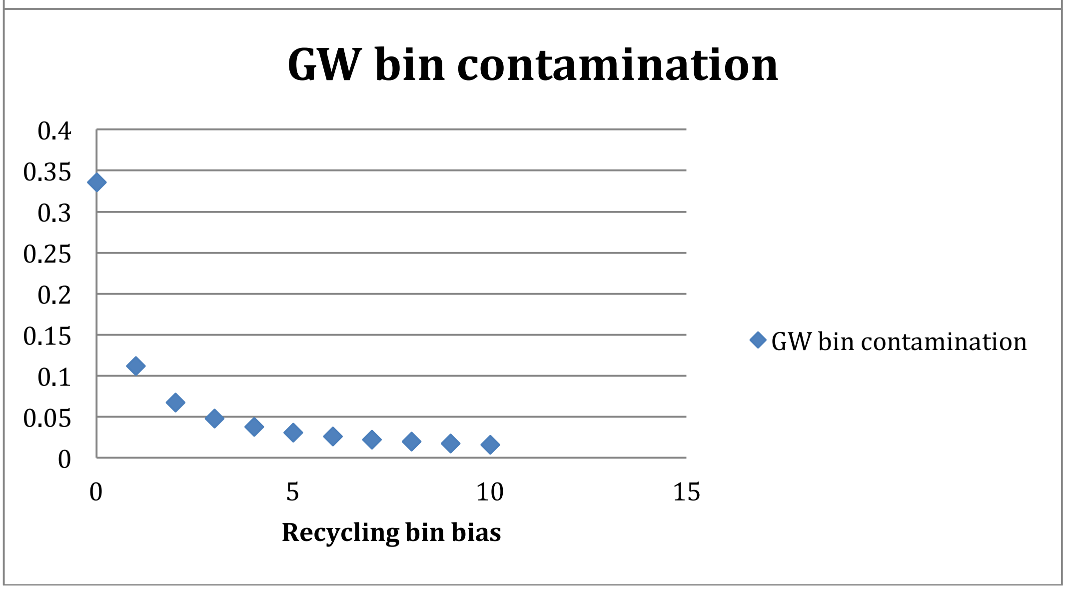




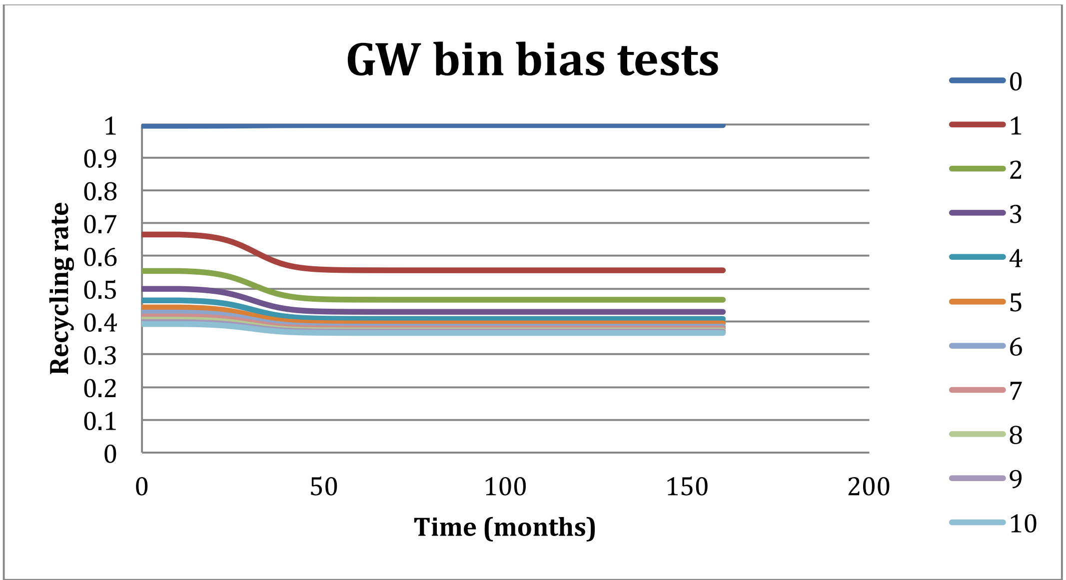
E.7. Sensitivity test of recycling bin bias parameter

