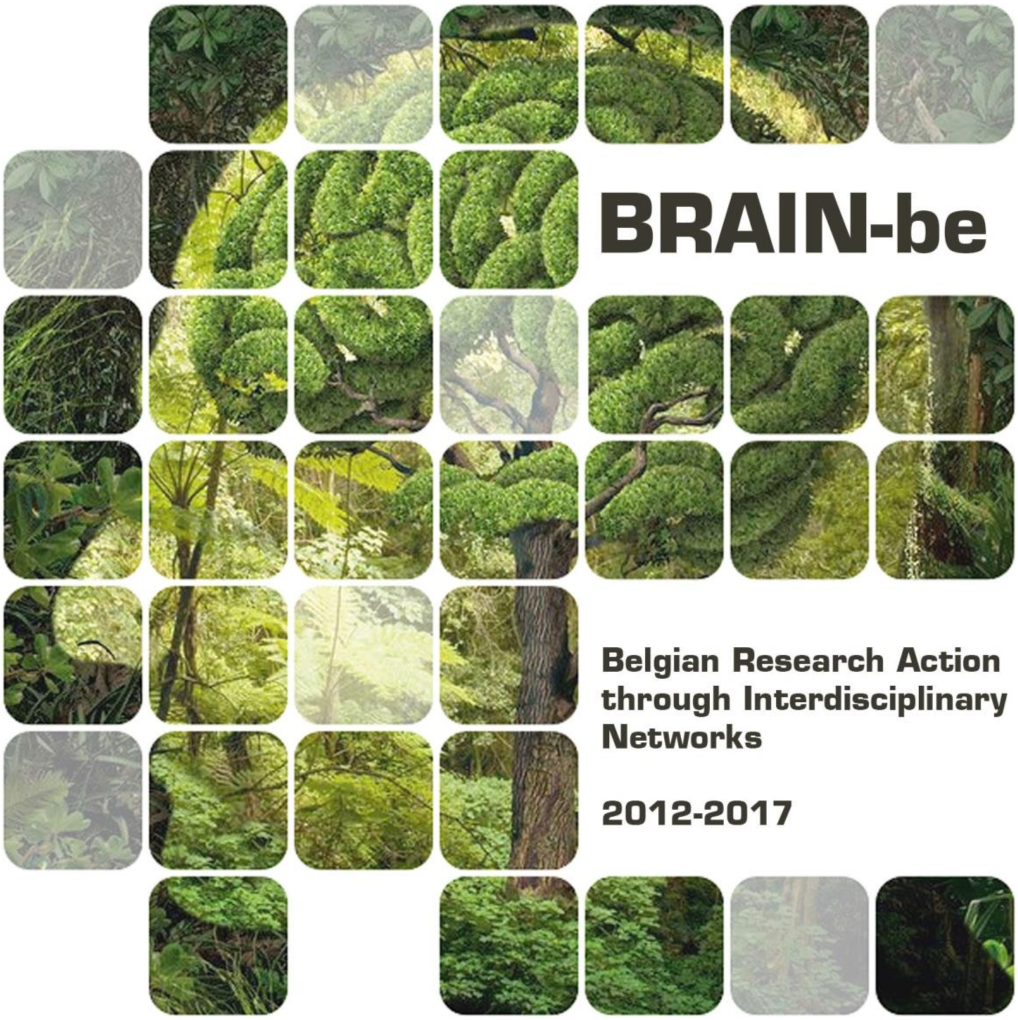

IECOMAT

Integrated Economic Modelling Of Material Flows

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IECOMAT

Integrated Economic Modelling Of Material Flows

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ABSTRACT

Sustainable material management and circular economy are high on the agenda of policy makers in many industrialized countries. The peak in resource prices of 2008, looming exhaustion of some critically important resources in the long term and short and medium term supply risk as result of changing political and strategic operating environments (for instance rare earths) have spurred interest in alternative concepts of material use in our economy. Against this background the IECOMAT project main objective was to investigate the **potential for the Belgian economy of the transition towards a more circular economy model**. First, a workable **definition of the concept of circular economy** was delineated. Secondly, the research teams **developed and applied a set of complementary numerical and analytical tools** that are each designed to study a particular aspect of sustainable material management. These models range from Input-Output models over partial, computable and general equilibrium models and analytical industrial organization models of economic incentives. Thirdly, the project has investigated in depth the **micro economic incentives of economic actors** (consumers, businesses, …) to adopt alternative material management **business models**.

