An Analysis of Subsidies within the Plastics Recycling Industry

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Abstract

Polyethylene terephthalate (PET) is widely used in the manufacture of food and beverage containers, in addition to a variety of fibres. PET is considered to be 100% recyclable and can be recycled into a number of different end-use streams: bottle-to-bottle; bottle-to-foodgrade, or bottle-to-fibre. In South Africa, the PET Recycling Company (trading as PETCO) was established to avoid the possibility of government-imposed punitive legislation and to alleviate the impact of PET-based litter. PETCO generates revenue through the collection of voluntary levies from PET manufacturers and supports the recycling of PET through the administration of recycling subsidies and the unlocking of constraints in the PET recycling value chain.

This study sets out to describe the PET recycling industry and empirically assess the effectiveness of PETCO's recycling subsidies through regression analysis. As a background to the regression analysis, the study builds the theory behind production and cost function analysis (in addition to the associated duality theory). However, due to the combination of the research question and the limited data availability, an alternative model was adopted, in order to explain as much variation in production tonnages as possible.

Contrary to logic, the coefficients on the subsidy rates in the regression output were found to be consistently statistically *insignificant* across end-use markets, in addition to regression results that are generally unstable. This could be due to a lack of variation in the subsidy rates over the study period; the use of an inappropriate proxy for recycling firm feedstock costs; or bias in the estimates due to missing variables.

Therefore, detailed graphical and descriptive analyses were conducted in an attempt to further explain the variation in the subsidy rates and production tonnages. This provided the basis for data collection recommendations, to hopefully support more valuable analyses of the subsidy rates in the future. These include the collection of more accurate input cost data; data on local fibre market saturation; and data on production capacity and technological efficiency for the local fibre and foodgrade end-use markets.

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Acknowledgements

The PET recycling company (trading as PETCO) commissioned a study to investigate the efficacy of its recycling subsidies and to identify strategic recommendations for the future. The final report was submitted to PETCO in June of 2015, which then formed the basis of my Masters dissertation. The financial compensation from PETCO helped to fund my Masters study through the University of Cape Town. I am very grateful to PETCO for this support, and also to Oscar Baruffa and Cheri Scholtz of PETCO for their continued support and feedback throughout the study.

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1. Introduction

This study sets out to describe the South African polyethylene terephthalate (PET) recycling industry and empirically analyse the effectiveness of the PET Recycling Company's (trading as PETCO) recycling subsidies.

PET is typically used in the manufacture of beverage and food containers, and a variety of fibres, and is essentially 100% recyclable (Nahman 2010; Paszun & Spychaj 1997; Ravindranath & Mashelkar 1986; Chilton et al. 2010). PETCO was established in 2004 as a means to address the significant waste associated with PET products across the value chain, and to avoid impending government legislation (Brink 2007; PETCO 2006). The responsibility imposed on PET converters by PETCO is a form of Extended Producer Responsibility (EPR). PETCO fills the role of a not-for-profit producer responsibility organisation (PRO), administering the collection of voluntary levies from PET converters, based on raw materials volumes purchased locally or imported, which are then used to support PET recycling firms in South Africa through subsidies administered per kilogram of post-consumer PET inputs. These projects are termed PETCO's Category A projects. PETCO's Category B projects entail the support of 'visible recycling' through various joint initiatives with partner organisations and shareholder members, which include the strategic unlocking of supply chain inefficiencies through increasing post-consumer PET collection (Brink 2007; PETCO 2014a; PETCO 2006).

Since PETCO's inception, it has been responsible for significant increases in the physical recycling of PET in South Africa - from 16% of post-consumer PET in 2005, up to 48.55% of post-consumer PET in 2014 (PETCO 2014a) - and increased awareness around the recyclability of PET, from both the consumer and brand-owners' perspective.

This paper first describes Extended Producer Responsibility (EPR) and Advance Recycling Fee's (ARF), followed by a description of the PET recycling industry. The theory behind production and cost function estimation is then established, followed by a description of the chosen estimation procedure. The regression results are then presented and discussed, outlining a series of data collection recommendations.

2. Extended Producer Responsibility: Advance Recycling Fee

Extended Producer Responsibility (EPR) was first implemented in Germany through the Packaging Ordinance in 1991, as a means to address the problem of landfill shortage, and has since become widely implemented in many countries for a range of products and objectives (Hanisch 2000; Dubois 2012; Lifset 1993; Tong et al. 2005; Sachs 2006; Smith 2005). EPR is essentially an extension of the 'polluter pays principle' (Forslind 2005), where producers retain responsibility (can be in a number of forms) for their products, through the products' lifecycle (Lifset 1993).

The basic premise of EPR is that firms internalise the cost associated with this responsibility into their production functions, and consider the environmental impacts associated with the design (referred to as 'design-for-environment' (DfE)) and marketing of their products. If appropriately designed, so that the financial burden on consumers directly reflects the costs of waste management, then "producers have a clear incentive to modify product design in order to reduce waste management costs" (Smith 2005).

A range of policy instruments fall under the 'EPR umbrella': end-of-life waste management fee; advance disposal fee; advance recycling fee; mandatory deposit-refund system; recycling incentives; and disposal disincentives, where the choice of policy instrument defines the characteristic type of EPR - informative responsibility; physical responsibility; economic responsibility (the most common); liability and ownership (Forslind 2005; Lifset 1993; Sachs 2006; Walls 2006).

Advance Recycling Fee's (ARF), levied on product sales, per unit or weight of product, are a means of generating revenue to support recycling activities. The revenue generated from an ARF can be used in a number of ways, one of which is a 'back-end recycling subsidy', paid to recycling companies per unit or weight of post-consumer waste recycled (Walls 2006; Sinha-Khetriwal et al. 2005). As outlined by Palmer & Walls (1997), the recycling subsidy "drives a wedge between the demand price and the price received by suppliers of used goods". ARF/subsidy combinations have been implemented in a number of industries, including the Californian; Swiss and Taiwanese e-waste programmes and the Californian used-oil programme (Walls 2006; Nixon & Saphores 2007; Sinha-Khetriwal et al. 2005; Hong & Ke 2011).

3. Industry Description

Polyethylene terephthalate (PET) is a plastic polymer formed through the reaction between purified terephthalic acid (PTA) and monoethelyne glycol (MEG) and a set of polymerization and polycondensation processes (Ravindranath & Mashelkar 1986; Paszun & Spychaj 1997). The combination of its physical ("high strength, low weight, and low permeability to gases") and aesthetic ("good light transmittance and smooth surface") characteristics, and it not being harmful to human health (Paszun & Spychaj 1997; Chilton et al. 2010), have swayed the wide use of PET in the manufacture of food and beverage containers, in addition to a variety of fibres (Nahman 2010; Paszun & Spychaj 1997; Ravindranath & Mashelkar 1986). In terms of the use of PET to manufacture beverage bottles, these characteristics pose considerable advantages over glass - in addition to consumer safety when dropped, the environmental and economic costs associated with the transport of PET are also far lower (Chilton et al. 2010).

According to PETCO (2014), 182 000 tonnes of virgin PET was produced in South Africa in 2013, and of this an approximate 40 000 tonnes was imported from China, Southeast Asia and the Middle East. Roughly 68% of this virgin PET is used to produce beverage bottles, where the majority of bottle and food-grade virgin PET resin is produced by HOSAF. This virgin PET resin is then sold on to various PET bottle converters. The remainder is used in the manufacture of various fibres (PETCO 2014a; Brink 2007), where these fibres include polyester carpets, fibre fillings for pillows and duvets, geotextiles and roof insulation (Brink 2007).

PET usage in South Africa is forecasted by PETCO (2014) to grow at a rate of 7 to 8% per annum, but at times has risen to as high 12% to 14% (Baruffa[1], pers comm. 2015; White[2], pers. comm. 2015). PET as a sole constituent is fully recyclable, and the recycling of PET is strongly advocated on environmental grounds (Paszun & Spychaj 1997; PETCO 2014a; Nahman 2010; Brink 2007). From an economic perspective, its viability depends on largely volatile virgin PET prices; the recycled PET end-use market and the quality and quantity of recyclate. Contaminants from other polymers, colourants and previous bottle contents can also pose considerable constraints (Nahman 2010; Chilton et al. 2010).

[1] At the time of writing, Oscar Baruffa was the manager of PETCO's Category A projects.
[2] Peter White is the former Managing Director of Hosaf.

The collection of PET takes place at either the household level or 'out of home'; post-consumer PET is sorted by centralised collection companies, from which recyclable PET is purchased by recycling firms; unrecyclable residual materials move to disposal in landfill.

PET can then be recovered through either closed-loop recycling or down-cycling. Closed-loop recycling refers to the process where post-consumer PET is used to make new containers of the same grade (e.g. bottle-to-foodgrade, or bottle-to-bottle), a more quality and aesthetically-demanding process requiring high levels of processing and cleaning, where caps, labels, colourants, previous bottle content and metals pose a high risk of contamination (Chilton et al. 2010). Down-cycling entails the conversion of post-consumer PET for use in lower-grade applications (Chilton et al. 2010) (e.g. bottle-to-fibre). In South Africa, post-consumer PET is recycled into four different end-use products, export fibre pellet; export fibre; local fibre; and local foodgrade (PETCO 2014a).