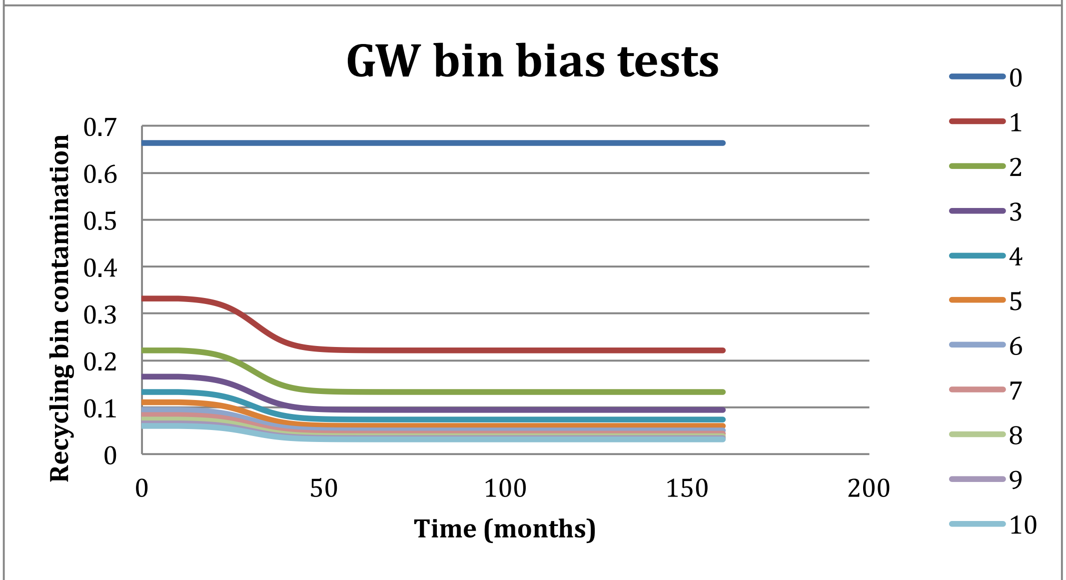


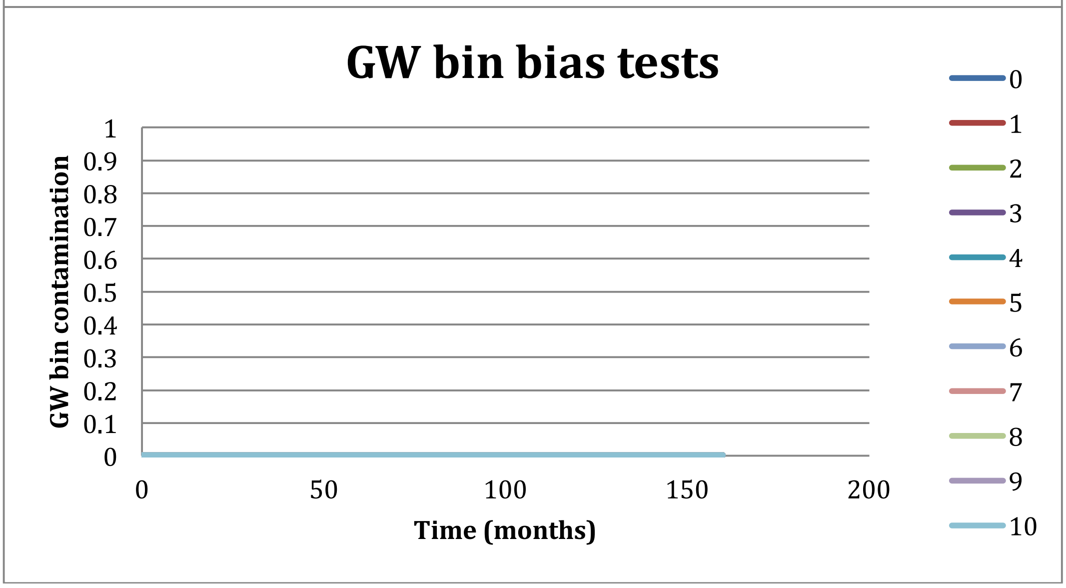




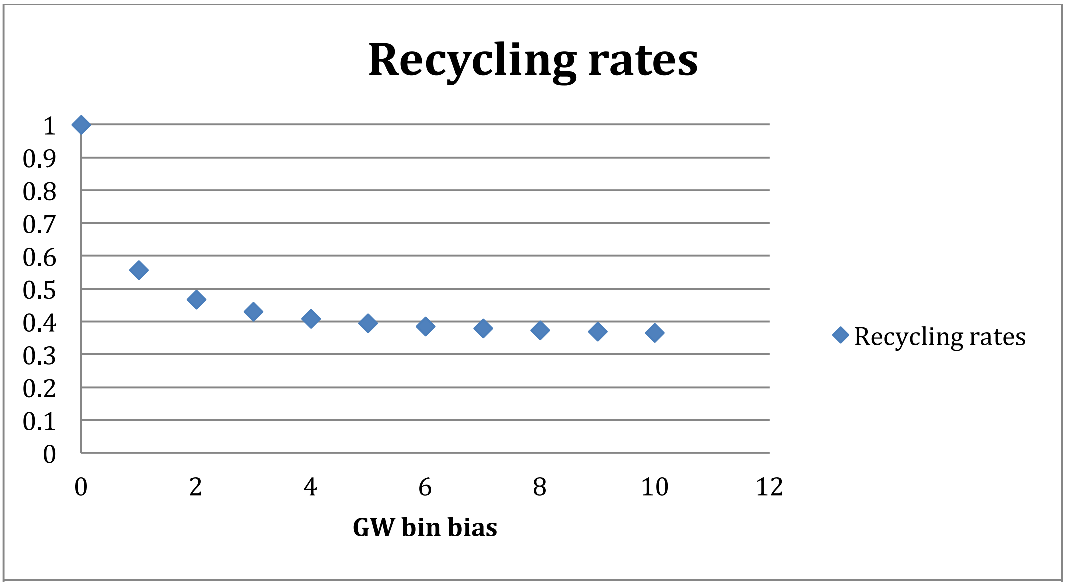
E.8. Sensitivity test of GW bin bias parameter