The project has made substantial progress in different areas related to circular economy. First, it has enhanced our understanding of the circular economy concept by developing a novel theoretical framework to ground indicators. Second, extended input-output modelling tools have been developed and used to study the interlinkages within the Belgian economy and with its trade partners. Thirdly, the potential impact of circular economy policies on primary and secondary sectors have been studied using both a novel and extended general equilibrium model for the Belgian economy and a stylized partial equilibrium model framework. Finally, circular business model adoption has been studied from a producer and consumer perspective. Overall the research conducted by the IECOMAT team shows that there are still important challenges in the economic modelling exercises to study the impact of the circular economy transition for a small open economy like Belgium, in particular relating to the data availability, domestically and abroad, for detailed analysis of downstream activities like recycling, remanufacturing, re-use, repair and second hand markets.

Keywords

circular economy; resource management; recycling of materials; partial and general equilibrium economic modelling; business models

1. INTRODUCTION

Despite its popularity, the concept of circular economy (CE) is not sharply defined yet among practitioners and scholars. Kirchherr et al. (2017) reports for example 114 CE definitions. A recurring theme in most definitions of CE is the need for a comprehensive view on the full life cycle of products and materials, from cradle to grave, comprising all stakeholders and decision makers along it. Although many of these definitions overlap strongly, there are also discernible differences in for example the importance they attach to energy use and environmental side-effects of a transition towards a more circular economy. Given this multitude of views on what CE really means, it was of critically important in the IECOMAT project to **delineate the concept and scope of CE**. In the beginning of the trajectory, the project team therefore devoted quite some time to this issue.

For **economic modelling of circular economy interactions**, it is crucial to track carefully the flow of materials, products, waste and secondary materials throughout the entire life cycle of a product. Raw materials are extracted, refined and prepared for use in components that are built into products and machines. After their useful life, these products are discarded resulting in an end-of-life stream. In many high-income countries like Belgium that end-of-life stream is carefully processed as to recover valuable components and materials that can be re-entered in the production process. All remaining residues of the recycling or re-manufacturing process are disposed of in different possible ways ranging from controlled landfilling to incineration with energy recovery. Throughout the value chain of a product, many **different actors in often different countries interact** with each other: miners of raw materials, commodity traders, producers, consumers, waste handlers, logistics companies, recyclers, governments etc. Each of these actors makes choices based on a mix of economic and regulatory incentives. And most importantly, changes at one instance of the value chain can have important downstream and upstream repercussions for choices made by other actors. For example, a price slump for virgin raw material (think of crude oil) will reduce the incentives of recyclers to process waste and recover material (think of recycling plastic waste that becomes less attractive if new virgin plastic is cheap because of low crude oil prices). Lower demand for sorted waste by recyclers leads to lower collection and sorting incentives and, perhaps, more illegal disposal or exports of consumer waste. Another example is the tendency to switch to alternative business models to satisfy needs like mobility, housing, communications etc. Many examples exist of companies that no longer sell their products but, rather, they are offering the services of their products for sale to consumers. This creates completely different incentives for producers and consumers regarding the management of the goods and embodied components and materials, both during and after its useful lifetime. These stylized examples illustrate that economic modelling for circular economy is all about interconnected choices made by different actors along the entire value chain. Any meaningful modelling of the circular economy has to deal with these interactions.

