An In-Depth Investigation into the Relationship Between Municipal Solid Waste Generation and Economic Growth in the City of Cape Town

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Carmen van der Merwe[1] and Martin de Wit[2]

Abstract

Issues of landfill scarcity are propelling cities and countries to direct policy instruments towards waste management. An objective of achieving a green economy, of which there is decoupling of waste, has become the forefront of policy design in many cities around the globe. The City of Cape Town (CCT), facing similar landfill scarcity issues, has begun taking steps towards waste minimisation. To determine whether it is possible for the City to rely on economic growth to achieve absolute decoupling of waste, this study investigates the long- and short-run relationship between economic growth and municipal solid waste generation. This is done using both time series regression analysis and decoupling calculations.

Furthermore, the Waste Kuznets Curve is investigated. Socio-economic and policy drivers of waste generation are included in the investigation to inform policy design. This study finds that the CCT has been experiencing long-run relative decoupling of waste, with short-run fluctuations of absolute decoupling during economic recessions. No strong long-run relationships between socio-economic variables and MSW generation for the CCT are found, however, in the short run it is deduced that population density is positively related to per capita MSW generation. The Think Twice waste minimisation programme, as a potential policy driver of MSW generation, is evaluated using a segmented linear regression. It is found that the Think Twice programme only has had temporal effects of reducing MSW generation, and that much of the reduction in MSW generation is rather explained by exogenous economic shocks, such as the 2008/2009 economic crash.

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1. Introduction

Solid waste management, in traditional views, has been considered an engineering problem, requiring a technical solution. More recently, problems associated with waste management has been identified to be economic in nature (Goddard, 1995). Solid wastes are the remnants of consumption and production processes, which are primarily determined by economic variables such as prices and income (Goddard, 1995: 188). The problem of waste management is therefore economic in nature, meaning it is characterised by resource scarcity and governed by choice. This economic problem requires economic solutions which achieve allocative efficiency through cost-effective options.

The CCT faces challenges of landfill scarcity and resource management in the waste sector. The estimated remaining airspace for the CCT's landfills is between 5 – 15 years (GreenCape, 2020: 18). This study attempts to fill the gap by determining the current state of the economy and waste, investigating whether decoupling exists between these two variables, and to what extent. This is conducted using two approaches; firstly, using economic theory surrounding the Environmental Kuznets Curve (EKC) for waste and analysing parameter elasticities under regression analysis, and, secondly, using a decoupling factor equation as introduced by the Organisation for Economic Co-operation and Development (OECD, 2002).

Moreover, the efficacy of current waste minimisation initiatives (the Think Twice recycling programme) is empirically assessed. The ultimate purpose of the study is to contribute to improved decision-making on municipal waste management by identifying targeted economic policy instruments that reduce the societal costs, that is both the municipal and the external costs, of municipal waste, with a specific consideration of the socio-economic conditions for the CCT.

2. Literature Review

Existing literature in waste economics considers issues facing landfill scarcity and how to achieve an economy that decouples from waste. To understand the underpinnings of the relationship between solid waste generation and the economy, a theoretical discussion surrounding the Environmental Kuznets Curve (EKC) and decoupling is needed.

The sections are presented as follows: Section 2.1 outlines and discusses the theory surrounding the EKC and decoupling and provides the waste management options. Section 2.2 discusses existing literature pertaining to this study's objectives and begins with a review that analyses both the WKC and broader waste-economy relationships. This section further provides insights of existing literature on an array of appropriate explanatory variables (socio-economic and policy variables) that have been shown to influence the rate of waste generation and discusses the appropriateness of these variables for the CCT case study.

2.1. Definitions and relevant concepts

The definition and description of important waste and economic concepts are crucial for the development of this study. The theory surrounding the Environmental Kuznets Curve (EKC) and decoupling is discussed in this section.

The EKC is a theoretical tool that can be used to investigate the relationship of environmental indicators and the economy, and to determine if decoupling between the respective variables exist. In 1955, the Kuznets economic hypothesis had been developed, through which Simon Kuznets argued for an inverted U-shaped relationship between economic growth and income inequality (Kuznets, 1955). This concept had been developed further to encompass an environmental perspective. The EKC developed by Grossman and Krueger (1991, 1995) argues that. at low levels of income, environmental degradation is low and, as income begins to increase, environmental degradation increases until a turning point is reached. From this turning point, as income increases (and countries become more developed) environmental degradation decreases due to advanced technologies and financial resources that are employed to address environmental issues.

The EKC hypothesis acts as a tool to determine whether long-term economic growth can combat environmental degradation. As noted by Raymond (2004: 328), caveats do exist when using or testing the EKC. On an empirical level, disagreements exist on the accuracy of such models in their ability to describe the full environmental impact of economic growth (Raymond, 2004: 328). On a theoretical level, there is disagreement on whether the EKC precisely depicts real-world scenarios, and, consequently, whether it can fully inform policy-making decisions. Rather, it is suggested that EKC results be examined within the context of study and other economic considerations and models (such as Cost-Benefit Analysis), should be undertaken in conjunction with EKC results.

Decoupling of waste, according to the WRAP report (2012: 3), involves the generation of less waste per unit of economic activity. There are four states of decoupling; *Absolute* decoupling, whereby waste generation remains constant or decreases as economic activity increases, *Relative* decoupling whereby economic activity increases whilst waste generation increases, but at a greater rate, *Coupled* decoupling whereby there is a one-on-one rate increase of waste generation and economic activity and *Negative* decoupling whereby an environmental pressure indicator such as waste generation increases at a faster rate than the rate of increase of an economic indicator. Waste decoupling essentially considers the relationship between waste generation and economic growth, with the goal to generate less waste per unit of economic activity.

There are two indicators used in the literature to determine the state of decoupling. Elasticities, as the first indictor, are the calculated ratio of the percentage change in one variable to the percentage change in another variable. From an empirical standpoint, where decoupling between economic growth and waste generation exists, an inverted U-shaped curve or WKC is found between waste generation and the economic performance indicator (Madden, Florin, Mohr & Giurco, 2019: 675). This relationship is graphically summarised in Diagram 2.1. Under the WKC framework, absolute decoupling exists if the economic variable is situated on the descending segment of the WKC, implying that regression coefficients (elasticities) must show evidence of a plausible turning point. A plausible turning point exists where the estimated economic turning point (TP) lies within the range of the economic indicator for the area under investigation. For example, when the $estimated\ TP < Average\ Income$ of a study period, absolute decoupling is present (Madden *et al.*, 2019: 675). Relative decoupling, whereby the estimated TP is larger than the range (or the average actual income) of the economic indicator for the study area, exists on the ascending segment of the WKC. This curve, when plotted, is often used to observe whether the implementation of structural changes or policy reform influences the state of decoupling.

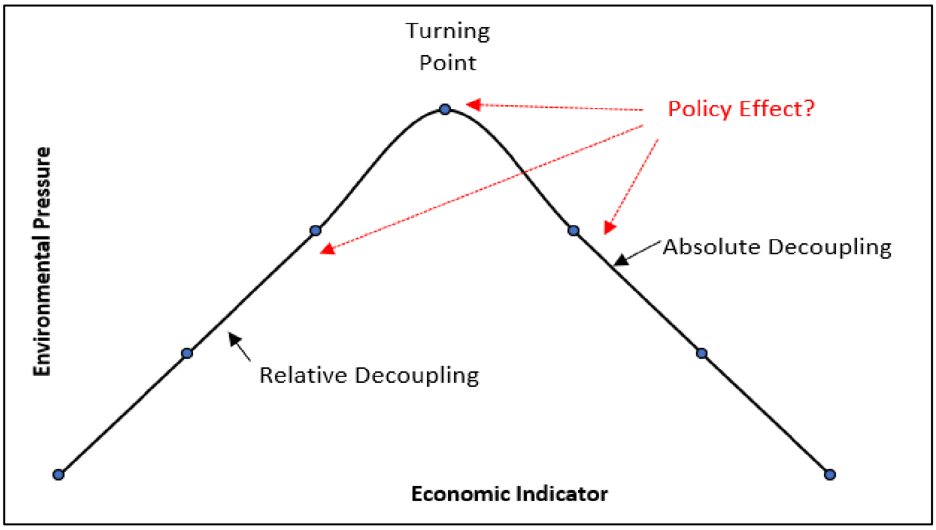

Diagram 2.1: Environmental Kuznets Curve and Decoupling

(Source: Constructed by author, adapted from Mazzanti & Zoboli (2009: 6))

Alternatively, as determined by the OECD (2002), decoupling can be calculated by obtaining a decoupling factor using the following formula:

$$D_f = \frac{(EP/DF)_{end\ of\ period}}{(EP/DF)_{start\ of\ period}}$$

D_f is the decoupling factor, *EP* is the environmental pressures, and *DF* is the driving force (Wang *et al.*, 2013: 675). D_f is equivalent to the decreasing rate of resource use per unit of GDP (*t*). When the decoupling indicator is larger or equal to one ($D_f \geq 1$), absolute decoupling is observed. When the decoupling indicator is between the interval 0 – 1 ($0 < D_f > 1$), relative decoupling exists and if the decoupling indicator is below or equal to 0 ($D_f \leq 0$), there is no decoupling (Wang *et al.*, 2013: 620). Decoupling, whether absolute, relative, or non-existent, can also be graphically analysed by plotting the environmental index and the economic index against the time series (Inglezakis *et al.*, 2012). The state of decoupling and the ascertainment of the WKC can be used to inform waste management decisions.