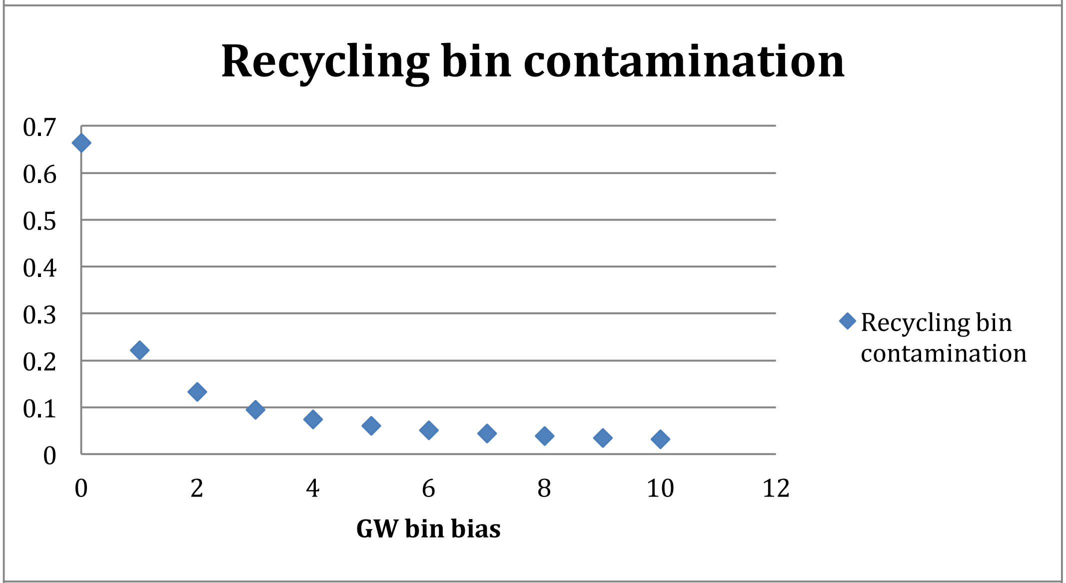


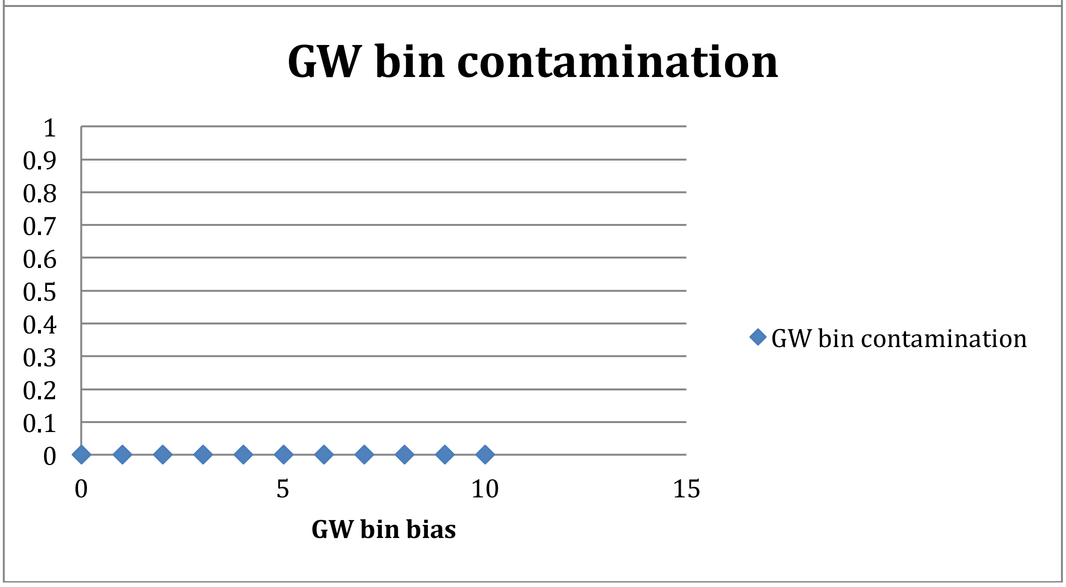




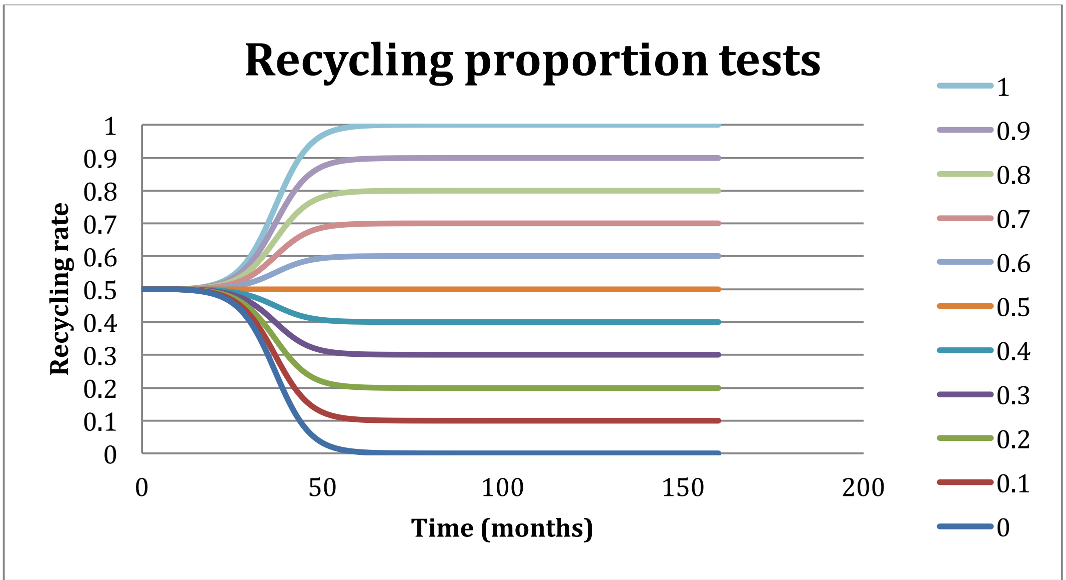
E.9. Sensitivity test of GW bin bias parameter