In the foodgrade value chain, recycling firms (Extrupet; MPact Polymers' commercial production expected to commence November 2015) purchase post-consumer PET in the baled bottle form from centralised collection companies. These bottles are then sorted into different colour grades, chopped into flake, washed, and extruded into foodgrade PET chip which is then sold on to bottle converters. In the fibre value chain, recycling firms either produce fibre from post-consumer PET through the production of recycled PET flake, which is then extruded into chip or pellet (only Extrupet makes fibre pellet; Propet uses pellet to make fibre), or recycled PET fibre is produced straight from post-consumer PET flake (Propet also uses flake to make fibre, in addition to Kaytech; Sen Li Da and Da Run Fa) (PETCO 2014b; Baruffa pers. comm. 2014).

3.1 The PETCO business model

The PET Recycling Company (trading as PETCO) was established in 2004, in an effort to avoid the possibility of government-imposed punitive legislation through self-regulated post-consumer PET recycling, and to alleviate the environmental impact of PET-based litter (PETCO 2006; Brink 2007).

Imposed punitive recycling legislation was found to be largely unsuccessful in the plastic bag manufacturing industry, which appears to have failed with respect to the long-term goal of plastic bag waste reduction due to the inelastic demand for plastic bags, while resulting in wide-scale job losses within the industry (Hasson et al. 2007; Dikgang et al. 2010; Brink 2007).

PETCO is unique in that it is an industry-driven and financed recycling organization, that comprises representation and ownership from stakeholders across the value chain, including "PET resin producers, the converters (PET bottle/pre-form and sheet producers), the PET bottling companies, brand owners, and specialist contracted resources", all of which are represented on the PETCO board (PETCO 2014a; Brink 2007). The establishment of PETCO was based on a Memorandum of Understanding (MoU) presented to the Department of Environmental Affairs and Tourism (DEAT) in 2006, in which DEAT would not impose regulation on the industry provided PETCO achieved mutually agreed upon recycling and job creation targets (PETCO 2006). However, this MoU was subsequently never signed, but PETCO has continued to work in the spirit of the MoU, achieving the set targets each year to date (Baruffa, pers. comm. 2014).

PETCO operates as a not-for-profit Producer Responsibility Organisation (PRO) that administers the economic responsibility associated with managing PET waste. PETCO's prime mandate is to use all funds to support recycling activities, and as a result reduce the environmental impact of the PET value chain and reduce volumes of post-consumer PET that go to landfill. PETCO generates revenue through the collection of a voluntary recycling levy[3] on both locally-manufactured PET (virgin and recycled) and on imported PET resin from roughly 70% of the market; grants from selected members (Hosaf and Coca-Cola); and through associate membership fees. Where possible, this voluntary levy is allowed to increase on an annual basis at a rate that is within the bounds of the CPI, where budgetary requirements are supplemented by the previous year's savings. However, if necessary, there is flexibility in setting the levy rate and PETCO can generate additional revenue through either increasing the levies when required (for example, this could be on a quarterly basis, in response to market shocks) or increasing the annual levy rate by greater than the CPI (Baruffa, pers. comm. 2014).

PETCO is not involved in the actual recycling of PET itself (Brink 2007), but rather its budget is allocated between Category A projects and Category B projects. Category A projects entail the support of the actual recycling of post-consumer PET, while the focus of Category B projects is to unlock constraints within the PET value chain, through increasing efficiencies and consumer awareness and education initiatives, contributing to 'visible recycling' (PETCO 2014a) (see Figure 1 below). PETCO's total 2013

[3] Current and historical voluntary recycling levies can be requested from PETCO.

budget amounted to R45.8 million, where roughly 72% (R33 million) was allocated to Category A projects, and 9% (R4.3 million) to Category B projects, the remainder contributing to administrative, operating and marketing costs and savings (Baruffa, pers. comm. 2014).

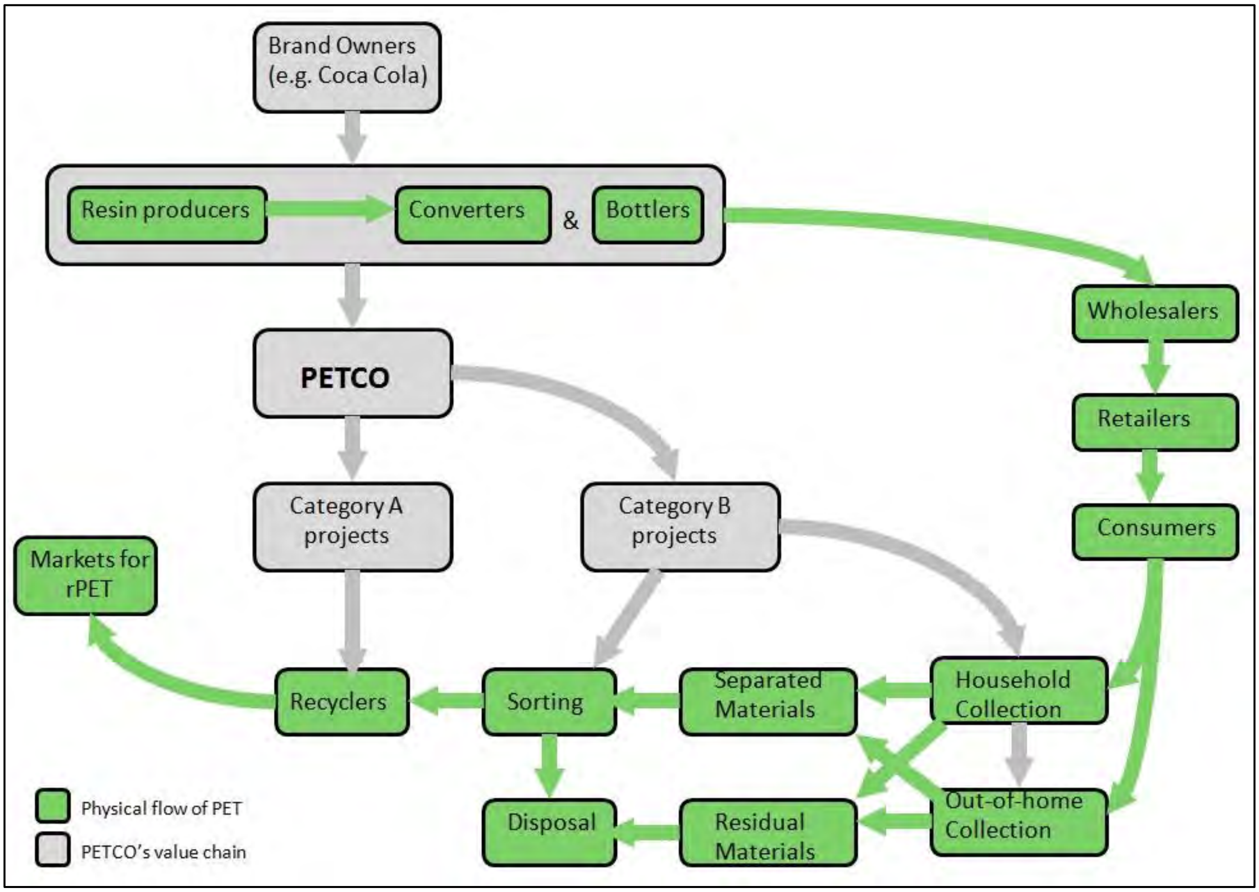

Figure 1: The physical flow of PET in South Africa and PETCO's value chain (adapted from (PETCO 2014a) and Brink (2007))

3.1.1 Category A Projects

Category A projects are volume-driven projects that are associated with the actual recycling of PET, and include activities that form part of the recycling value chain, such as the support of collection and recycling infrastructure; recycling technologies; and end-use production. Provided recycling firms meet the qualifying criteria (Category A partners[4]), PETCO provides support through a subsidy system, to

[4] Category A project partners include Extrupet (bottle-to-fibre; bottle-to-foodgrade); Sen Li Da (bottle-to-fibre); Kaytech engineered fabrics (bottle-to-filament: geotextiles with civil engineering end use); SAfrepet (industrial); and Mpact (bottle-to-foodgrade).

ensure annual recycling targets are met and that the recycling of PET is sustained through adverse economic conditions (PETCO 2014a). Subsidies, also referred to as 'recycling fees', are granted at a rate per kilogram of post-consumer PET feedstock for recycling firms, subsidising input costs.