There are three identified types of policy instruments for waste management. These are regulatory, economic, and informational instruments (Montevecchi, 2016: 4). Regulatory instruments, or commonly called 'command and control' (CAC), are the norms and standards governing the actions of economic agents. These instruments focus on standards, permits, recycling and final disposal within the waste sector. Examples of such regulations include height restrictions on landfills and regulations of what waste materials may or may not be recycled. Typically, there penalties are issued for non-compliance with regulatory instruments.

Economic Instruments (EI's) internalise the environmental degradation costs into the production and consumption processes. EI's, according to the United Nations Environment Programme (UNEP) (2005:5), can be defined as:

> *"a policy, tool or action which has the purpose of affecting the behaviour of economic agents by changing their financial incentives in order to improve the cost-effectiveness of environmental and natural resource management".*

Unlike CAC's, EI's are far less rigid and are non-prescriptive to actions. EI's are acknowledged for their ability to incentivise or disincentivise economic agents to go beyond what laws and regulations require. EI's can be categorised as revenue raising instruments , which involve user charges for the provision of waste services; revenue providing instruments, that are targeted at rewarding desired consumer and producer behaviors, such as efforts of waste minimisation; and non-revenue instruments which include the combined incentive effects of the former two categories (UNEP, 2005: 7-8). The latter, non-revenue instruments, include deposit-refund schemes as well as property-rights based instruments. Lastly, informational instruments are aimed at deploying resources to educate economic agents about the responsibilities and actions that can be taken towards minimising the amount of waste generated. These include awareness-raising programmes on composting and recycling (Montevecchi, 2016: 10 and Oosterhuis, Bartelings, Linderhof & van Beukering, 2009: iii).

EI's can incentivise or disincentivise polluters to go beyond what is formulated by regulation. In developing countries, it is recommended that a policy-mix between EI's and CAC's be implemented (UNEP, 2005: 2). Montevecchi (2016: 2) notes that, when compared to a single policy instrument that is employed in isolation, policy mixes tend to yield a higher performance towards given policy objectives. Policy mixes are preferred over stand-alone policy instruments since they are better at achieving the two objectives of solid waste management; to cover costs and thus improve service delivery, and to influence behaviour by means of the pricing mechanism aimed at waste minimisation, avoidance of negative impacts (e.g., from landfilling) or to strengthen resource recovery and recycling (Federal Ministry for Economic Cooperation and Development, undated: 5). Other waste management options include waste-picking schemes. Simatele *et al.* (2017) conclude that the informal waste sector (specifically, waste pickers) play a significant role in solid waste management, particularly in waste collection and recycling.

2.2) Empirical evidence on the relationship between waste and the economy

There is an array of empirical literature investigating the relationship between environmental degradation and economic conditions. This section summarises the empirical findings related to the objectives of this study. In section 2.3.1, a description of the various methods for obtaining empirical results investigating the relationship between waste and the economy is provided. In section 2.3.2, literature investigating the WKC hypothesis is summarised. Lastly, in section 2.3.3 and 2.3.4, a breakdown of the explanatory variables (policy and socio-economic variables), used in empirical literature are discussed and summarised.

2.3.1) Research methods

Literature that investigates the relationship between waste generation and the economy and the effect of influencing drivers on waste generation has been making headway, however, there exists differences between methodologies, data and definitions used in the literature (Grazhdani, 2016: 4).

The methods within the existing literature act as an important guiding tool for this study. According to Grazhdani (2016:5), methodologies used by researchers investigating the waste-economy relationship range from regression analysis and group comparison trend analysis, to artificial intelligence models. This study makes use of regression analysis, using municipal-level data. Regression modelling is widely employed in EKC analysis due to the availability of developed theory and simple algorithms (Grazhdani, 2016: 5).

This study utilises municipal-level time-series datasets. Time-series regression is widely employed in research investigating environmental degradation and its relation to the economy in an individual study area. The environmental component of these studies are often greenhouse gas (GHG) emissions (Abid, 2015; Jalil & Mahmud, 2009; Ozturka & Al-Mulalib, 2015; Shuai Chen, She, Jiao, Wu & Tan, Yang 2017[3]; Tutulmaz, 2015; and Yang, Yuan & Sun, 2012).

Whilst it is more common to investigate delinking of waste using a panel data regression, there are studies investigating the WKC hypothesis using time-series regression (Magazzino, Mele & Schneider, 2020; Miyata, Shibusawa, & Hossain, 2013; Wu, Zhang, Xu & Che, 2015; and Yang *et al.*, 2012). Despite the drawback of having to account for serial correlation and individual heterogeneity when using time-series linear regression, there are benefits in using such a dataset. As highlighted by Jalil and Mahmud (2009: 5168), using time series data on a single country or city level can provide a better framework for understanding the relationship between the economy and environmental degradation. Moreover, this type of analysis allows for the examination of various policies and other exogenous factors that may apply singularly to the country or city of study, thus allowing for more appropriate and targeted policy suggestions (Jalil & Mahmud, 2009: 5168). This is further reinstated by Chang and Lin (1997: 167), who argue that these models are flexible enough to allow for policy intervention adaptions. With panel data, this may not be possible since not all cities employ the same policy interventions.

The secondary objective of this study is to identify indicators that influence waste generation rates. These indicators, namely socio-economic and policy variables, can be included in time series models, however, caution is drawn when including too many variables due to greater chances of autocorrelation (Simonoff, 2020).

2.3.2) Empirical findings on the WKC

Several studies have investigated whether economic growth can ultimately resolve the issue of increasing waste generation by testing the WKC hypothesis. Typically, economic studies geared around waste management investigate three primary objectives; the general relationship between waste and the economy, testing of the WKC, and testing which indicators impact waste generation rates the most.

It can be shown that the scale of the empirical data used for investigating the relationship between waste and the economy often informs the findings reported by authors. Table 2.1 summarises these results. Ercolano, Gaeta, Ghinoi, & Silvestri. (2018), note that the majority of cross-national studies show evidence of a monotonically increasing relationship between

[3] Shuai *et al.* (2017) investigates the EKC using both panel and time series data.

waste generation and the economy. Although the cross-country results of a non-existent WKC is presiding, these conclusions are not unequivocal. Raymond (2004) finds evidence of a U-shaped WKC when investigating empirical evidence provided by 142 countries.

On a single-country level, case studies utilise more concise datasets that better inform sub-national administrative targets. An example of such a study is provided by Mazzanti *et al.* (2008), who apply a dataset of 103 Italian provinces from 2000 to 2004 to an empirical model. Their findings are in support of an inverted U-shaped WKC for waste and per capita added value. Similarly, Magazzino *et al.* (2020) confirm the existence of the WKC in Switzerland for the years 1990-2017. Wu *et al.* (2015) find the same result when using pooled data of 31 provinces in China, using data from 1997-2011.

Lastly, municipal-level studies, which are most appropriate for institutional contexts, whereby municipalities handle administrative and operational tasks surrounding waste management have been conducted in recent years. Ercolano *et al.* (2018) conduct panel regression analysis using a dataset consisting of 1,497 municipalities from the Lombardy region in Italy from 2005 to 2011. They find evidence that supports the WKC, however only several municipalities reach the turning point of the estimated curve. A study by Trujillo, Carrillo, Charris & Iglesias (2013), observe 707 municipalities located in Colombia over the period 2008–2011. They conclude evidence for an inverted U-shaped WKC with a heterogeneous turning point across the regions of the country. Madden *et al.* (2019) use a geographically and temporally weighted regression (GTWR) model to investigate the WKC hypothesis for municipal waste from 2011 to 2015 and find mixed results for the WKC hypothesis.

Given the findings from previous literature in this field, it is emphasised that the WKC results are dependent on the context of the study area. As per the theory discussed in relation to Diagram 2.1, only absolute decoupling of waste is observed when the study area, or municipality, reaches the turning point of the estimated curve. From the above-reviewed literary results, only a few study areas reach the turning point of the estimated curve, implying that it is more common to observe relative decoupling of waste as opposed to absolute decoupling of waste. Provided that this study investigates municipal-level data, and should it be found that the WKC hypothesis holds for the CCT and that the estimated turning point falls within the CCT's income range, absolute decoupling will be present. These results will be corroborated using calculations for the decoupling factor.