Obviously, a simple demand-supply diagram from an introductory economics course cannot capture the interactions along the value chain as it focusses on only one market. Fortunately, more sophisticated modelling tools are available to perform this job, each with specific capabilities and shortcomings. In the IECOMAT project, several of these economic modelling tools have been used and developed to respond to the project's needs. Models pertaining to three big families of economic models have been used in the project. The first family can be labelled as environmentally extended **input-output** (EEIO) models. These models go back to Leontief's Input-Output modelling framework which tracks for each sector in the economy where it sources its inputs from and where its outputs are used. In a mathematically consistent way, this type of models can track the embedded materials, energy use, CO_2 emissions, labour etc. in the entire supply chain of a particular sector. It can distinguish between direct and indirect materials' and energy use. Hence, it can track upstream use of materials and energy to produce inputs for a particular sector, both domestically and abroad. Recently, this type of models has been used to calculate carbon and material footprints of national economies, see for example Wiedmann et al. (2015). Such a multi-region environmentally extended input-output model for Belgium has been further developed and applied by the VITO team under the IECOMAT project.

Input-output models are very useful instruments to visualize linkages between sectors in an economy but they come also with some shortcomings. For example, they assume linear production technologies and fixed prices at a given moment in time. Over time, production relationships are changing in response to price changes and changes in regulation and technologies. For modelling more dynamic and endogenous interactions within the value chain of a product, the VITO team has developed a **general equilibrium model** to overcome these shortcoming of standard input-output methodology This type of model is different from input-output models as it allow for endogenous price responses across connected markets for inputs and outputs. It also models the labour market as this constitutes an important input in most production processes. Over the course of the last decades, many computable general equilibrium models have been developed academics and by public and private policy research institutes. However, very few of these models have been extended to model material flows and balances. So an important effort has been spent on extending the standard general equilibrium framework to adapt it to CE modelling.

But even general equilibrium models often fall short of capturing in sufficient detail all relevant and connected markets in the value chain of a very specific product of service. General equilibrium models are calibrated on input-output data whose sector granularity (typically a few dozen to at most 100 or 200 sectors) is often not fine enough to distinguish between subproducts (say electric versus internal combustion engine passenger vehicles). Also, very few of these models include the downstream part of the life cycle in the re-use, remanufacturing, recycling and waste stages of the value chain of a product. To accommodate this shortcoming, the IECOMAT project also developed an **integrated partial equilibrium modelling framework** to encompass also the interconnected life cycle stages. The novelty of this type of models is that prices are endogenous and interconnected throughout the different stages of the life cycle of a product. This task was taken up by the KU Leuven team.

Finally, the IECOMAT project also used so-called micro-economic Industrial Organization modelling tools in order to better understand the incentives of producers to choose for particular business models when engaging with their customers. Product-service business models are often hailed in the circular economy literature because of their supposedly superior performance on efficiency and environmental impacts compared to traditional business models based on product sales and private ownership. However, both producers and consumers often hesitate to switch to these new **business models**. The UCL CORE team has made important progress in the theoretical modelling of producers' incentives for switching to product-service business models and the KU Leuven CEDON team has contributed to this task by empirically testing the willingness of consumers to switch to more circular economy business models, in particular smartphones and clothing.

In order to report in an integrated way over all the scientific activities that were conducted under the IECOMAT project, we have chosen to first sketch briefly the state of the art and objectives (section 2). Then we provide details on the different methodologies used (section 3) and scientific results and recommendations (section 4). In each of these sections, we distinguish between three main parts, each referring to one of the three main objectives of the IECOMAT project: (1) what is circular economy?, (2) economic modelling of CE interactions, and (3) micro economic incentives and business models. The part on economic modelling distinguishes further between (1) input-output modelling, (2) general equilibrium and (3) partial equilibrium approaches. The micro economic incentives and business models sections are broken down in two parts: (1) producer and (2) consumer perspective.

We are aware that the description in this report of all the research that has been conducted over the course of four years by three different teams is often very condense and can only provide a glimpse of the richness of detail of the different approaches. We therefore refer interested readers to the scientific papers and reports that have been produced in the course of this IECOMAT project.

2. STATE OF THE ART AND OBJECTIVES

The overall objectives of the IECOMAT project, as stated in the project proposal in 2014, are the following:

- Provide a better understanding of the concept of circular economy and its macroeconomic, social and environmental potential in Belgium.
- Investigate the implications of the small open economy nature of the Belgian economy on the potential to develop a more circular economy model.
- Illustrate the potential of circular economy for Belgium by comparing different transition scenarios to autonomous developments in the use of materials.
- Co-develop business cases with stakeholders in the value chain in order to illustrate the leverage effect of new circular economy business models.