There are a number of reasons why the recycling subsidy is administered per kilogram of post-consumer PET inputs, as opposed to the volume of recycled outputs, but chiefly because efficiency losses vary greatly with the recycled end-use product. Because higher efficiency losses are associated with up-cycling (bottle-to-bottle and bottle-to-foodgrade, due to higher quality and aesthetic standards), measurement of recycling volumes based on output, and thus administering a subsidy on a per output basis, would typically encourage down-cycling within a recycling value chain (Huysman et al. 2014). In addition, subsidies based on tonnages of post-consumer PET inputs ensures that the recyclers help PETCO fulfil its mandate of ensuring post-consumer PET is indeed collected (Baruffa, pers. comm. 2015).

Prior to 2014, subsidies were based on a flat rate per kg, where this base rate varied across value chains, adjusted through an annual negotiation process[5]. In 2014, an alternative subsidy calculation method was implemented, in which subsidies are calculated according to a base rate per kilogram of post-use PET bottle inputs, plus an additional rate that is fixed or variable dependent on the end-use value chain. According to PETCO's estimates, the total subsidy for each recycled PET value chain accounts for between 11% and 14% of post-consumer PET input costs for recycling firms(PETCO 2014b).

For the foodgrade value chain, the additional rate is calculated according to two separate, but interacting sigmoid functions, where the additional rate is a function of the recycler's average baled bottle price per quarter and the virgin PET landed DDP (Delivered Duty Paid) price per quarter (an inverse relationship). The baled bottle price is the price paid by recycling firms for baled post-consumer PET bottles, purchased from collection companies; virgin PET landed DDP is the price paid for imported virgin PET. The baled bottle price (major input) and virgin PET landed DDP (major price determinant for rPET) essentially form the lower and upper bounds, respectively, of the foodgrade recycler's profit margins. The resultant additional fee is calculated according to a weighted average between each of these sigmoid functions (70% virgin PET landed DDP; 30% baled bottle price). Profit margins have proven far more sensitive to the virgin PET landed DDP price in the past, and hence this additional fee has been weighted accordingly.

[5] Except for bottle to foodgrade PET chip, in which subsidies were renegotiated on a six monthly basis, but only for 2013.

These interacting sigmoid functions were developed to meet two objectives, firstly to match the 2012 and 2013 subsidy rates as closely as possible to ensure a smooth transition, and secondly to provide a smooth (as opposed to discrete), flexible and responsive subsidy adjustment mechanism, where subsidy adjustments are not reliant on a protracted negotiation process (Baruffa, pers. comm. 2014).

Because of the typically tight theoretical profit margins within the rPET fibre market, and thus little room for the formula to fluctuate, a variable additional rate essentially has little use, and thus a fixed additional rate has been implemented (Baruffa, pers. comm. 2014).

In addition to the input cost subsidies described above, PETCO also administers an export assistance fee under Category A projects on fibre and fibre pellet, in order to alleviate the transport costs and export charges associated with fibre and fibre pellet exports, to ensure fibre and fibre pellet exports remain competitive with exports from other markets. This assistance fee is calculated based on exchange rate fluctuations and is in addition to the bottle to fibre subsidy rates described above. Only two firms are involved in the export of an rPET fibre end-product, Sen Li Da and Propet. This assistance fee is administered per kg of baled PET inputs for Sen Li Da, and per kg of fibre output for Propet.

However, with the rise in demand and production capacity within the local fibre and foodgrade end-use markets, PETCO discourages the export of rPET unless the local rPET market is saturated. The reasons for this are: these export markets are the most expensive to support on a subsidy basis; it is difficult to ascertain the effectiveness of these export tonnages on the local recycling market relative to other end-uses; and thirdly, local end-use markets support further beneficiation, in turn creating additional local employment opportunities. But on the basis of local market saturation, PETCO provides support through the export assistance fees.

In order to administer these funds effectively, PETCO tracks a detailed market data set in order to inform decisions (PETCO 2014a). Variables in this data set include the dollar prices of terephthalic acid and monoethylene glycol (the two major chemical constituents of PET); the polyester staple fibre (PSF) price in the Chinese market; the PSF virgin landed DDP Rand price; rPET conjugate 3D hollow dollar price (the price trend that is most representative of the fibre market); the PETCO baseline (estimated breakeven point for South African PET recycling firms); the theoretical Rand per kg product margin for PET recyclers; and the rand-dollar and rand-euro exchange rates (Baruffa, pers. comm. 2014).

PETCO's Category A project partners accounted for the recycling of 48.55% (64 053 tonnes) of post-consumer PET bottles in 2014, up from 45% (or 50 274 tonnes) in 2012, and 16% (or 9 840 tonnes) in 2005, the year of PETCO's inception (PETCO 2014a; PETCO 2014c). However, it is important to note that the recycling firms contracted by PETCO do not account for the entire recycling tonnage. Some post-consumer PET is exported as bale or flake (approximately 10%). This falls outside of the volumes that PETCO supports financially, but the tonnages are recorded for reporting purposes (Baruffa pers. comm 2015).

3.1.2 Category B Projects

PETCO defines its Category B projects as those that do not directly contribute to the volume recycling of PET, but contribute to the 'visible recycling' of PET through a number of activities and initiatives through joint ventures with various partner organisations[6] and shareholder members[7]. These activities include the strategic unlocking of supply chain inefficiencies by improving collection and recycling infrastructure and equipment, fostering government partnerships, building the recycling network, and changing consumer culture through "growing awareness and consumer education". A large focus under the Category B projects is job creation. PETCO boasts a number of success stories under the Category B projects, including the creation of 2 699 jobs through the sponsorship of collection and recycling infrastructure and equipment over the past decade; PETCO exposure through twenty five education and awareness national events in 2013; and a large range of school and government projects (PETCO 2014a; PETCO 2006).

[6] These include: Plastics SA's Sustainability Council; Collect-a-Can; The Glass Recycling Company; Hulamin Limited; the Paper Manufacturers Association of SA (PAMSA); the Paper Recycling Association of SA (PRASA); South African Plastics Recyclers Organisation (SAPRO); the South African Vinyls Association (SAVA); and the Polystyrene Packaging Council (PSPC).
[7] These include: ABI; Coca-Cola SA; Coca-Cola Shanduka; Penbev; Nampak and others.

4. Methodology

As has been highlighted, the chief objective of this study is to analyse the effectiveness of PETCO's recycling subsidy rates. PETCO's recycling subsidies are intended to stabilise the price of post-consumer PET, ensuring the constant supply of post-consumer PET to recyclers, and that operators across the PET recycling value chain remain viable through adverse economic conditions. As these recycling subsidies are most likely to have an impact on the cost and availability of feedstock, it is appropriate that the impact of the subsidies is assessed within either a production or cost function framework, or some derivative thereof (i.e. using duality theory). On this basis, the theory behind production and cost function estimation, and duality theory, is established.

However, based on limitations in the available data, neither of these estimation procedures are practically feasible. This is explained below, together with the chosen estimation procedures. Following this, the data available for estimation is described.

4.1 Theory

The section below expands on the theory behind production and cost function estimation.

4.1.1 Production function estimation

Central to microeconomic theory, a firm's production function reflects the best combination of inputs that yields the maximum level of output, where production is a function of input quantities: $y = f(\boldsymbol{x})$, where $\boldsymbol{x}$ represents a vector of input quantities. The following properties are logically imposed on production functions: continuity; strictly increasing; strictly quasiconcave; and that $f(\mathbf{0}) = 0$ (Jehle & Reny 2011). In order to estimate production functions, we require "input quantities for different levels of [output]" (Davis & Garces 2010).

Firms typically have input substitution possibilities (for example, the substitution of capital for labour), and this needs to be reflected in the chosen production function specification. One of the most well-known production functions is the Cobb-Douglas production function, which can reflect varying degrees of substitutability between inputs, and imposes the requirement of at least some capital and some labour in order to produce output (Davis & Garces 2010; Collard-Wexler 2012):

$$Y_{it} = A_{it} K_{it}^{\beta_k} L_{it}^{\beta_l}$$

Taking logs presents the following log-linear form, with unobserved 'inputs' represented by the econometric error term (ϵ_{it}) (Davis & Garces 2010; Collard-Wexler 2012):

$$y_{it} = \beta_k k_{it} + \beta_l l_{it} + \epsilon_{it}$$

As outlined by Davis & Garces (2010), the functional form needs to reflect the "technological realities of the production process". Alternative production function specifications include the translog; CES (constant elasticity of substitution); or Leontieff functional forms (Collard-Wexler 2012; Border 2001):

Translog:

$$y_{it} = \beta_k k_{it} + \beta_l l_{it} + \beta_{kk}(k_{it})^2 + \beta_{ll}(l_{it})^2 + \beta_{lk} l_{it} k_{it}$$

CES:

$$Y_{it} = A(\beta_k (K_{it})^\rho + \beta_l (L_{it})^\rho)^{\frac{1}{\rho}}$$

The CES production function is more complicated to estimate as it is non-linear in parameters. However, it can be approximated by using non-linear least-squares methods or by deriving an approximation based on Taylor's formula (Henningsen & Henningsen 2011; Kmenta 1967).