Table 2.1: Literature investigating the waste-economy relationship

	Level of Study			
Author(s)	**Municipal**	**Single-country**	**Cross-national**	**Waste-economy Relationship**
Cole, Rayner & Bates (1997)			✓	Waste generation monotonically increases throughout the income range examined
Berrens, Bohara, Gawande, & Wang (1997)		✓		Confirm an inverted-U relationship for two separate indicators of US hazardous waste
Johnstone & Labonne (2004)			✓	Waste generation monotonically increases with income
Raymond (2004)			✓	Waste/consumption stress indicator exhibits an inverted U-shape relation with income
Mazzanti, Montini & Zoboli (2008)		✓		An inverted U-shaped relationship exists with a turning point at very high levels of per capita income
Mazzanti & Zoboli (2009)			✓	Waste generation monotonically increases with income
Karousakis (2009)			✓	Waste generation monotonically increases with income
Trujillo Lora, Carrillo Bermúdez, Charris Vizcaino & Iglesias Pinedo (2013)	✓			Quantity of landfilled solid waste exhibits a WKC relationship with economic development, whose turning point is heterogeneous across the regions of the country
Arbulú, Lozano & Rey-Maquieira (2015)			✓	Results accept the hypothesis for WCK for a panel of 32 European countries
Wu, Zhang, Xu & Che (2015)	✓	✓		WCK accepted for the pooled single region model, and WKC only accepted for two of the three cities analysed
Alajimi (2016)		✓		There is a long-standing relationship between the variables under examination, and that the EKC hypothesis is not valid for MSW in Saudi Arabia
Gardiner & Hajek (2017)			✓	No EKC hypothesis tested but causal relationships are tested. In the short run: bidirectional causal relation running from GDP to waste in Germany, bidirectional causality running from GDP and gross capital formation to waste for the UK. For France, causality running only from gross capital formation to waste was found. In the long run, the variables had no impact on waste in France and Germany. A unidirectional and bidirectional granger causality running from gross capital formation, GDP and employment to waste in the UK.
Ercolano, Lucio Gaeta, Ghinoi, & Silvestri (2018)	✓			Find evidence of an inverted U-shaped curve. However, only a few of the municipalities reach the turning point indicated by the estimated model.
Jaligot & Chenal (2018)	✓			Evidence of EKC cannot be confirmed as waste generation tends to stabalise as income increases.
Madden Florin, Mohr & Giurco(2019)	✓			Both WKC- conforming and non-conforming municipalities identified. WKCconforming municipalities had higher per-capita rates of waste generation, and lower mean incomes comparedto non-conforming municipalities.
Magazzino, Mele & Schneider (2020)		✓		WKC confirmed under time-series regression

Source: Own analysis, based on references as listed in the Table

2.3.3) Empirical findings on explanatory variables

Table 2.2 is a compilation of literature that employs empirical regression methodologies, the applied socio-economic and policy proxy explanatory variables and the fundamental conclusions drawn for the respective variables.

2.3.3.1) Socio-economic Indicators

It is evident that the chosen variables render mixed results. Population density, a common explanatory variable, often used as an urbanisation proxy for waste generation, most often has been shown to have a positively, statistically significant, relationship with waste in the Mazzanti *et al.* (2008) and Mazzanti and Zoboli (2009) studies[4]. In contrast, Jaligot and Chenal (2018) and Ercolano *et al.* (2018) find a negative relationship between waste generation and population density. Jaligot and Chenal (2018: 264) attribute this result to factors such as the differences of waste management strategies in urban areas (more densely populated) and rural areas. Other explanations include that higher population densities may imply a greater level of land resource scarcity; hence a more dedicated approach to preserve land may result in waste minimisation efforts (Mazzanti *et al.*, 2008: 60).

Another common explanatory variable often used in these studies include tourism proxies. Arbulú, Lozano, and Maquieira (2015) and Mazzanti *et al*. (2008) observe that tourism flows have a positive relationship with waste generation. Arbulú *et al.* (2015), exploiting the variables TUR (tourism arrivals) and TUREXPIND (expenditure per tourist index), concludes that tourism inflows exert a significant upward pressure on MSW generation until a turning point is reached, where more tourism arrivals contribute to lowering MSW. The turning point is argued for as follows: an increase in per tourist expenditure implies higher material consumption which subsequently suggests sophisticated preferences and, therefore, a greener demand that incentivises the implementation of greener management by tourism suppliers (Arbulú *et al.*, 2015: 633). Ercolano *et al.* (2018) observe a negative relationship between tourism flows and waste generation, which could be attributed to the above explanation provided by Arbulú *et al.* (2015).

Of the remaining socio-economic variables, which include the proportion of elderly persons, education and unemployment, Chen (2010) and Ercolano *et al.* (2018) report a negative,

[4] Mazzanti and Zoboli (2009) test 3 different dependent variables but this section only summaries the model which tests for MSW generation.

statistically significant, relationship between waste generation and the proportion of elderly persons. Chen (2010: 449) explains this result in that the elderly are more inclined to participate in recycling programs than the younger generation. Other authors who tested this hypothesis, such as Werner & Makela (1998), Mazzanti & Zoboli (2009), find no statistical significance between waste generation and proportion of elderly persons in the population. Struck & Soukopová (2016), who investigate the relationship between population age structure and waste reduction activities in Czech municipalities, also find that the eldest population group contribute the most to separation at source activities. Chen (2010) reports statistically significant results of the relationship between unemployment and waste disposal. This relationship is found to be negative, implying that an increase in unemployment reduces the rate of MSW. Chen (2010: 451) explains that, in rural areas, labourers are forced into tasks such as waste picking and recycling to generate income, thus reducing MSW disposal rates. Arbulú *et al.* (2015) argues that an increase in the unemployment rate reduces the consumption capacity, therefore reducing MSW generation rates.

2.3.3.2 Policy Indicators and Management Suggestions

Policy proxy variables are more complex since they are obtained by researching the specific waste management strategies used in respective study areas. Administrative units in one country rarely have the same waste management strategies and policies as another country. For these variables to best inform this study, it is argued that global case studies which analyse various policy strategies for waste management should be consulted. Table 2.3 offers a broad summary of literature that analyses various waste policy instruments. The literature of which Table 2.3 is compiled, includes research with quantitative (Carattini, Baranzinic & Lalived, 2018; Jaligot & Chenal, 2018; Mazzanti *et al.*, 2008; Massoud, Mokbel, Alawieh & Yassin, 2019; Sjöström & Östblom, 2010 and Wu *et al.* 2015), and qualitative (Greyson, 2006) arguments. For the purposes of this paper, provided that the CCT has not developed any policy variables for waste generation management, an in-depth discussion of these studies are ommitted.

Table 2.2: Explanatory variables used in regression analysis

Author(s)	Socio-economic Explanatory Variables	Policy Proxy Explanatory Variables	Statistically Significant Relationship to Waste Variable
Mazzanti, Montini & Zoboli (2008)	Population density, separated waste collection, tourist flows	Tariff proxy and waste Cost-Recovery proxy	• Population density: positively statistically significant • Separated collection: negatively statistically significant • Tourist flows: positively statistically significant • Tariff proxy: positively statistically significant • Cost-Recovery proxy: negatively statistically significant
Mazzanti & Zoboli (2009)	Population density, urban population, household size, single households, age index, share of munufacturing value added.	Decentralised waste management policy drivers, Incineration directive, Landfill directive, Waste strategy policy index, landfill strategy policy directive	• Population density: positively statistically significant • Urban population: positively statistically significant (except REM model) • Share of munufacturing value added: negatively statistically significant
Chen (2010)	Population density (POPD), old age composition (OLD), unemployment (UNEMP), education (EDU)		• POPD: positively statistically significant • OLD: negatively statistically significant • UNEMP: negatively statistically significant
Arbulú, Lozano & Rey-Maquieira (2015)	International inbound tourists arrivals (TUR), Tourist expenditure index (TUREXPIND), Merchandise trade (TRADE), Dummy variable–tourism especialization (DX_Q1), Unemployment rate (UNEMP) Rural population (RURP), Government effectiveness (GOVEFF) & Education (EDU)		• TUR: positively statistically significant • TUREXPIND: negatively statistically expenditure • TRADE: positively statistically significant • DX_Q1*TUR: positively statistically significant • UNEMP: negatively statistically significant • EDU: negatively statistically significant
Wu, Zhang, Xu & Che (2015)		1) Regional level: Environmental Policy dummy; domestic garbage harmless treatment rate (HLT) 2) City level:Dummy of the waste charges policy (D): fixed disposal fee, potable water-based disposal fee and a plastic bag-disposal fee	• HLT: negatively statistical significant • Plastic bag-based disposal fee: negatively statistically significant
Alajimi (2016)	Population growth		• Population Growth: positively statistically significant
Gardiner & Hajek (2017)	Gross capital formation (CAPIT), employment (EMPL)		• CAPIT: positively statistically significant for France, Germany and the UK • EMPL: only negatively statistically significant for Germany
Jaligot & Chenal (2018)	Population density	Variable waste tax (BTAX) and a fixed waste tax (FTAX)	• Poor significance overall but finds that population density is negatively correlated to waste generation • BTAX: negatively statistically significant
Ercolano, Lucio Gaeta, Ghinoi, & Silvestri (2018)	Population density, consumption by the elderly (OLDSHARE), tourist receptivity rate (ACCOMODATION) and share of foreign residents (FOREIGN)		• Population density: negatively statistically significant • OLDSHARE: positively statistically significant • ACCOMODATION: positively statistically significant • FOREIGN: negatively statistically significant
Madden Florin, Mohr & Giurco(2019)	Population density (POP.DENS), number of households (HHLDS), household size (HHLD.SIZE) and distance to urban areas (DIST.URBAN)	proportion of recycling (PROP.REC)	In their global model: • PROP.REC: positively statistically significant