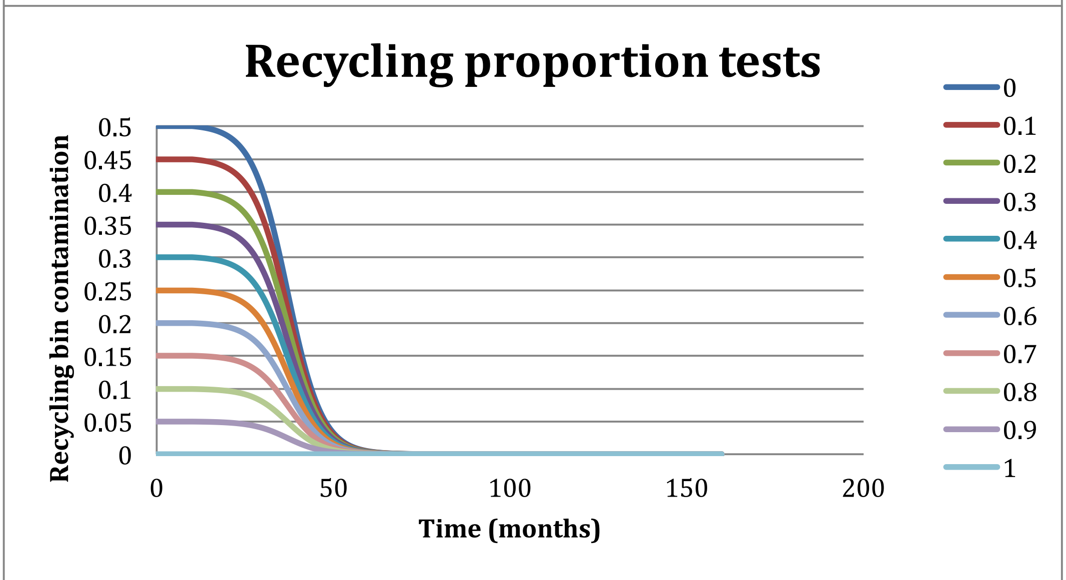


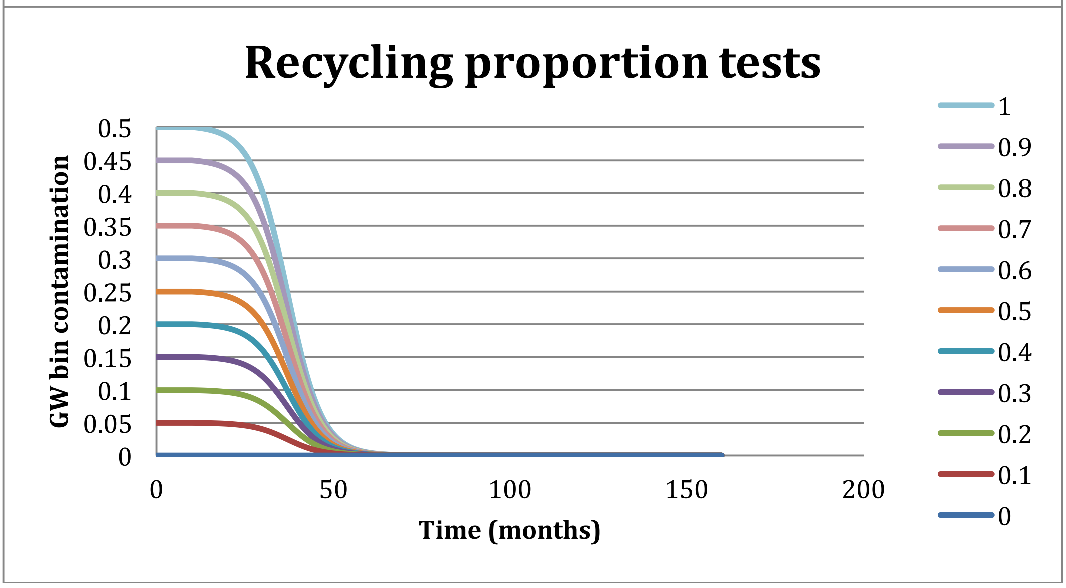




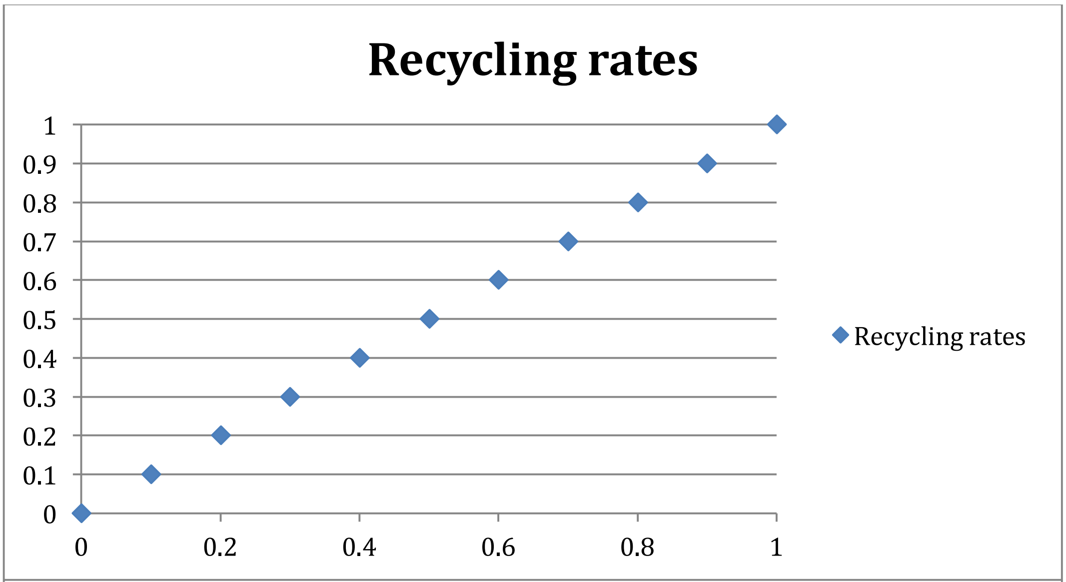
E.10. Sensitivity test of recycling proportion parameter