Leontieff:

$$y = \min\left\{\frac{x_1}{\alpha_1}; \dots; \frac{x_n}{\alpha_n}\right\}$$

Problems associated with production function estimation include the measuring of heterogeneous factors of production, as in the case where capital inputs change over time (Robinson 1953); and the presence of endogeneity or transmission bias (Marschak & Andrews 1944; Klett & Griliches 1996), "caused by the correlation between input growth and productivity shocks" (Klett & Griliches 1996).

4.1.2 Cost function estimation

Cost functions are strongly linked to production functions, defined as "the least costly vector of inputs capable of producing" output, y, where it is assumed that firms face fixed input prices (firms are perfectly competitive in input markets). Cost minimisation can be described as:

$$C(y,w,r) = \min_{K,L} rK + wL \quad subject\ to \quad y \leq f(K,L)$$

Given the strictly increasing property of production functions, "cost minimisation implies that the marginal rate of substitution between any two inputs is equal to the ratio of their prices". Properties of cost functions include: $c(y,w,r) = 0$ when $y = 0$; continuity; strictly increasing and unbounded above in output (y); increasing in input prices; homogenous of degree one in input prices; and concave in input prices (Jehle & Reny 2011)**.**

As is reflected above, for the estimation of cost functions, data is required on output quantities and input prices. However, through Shephard's lemma, the relationship between cost functions and input demand equations can be demonstrated below (where $p_1, \dots, p_n$ represents inputs prices):

$$x_j = \frac{\partial C(y; p_1, \dots, p_n)}{\partial p_j}$$

Where, accordingly, "input demand schedules relate the optimal demand for inputs to the quantity produced and the input prices" (Davis & Garces 2010): $x_j = D_i(y; p_1, \dots, p_m)$. The estimation of cost functions "can of course be done only in cases where firms behave in the manner assumed by the model: they must minimise costs and they must typically be price-takers in the input markets" (Davis & Garces 2010).

The functional form of the final cost function is dependent on the choice of functional form of the production function. This is demonstrated through Nerlove's (1963) estimation of the returns to scale in electricity supply in the US. Nerlove (1963) assumes a generalized Cobb-Douglas production function (in which constant returns to scale are assumed):

$$y = \alpha_0 x_1^{\alpha_1} x_2^{\alpha_2} x_3^{\alpha_3} \mu$$

Cost-minimization implies the marginal substitution conditions:

$$\frac{p_1 x_1}{\alpha_1} = \frac{p_2 x_2}{\alpha_2} = \frac{p_3 x_3}{\alpha_3}$$

And a reduced form cost function:

$$c = k y^{1/r} p_1^{\alpha_1/r} p_2^{\alpha_2/r} p_3^{\alpha_3/r} v$$

Taking logs (denoted by capital letters) of both sides leaves a function that is linear in logarithms:

$$C = K + \frac{1}{r} Y + \frac{\alpha_1}{r} P_1 + \frac{\alpha_2}{r} P_2 + \frac{\alpha_3}{r} P_3 + V$$

The Leontieff production function imposes that inputs can only be used in the correct proportions. The function is not practically differentiable, but it is easy to reason that conditional factor demands must satisfy $y = \frac{x_i}{\alpha_i}$ for each i (Border 2001). Therefore:

$$x_i(y, w) = \alpha_i y$$

And the cost function is therefore:

$$c(w, y) = y \sum_{i=1}^{n} w_i \alpha_i$$

4.1.3 Duality theory

As challenges are faced in the collection of data that reflects technological quantities for the estimation of production functions, a significant development in modern theory is the duality between production and cost functions, with positive implications for applied analysis (Jehle & Reny 2011; Davis & Garces 2010). Given certain conditions, "the choice of which to employ is only a matter of convenience since the theory ensures consistency in the results" (Charnes et al. 1988).

Given any technology, we can solve for a cost function via cost-minimization. For any given cost function, we can solve for the technology that generated it. In order for this to hold, technology must be convex and monotonic. If a cost function is homogenous, concave, continuous and non-decreasing, then the function will have arisen from some technology. Hence, we are able to work backwards from a cost function to recover the technology function. This can be demonstrated below using a Cobb-Douglas production function (Jehle & Reny 2011):

$$C(w,y) = yw_1^{\alpha}w_2^{1-\alpha}$$

By Shephard's Lemma:

$$x(w,y) = \frac{\partial C(w,y)}{\partial w}$$

Thus:

$$x_1 = \alpha y w_1^{\alpha-1}w_2^{1-\alpha} = \alpha y[\frac{w_2}{w_1}]^{1-\alpha}$$

$$x_2 = (1-\alpha)yw_1^{\alpha}w_2^{-\alpha} = (1-\alpha)y[\frac{w_2}{w_1}]^{-\alpha}$$

Rearranging both equations to be in terms of $\left[\frac{w_2}{w_1}\right]$:

$$\left[\frac{w_2}{w_1}\right] = \left[\frac{x_1}{\alpha y}\right]^{\frac{1}{1-\alpha}}$$

$$\left[\frac{w_2}{w_1}\right] = \left[\frac{x_2}{y(1-\alpha)}\right]^{\frac{-1}{\alpha}}$$

Equating to each other, and solving for y, yields a Cobb-Douglas production function:

$$[\frac{x_1}{\alpha y}]^{\frac{1}{1-\alpha}} = [\frac{x_2}{y(1-\alpha)}]^{\frac{-1}{\alpha}}$$

$$y[\alpha^{\alpha}(1-\alpha)^{1-\alpha}] = x_1^{\alpha}x_2^{1-\alpha}$$

4.2 Estimation procedures

While in theory it would be best to run regression estimations of production and cost functions, the reality of data availability, and the questions at hand, may provide limitations. In this case, the research was commissioned by PETCO, in which the chief question was to determine the impact of recycling input subsidies on production tonnages. If there were no limitations on the available data, the most suitable approach to assessing the effectiveness of the recycling subsidies would have been through some form of cost function derivation. However, the data available for estimation includes only a combination of total production tonnages and input cost data - insufficient for either full cost or full production function estimation.

Therefore, an alternative approach was adopted. Based on the description of the South African PET recycling industry, the PETCO business model and the available data, it was determined that production tonnages in each end-use market are a function of recycling subsidies; input costs (post-consumer PET feedstock; energy; and labour costs); the rand-dollar exchange rate; GDP growth; and in some cases, the production tonnages of adjacent end-use markets.

The data set contains observations for most of the variables listed above, but there is no data available for post-consumer PET feedstock costs and energy and labour costs. While energy and labour costs have therefore been excluded from the estimations, the variable 'Virgin PET Inputs' has been used as a proxy for post-consumer PET feedstock costs.

It was initially noted that the variable 'Virgin PET Inputs' might not be a good approximation of post-consumer PET input costs, but it was presumed that there would be at least some correlation between 'Virgin PET Inputs' and post-consumer PET feedstock costs on the basis that part of the virgin PET price would be passed on to the post-consumer PET price further down the value chain. 'Virgin PET Inputs' was therefore deemed to serve as a suitable proxy.

The basic level-level specifications of the estimations are shown in the equations below, but variations of these level-level specifications were run in order to obtain the 'best fit' relationship for the production functions, including log-log relationships and time-lagged covariates. The output from these regression estimations is presented in the results section below, and discussed later.

Export fibre pellet end-use market

$$\begin{aligned} &\mathit{export\ fibre\ pellet\ tonnages} \\ &\quad = \beta_0 + \beta_1(\mathit{export\ fibre\ pellet\ subsidy}) + \beta_2(R/\$\,\mathit{exchange\ rate}) \\ &\quad + \beta_3(\mathit{virgin\ PET\ inputs}) + \beta_4(\mathrm{GDPGrowth}) + \beta_5(\mathit{local\ fibre\ tonnages}) + \epsilon \end{aligned}$$

Export fibre end-use market

$$\begin{aligned} &\mathit{export\ fibre\ tonnages} \\ &\quad = \beta_0 + \beta_1(\mathit{export\ fibre\ subsidy}) + \beta_2(R/\$\,\mathit{exchange\ rate}) \\ &\quad + \beta_3(\mathit{virgin\ PET\ inputs}) + \beta_4(\mathrm{GDPGrowth}) + \beta_5(\mathit{local\ fibre\ tonnages}) + \epsilon \end{aligned}$$

Local fibre end-use market

$$\begin{aligned} local\ fibre\ production\ tonnages \\ = \beta_0 + \beta_1(local\ fibre\ subsidy) + \beta_2(R/\$\ exchange\ rate) \\ + \beta_4(virgin\ PET\ inputs) + \beta_5(\text{GDPGrowth}) + \epsilon \end{aligned}$$

Foodgrade end-use market

$$\begin{aligned} foodgrade\ production\ tonnages \\ = \beta_0 + \beta_1(foodgrade\ subsidy) + \beta_2(R/\$\ Exchange\ Rate) \\ + \beta_3(virgin\ PET\ inputs) + \beta_4(\text{GDPGrowth}) + \epsilon \end{aligned}$$

Each of the specifications above were estimated by means of Ordinary Least Squares (OLS), using the statistical package, Stata 12. In each specification above, ϵ represents the unobserved error term. In order for the OLS estimator to be consistent, the assumptions of the Classic Linear Regression Model (CLRM) need to hold, namely: linearity in the dependent variable and covariates; full rank; conditional mean zero $[E(\epsilon|X) = 0]$; exogeneity of the covariates; the error terms must be homoscedastic and independent; and that the error term is normally distributed $[\epsilon|X \sim N(0, \sigma^2, I_n)]$ (Greene 2008).