Source: Various authors (2008-2019); Constructed by author

Table 2.3: Summary of literature that analyses various waste policy instruments

Author(s)	Geographical Area	Time period	Policies / Waste Management Suggestions	Policy Implications
Greyson (2006)	NA	NA	1) Precycling insurance scheme	1) Precycling insurance scheme: although newly implemented in China under the 'Law on the Promotion of the Development of Circular Economy', it claims to have several benefits for producers, the environment and society.
Mazzanti, Montini & Zoboli (2008)	103 Italian Provinces	1999-2005	1) Tariff proxy (Share of population living in municipalities that introduced a waste tariff substituting the former waste tax) 2) Waste Cost-Recovery proxy (tax or tariff revenues on variable service costs)	1) TARIFF is positively and significantly correlated to waste generation, showing a possible signal of endogeneity of policy cycles with regard to income: Richer areas show a stronger environmental policy commitment. 2) Cost-recovery, which captures the way the approach to waste management is moving toward an "enterprise approach", has a statistically significant and negative relationship with waste generation
Sjöström & Östblom (2010)	Sweden	2006–2030.	1) Preventative policy instruments (i.e.: virgin material taxes) 2) Household behaviour policy instruments	To achieve absolute decoupling: 1) Preventative taxes such as virgin material taxes can affect production techniques to reduce waste generation 2) Policy instruments must affect the pattern of household consumption such as a differentiation of the value added tax (VAT) in favour of goods and services, which reduce the waste intensity of household consumption.
Wu, Zhang, Xu & Che (2015)	31 provinces in mainland China	1997 - 2011.	1) Fixed disposal fee: charging a set amount per household per month 2) Potable water-based disposal fee: charging disposal costs based on potable water consumption per household per month 3) Plastic bag-based disposal fee: based on the weight / volume produced by households per month. Requires households to pack their waste in plastic bags sold by local government at a set price per month	1) the MSW policies implemented over the study period were effective in reducing waste generation, 2) the household waste discharge fee policy did not act as a strong driver in terms of waste prevention and reduction, and 3) the plastic bag-based disposal fee appeared to be performing well according to qualitative and quantitative analysis.
Jaligot & Chenal (2018)	Canton of Vaud, Switzerland	1996-2015	1) Variable waste tax (BTAX) 2) Fixed waste tax (FTAX)	1) BTAX is negatively and significantly correlated with MSW generation, which shows that specific charge policies are effective to reduce MSW generation.
Carattini, Baranzinic & Lalived (2018)	Canton of Vaud, Switzerland	2008 to 2015	1) Pricing garbage by the bag (PGB)	1) PGB is highly effective, reducing unsorted garbage by 40%, increasing recycling of aluminium and organic waste, without causing negative spillovers on adjacent regions
Massoud, Mokbel, Alawieh & Yassin (2019)	Lebanon, Western Asia	NA	1) Centralised approach to waste management 2) Decentralised approach to waste management	1) Delegation and the construction of centralised treatment facilities is recommended as it incentivises municipal cooperation and permits the installation of methodologies and technologies that reflect the limitations, public attitudes, and waste dynamics of each distinct geographical territory 2) Deconcentrating disposal would limit the number of landfills constructed and facilitate monitoring

Source: Various authors (2006-2019); Constructed by author

3. Data and Methodology

The empirical process employed in this study follows the format provided by Shrestha & Bhatta (2018). Time-series regression analysis is conducted to determine the long- and short-term relationships between per capita MSW and per capita GVA, as well as to investigate the existence of a WKC and to determine the relationship between other socio-economic factors on per capita MSW generation rates. Before the model specification can be determined, the stationarity of the variables' series is investigated through unit root tests. The cointegrating relationships between variables are investigated through cointegration tests. These tests will determine whether an OLS estimation, an ARDL estimation, an ECM model or all three model specifications can be run.

The data used in the section comprises both of primary and secondary sources. The time-series dataset ranges from 1997 to 2019. Waste data, specifically the values for total MSW and amounts of waste diverted via the 'Think Twice' programme had been obtained from the CCT's Solid Waste Department (2020b). The primary data for waste as provided by the City is available for the years 2007-2019. For the years 1997-2006, statistics reported on data for waste as provided by the City at that time by De Wit, Swilling and Musango (2008) are used. Statistics reported in financial years are converted to calendar years to ensure identical units of measurement are achieved throughout the dataset.[5]

Statistics on the Real Gross Value Added (RGVA), Population, Population Density, Population by Age Group and Unemployment values for the CCT are accessed from the Quantec data portal (2020). Tourism values are gathered from the Statistics South Africa Tourism and Migration archived publications (StatsSA, 2020a). The proxy values used for tourism are the values derived from 'Foreign Arrivals into the Cape Town International Airport'. It is argued by Ercolano *et al*. (2018) and Hage, Sandberg, Söderholm & Berglund (2008), that using foreign travelers as a proxy for tourism flows is suitable, since international travelers may face notable difficulties in understanding recycling rules in host countries. Studies that consider foreign / international tourists / residents as a tourism proxy include Ercolano *et al*. (2018) and Arbulú *et al*. (2015).

Multiple methods are used in this study is to meet all objectives of this study and to ensure the robustness of the findings. Once the descriptive statistics, relevant variable transformations,

[5] For example, financial year 2006/2007 is reported as calendar year 2006.

unit root[6] and cointegration[7] tests are run, and described, the methodological process continues as follows: the first model presented is a simple linear model regressing GVA per capita and GVA^2 per capita on MSW per capita. This model is extended to include socio-economic explanatory variables, population density ($POPD$), share of elderly (60+ years) population (OLD_SHARE) , share of unemployed population ($UNEMP$) and tourism flows ($TOUR$). This model expansion is done by including one variable at a time, firstly including the variables considered to be most influential on MSW generation, to variables considered to be the least influential[8]. These results are then analysed in terms of the relationship between MSW generation and economic growth, whether the WKC exists and whether there is evidence of decoupling. Furthermore, the decoupling factor is calculated to cross-check whether the decoupling results from the regression model are robust. Finally, to analyse the effects of policy interventions, a segmented linear regression is used, as proposed by Lagarde (2012). This investigates the effectiveness of the Think Twice Programme. The above-described results act as an informative tool for policy decision-making in the CCT.

For the primary objective of determining the relationship between MSW generation and economic growth, and to test the WKC hypothesis, the method selection process for the time series data is adopted from EKC literature. Empirical literature applying these time-series regression techniques, of which this study's methodologies are derived, include Madden *et al.* (2019); Shahbaz, *et al.* (2010); Shuai *et al.* (2017) and Miyata *et al.* (2013). Here the specification of the EKC model using time-series data is defined and the parameters are discussed and regressed.

The specification of the EKC model, in its functional form is as follows (Shuai *et al.*, 2017: 1033):

$$E = f(Y, Y^2, Z) \qquad (1)$$

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[6] Unit Root tests determine whether the regression is 'spurious' or not.
[7] Cointegration tests determine whether long-run parameters between variables can be determined in the presence of unit root variables.
[8] This is done by considering the results obtained from the explanatory variables described in the literature review.

E represents the Environmental Indicator of study, in this case, per capita MSW. *Y* is the income proxy variable, which is per capita GVA[9]. *Z* represents other explanatory variables which may impact the rate of per capita MSW. Whilst most EKC studies omit Z, Harbaugh Levinson & Wilson. (2002:541) observe that, by omitting explanatory variables there is not only potential for omitted variable bias, but it can completely alter the shape of the estimated EKC curve, producing vastly different results compared to studies that do include other explanatory variables. Equation (1) can be log-transformed, which, as indicated by Shahbaz Jalil & Dube, (2010); Cameron (1994) and Ehrlich (1975, 1996), provide more appropriate and efficient results relative to simple level-level regression models. Moreover, the log transformation is preferred since coefficients can be directly interpreted as elasticities. The (natural) log-transformed WKC model for this study, which provided the long-run relationships between variables, is given as:

$$LMSW = \alpha + \beta_1 LGVA + \beta_2 LGVA^2 + \beta_3 LPOPD + \beta_4 LTOUR + \beta_5 OLD\_SHARE + \beta_6 UNEMP\_SHARE \quad (2)$$

LPOPD is the population density (number of inhabitants / km^2), which is used as an urbanisation proxy. *LUNEMP_SHARE* is described as the share of the population which is unemployed. *LOLD_SHARE* is described as the share of the population 60 years or older. *LTOUR* is the number of foreign arrivals into Cape Town International Airport. THINK_TWICE, not listed in equation (2), is the amount of waste diverted via the Think Twice initiative. This variable is later described in the segmented regression model. To determine whether the WKC results estimate an accurate turning point, equation (3) will be used to determine the income at the turning point of model (2), which will then be compared with the mean GVA of the given period (Madden *et al.*, 2019: 679):

$$\exp\left(-\beta_1/[2\beta_2]\right) \quad (3)$$

The results from equation (2) are then compared with the decoupling factor equation and a graphical representation of MSW and GVA growth to determine whether the decoupling of waste is accurately represented in the regression results. Finally, the segmented linear regression is specified in subsequent sections, and is used to determine the policy effectiveness

[9] Gross Value Added (GVA) is the value of goods of services produced within a given area, minus all input costs and raw materials used in the production process. The per capita GVA is GVA / total population.

of the Think Twice programme. To compute and run the above models, various variable transformations and series tests need to be done to determine the nature of the dataset and to determine the appropriateness of selected models.

3.2) Descriptive statistics and data transformations

MSW per capita is converted from tonnages to kilograms to ensure comparability with existing literature. GVA is reported in per capita terms. The mean of GVA per capita is R 60,693.93, which will later be compared to the turning point of the estimated WKC, should one exist. As discussed above, log-transformations are preferred. All variables, barring *UNEMP_SHARE* and *OLD_SHARE*, are log-transformed. The descriptive statistics for the transformed variables are shown in Table 3.1. All variables need to be tested for stationarity and cointegration prior to running the respective models.