The first of these objectives (better understanding of the concept of circular economy) will be the focus of section 2.1. Investigating the potential for CE in Belgium and transition scenarios is closely linked to development of modelling tools which is the subject of section 2.2. Section 2.3 deals with the producer and consumer perspective of the transition from linear towards more circular business models.

2.1 What is circular economy?

Many different definitions have been put forward for the concept of circular economy. A recent review by Kirchherr et al. (2017) counted no less than 114 definitions of circular economy. And of course, definitions matter because they form, among other things, the foundation of indicators to measure the degree of circularity of an economy, product or material. A common criticism against the concept of CE is that there are so many definitions that people can understand very different things as being circular. A case in point is the importance attached to environmental impacts in the concept of CE. Some early definition of CE focused strongly on "closing loops" without considering possible negative side effects like energy use and pollution that might result from a narrow focus on boosting recycling rates.

In order to delineating the circular economy concept to be used during the IECOMAT project, a joint scoping exercise was performed based on the Belspo call text, research proposal text, recent literature sources on CE and a dialogue with the Follow-up Committee. This scoping exercise, performed in the first year of IECOMAT, resulted in the following guidance principles for the project teams:

- CE means from linear to circular and from circular to more circular
- CE is not identical to a Resource Efficient Economy or a Low-carbon Economy but parts of the CE will contribute to them.
- Circular economy systems aim to conserve the value contained in products for as long as possible
- The entire second hand market should be seen as part of CE
- IECOMAT takes an a-priori neutral point of view regarding CE (introducing more circular production and consumption cycles) and will investigate both socio-economic and environmental effects within Belgium and abroad (small open economy)
- IECOMAT will focus on abiotic materials and include materials made from fossil resources as well
- IECOMAT will not focus on food systems and biomass

- IECOMAT will focus on the economic activities and on its relations with the natural asset base and not study the possible substitution of abiotic materials by biotic materials. (Circular cascading use loops of biotic materials are included in the general CE definition but not studied within IECOMAT)

Starting from these guiding principles, a novel theoretical framework was developed starting from two basic ideas. The first idea is that a conceptualization of CE should focusses on **preserving and maximizing the value of resources and materials for society**, taking into account also environmental impacts along the entire life cycle. In that sense, we are consistent with the definition of CE as provided by for example Van Acker et al. (2016), p.4: "Circular economy refers to new technologies and business models designed to preserve wherever possible the value of resources and materials within the economy, to avoid waste, and to minimize the environmental impact of the resulting material cycles." A similar idea is behind the EU Commission's conceptualization of CE (EU Commission 2015): "[…] value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized […]". We stress the importance of value as it indicates that we are not interested in closing material loops as a goal in itself. Instead, the transition towards a more circular economy should improve social welfare in a broad sense, i.e. including environmental impacts in all stages of the life cycle. The second idea behind the framework is that it should also be able to capture the so-called **inner circle strategies of CE** like re-use, repair, refurbishment, re-manufacturing, extending the life time of products, products-as-a-service (PAAS), sharing etc., as they are for example visualized in the butterfly model of the Ellen MacArthur foundation[1]. As of today, most indicator frameworks for CE still focus on material use, material efficiency and recycling only. The resource efficiency indicators and scoreboard of the EU[2] is an example of this. In order to accommodate for these CE strategies as well, we started from the idea that consumers care, not as much about a product as such but rather about its functionality, i.e. the useful services it provides to its user. In this way, our approach is closely related to the concept of the functional economy as advocated by W. Stahel (1997): "A functional economy […] is one that optimizes the use (or function) of goods and services and thus the management of existing wealth (goods, knowledge, and nature). The economic objective of the functional economy is to create the highest possible use value for the longest possible time while consuming as few material resources and energy as possible." These are the two basic starting points for a conceptual framework that we will discuss in more detail in section 3.