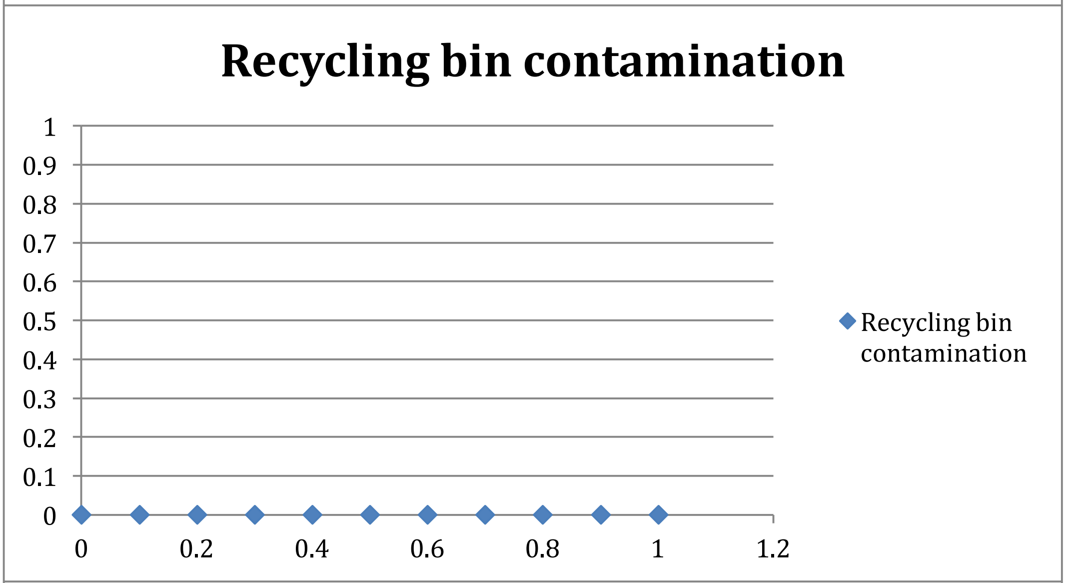


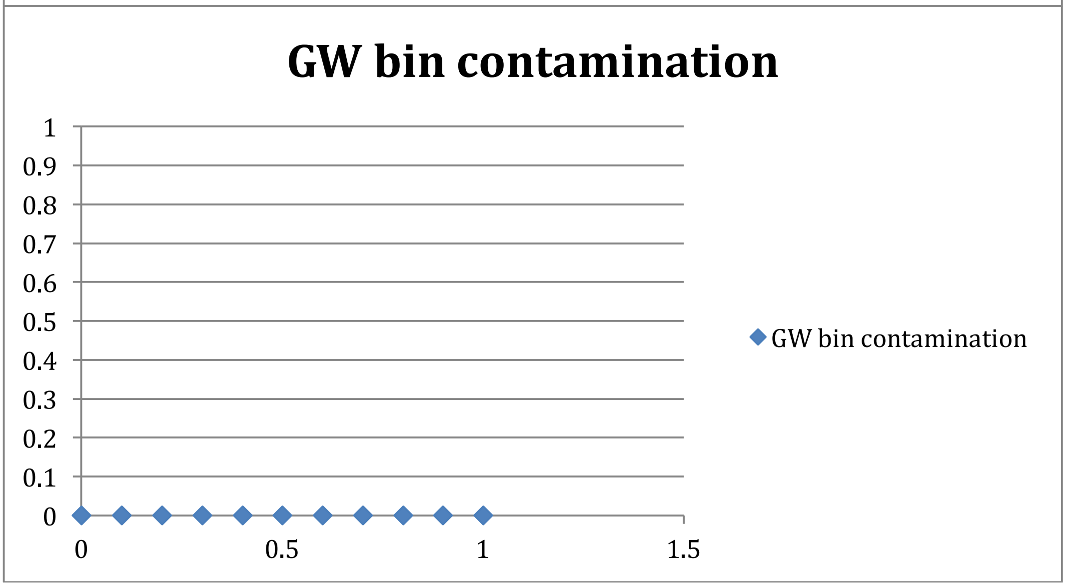




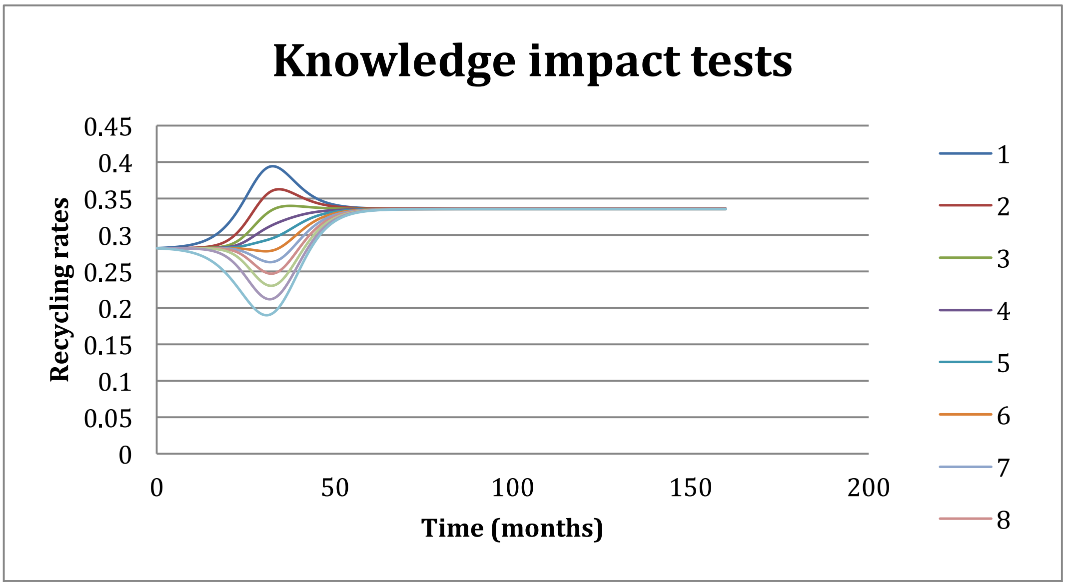
E.11. Sensitivity test of recycling proportion parameter