Table 3.1: Descriptive Statistics of log-transformed

Variable Acronym	*N*	*Mean* (*SD*)
LMSW	23	6.319018 (0.211116)
LGVA	23	10.92357 (0.451141)
LPOPD	23	7.236608 (0.163282)
UNEMP_SHARE	23	7.804712 (2.035574)
OLD_SHARE	23	8.231671 (0.866225)
LTOUR	21	13.11396 (0.294356)

(Source: Own analysis based on various data sources)

3.3) Unit Root and Cointegration Tests

Unit Root tests are conducted to determine the stationarity of a series. The presence of non-stationary variables within a regression may lead to 'spurious' results, which render the estimated parameters inappropriate for inference. For time-series data, the augmented Dickey-Fuller (ADF) and the Philips-Perron (PP) unit root tests are widely employed to determine stationarity (Shrestha & Bhatta, 2018 :74). Tables 3.2 and 3.3 present the results of the ADF and PP unit root tests, respectively.

Table 3.2:
ADF test results

Variable	Intercept				Trend and Intercept			
	Level		First Difference		Level		First Difference	
	t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value
LMSW	-1.922	0.3162	-3.116	0.0407**	-1.957	0.5894	-3.399	0.0783*
LGVA	-2.223	0.204	-3.436	0.0211**	0.203	0.9963	-4.776	0.0058***
LPOPD	2.136	0.9998	-3.324	0.0266**	-0.548	0.9722	-4.103	0.0207**
UNEMP_SHARE	-1.634	0.4491	-3.491	0.0188***	-2.923	0.1762	-3.443	0.0724*
OLD_SHARE	4.854	1	0.937	0.9938	2.982	1	-4.342	0.0129***
LTOUR	-0.217	0.9213	-3.551	0.0178***	-3.760	0.0478**	-3.450	0.0744*

, **, and * indicate statistical signifcance at the 10%, 5%, and 1% levels respectively.*

Table 3.5:
PP test results

Variable	Intercept				Trend and Intercept			
	Level		First Difference		Level		First Difference	
	t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value
LMSW	-1.296	0.6122	-3.069	0.0446**	-1.023	0.9195	-3.343	0.0867*
LGVA	-2.153	0.2275	-3.533	0.0172***	0.263	0.9969	-15.70	0.00***
LPOPD	2.136	0.9998	-3.622	0.0143***	-0.548	0.9722	-4.116	0.0202**
UNEMP_SHARE	-1.630	0.4507	-3.485	0.0191***	-1.938	0.6008	-3.437	0.0732*
OLD_SHARE	12.563	1	-0.907	0.7652	2.481	1	-4.345	0.0128***
LTOUR	-0.405	0.8904	-3.609	0.0158***	-1.600	0.7561	-3.520	0.0657*

, **, and * indicate statistical signifcance at the 10%, 5%, and 1% levels respectively.*

From the ADF and PP unit root tests, all series are of I(1); with stationary at first differences. Given that the statistical significance of the first difference of LTOUR, is greater than when the series is at level, this variable is differenced to obtain integration I(0). This is reinforced by the graphical representations of each level / log variable to the differenced variable, whereby, after applying first differences to the variables, there is reversion to the mean. Appendix A provides the graphical representations of transformed variables from log to log-differenced.

Since all series are integrated of order 1; I(1), using Ordinary Least Squares (OLS) or similar methodologies to derive estimates, may provide spurious results. To determine whether the long-run relationships amongst the variables are spurious or not, Engle and Granger (1987) have developed cointegration tests to analyse the relationships between non-stationary variables. Johansen (1988) and Johansen and Juselius (1990) have since improved the weaknesses of the Engle and Granger (1987) methodologies[10] and developed the Johansen cointegration test models. The Johansen cointegration test can be applied directly should all variables be non-stationary, which, given the ADF and PP test results, applies to this dataset.

A Johansen cointegration test is applied for the following annual series'; LMSW, LGVA, LGVA2, LPOPD, UNEMP_SHARE and OLD_SHARE. Whilst the LTOUR series shows evidence of cointegration with the other series (refer to Appendix B), it does not contain the years 1997 and 1998, therefore, to ensure comparability, it is omitted. The Johansen cointegration test result rejects the Null Hypothesis of no cointegration, and the alternative, that there is cointegration between investigated variables is accepted.

Whilst some studies do not run the Engle-Granger cointegration test, it is acknowledged that the Johansen cointegration may not always be reliable for small sample sizes. As such, to ensure cogent results, the Engle-Granger two step cointegration procedure is conducted. The tau value of | -4.369346| is compared to that of the Engle-Granger critical table with a constant and no trend[11]. The Null Hypothesis of no cointegrating equations is rejected and the alternative is accepted at a 1%, 5% and 10% critical value. From both the Johansen cointegration, and the Engle-Granger test results, the variables are cointegrated.

4. Results and discussion

This section provides the relevant model results and estimations to assist in meeting the objectives of (i) determining the relationship between MSW generation and economic growth, (ii) investigating the WKC hypothesis for the CCT and (iii) identifying the main socio-economic and policy drivers of MSW generation. As indicated by the test results provided in Section 3, OLS and ARDL models can be run to investigate the relationship between per capita MSW and per capita GVA, as well as to determine the existence of a WKC and the relationship between other explanatory socio-economic variables and per capita MSW generation. This section begins by addressing these objectives in Section 4.1. by computing 5 OLS models. To determine the long- and short-run relationships between variables, an ARDL estimation technique is employed, following the same process as the 5-step OLS model format. To

[10] These weaknesses refer to the Engle and Granger (1987) unit root test showing more than two cointegrating relationships when considering more than two variables.
[11] The tau value of the residual ADF when LTOUR is included in the estimation equation is -4.726911, rendering analogues results.

determine which model is most appropriate for analysis, diagnostic tests are run. The final chosen model is discussed. Section 4.2. determines the efficacy of the Think Twice programme as a policy variable. This section also controls for periods of economic decline to determine the effects of the 2008/2009 economic crash and the 2018 economic recession in South Africa.

4.1) Investigating the relationship between MSW generation and the economy

This section conducts empirical analysis to answer the first set of objectives; whether economic growth and MSW generation are related, whether the WKC is present for the CCT, whether there is evidence of decoupling, and what socio-economic drivers affect waste generation.

Once cointegration amongst variables have been confirmed, the parameters of the variables in WKC estimation model can be computed. The first estimation technique adopted is the OLS estimation, as described by the model specification (2) in Section 3 (Madden *et al.*, 2019; Miyata *et al.*, 2013; Shabaz *et al.*, 2010: and Shuai *et al.*, 2017). It is acknowledged that employing an OLS regression to a small dataset is not preferred. Provided, this study computes an Autoregressive Distributed Lag Model (ARDL), which is more appropriate for smaller and finite datasets and provides long-run unbiased estimates (Nkoro & Uko, 2016: 76).

The OLS model is run by using a 5-step procedure, with the first model regressing GVA and GVA^2 on *LMSW*. Model 2 includes the variable *LPOPD*, which is the most adopted variable in EKC and WKC literature. Model 3 includes the variable *LTOUR*. Whilst this variable does reduce the model by two years, it has been identified as an important driver of MSW generation in waste management literature. Model 4 includes the variable *OLD_SHARE*, which has been found to show ambiguous results in the literature. Lastly, Model 5 includes *UNEMP_SHARE*, which is mostly found to have a negative effect on MSW generation in the literature. For all models, a one-period lag of *LMSW* is included under the expectation that past solid waste generation rates influence waste management decision-making, and therefore, would be a driver of waste generation rates in the future.

The OLS model output is presented in Table 4.1.1. An optimal lag structure, using the Akaike Information Criteria (AIC), most appropriate for smaller datasets, is used when computing the OLS estimation. *LPOPD* has a positive statistically significant effect on *LMSW* in Model 4, however this is only statistically significant at a 10% level of significance. *LTOUR* has a negative statistically significant effect on *LMSW* in Model 3, at a 5% level of significance.

Ercolano *et al.* (2018) finds a similar result. When diagnostically tested, however, this model (Model 4) shows evidence of heteroscedasticity, using the Breusch-Pagan-Godfrey Heteroskedasticity Test, rendering the Standard Error incorrect. Finally, per capita MSW generation in the previous period, has a positive statistically significant effect on future per capita MSW generation rates for all models.

Table 4.4.1:
OLS estimation output

	Dependent Variable: LMSW									
	Model 1		Model 2		Model 3		Model 4		Model 5	
Variable	β Estimate (SE)	T-value	β Estimate (SE)	T-value	β Estimate (SE)	T-value	β Estimate (SE)	T-value	β Estimate (SE)	T-value
C	-33.03706 (27.21018)	-1.214	5.598591 (77.66641)	0.072	-101.8398 (108.1042)	-0.942	-141.3118 (106.3657)	-1.329	103.4521 (134.239)	0.771
LMSW(-1)	0.717261*** (0.20947)	3.424	0.663882*** (0.236095)	2.812	1.042711*** (0.291585)	3.576	1.187786*** (0.293788)	4.043	0.957386*** (0.26786)	3.574
LGVA	6.552879 (5.127385)	1.278	0.970404 (11.71391)	0.083	16.6569 (16.33933)	1.019	10.68818 (16.07699)	0.665	-25.58891 (20.07779)	-1.274
LGVA2	-0.307638 (0.23604)	-1.303	-0.02555 (0.581791)	-0.044	-0.807753 (0.807606)	-1.000	-0.650122 (0.778347)	-0.835	1.131217 (0.979423)	1.155
LPOPD			-1.52402 (2.861122)	-0.533	3.395065 (3.954509)	0.859	15.43777* (8.604991)	1.794	7.349795 (8.049021)	0.913
LTOUR					-0.646123** (0.31443)	-2.055	-0.073514 (0.474763)	-0.155	-0.299508 (0.416084)	-0.720
OLD_SHARE							-1.182311 (0.758987)	-1.558	-1.10116 (0.649843)	-1.695
UNEMP_SHARE									0.116331 (0.046924)	2.479
Observations:	23		23		21		21		21	
Adjusted R^2	0.5148		0.4947		0.5734		0.6104		0.71518	
P-value	0.0010		0.0030		0.0022		0.0023		0.00065	
Durbin-Watson	1.3541		1.3636		1.9883		2.1466		2.42864	
Turning Point	R43,088		R182,016,489		R30,324		R3,517		R81,675	