4.3 Data description

The data used in this analysis is derived from PETCO's production and subsidy data and the set of market data variables that PETCO uses to track market dynamics and inform decision-making processes. Although not at the firm level, according to Baruffa (pers. comm. 2014), this data is of a high enough quality to accurately reflect market trends. While the production and subsidy data from PETCO spans the period from 2005 through to end-2014, due to limitations in the availability of polymer pricing data from the China Chemical Fibre Economic Information (CCFEI 2015) Network, the time-series analysis covers the period from July 2009 through to end-2014. The variables used for analysis are listed and described in Table 1, together with sample statistics in Table 2, and expanded upon below. Correlation coefficients for each of the end-use markets under analysis are provided in the Appendix.

Note that while the data on input subsidies (ExportFibrePelletSubsidy; ExportFibreSubsidy; LocalFibreSubsidy; and FoodgradeSubsidy) is used in the regression analyses, due to confidentiality requirements the sample statistics cannot be presented below[8].

[8] A table presenting the subsidy sample statistics is available to reviewers on request.

Table 1: Variables with descriptions used in time series analysis.

Variable Name	Variable Description	Source
ExportFibrePelletTonne	Production tonnages for the export fibre pellet end-use market	PETCO (2014)
ExportFibreTonne	Production tonnages for the export fibre end-use market	PETCO (2014)
LocalFibreTonne	Production tonnages for the local fibre end-use market	PETCO (2014)
FoodgradeTonne	Production tonnages for the foodgrade end-use market	PETCO (2014)
ExportFibrePelletSubsidy	Subsidy paid by PETCO to recycling firms for the export fibre pellet end-use market at a rate (Rand) per kg of post-consumer PET inputs	PETCO (2014)
ExportFibreSubsidy	Subsidy paid by PETCO to recycling firms for the export fibre end-use market at a rate (Rand) per kg of post-consumer PET inputs	PETCO (2014)
LocalFibreSubsidy	Subsidy paid by PETCO to recycling firms for the local fibre end-use market at a rate (Rand) per kg of post-consumer PET inputs	PETCO (2014)
FoodgradeSubsidy	Subsidy paid by PETCO to recycling firms for the foodgrade end-use market at a rate (Rand) per kg of post-consumer PET inputs	PETCO (2014)
Exranddoll	Rand-dollar exchange rate	XE Currencies
VirginPETinputs	The formulated ratio of the chief chemical inputs prices (USD per tonne) used in the production of PET: purified terephthalic acid (PTA) and monoethylene glycol (MEG)	CCFEI
GDPGrowth	South African annualised percentage change in GDP at 2010 prices	StatsSA

Table 2: Sample statistics of variables used in time-series analysis

Variable Name	Observations	Mean	Std. Deviation	Min.	Max.
ExportFibrePelletTonne	66	475.06	142.84	239	868.38
ExportFibreTonne	66	112.8	217.13	0	983
LocalFibreTonne	66	2326.12	793.67	381.55	4360
FoodgradeTonne	60	652.64	237.41	310	1238
Exranddoll	66	8.56	1.43	6.69	11.56
VirginPETinputs	66	1246.86	188.09	852.09	1730.37
GDPGrowth	66	2.495	1.652	-1.6	5.1

Production tonnages

For the purpose of using a standard unit of production across end-use markets, post-consumer PET input tonnages are used as a proxy for production figures for the end-use markets that are supported by PETCO (export fibre pellet; export fibre; local fibre; and foodgradE). Tonnage losses inherent in the collection and sorting processes of post-consumer PET in the rPET value chain generally accrue to between 25% (fibre) and 32% (foodgrade) in the final production of rPET, but apart from these fairly constant losses, the post-consumer input tonnages are considered to be a good proxy of final production volumes. PETCO has monthly post-consumer PET input volumes for each firm and end-use value chain, audited on an quarterly basis, from 2007 through to end-2014.

Recycling Subsidies and Export Assistance Fees

Through its contractual relationship with recycling firms under Category A Projects, PETCO administers a recycling subsidy per volume of post-consumer PET. This recycling subsidy has generally been administered on a quarterly basis since 2005, with an amount that varies per end-use market. Prior to 2014, the input subsidies were set through an initial consultative process with industry. These subsidies remained set over this period, except over two quarters within the global financial crisis of 2008 and 2009 in which an additional, emergency subsidy was negotiated with industry (Scholtz[9] pers. comm. 2014). Since beginning 2014, subsides for the foodgrade end-use market were set through two interrelated sigmoid functions on a quarterly basis, where the subsidies are a function of the baled bottle price and the price of virgin PET resin. For the fibre export and fibre pellet export end-use markets, subsidies are calculated according to a combination of a flat rate and a linear function. The subsidies for the local fibre end-use market are still administered as a flat rate. For the purposes of the time-series analysis, the subsidies have been averaged across months for each quarter.

Virgin PET Chemical Inputs

PET is a plastic polymer formed through the reaction between purified terephthalic acid (PTA) and monoethylene glycol (MEG), and a set of polymerization and polycondensation processes (Ravindranath & Mashelkar 1986; Paszun & Spychaj 1997). PTA and MEG are therefore the two major chemical inputs in the production of virgin PET, and together with energy and labour costs, also form the majority share of input costs for virgin PET. The prices of both PTA and MEG are driven by the crude oil price, PTA being a derivative of para xylene and acetic acid (Sheehan 2000), and MEG being a derivative of ethylene oxide (Rebsdat & Mayer 2001). PETCO tracks the weekly average dollar prices of each of these inputs to inform decision-making processes, where the historical prices of each of these inputs are sourced through the China Chemical and Fibre Economic Information Network (CCFEI 2015) and date back to the week-end 29th May, 2009.

From these prices, the price of virgin PET is formulated according to the required proportions of each of these chemicals in the production of virgin PET resin[10] (i.e. the variable VirginPETInputs). The proportions of this formulation sum to greater than one as water is removed as a buy-product in the chemical production process (Baruffa, pers. comm. 2015). This formulation price is the cost of virgin PET

[9] Cheri Scholtz is the CEO of PETCO.

[10] Formulation: (PTA x 0.86) + (MEG x 0.35)

in terms of its chemical inputs, and is essentially the minimum price per tonne that can be charged for virgin PET resin, excluding other input costs and import and customs duties.

GDP Growth

It was found that some of the coefficients in the regression analyses were contrary to logic, which was attributed to 'omitted variable bias' due to the absence of a variable, or variables, controlling for changing economic conditions. The South African 'annualised percentage change in GDP, in 2010 prices' (obtained from StatsSA (2015)) was therefore included in the regression analyses as a proxy for economic conditions.

5. Results

Time-series regressions were estimated for each of the PET end-use markets that are subsidised by PETCO. Both level-level and log-log specifications were run. For the log-log specifications, the variables are 'linearised', and are thus likely to be more stable - these are presented in the body of the text, while the level-level regressions are presented in the Appendix. The regression results are described below.

4.1 Export Fibre Pellet End-use Market

For the log-log regression estimations for the export fibre pellet end-use market, only the coefficient on log(LocalFibreTonne) is negative and statistically significant at the 1% level; no other variables across the different specifications are statistically significant. This reflects a negative relationship between local fibre production tonnages and export fibre pellet tonnages. This is supported by the PET recycling market dynamics - as the local fibre market saturation point rises, allowing firms to sell more fibre locally, there is a decrease in the fibre pellet export tonnages (and vice versa), ceteris paribus. Taking regression (3) of the log-log specifications, which includes two month time lags in Exranddoll and ExportFibrePelletSubsidy, an increase of 10% in the LocalFibreTonne will result in a 4.34% decrease in ExportFibrePellet, ceteris paribus.

For the level-level estimations for the export fibre pellet end-use market, the coefficient on the variable LocalFibreTonne is negative and statistically significant at the 1% level, with and without the inclusion of one and two month time lags in Exranddoll and ExportFibrePelletSubsidy. Again, this reflects a negative relationship between export fibre pellet tonnages and local fibre tonnages. In addition, the coefficients on GDPGrowth are positive and statistically significant at the 5% level, with and without the inclusion of one and two month time lags in Exranddoll and ExportFibrePelletSubsidy. This is contrary to expectation, where an increase in GDPGrowth should be associated with an rising saturation point in the local fibre end-use market, and thus a decrease in export fibre pellet tonnages. The coefficient on VirginPETInputs is positive, but only statistically significant at the 10% level, when one and two month time lags on Exranddoll and ExportFibrePelletSubsidy are applied.