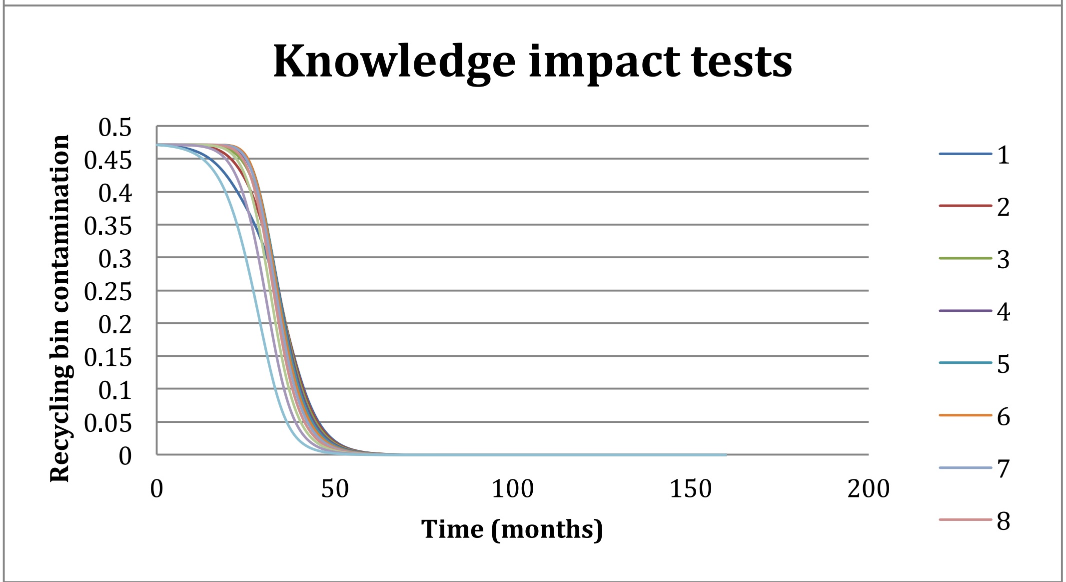


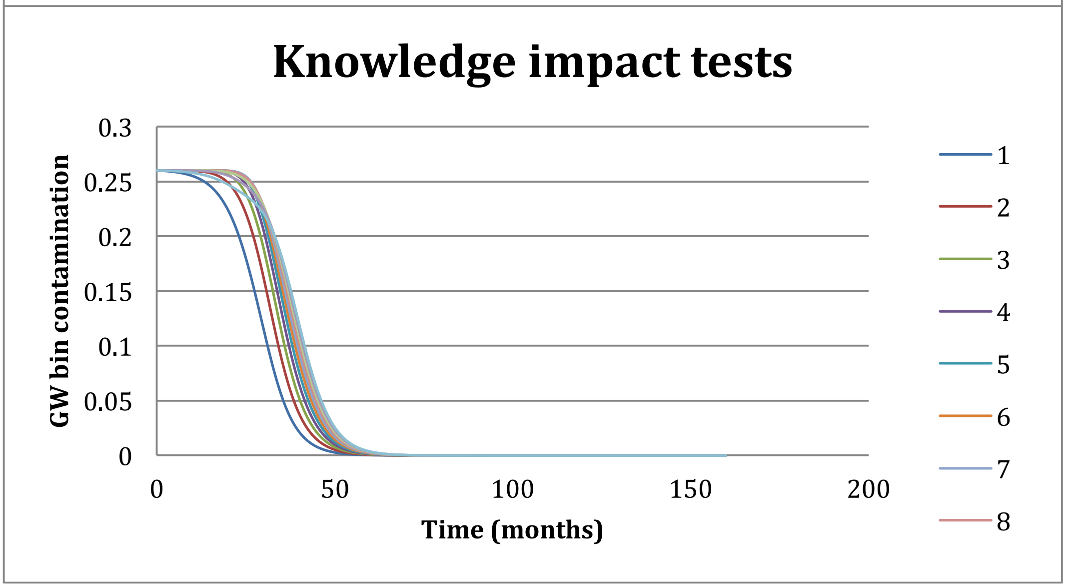




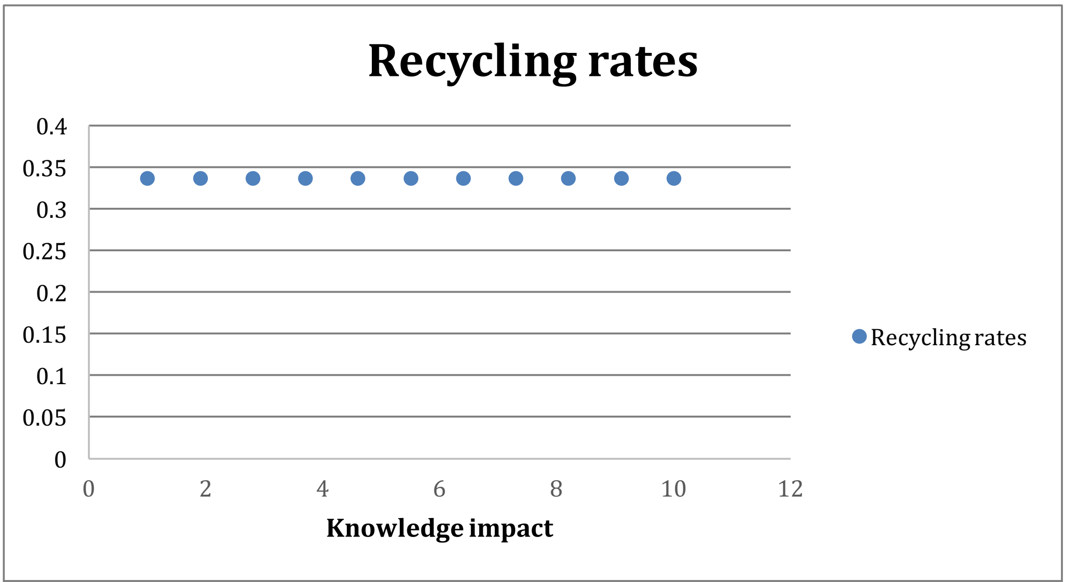
E.12. Sensitivity test of knowledge impact parameter

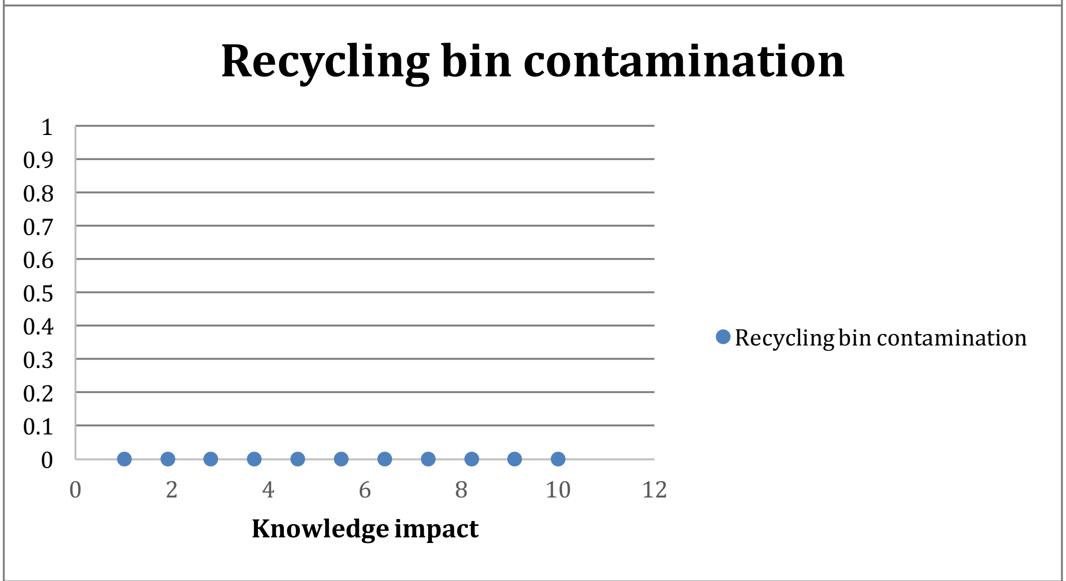