, **, and * indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

Under the ARDL specification, the dependent variable is a function of its lagged values and the current and lagged values of other explanatory variables in the model. The ARDL method has often been applied in EKC research (Alrajhi & Alabdulrazag, 2016; Islam, Shahbaz & Butt, 2013; Köhler & de Wit, 2019 and Yang, 2019). A 5-step modelling procedure for the ARDL model is run, following the same process as the OLS estimations. Various diagnostic tests on each model are run to test which model is best-fitted for hypothesis testing . Model 2, the ARDL (1,1,1,1) Model, produces the best diagnostic test results to perform hypothesis testing. A CUSUM test for stability further reinstates that there are no structural breaks and that the model is stable

Economists and policy-makers are concerned with long-term relationships between variables. The ARDL Least Squares estimates are reparamitised into the Conditional Error Correction Model (ECM) – presented in Appendix C. The results from the ARDL bounds test indicate that there exists a long-run relationship, but only at 10% level of significance. Only the ARDL ECM short-run estimates are analysed, all of which, show statistical significance, rendering them appropriate for analysis (Table 4.1.2).

Table 4.1.2:
ARDL ECM regression output

Short Run Estimates			
Dependent Variable: D(LMSW)			
Variable	β Estimate (SE)	T-value	P-value
D(LGVA)	-52.6524** (20.43400)	-2.576707	0.0219
D(LGVA2)	2.44673** (0.954702)	2.562821	0.0225
D(LPOPD)	-15.4537*** (4.133416)	-3.738731	0.0022
CointEq(-1)	-0.53099*** (0.144117)	-3.684420	0.0025
Adjusted R^2	0.374		
AIC	-1.172851		

, **, and * indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

From these estimates, in the short run, *LGVA* is shown to have a negative statistically significant relationship with *LMSW* generation. This relationship is occurring at an increasing rate, as shown by the squared GVA coefficient, which is also statistically significant. This implies that, rather than observing an inverted U-shaped relationship, the CCT's waste generation and economic growth exhibit a positive parabolic (U-shaped) trend and there is no evidence of a Waste Kuznets Curve in the short-run. The turning point of the estimated U-shaped curve is found at R47,086.83 per capita, and, given that the average annual income for the time-period under investigation is R60,693.93 per capita, the CCT is situated on the inclining segment of the U-curve. This suggests there is relative short-run decoupling of waste from economic growth. To determine the long-run status of decoupling, the Decoupling Factor equation is used. To determine the annual fluctuations of waste decoupling, indexed values of per capita GVA and per capita MSW are plotted.

The results of the short-run estimates are cross-checked by calculating the Decoupling Factor (D_f)[12] and by analysing the per capita GVA and per capita MSW indices. The D_f for the entire period (1997-2019) is 0.713, implying that long-run decoupling of waste is relative. To determine short-run fluctuations of waste decoupling, indexed (growth) values (using 1997 = 100) of MSW per capita and GVA per capita are plotted and reported in Figure 4.1.3. Between 1997 and 1999, where per capita $MSW_{1997=100}$ is above per capita $GVA_{1997=100}$, there is no decoupling of waste. Relative decoupling of waste took place between 2000-2006 and 2008-2017. The CCT experiences absolute decoupling of waste between 2006-2008 and 2017-2019. Evidently, during the study period of 1997-2019, the CCT has mostly been experiencing relative decoupling of waste, with short fluctuations of absolute decoupling of waste. Financial and economic downturns, which effect consumer purchasing power may explain why these periods of absolute decoupling occur briefly (Khajevand, 2016). Ruiz-Peñalver, Rodríguez and Camacho (2019), Rodriguez, Ruiz-Peñalver & Camacho-Ballesta (2016) and Khajevand (2016), conclude that the overall reduction in waste generation is explained by a downturn in the economy. From an empirical standpoint, the speed of these adjustments of these short-run fluctuations towards long-run equilibrium is given by the Error Correction Term (ECT), which is presented in Table 4.1.2's ARDL ECM short-run estimation output. The speed of adjustment brought about by external shocks, such as the global financial crises, is -0.5. This suggests, that even in times of economic contractions, the CCT cannot rely on the economy to reduce per capita MSW generation. In times of economic downturn, whilst the CCT does experience reductions in per capita MSW generation rates, this is brought about by a reduction in consumption and is not sustainable. Declining MSW generation rates are, therefore, signals of economic stress.

Finally, whilst most socio-economic variables are shown to be insignificant using the OLS and ARDL model, population density, as an urbanisation proxy, is shown to have a negative statistically significant relationship with LMSW generation in the ARDL ECM model. This result, which is ambiguous in the literature, is analogous with Jaligot & Chenal (2018), Ercolano *et al.* (2018) and Madden *et al.* (2019). This effect can be attributed to these areas having a higher proportion of high-density residential development, where rates of per-capita generation are typically lower due to, for example, reduced green waste generated (Madden *et al.*, 2019: 681). Jaligot & Chenal (2018) and Ercolano *et al.* (2018) argue that decreases in

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[12] To reiterate, if $0 < D_f > 1$, relative decoupling exists.

land availability implies greater scarcity of land resources, which spurs directed efforts towards waste minimisation strategies to preserve land scarcity.

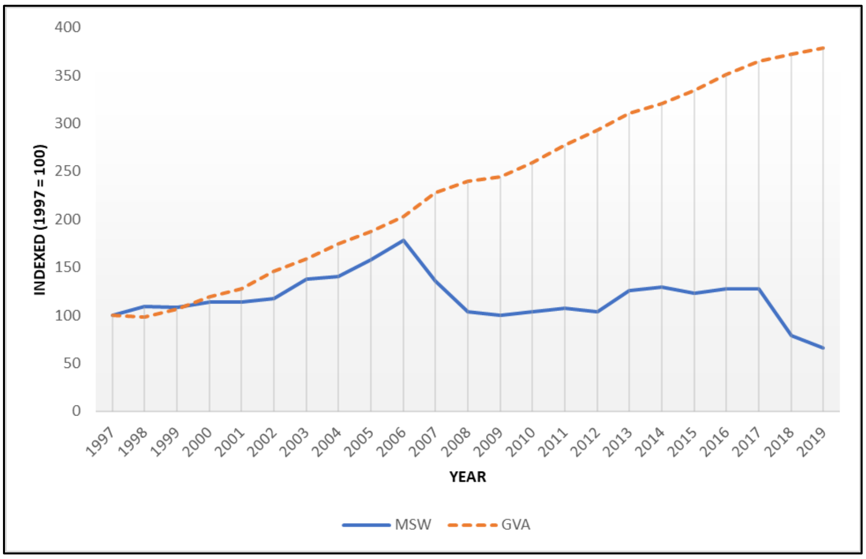

Figure 4.1.3: Absolute and relative decoupling analysis for the CCT

(Source: Own analysis)

In summary, the short-run relationships between per capita MSW and GVA exhibit a U-shaped curve. In the long run, the estimates show evidence of the WKC, however, the statistical insignificance of these estimates render the analysis ineffectual. The implications of these results suggest that, whilst economic growth generation may have a negative relationship with MSW in the short run, the CCT cannot fully rely on economic growth alone to reduce waste generation in the long run. This is further expressed by calculating the U-shaped curve's turning point and graphical representations of per capita $MSW_{1997=100}$ and per capita $GVA_{1997=100}$. CCT is mostly experiencing relative decoupling of waste from economic growth, with short periods of absolute decoupling of waste. Furthermore, other possible drivers of per capita MSW generation reduction need to be accounted for when considering these policy suggestions, such as the rate of urbanisation, or more directly; population density.

4.2) Investigating waste policy effectiveness

This section begins by investigating the efficacy of the Think Twice recycling programme using a segmented linear regression. The segmented linear regression is often conducted in health and medical studies to inform the effectiveness of health interventions (Lagarde, 2012 and Wagner, Soumerai, Zhang & Ross-Degnan, 2002). This method of analysis has expanded to other domains of research. Stinson and Lubov (1982) compute a segmented linear regression to determine how population changes effect government expenditures, specifically, expenditures related to police services. More pertinent, Park and Lah (2015) consider the efficacy of a volume-based waste fee on recycling rates in South Korea.

To determine the impact of the Think Twice recycling programme on per capita MSW generation, a segmented linear regression is specified. The specification is computed as (Lagarde, 2010: 79):

$$Y_t = \beta_0 + \beta_1{}^{*}time + \beta_2{}^{*}intervention + \beta_3{}^{*}postslope + \varepsilon_t \qquad (4)$$

Y_t is the outcome variable at time t. This variable is MSW generated per capita. Time is a continuous variable, ranging from the beginning of the study period (1997) to the end of the study period (2019). β_0, the intercept, is the baseline level of the outcome before the intervention. β_1 estimates the structural trend of utilisation, alternatively, it can be interpreted as the year-on-year change in per capita MSW generation before the intervention. β_2, estimates the immediate effect of the intervention, the Think Twice programme. β_3 represents the change in the trend after the intervention.