2.2. Economic modelling of circular economy interactions

A number of modelling efforts have tried to address the circular economy, or tried to simulate its uptake. Despite these efforts however, the modelling analysis in this area remains relatively underdeveloped according to Winning, et al. (2017). McCarthy et al. (2018) provided a recent and extensive overview of 24 modelling-based assessments of a circular economy transition. They classified the numerical simulation models according to four aspects:

[1] See https://www.ellenmacarthurfoundation.org/circular-economy/infographic

[2] See https://ec.europa.eu/eurostat/web/environmental-data-centre-on-natural-resources/resource-efficiency-indicators/resource-efficiency-scoreboard

- Geographical coverage;
- Sectoral coverage;
- Material coverage and linking of economic and physical flows;
- Decoupling mechanisms.

Geographical coverage refers to the number of regions covered. Many models zoom in on only one country or region but there are also models that cover up to 40 regions. Some models cover only a handful of sectors while other distinguish between 60 sectors. The level of material coverage ranges between one (a hypothetical composite material) and more than 30 materials. Most models are however limited to a handful of materials: biomass, non-metallic minerals, (non)ferrous metals and fossil fuel energy materials/carriers. Most models are strong in representing upstream linkages, i.e. tracking which material inputs are used by a particular sector and where these originate from. But only a few models introduce downstream sectors (repair, recycling, secondary materials management, …) in a consistent way and these models are mostly single region models. Regarding decoupling between GDP and material consumption, models also differ widely in flexibility. All models allow for improvements in material intensity of production as result of technological progress (mostly exogenously modelled). Lifetime extension of products and substitution between materials (also between primary and secondary ones) is present in several models. Substitution at the consumer side between goods and services that fulfil the same function is not systematically modelled in the macroeconomic models that were reviewed. There is one important conclusion from this review to be remembered: there seems to be a strong trade-off between level of complexity and interconnection and level of detail in terms of regions, sectors and materials. Models that focus on downstream linkages are typically single region models and no model currently captures endogenously and in a comprehensive way a shift from linear to more circular business models.

Given the results of the review by McCarthy, et al. (2018), it is clear that it is not realistic to aim for a single super model that can meet the needs of the IECOMAT project research objectives. Rather, a combination of modelling approaches will be necessary in order to focus on particular sub questions. Following their efforts, and the conclusion by this research opted for an approach which allowed a sufficient level of detail to specify circular activities, products or services. The IECOMAT project has made use of three broad categories of numerical economic modelling tools: extended input-output models, computable general equilibrium models and integrated partial equilibrium models of the life cycle of a good.

2.3. Micro economic incentives and business models

The transition towards a more circular economy requires the introduction of new business models in existing industries. The interaction between incumbents and new entrants is therefore unavoidable. The general objective of this task is to study the interactions between the incumbents in an industry and the new business or market that enter the industry to shed light on consequences of the interaction on the economy and the environment, as well as the motivation of to develop new business models. To this goal, we specifically look into the literature in industrial organization involving the topics of recycling, remanufacturing, sharing economy and servitisation.

In a first study, we focus on the literature on recycling. Economists have studied the “recycling problem” since the famous Alcoa case (Walter, 1951). In 1945, the virgin aluminium producer Alcoa was found in a monopolistic position by virtue of its control over 90% of virgin aluminium output. This position had the potential to limit the competitiveness of the recycling industry, which captured roughly 20% of the total aluminium market. The case was concluded by the judgment of Judge Learned Hand, according to which Alcoa constituted an illegal monopoly, in violation with the Sherman Antitrust Act. One of the motives was that Alcoa strategically controlled the supply of the recycling sector by manipulating the virgin aluminium production. Starting in the mid-1970s, a literature in industrial organization focused, both theoretically and empirically, on analysing the validity of this judgment. While the early studies (Gaskins ,1974; Swan, 1977) support the reasoning of the Judge, later studies such as Grant (1999) point out that Alcoa’s market power should be attributed to the fact that over half of the aluminium sold by Alcoa was never recycled, rather than to an abuse of dominant power by Alcoa to limit the competitiveness of the new entrant. There exists also a recent strand of the literature on “remanufacturing” (i.e., repairing or rebuilding a used product to its original—or larger—performance), which analyses its impacts on the profitability of primary manufacturers (Atasu et al., 2008; Ferguson and Toktay, 2009; Mitra and Webster, 2008). These studies investigate the conditions for the manufacturers to benefits from remanufacturing, for the manufacturer to choose to remanufacture its products or the impact of government’s subsidies on remanufacturing.