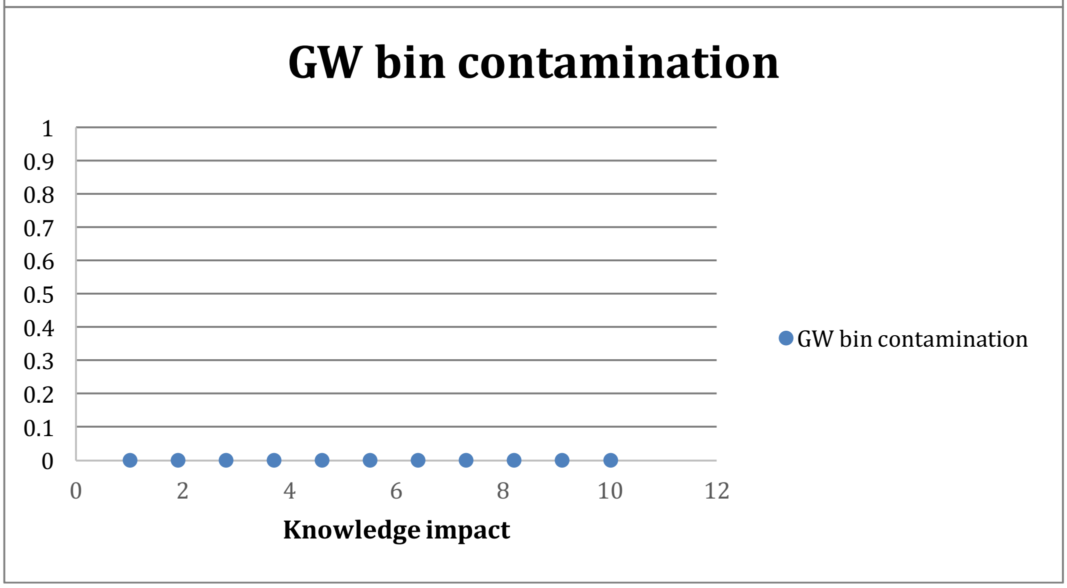




E.13. Sensitivity test of knowledge impact parameter







E.14. System Dynamics model variables, algorithms and dimensions for testing recycling plateaus