Three models are estimated using the specification equation (4). Model 1 does not control for autocorrelation and has a Durbin Watson statistic of 0.8399, suggesting the presence of serial correlation. Model 2 is run using the Prais–Winsten estimator that corrects for data auto-correlation (Lagarde, 2012: 80). Model 2's Durbin Watson statistic of 1.482, however, provides evidence that there is still auto-correlation present in the estimation. Unlike the Lagarde (2010) and Park and Lah (2015) studies, this study proceeds to control for second-order auto-correlation. An OLS regression is computed using 2 lagged variables of the dependent variable (MSW per capita, alternatively termed 'outcome') and is presented as Model 3. The Breusch-Godfrey Serial Correlation LM Test is conducted on Model 3 and confirms that there is no evidence of autocorrelation in the model. All models have statistically significant estimates either at a 1% or 5% level of significance and are presented in Table 4.2.1.

Table 4.2.1:
Regression output for the Think Twice programme

Model 1 *(no correction for autocorrelation)*			
Variables	β Estimate (SE)	T-value	P-value
β0	408.9482*** (55.7228)	7.34	0.000
Secular trend β1	37.35887*** (8.980542)	4.16	0.001
Change in level β2	-196.0036*** (67.83591)	-2.89	0.009
Change in trend β3	-45.46523*** (10.82629)	-4.2	0.000
Model 2 *(correcting for first-order correlation)*			
Variables	β Estimate (SE)	T-value	P-value
β0	410.772*** (90.64515)	4.53	0.000
Secular trend β1	39.23557*** (13.14051)	2.99	0.008
Change in level β2	-178.6816** (74.87226)	-2.39	0.028
Change in trend b3	-55.46049*** (18.69449)	-2.97	0.008
Model 3 *(correcting for second-order correlation)*			
Variables	β Estimate (SE)	T-value	P-value
outcome_L1	0.7125593*** (0.1931839)	3.69	0.002
outcome_L2	-0.4595474** (0.2011652)	-2.28	0.037
β0	248.3189** (103.3544)	2.4	0.03
Secular trend β1	34.79341*** (11.52982)	3.02	0.009
Change in level β2	-163.9043*** (58.02297)	-2.82	0.013
Change in trend β3	-39.62451*** (13.5269)	-2.93	0.01

, **, and * indicate statistical significance at the 10%, 5%, and 1% levels, respectively.*

Lagarde (2012: 81-82) notes that policy interventions may be implemented amidst broader economic changes, which may affect the sector of study. In the period of study (1997-2019), there had been two periods of economic decline. Economic recessions, typically defined as two consecutive periods of economic decline, had occurred in 2008/2009 and in 2018 in South Africa (StatsSA, 2020b). To control for this effect, a dummy variable of South African recession periods is included in the model for the years 2008, 2009 and 2019. The model estimates are presented in Table 4.2.2.

In Model 4, at the beginning of the observation period, the average amount of per capita MSW generated per annum is 183.98 kg. Inter annual changes in the amount of waste generated per person before and after the intervention is shown to be statistically significant, as can be observed from the secular trend β1 and the change in trend β3. Prior to the implementation of the Think Twice initiative, there is an increasing change of the amount of MSW generation on an annual basis, estimated with a 24.5kg increase per capita annually. Immediately after the implementation of the Think Twice initiative, there is evidence of a significant immediate effect of the amount of solid waste generation, whereby solid waste generation is shown to decrease by 125.72 kg per capita. The trend post-intervention shows that per capita waste generation decreases annually by 29.83kg. Most notably, all these above-mentioned values are lower than that of Model 3, mostly due to the decrease in explanatory power from including the 'Recession' variable. The recession variable estimates indicate that, during periods of economic decline (2008/2009 and 2018 specifically), the amount of MSW generated decreases by 118.11 kg/capita on average. This statistical evidence indicates that it is not only the Think Twice programme (or the waste infrastructural developments in 2017) that has resulted in a long-run reduction of per capita MSW generation in the CCT, but rather, economic recessions contribute towards reducing the amounts of per capita MSW generation.

Table 4.2.3:
Regression output for Think Twice and recessions

Model 4 *(correcting for first-order correlation, controlling for economic shocks)*			
Variables	β Estimate (SE)	T-value	P-value
outcome_L1	.5071179*** (.15407047)	3.29	0.005
β0	183.9821** (79.55534)	-2.97	0.034
Secular trend β1	24.57455** (9.023538)	2.72	0.015
Change in level β2	-125.7237** (53.71509)	-2.34	0.033
Change in trend β3	-29.83742** (10.94914)	-2.73	0.015
Recession	-118.115*** (39.82664)	-2.97	0.009

, **, and * indicate statistical significance at the 10%, 5%, and 1% levels, respectively*

5. Policy suggestions for waste management

Provided that the CCT has not yet implemented incentivising structures which minimise MSW generation reduction, there is a need to reform policy design to better achieve goals of absolute decoupling of waste and a greener economy for the waste sector. This section considers the statistical results obtained in this paper to help guide waste policy design. This section begins by reiterating the main findings of the empirical analysis and providing the appropriate policy suggestions for the CCT.

The empirical evidence in Section 4 suggests that the CCT should not rely only on economic growth to achieve desired results of MSW generation reductions in the longer run. From the short-run estimates, economic growth is shown to have an inverse relationship with MSW waste generation, however, this relationship is occurring at an increasing rate, implying that economic growth in the CCT will result in higher rates of per capita MSW generation in the short run.

Evidence from the decoupling factor and the plotted indices of MSW and GVA indicate that the CCT has experienced long-run relative decoupling of waste, with short-run fluctuations of absolute decoupling. These periods of absolute decoupling predominantly occur during years of economic decline, implying that, even if the CCT did rely on the economy to reduce MSW generation, absolute decoupling would not be achieved sustainably.

It is proposed that specific economic policy interventions be designed and implemented to target the goal of MSW reduction. These policy interventions, consisting of complementary instruments (regulatory, economic, and informational), must account for the impacts brought on MSW generation rates during periods of economic growth and economic decline, whereby there is a loosening of policy instruments (such as waste taxes) during periods of economic decline. It is advised that these policy interventions consist of coherent and complementary policy packages that include Economic Instrument's (EI's) and Command-and-Control's (CAC), as well as 'softer' instruments.

Provided the lack of statistical significance from the long-run models, only the short-run relationship between MSW generation and economic growth is analysed. The short-run relationship between the degree of urbanisation and per capita MSW generation is negative, which indicates that an increase in land scarcity, prompted by increases in population densities, has resulted in the promotion of waste minimising strategies to preserve land and resources (Ercolano *et al.*, 2018; Jaligot & Chenal, 2018; and Madden *et al.*, 2019). Provided that the CCT has begun taking a more dedicated approach to waste minimisation through the employment of the IWMP, and other instruments and regulations, this argument is feasible. This is also in line with Wilson, Rodic, Scgeinberg, Velis & Alabaster's (2012) study of global waste management strategies, whereby it is found that low- and middle-income cities are directing investments towards improving controlled waste disposal and waste recovery facilities.

Since long-run relationships between population density and MSW generation cannot be determined, advising policy targets using population density is not advisable from this paper. Moreover, there is uncertainty in the statistical result found between population density and MSW generation, since this relationship could be attributed to the disproportionate amounts of waste generated in construction, manufacturing, and park management[13] (GreenCape, 2020: 15). Provided that this relationship is only found in the short run, this study suggests that per capita MSW generation and population density should be investigated in the long run, by

[13] These streams are often handled by the private sector.

employing other models such as geographically and temporally weighted regression model (GTWR), which requires a panel dataset.

Finally, since the CCT has not employed any EI's which incentivise MSW generation reductions, this study investigates the effect of the Think Twice programme, a waste diversion programme, and how it has impacted the amounts of per capita MSW generated in the CCT. The segmented linear regression results indicate that the success of the Think Twice programme is transient.

Current waste Economic Instrument's employed by the CCT are waste charges that generate revenue, used to finance administrative costs (collection charges based on property value and fixed disposal tariffs[14]). Waste taxes on landfilling and incineration have been argued to have minimal impacts on the amount of MSW generated (Oosterhuis *et al.*, 2009: iv). This is largely on account of households not being able to 'internalise' the incentive of the waste tax. Current waste policy strategies implemented by the CCT are mainly aimed at diverting post-consumer waste; IWEX, Think Twice, composting programmes and deposit-refund schemes.

Since the CCT cannot rely on economic growth to reduce MSW generation rates, it is suggested that policy design be adjusted to include policies that target not only MSW *diversion*, but MSW *generation*. Policies targeted at MSW generation include variable tariffs based on volume or quantity of waste produced; although, it is emphasised that it is difficult to determine the effects of these variable waste taxes on illegal dumping (Oosterhuis *et al*., 2009: 27). Moreover, taxes on raw materials and products are alternative forms of EI's that can be implemented to reduce the amount of waste produced. Unlike collection charges, which are rates on waste at the end of the waste chain (downstream instruments), taxes on raw materials are applied at the beginning of the waste chain (upstream instruments) to financially incentivise producers to avoid using virgin materials and to substitute with production materials that are, and can be, reused and recycled (Oosterhuis *et al.*, 2009: 42). Although there have been considerations of implementing EPR schemes, which target producer waste generation, caution must be drawn when considering these schemes. There are notable financial implications for South African producer responsibility organisations (PRO's) that would discourage them from supporting EPR systems (Le Roux, 2020).

6. Conclusion

[14] See CCT (2017: 44-45) for details of waste collection and disposal tariffs for the CCT.