However, these studies, are not concerned with the impact of changes in the collection rate of end-of-life products on the strategy of the manufacturer. Particularly, the strand of literature on recycling has focused only on the impact of a competitive recycling sector on the market power of the primary producer to study the pro-competitive effect of recycling. As most of these studies are conducted before the focus of governments on recycling, they do not investigate how external efforts to improve the collection system can affect the strategic choice of the virgin producer. In recent years, governments have made great effort and commitment to scale up the collection of scraps for recycling, expecting that the growing recycling activities can reduce the volume of virgin production and result in a smaller impact on the environment. To cite an example among many, in 2012, the European Commission sets the collection target of minimum 85% of Waste Electrical and Electronic Equipment generated on the territory of Member States (European Parliament, 2012). Another ambitious target, voted by the European Parliament in the plastic program in 2018, requires Member States to ensure that 90% of all plastic drinks bottles are collected for recycling by 2025 (European Parliament, 2018). These initiatives create an external push that ease the input constraints of the recycling sector: with the commitments to achieve high target in the collection of scraps for recycling, the recycling firms now have more input to recycling and hence, better capacity to compete against the primary producers. It is this question that motivate our first study. To the best of our knowledge, our study is the first to study the impact of changes in the collection rate on the interaction between virgin producers and recycling firms.

In the second study, we shift the focus to a smaller loop of the circular economy, namely the reuse of durable goods through the so-called ‘sharing economy’, which comprises activities through which owners of underused resources make these resources available to other individuals. We study the threats and opportunities that a peer-to-peer rental (sharing) market, together with a second-hand market, implies on the profitability of a manufacturing firm of a durable good. Our aim is to shed light on how the manufacturing firm can profit from a better peer-to-peer sharing market and how this type of market can be more environmentally friendly, given the reaction of the manufacturing firm.

The literature in industrial organization has investigated the impacts of second-hand markets on the manufacturing of durable goods since the 1970s. By the end of 1990s and early 2000s, papers such as Waldman (1996), Hendel and Lizzeri (1999) and Anderson and Ginsburgh (1994) typically conclude that a durable good monopolist may find it optimal to reduce the durability of the good to reduce the substitutability between new and used units, which, in turn, allows the firm to increase the price of new units and hence, increase its profitability. In recent papers, Esteban and Shum (2007) and Chen et al. (2013) empirically study the impact of secondary markets on the profitability of manufacturers. They use the data from the US automobile industry to estimate that the second-hand market for cars decreases the profits of car manufacturers by 35 percent but, when products become less durable, the second-hand market increases instead the profitability of the manufacturers. These results confirm the conclusion of previous theoretical studies, according to which manufacturers facing a secondary market have an incentive to reduce the durability of the products below the socially optimum level (i.e., to “plan the obsolescence” of their goods).

However, the landscape of the economy has changed significantly with the emergence of a new competitor: the peer-to-peer rental market. Typical P2P platforms, like Blablacar and Uber, have grown rapidly and become real competitors to traditional manufacturing firms. Therefore, it is necessary to shed some light on the comparison between the P2P rental market and the more traditional second-hand market, together with their impacts on manufacturing firms. These two types of markets have received emerging attention due to their (arguable) potential to reduce the environmental impacts. While peer-to-peer rental markets help increase the utilization of underused durable assets by allowing people to rent out the product they own for a fee during their idle time, second-hand markets make it possible to recirculate products among consumers. As such, both types of markets contribute to the “circular economy” by reducing resource consumption via the increase in the intensity of product usage and, other things being equal, the reduction in production (and hence in the consumption of raw material).