Parameter	Initial value/Algorithm	Dimension
Effectiveness of observational learning	0.1	1/month
Learning rate	IF population knowledge >= 1 THEN 0 ELSE (available learning time * effectiveness of observational learning* population knowledge) + (learning from council education * available learning time)	Unit knowledge/month
Available learning time	(learning time limit – required learning time)/learning time limit	Dimensionless
Learning time limit	Varies between collection zones	Minutes
Time Knowledge Ratio	20	Minutes/unit knowledge
Required learning time	Population knowledge * time knowledge ratio	Minutes
Effectiveness of education	STEP(0.01, 0)	1/month
Learning from council education	(1 - Population knowledge) * effectiveness of education	Knowledge unit/month
Population knowledge	0	Unit Knowledge
Accuracy of sorting	Population knowledge	Unit Knowledge
Population knowledge impact on recyc contamination	1	Dimensionless
Population knowledge impact on GW contamination	10	Dimensionless
Recycling contamination index	IF (1 – Accuracy of sorting^P1) > 0 THEN (1 – Accuracy of sorting^P1) ELSE 0.0001	Dimensionless
GW contamination	IF (1- Accuracy of sorting^P2) > 0 THEN (1 – Accuracy of sorting^P2) ELSE	Dimensionless

E.14. System Dynamics model variables, algorithms and dimensions for testing recycling plateaus

index	0.0001	
Rate of consumption	1	Dimensionless
Proportion of recyclables	Varies between collection zones	Dimensionless
Proportion of GW	Varies between collection zones	Dimensionless
Household material	1	Dimensionless
Absolute amount of recyclables	Proportion of recyclables * household material	Dimensionless
Absolute amount of GW	Household material * proportion of GW	Dimensionless
Average fraction absorbed		Dimensionless
Absorption	Average fraction absorbed * household material	Dimensionless
GW bin bias	Varies between collection zones	Dimensionless
Recycling bin bias	Varies between collection zones	Dimensionless
Correctly separated GW	Proportion of GW/((GW contamination index/GW bin bias)+1)	Dimensionless
Incorrectly separated GW	Proportion of GW/((GW bin bias/GW contamination index)+1)	Dimensionless
Correctly separated recyclables	Proportion of recyclables/((recycling contamination index/recycling bin bias)+1)	Dimensionless
Incorrectly separated recyclables	Proportion of recyclables/((recycling bin bias/recycling contamination index)+1)	Dimensionless
Recycling bin	0	Dimensionless
GW bin	0	Dimensionless
Rate of flow of recyclable material	Correctly separated recyclables + incorrectly separated GW	Dimensionless
Stock of material at MRF	0	Dimensionless
Rate of flow of commodities	DELAY(correctly separated recyclables,1)	Dimensionless
Rate of flow of sorted recycling contamination	DELAY(incorrectly separated GW,1)	Dimensionless
Rate of flow of GW	Correctly separated GW + incorrectly separated recyclables	Dimensionless
Stock of material in landfill	0	Dimensionless
Recycling rate	Rate of flow of recyclable material/(rate of glow of recyclable material + rate of	Dimensionless

	flow of GW)	
GW	0	Dimensionless
Recyclables	0	Dimensionless

E.15. System Dynamics model variables, algorithms and dimensions for recycling growth

If variables do not appear then they remain unchanged from E.14.

	Model	Units
GW bin bias	11.4	Dimensionless
Recycling bin bias	0.879	Dimensionless
GW proportion	0.3596	Dimensionless
Recycling proportion	0.6404	Dimensionless
Effectiveness of observational learning	0.01	1/month
Effectiveness of council education	0.1	1/month
Recycling knowledge weighting	1	Dimensionless
GW knowledge weighting	10	Dimensionless
Learning time limit	15	Minutes
Time knowledge ratio	20	Minutes/unit knowledge

E.16. System Dynamics model variables, algorithms and dimensions for endogenous loop

If variables do not appear then they remain unchanged from E.14.

	Model	Units
GW bin bias	11.4	Dimensionless
Recycling bin bias	0.879	Dimensionless
GW proportion	0.3596	Dimensionless
Recycling proportion	0.6404	Dimensionless
Effectiveness of observational learning	0.01	1/month
Effectiveness of council education	0.1	1/month
Recycling knowledge weighting	1	Dimensionless
GW knowledge weighting	10	Dimensionless
Learning time limit	15	Minutes
Time knowledge ratio	20	Minutes/unit knowledge
Spend vs contamination ratio	20000	$
Contamination threshold	1- STEP(0.85, 60)	Dimensionless
Ease of learning vs education spend ratio	0.008	minutes per unit knowledge/$
Forgetting rate	STEP (0.1 * population knowledge, 60)	Unit knowledge/time step
Rate of spending change	DELAY((Recycling contamination-contamination	$/time step

	threshold) * spend vs contamination ratio,3)	