Across both the level-level and log-log specifications, the export fibre subsidy rate does not have a statistically significant impact on export fibre production tonnages, ceteris paribus.

Table 3: Log-log regression output for the export fibre pellet end-use market

	1	2	3
	log(ExportFibre PelletTonne)	**log(ExportFibre PelletTonne)**	**log(ExportFibre PelletTonne)**
log(ExportFibrePellet Subsidy)	-0.076 (NS)	-0.008 (NS)	0.008 (NS)
L1.log(ExportFibrePellet Subsidy)	-	-0.111 (NS)	0.079 (NS)
L2.log(ExportFibrePellet Subsidy)	-	-	-0.218 (NS)
log(Exranddoll)	-0.314 (NS)	-0.973 (NS)	-0.909 (NS)
L1.log(Exranddoll)	-	0.677 (NS)	0.242 (NS)
L2.log(Exranddoll)	-	-	0.469 (NS)
log(VirginPETinputs)	0.283 (NS)	0.325 (NS)	0.446 (NS)
log(GDPGrowth)	0.010 (NS)	0.011 (NS)	0.008 (NS)
log(LocalFibreTonne)	-0.382 (***)	-0.382 (***)	-0.465 (***)
Constant	7.734	7.408	7
Observations	66	65	64
R squared	0.452	0.438	0.47
adjusted-R squared	0.406	0.369	0.381

(* statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level; NS Not Significant; t-stats in parenthesis)**

Table 4: Log-log regression output for the export fibre end-use market

	1	2	3
	log(ExportFibre Tonne)	**log(ExportFibre Tonne)**	**log(ExportFibre Tonne)**
log(ExportFibreSubsisdy)	-2.099 (NS)	-2.951 (NS)	-2.511 (NS)
log(L1.ExportFibre Subsidy)	-	0.670 (NS)	1.653 (NS)
log(L2.ExportFibre Subsidy)	-	-	-1.533 (NS)
zerolog(ExportFibre Subsidy)	-1.556 (*)	-0.159 (NS)	-0.493 (NS)
L1.zerolog(ExportFibe Subsidy)		-1.225 (NS)	-1.003 (NS)
log(Exranddoll)	5.033 (**)	-18.805 (**)	-17.711 (**)
Log(L1.Exranddoll)	-	25.914 (***)	19.065 (NS)
Log(L2.Exranddoll)	-	-	5.975 (NS)
log(VirginPETinputS)	-0.685 (NS)	0.513 (NS)	0.722 (NS)
log(GDPGrowth)	0.745 (**)	0.883 (***)	0.792 (**)
log(LocalFibreTonne)	0.356 (NS)	0.302 (NS)	0.232 (NS)
Constant	-6.407	-18.983	-20.303
Observations	66	65	64
R-squared	0.482	0.565	0.581
Adjusted R-squared	0.43	0.493	0.493

(* statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level; NS Not Significant; t-stats in parenthesis)**

Table 5: Log-log regression output for the local fibre end-use market

	1	2	3
	log(LocalFibre Tonne)	**log(LocalFibre Tonne)**	**log(LocalFibre Tonne)**
log(LocalFibre Subsidy)	-0.852 (***)	-0.646 (**)	0.081 (NS)
log(L1.LocalFibre Subsidy)	-	-0.191 (NS)	0.005 (NS)
log(L2.LocalFibre Subsidy)	-	-	-0.137 (NS)
log(Exranddoll)	1.151 (***)	0.794 (NS)	2.540 (NS)
log(L1.Exranddoll)	-	0.359 (NS)	-1.150 (NS)
log(L2.Exranddoll)	-	-	0.758 (NS)
log(VirginPETinputS)	0.850 (***)	0.827 (***)	1.414 (***)
log(GDPGrowth)	0.081 (**)	0.082 (**)	0.088 (*)
log(ExportFibre Tonne)	-0.006 (NS)	-0.007 (NS)	-0.055 (**)
Constant	-1.282	-1.101	-8.142
Observations	66	65	64
R-squared	0.788	0.762	0.596
adjusted R-squared	0.771	0.733	0.528

(* statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level; NS Not Significant; t-stats in parenthesis)**

Table 6: Log-log regression output for the foodgrade end-use market

	1	2	3
	log(Foodgrade Tonne)	**log(Foodgrade Tonne)**	**log(Foodgrade Tonne)**
log(Foodgrade Subsidy)	0.018 (NS)	0.051 (NS)	0.261 (NS)
L1.logFoodgrade Subsidy	-	0.055 (NS)	0.226 (NS)
L2.logFoodgrade Subsidy	-	-	0.228 (NS)
log(Exranddoll)	2.128 (***)	0.564 (NS)	1.478 (NS)
L1.logexranddoll	-	1.782 (NS)	0.147 (NS)
L2.logexranddoll	-	-	0.952 (NS)
log(VirginPETinputs)	0.331 (NS)	0.482 (NS)	0.698 (*)
log(GDPGrowth)	0.045 (NS)	0.053 (NS)	0.061 (*)
Constant	-0.535	-2.038	-4.014
Observations	60	59	58
R-squared	0.695	0.716	0.74
Adjusted R-squared	0.673	0.683	0.698

(* statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level; NS Not Significant; t-stats in parenthesis)**

4.2 Export Fibre End-use Market

For the log-log estimations for the export fibre end-use market, the coefficients on log(GDPGrowth) are positive and consistently statistically significant across specifications (1), (2) and (3), with and without the inclusion of one and two month time lags on Exranddoll and ExportFibeSubsidy. As before, this is counter to expectations, in that an increase in the local fibre market saturation point should be associated with a decrease in export fibre tonnages, ceteris paribus.

The coefficients on log(Exranddoll) are also statistically significant across specifications (1), (2) and (3), both with and without the inclusion of one and two month time lags on Exranddoll and ExportFibreSubsidy. However, only without any time lags, specification (1), is the coefficient for log(Exranddoll) positive, and negative for (2) and (3). The negative coefficient makes intuitive sense, given knowledge of the PET recycling market - an exchange rate depreciation will favour the local recycled fibre market, through a rise in the virgin PET fibre price. This should push up the local fibre market saturation point, resulting in a decrease in export fibre tonnages, ceteris paribus.

For the level-level regressions for the export fibre end-use market, again the coefficient on the variable LocalFibreTonne is negative and statistically significant at the 1% level, with and without the inclusion of one and two month time lags on Exranddoll and ExportFibreSubsidy. As before, this reinforces the export fibre market dynamics: as the local fibre market saturation point increases, local fibre production tonnages increase, and export fibre pellet tonnages decrease, ceteris paribus. Again, the coefficients on GDPGrowth are positive and at least statistically significant at the 10% level, with and without the inclusion of one and two month time lags on Exranddoll and ExportFibreSubsidy. The coefficients on VirginPETInputs are also positive and at least statistically significant at the 10% level, both with and without the inclusion of one and two month time lags on Exranddoll and ExportFibreSubsidy. This is slightly more complex to interpret - if VirginPETInputs was a good proxy for the post-consumer PET input costs faced by recycling firms, then the positive coefficient would be counter to expectations. But, even if VirginPETInputs is strongly correlated with the price of virgin fibre in export markets, PETCO only supports the export of fibre on the basis of local market saturation, and thus this relationship should also be reflected through a negative coefficient.

The coefficients for ExportFibreSubsidy are statistically insignificant across all specifications (level-level and log-log). Based on these regression results, it can be concluded that the subsidy rate does not have an impact on the export fibre tonnages, ceteris paribus.

4.3 Local Fibre End-use Market

For the log-log regressions for the local fibre end-use market, the coefficients on log(VirginPETInputs) are positive and statistically significant at the 1% level, both with and without the inclusion of one and two month time lags on Exranddoll and LocalFibreSubsidy. If VirginPETInputs is taken as a proxy for post-consumer PET feedstock costs (as outlined above), these positive coefficients are counter to expectations, where an increase in input costs should be associated with a decrease in local fibre production tonnages, ceteris paribus. However, if the variable VirginPETInputs is strongly correlated with the South African virgin PET fibre price, then these positive coefficients would make more intuitive sense, where an increase in local fibre production would be associated with a more favourable market for recycled PET fibre. This reinforces that VirginPETInputs may not be a suitable proxy for post-consumer PET input costs.

The coefficients for the variable log(GDPGrowth) are also positive and are at least statistically significant at the 10% level, both with and without the inclusion of one and two month time lags on the rand-dollar exchange rate the LocalFibreSubsidy. This again makes intuitive sense.

The coefficients on the variable log(ExportFibreTonne) are all negative, but only statistically significant at the 5% level with the inclusion of one and two month time lags on Exranddoll and LocalFibreSubsidy. This makes intuitive sense, and reflects the inverse relationship between local fibre and export fibre production tonnages highlighted above.