The purpose of this study is to investigate the relationship between MSW generation and economic growth for the CCT. Furthermore, the extension of this objective includes an investigation of the WKC hypothesis for the CCT and determining the impacts of various socio-economic drivers and waste policy interventions in the CCT. There are several research hypotheses described in the introductory section. The first is that MSW generation is positively correlated to economic growth (as measured by change in GVA) in both the short and long run. The second is that a WKC for the CCT exists, but that only relative decoupling is observable in the long run, with temporary absolute decoupling taking place during economic recessions. The socio-economic driver, population density, is hypothesised to have a positive relationship with MSW generation. Finally, the Think Twice programme is hypothesised to only have an immediate impact of reducing MSW generation.

This study makes use of data and the data sources for the study period (1997-2019) for the City of Cape Town. Statistical tests, relevant for time series datasets are run, presented, and discussed. Regression outputs for the OLS model, the ARDL (ECM) model and the segmented linear regression model are run and presented in Section 4. The conclusion drawn from this section is that no long-run relationship between per capita GVA and per capita MSW can be confirmed. In the short run, there is evidence of a parabolic relationship between per capita MSW and per capita GVA, implying that the CCT is non-WKC conforming. The CCT has experienced long-run relative decoupling of waste with short fluctuations of absolute decoupling of waste for the given period. Here, the hypothesis of an existing WKC for the CCT is rejected, however the hypothesis that only relative decoupling is observable in the long run, with temporary absolute decoupling taking place during economic recessions is accepted. The degree of urbanisation has a short-run negative statistically significant relationship with per capita MSW generation. The long-run relationship between population density and MSW generation remains unanswered, meaning that this study cannot accept nor deny the stated hypothesis that population density increases MSW generation. When investigating the Think Twice programme, it is inferred that this waste-minimising intervention had been successful in the short run, but that periods of economic recession reduce the amount of waste generated in the CCT (with 48% of the reduction of MSW generation between 2008/2009 being explained by the economic recession).

When applying the results found in Section 4, Section 5 provides various waste management policy options for the CCT. It is concluded that the CCT should not depend solely on economic growth to decrease the rate of MSW generation but should rather implement a policy package consisting of complementary instruments. Short-run estimates obtained to determine the relationship between per capita MSW generation and population density cannot fully advise long-run policy objectives. Finally, policy packages must be realigned to target MSW generation, as opposed to only targeting MSW diversion.

The research conducted in this study assists in investigating the relationship between economic growth and MSW generation in the CCT. However, there are several research limitations noted in this study. The empirical findings obtained in this study are based off a relatively small sample (n<30), and, although general relationships between investigated variables have been found, strong causal long-run relationships cannot be identified. Provided that it is unlikely to obtain a larger time-series dataset for this type of investigation, this study suggests that a panel dataset, compiled of data for the broader CCT region, or other South African cities, be obtained. Fixed effects, Random effects and GTWR models can be used to determine similar objectives as outlined by this study, with possible greater statistical significance.

This study had investigated several hypotheses regarding the relationship between MSW generation, economic growth and socio-economic variables. Some of these hypothesis had failed to be statistically determined; therefore, it is suggested that the following relationships be investigated in future research; the long-run (causal) relationship between MSW generation and economic growth in the CCT and the long-run (causal) relationship between population density, tourism flows, unemployment share and the share of the elderly population with MSW generation.

It is further suggested that the policy suggestions that are geared around waste generation and diversion targets should be investigated using Full-Cost Pricing (Accounting) strategies and Cost-Benefit analysis. These approaches should not overlook the possible externalities incurred by the various suggestions, to obtain a socially optimum solution and longer-term sustainable solution. To reiterate, these techniques can be used to determine the (full) costs and benefits of implementing EI’s that target MSW generation, which can then inform policy-makers as to whether these EI’s will provide net municipal and societal benefits if implemented for the CCT.

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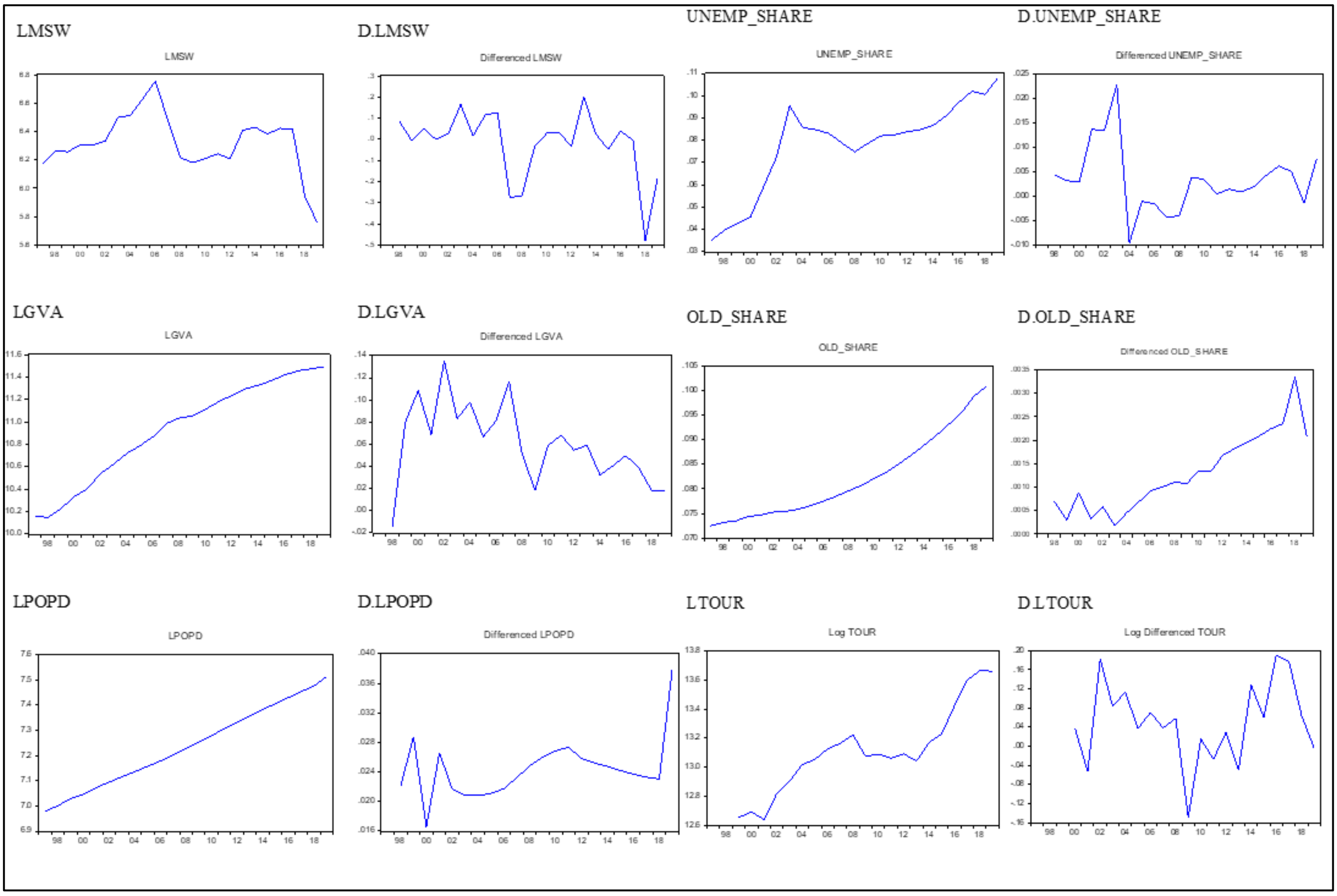
Appendices

Appendix A:

Graphical representation of the logged variable series and the log of the first differenced variable series



Appendix B:

Johansen Cointegration test results for series: LMSW, LGVA, LGVA2, LPOPD and LTOUR

Unrestricted cointegration tank test (Trace)					Unrestricted cointegration tank test (Maximum eigenvalue)				
Hypothesised No. of CE(s)	Eigenvalue	Trace statistics	0.05 Critical value	Prob.	Hypothesised no. of CE(s)	Eigenvalue	Trace statistics	0.05 Critical value	Prob.
None *	0.950065	130.1684	69.81889	0	None *	0.950065	56.94364	33.87687	0
At most 1 *	0.806334	73.22476	47.85613	0	At most 1 *	0.806334	31.19081	27.58434	0.0164
At most 2 *	0.725124	42.03396	29.79707	0.0012	At most 2 *	0.725124	24.53726	21.13162	0.0159
At most 3 *	0.534492	17.4967	15.49471	0.0247	At most 3 *	0.534492	14.52791	14.2646	0.0454
At most 4	0.144656	2.968786	3.841466	0.0849	At most 4	0.144656	2.968786	3.841466	0.0849

Appendix C:

ARDL (1,1,1,1) Model 2 long-run estimate results

Dependent Variable: LMSW			
Long Run Coefficients			
Variable	β estimate (SE)	T-value	P-value
LGVA	35.10715 (33.64889)	1.043337	0.3145
LGVA2	-1.77746 (1.688876)	-1.05245	0.3104
LPOPD	8.097783 (8.324883)	0.97272	0.3472
C	-222.678 (224.3556)	-0.99252	0.3378
	Turning Point:	R19,762	

All models were estimated using Newey-West standard errors to account for the presence of heteroscedasticity and autocorrelation.
, **, and * indicate statistical significance at the 10%, 5%, and 1% levels respectively*