The coefficients for LocalFibreSubsidy are negative and at least statistically significant at the 5% level in specifications (1) and (2) of the log-log regressions (without any time lags and with a one month time lag on Exranddoll and LocalFibreSubsidy). This is counter-intuitive as it would be expected that an increase in local fibre production tonnages would be associated with an increase in the LocalFibreSubsidy, ceteris paribus, especially when changing economic conditions are controlled for through GDPGrowth.

For the level-level regressions for the local fibre end-use market, the coefficients on VirginPETInputs are positive and significant at the 1% level, both with and without the inclusion of one and two month time lags on Exranddoll and LocalFibreSubsidy. This reaffirms that VirginPETInputs is more strongly correlated with the South African virgin PET fibre price than post-consumer PET input costs, and is perhaps not a suitable proxy for the post-consumer PET feedstock costs.

The coefficients on GDPGrowth are also all positive and statistically significant at the 1% level, both with and without the inclusion of one and two month time lags on Exranddoll and LocalFibreSubsidy. This makes intuitive sense, where an increase in GDPGrowth is associated with an increase in the demand for local fibre, and thus an increase in local fibre production tonnages, ceteris paribus.

The coefficients on the ExportFibreTonne variable are negative and statistically significant at the 1% level, both with and without the inclusion of the one and two month time lags on Exranddoll and LocalFibreSubsidy. This makes intuitive sense, and reflects the inverse relationship between local fibre and export fibre production tonnages highlighted above.

There are no positive and significant coefficients on either LocalFibreSubsidy or log(LocalFibreSubsidy), as would be expected.

4.4 Foodgrade End-use Market

For the log-log specifications for the Foodgrade end-use market, the coefficient on log(Exranddoll) is positive and statistically significant at the 1% level for regression (1). As before, this makes intuitive sense. However, it does not hold for regressions (2) and (3), and is therefore deemed to not be a stable relationship. The coefficient on the variable log(VirginPETInputs) is positive and significant at the 10% level, but only for regression (3) (i.e. with the inclusion of two month time lags on Exranddoll and FoodgradeSubsidy). However, this statistical significance does not hold for regressions (1) and (2), and the relationship is therefore concluded to be unstable. Similarly, the coefficient on the variable log(GDPGrowth) is positive and significant at the 1% level, but only for regression (3). However, this statistical significance does not hold for regressions (1) and (2), and the relationship is again concluded to be unstable.

For the level-level regressions for the foodgrade end-use market, the rand-dollar exchange rate is positive and statistically significant at the 1% level, only without the inclusion of one and two month time lags on Exranddoll and FoodgradeSubsidy. As before, this makes intuitive sense. However, because it doesn't continue to hold with the inclusion of time lags, it is not deemed to be a stable relationship.

The coefficient on the variable GDPGrowth is positive and significant at the 10% level, but only with the inclusion of a two month time lag on Exranddoll and FoodgradeSubsidy. This also makes intuitive sense, but as this does not hold across the other specifications, it is not deemed to be a stable relationship.

The rest of the coefficients across all specifications in the level-level specifications are all statistically insignificant. It is therefore concluded that the model suffers from misspecification, the results not being sufficiently stable to draw conclusions.

From both the level-level and log-log regressions for the foodgrade end-use markets, none of the coefficients on FoodgradeSubsidy are statistically significant, and it is therefore concluded that FoodgradeSubsidy is not a driver of production tonnages, ceteris paribus.

6. Discussion

The primary objective of this study was to determine whether the recycling subsidies, administered by PETCO, have an impact on recycled PET production tonnages in each end-use market: export fibre pellet; export fibre; local fibre; and foodgrade. Based on logic, the recycled PET production tonnages should respond to changes in the subsidy rate, especially over periods in which the subsidy rate has been hiked substantially. Additionally, according to PETCO's estimates, the total subsidy for each end-use market accounts for between 11 and 14% of post-consumer PET input costs for the recycling firms.

The optimal approach would have been through cost function estimation, or alternatively utilising the duality theory between cost and production functions. However, due to data limitations, this was not possible - only a mix of total production tonnages and input cost data was available. Therefore, the approach chosen was to attempt to control for the variation in production tonnages using the rand-dollar exchange rate; virgin PET price formulation; GDP growth; and production tonnages in adjacent end-use markets, and through this, determine the impact of the recycling subsidies on production tonnages.

However, the results of the regression analyses do not reflect the expected relationships between production tonnages and the covariates. This is particularly true for the subsidy rates, where the subsidy rates do not have a statistically significant impact on production tonnages. It is therefore concluded that the results are not stable enough to draw any conclusions about the impact of the subsidy rates.

This could be due to a few different reasons. Firstly, this may be due to insufficient variation in the subsidy rates over the study period. Secondly, the unstable regression results could be attributed to omitted variable bias through model misspecification (for example, the lack of data on capital, labour and energy costs). Thirdly, following further discussions with PETCO, it was concluded that 'VirginPETInputs' is in fact a poor approximation of post-consumer PET feedstock costs for recycling firms (Baruffa and Scholtz, pers. comm. 2015), thus resulting in biased coefficients. Virgin PET inputs are derived from the crude oil price and are thus subject to global market fluctuations; they do not reflect local market drivers. However, it was decided that this variable should still be included in the estimations on the basis of a lack of an alternative variable, and for preserving the theoretical standpoint.

For the purposes of the research contract with PETCO, additional in-depth graphical and descriptive analyses were conducted to assist in explaining the variation in production tonnages over the study period. From this, various data collection recommendations were proposed to PETCO, in the hope that these might support more meaningful analyses of the recycling subsidies in the future. These are outlined below.

Across all the end-use markets, it was recommended that PETCO collect as accurate as possible post-consumer PET feedstock costs from contracted recycling firms in the future, together with labour and energy costs. As discussed with Baruffa (pers. Comm,. 2015), perhaps it is possible for PETCO to include this as a requirement in the contractual agreements with recycling firms. These accurate post-consumer feedstock costs faced by the recycling firms might, however, present the issue of endogeneity, where the feedstock costs are correlated with the heterogeneous errors in the regression estimation (i.e. correlated with local demand shocks for the rPET end-products). Issues of endogeneity are common in production function estimation, be it through price, R&D, or firm exits from an industry (Doraszelski 2007; Klette & Griliches 1996; Van Biesebroeck 2005). One method for controlling for endogeneity is through instrumental variables estimation using two stage least squares. A suitable instrumental variable is one that is correlated with the endogenous variable, but uncorrelated with the heterogeneous errors of the regression estimation (Wooldridge 2009; Greene 2008; Angrist & Pischke 2009). For accurate feedstock costs, possible instrumental variables could include labour or energy costs faced by collection companies, which are then passed on to the recycling firms through post-consumer PET feedstock costs.

As is outlined, the lack of explanatory power in the subsidy rates could simply be due to a lack of variation in the subsidy rates. In many cases this is evident in the graphical analyses where large variations in the production tonnages do not coincide with any variation in the subsidy rate, even if lagged. While this might not be practically feasible, if the opportunity does arise, it is suggested that

PETCO take the opportunity to vary the subsidy rates. This could be done through a single shift, large enough to influence a change in production tonnages, or a series of step-wise changes at a monthly frequency.

As is outlined in the results, it is clear that the export fibre and export fibre pellet production tonnages are inversely driven by the local fibre production tonnages. However, it is felt that this alone is insufficient to control for the variation in export production tonnages. It is therefore proposed that the variation could be better explained through the interaction between local fibre production tonnages and the local fibre market saturation point. It is thus recommended that PETCO should collect as accurate as possible estimates of the local fibre market saturation point for the local fibre end-use market in the future.

On the other hand, it is thought that a chief driver of increasing local fibre production tonnages is changing production capacity, together with input costs. It is therefore recommended that PETCO records data that indicates changes in local fibre production capacity.

The chief drivers of production tonnages in the foodgrade end-use market are theorised to be combinations of capacity, efficiency, and economies of scale, together with post-consumer PET feedstock costs and the rand-dollar exchange rate. Similar to the local fibre end-use market, it is recommended that PETCO records data that indicates changes in production capacity, together with a dummy variable that indicates changes in technological efficiency.

7. Conclusion

The objective of this paper was to describe the South African PET recycling industry, and assess the efficacy of PETCO's recycling subsidies through a series of regression analyses applied to each recycling end-use market.

Polyethylene terephthalate (PET) is widely used in the manufacture of food and beverage containers, in addition to a variety of fibres. According to PETCO, 182 000 tonnes of virgin PET was produced in South Africa in 2013, and of this an approximate 40 000 tonnes was imported from China, Southeast Asia and the Middle East. Roughly 68% of this virgin PET is used to produce beverage bottles, where the majority of bottle and food-grade virgin PET resin is produced by HOSAF. This virgin PET resin is then sold on to various PET bottle converters. The remainder is used in the manufacture of various fibres, where these fibres include polyester carpets, fibre fillings for pillows and duvets, geotextiles and roof insulation. PET is considered to be 100% recyclable and can be recycled into a number of different end-use streams: bottle-to-bottle; bottle-to-foodgrade (closed-loop recycling), or bottle-to-fibre (down-cycling).

The responsibility imposed on PET converters by PETCO is a form of Extended Producer Responsibility (EPR). PETCO fills the role of a not-for-profit producer responsibility organisation (PRO), administering the collection of voluntary levies from PET converters, based on raw materials volumes purchased locally or imported, which are then used to support PET recycling firms in South Africa through subsidies administered per kg of post-consumer PET inputs. These projects are termed PETCO's Category A projects. PETCO's Category B projects entail the support of 'visible recycling' through various joint initiatives with partner organisations and shareholder members, which include the strategic unlocking of supply chain inefficiencies through increasing post-consumer PET collection.

Subsidies are granted at a rate per kilogram of post-consumer PET feedstock for recycling firms, subsidising input costs. Across the different PET recycling end-use markets, the subsidies are administered as combinations of flat rates, fixed additional rates and variable additional rates, where the total subsidy for each recycled PET value chain accounts for between 11% and 14% of post-consumer PET input costs for recycling firms.

As a background to the regression analyses, the study builds the theory behind production and cost function estimation (and the associated duality theory). However, due to the combination of the research question and the limited data availability, an alternative model was adopted, in order to explain as much variation in production tonnages as possible.

Based on logic, the recycling subsidies should have an impact on production tonnages, and this should be reflected in the regression output. However, the coefficients on the subsidy rates are either negative (contrary to expectations) or consistently statistically *insignificant* across end-use markets. This could be due to a lack of variation in the subsidy rates over the study period; the use of an inappropriate proxy for recycling firm feedstock costs; or bias in the estimates due to missing variables. In addition, it is concluded that the regression results in general are not very stable, and thus concrete conclusions about the efficacy of the subsidy rates cannot be drawn.

Therefore, for the purposes of the research contract with PETCO, detailed graphical and descriptive analyses were conducted in an attempt to further explain the variation in the subsidy rates and production tonnages. This provided the basis for data collection recommendations, to hopefully support more valuable analyses of the subsidy rates in the future.

The overarching recommendation applicable to all end-use markets is the collection of more accurate input cost data, which could potentially be mandated in the recycling firms' contractual agreements. For the export fibre and export fibre pellet end-use markets, it is thought that the interaction between local fibre production tonnages and the local fibre market saturation point might help to explain variation in the production tonnages. It is thus suggested that PETCO also collects as accurate as possible estimates of the local fibre market saturation point for the local fibre end-use market.

The upward trend in local fibre production tonnages over time can be attributed to increasing production capacity - thus, data on production capacity needs to be recorded. Similarly, the foodgrade end-use market requires data on production capacity, in addition to data that captures changes in technological efficiency.

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Appendix

8.1 Correlation coefficients

Table 7: Correlation coefficients for all the variables used in the regression analyses.

	Exranddoll	VirginPETInputs	GDPGrowth	ExportFibre PelletTonne	ExportFibre PelletSubsidy	ExportFibre Tonne	ExportFibre Subsidy	LocalFibre Tonne	LocalFibre Subsidy	Foodgrade Tonne	Foodgrade Subsidy
Exranddoll	1										
VirginPETInputs	-0.522	1									
GDPGrowth	-0.243	-0.153	1								
ExportFibrePelletTonne	-0.317	0.219	0.119	1							
ExportFibrePelletSubsidy	-0.845	0.248	0.435	0.373	1						
ExportFibreTonne	0.6	-0.358	-0.094	0.204	-0.463	1					
ExportFibreSubsidy	0.482	-0.526	0.231	-0.182	-0.212	0.268	1				
LocalFibreTonne	0.427	0.075	0.076	-0.432	-0.462	-0.029	0.39	1			
LocalFibreSubsidy	-0.08	-0.082	0.241	0.197	0.235	-0.051	0.284	-0.161	1		
FoodgradeTonne	0.846	-0.39	-0.13	-0.314	-0.751	0.503	0.304	0.482	-0.255	1	
FoodgradeSubsidy	-0.585	-0.247	0.472	0.301	0.807	-0.264	-0.005	-0.546	0.27	-0.526	1

8.2 Level-level regression output

Table 8: Level-level regression output for the export fibre pellet end-use market

	1	2	3
	ExportFibre PelletTonne	**ExportFibre PelletTonne**	**ExportFibre PelletTonne**
ExportFibre PelletSubsidy	-107.295 (**)	-71.646 (NS)	-76.952 (NS)
L1.ExportFibre PelletSubsidy	-	-42.676 (NS)	7.806 (NS)
L2.ExportFibre PelletSubsidy	-	-	-65.770 (NS)
Exranddoll	-11.846 (NS)	-68.268 (NS)	-71.730 (NS)
L1.Exranddoll	-	59.903 (NS)	20.275 (NS)
L2.Exranddoll	-	-	41.906 (NS)
VirginPETinputs	0.156 (NS)	0.188 (*)	0.202 (*)
GDPGrowth	26.463 (**)	27.767 (**)	27.009 (**)
LocalFibreTonne	-0.135 (***)	-0.135 (***)	-0.138 (***)
Constant	798.317	739.04	777.469
Observations	66	65	64
R squared	0.516	0.506	0.519
Adjusted R-squared	0.475	0.446	0.438

(* statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level; NS Not Significant; t-stats in parenthesis)**

Table 9: Level-level regression output for the export fibre end-use market

	1	2	3
	ExportFibre Tonne	**ExportFibre Tonne**	**ExportFibre Tonne**
ExportFibre Subsidy	28.509 (NS)	-37.277 (NS)	-5.776 (NS)
L1.ExportFibre Subsidy	-	42.184 (NS)	11.702 (NS)
L2.ExportFibre Subsidy	-	-	1.219 (NS)
Exranddoll	146.262 (NS)	-42.147 (NS)	-19.290 (NS)
L1.Exranddoll	-	204.761 (**)	82.114 (NS)
L2.Exranddoll	-	-	108.043 (NS)
VirginPETinputs	0.339 (*)	0.384 (**)	0.425 (**)
GDPGrowth	32.958 (*)	38.819 (**)	39.077 (**)
LocalFibreTonne	-0.133 (***)	-0.138 (***)	-0.152 (***)
Constant	-1352.476	-1528.055	-1610.784
Observations	66	65	64
R-squared	0.467	0.504	0.522
Adjusted R-squared	0.423	0.443	0.442

(* statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level; NS Not Significant; t-stats in parenthesis)**

Table 10: Level-level regression output for the local fibre end-use market

	1	2	3
	LocalFibre Tonne	**LocalFibre Tonne**	**LocalFibre Tonne**
LocalFibre Subsidy	-853.761 (***)	-240.522 (NS)	-144.918 (NS)
L1.LocalFibre Subsidy	-	-615.067 (NS)	-359.687 (NS)
L2.LocalFibre Subsidy	-	-	-299.860 (NS)
Exranddoll	421.444 (***)	78.921 (NS)	147.310 (NS)
L1.exranddoll	-	367.467 (NS)	-7.432 (NS)
L2.exranddoll	-	-	321.278 (NS)
VirginPETInputs	1.615 (***)	1.683 (***)	1.721 (***)
GDPGrowth	158.411 (***)	172.331 (***)	175.676 (***)
ExportFibre Tonne	-1.176 (***)	-1.265 (***)	-1.302 (***)
Constant	-2990.815	919.335	-3470.195
Observations	66	65	64
R-squared	0.756	0.753	0.738
adjusted R-squared	0.736	0.723	0.694

(* statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level; NS Not Significant; t-stats in parenthesis)**

Table 11: Level-level regression output for the foodgrade end-use market

	1	2	3
	Foodgrade Tonne	**Foodgrade Tonne**	**Foodgrade Tonne**
Foodgrade Subsidy	31.944 (NS)	71.169 (NS)	173.188 (NS)
L1.Foodgrade Subsidy	-	-36.856 (NS)	120.478 (NS)
L2.Foodgrade Subsidy	-	-	-216.081 (NS)
Exranddoll	140.911 (***)	28.222 (NS)	73.131 (NS)
L1.Exranddoll	-	123.104 (NS)	25.050 (NS)
L2.Exranddoll	-	-	65.844 (NS)
VirginPETInputs	0.097 (NS)	0.150 (NS)	0.255 (NS)
GDPGrowth	10.657 (NS)	16.872 (NS)	24.577 (*)
LocalFibreTonne	0.047 (NS)	0.035 (NS)	0.018 (NS)
Constant	-858.868	-993.257	-1238.456
Observations	60	59	58
R-squared	0.737	0.749	0.762
Adjusted R-squared	0.713	0.715	0.717

(* statistically significant at the 1% level; ** statistically significant at the 5% level; * statistically significant at the 10% level; NS Not Significant; t-stats in parenthesis)**