Scholars have started to look at the problem of peer-to-peer sharing economy. Fraiberger and Sundararajan (2017) develop a dynamic model of peer-to-peer Internet-based rental market for durable goods to characterize the stationary equilibrium of the model. Using the data of rental transaction through a San Francisco-based P2P car sharing platform (Getaround5) to calibrate their dynamic model, the authors confirm that a small fraction of below-median income consumers switch from being non-owners to being owners. They also predict an increase in consumer surplus, particularly the below-median income population follow the possibility of the peer-to-peer P2P market. Horton and Zeckhauser (2019) analyse theoretically the Internet-based rental market to determine the ownership, rental rates, quantities, and surplus of the society both in the short and long run. The authors also examine bringing-to-market costs and consider the platform’s pricing problem, showing mixed results of the impact of the sharing economy on ownership and surplus. Benjaafar et al. (2019) consider the ownership choice with and without the possibility of peer-to-peer rental. Einav et al., (2016) explain why peer-to-peer markets are flourishing, they emphasize the role of platforms in matching buyers and sellers, maintaining a reputation system and using prices to clear the market. They also provide a model focusing on the competition between the peer-to-peer market and the traditional firms. The empirical works on peer-to-peer P2P markets have also been rising in the recent years, using data from all over the world. Edelman and Geradin (2016) enumerate the efficiency gains from peer-to-peer rental markets, such as reducing transaction costs and improving allocative efficiency. Hampshire and Gaites (2011) analyse the feasibility of peer-to-peer car-sharing in Pittsburgh. These papers, however, do not study the implication of peer-to-peer markets on manufacturing firms. To the best of our knowledge, Abhishek et al. (2018) is the only study that puts the manufacturing firm in the model. The authors analyse the impact of the P2P market on the profitability of a manufacturing firm by characterizing consumers who vary in both usage rates and the valuation for the usage of the OEM's product. They show that the OEM and consumers are both worse off with the P2P market if consumers' heterogeneity in usage rate is too high or too low and both better off otherwise. However, they do not characterize the second-hand market and its impact on the choice of durability of the manufacturing firm. Since the existence of the second-hand market is common for many durable products and has important implications on the strategy of the manufacturing firm, we aim to shed light on the interaction between a sharing market, a second-hand market and the strategies of a manufacturing firm.

Lastly, we study the motivation of the manufacturing firm itself to adopt a service-oriented business model: the pay-per-use (PPU) business model. This model belongs to the family of innovating business models that consist in selling functionality of the product rather than the product itself – the so-called Product-service system or Servitisation. Under PPU, instead of selling the products to consumers for a fixed selling price, the manufacturer charges consumers a per-use fee for each time they use the product. The "document management" service of Xerox (Xerox, 2015), for example, does not sell or lease photocopy machines to consumers but instead provides the printing service with a fee for each page that consumers print. With this service, Xerox takes care of all the operating process and charges consumers a fee for each page that covers every cost during the printing process. In the lighting industry, Philips provides the "light-per-lux" business model that charges a fee for every unit of lux that consumers use while taking care of the whole lighting system (Philips, 2011). The most famous case study of servitisation is Rolls Royce. The firm earns more than 50% of its revenue from services, particularly via the TotalCare service (Rolls Royce, 2017), where the firm leases jet engines to airline consumers, manages them throughout their life cycle, and charge consumers a fee for every flying hour of the engines. PPU also emerged recently in the B2C context with the car-sharing firms. Cambio or Zipcar, among many others, allow consumers to rent the cars and pay only for the minutes or kilometres that they drive while the firm takes care of the insurance, gasoline, parking and maintenance costs.

On the topic of servitisation, there exist many conceptual and case studies conducted by researchers in management (see, e.g., Tukker (2015) for a recent review of this literature). Although these studies are very useful in defining the values of servitisation for the firm and for the environment, they rely on anecdotal evidence and discrete case studies to support their argument. There are, to the best of our knowledge, surprisingly few analytical studies on the topic. Agrawal and Bellos (2017) study the impact of resource pooling on the profitability, efficiency and environmental impacts of servitisation. They also provide an investigation of pure servitisation and the hybrid business model under which the firm provides selling and servitisation at the same time. Orsdemir et al. (2019) take the operating cost as exogenous and investigate the durability choice of a firm facing two segments of consumers identified by their valuation for the product: the high-end and low-end consumers. Applying the concept of life-cycle assessment to describe the environmental impacts of products, they find ambiguous effects of servitisation on profitability and environmental benefit of the firm;

the win-win equilibrium depends on the firm's relative operating efficiency, the environmental impacts of the product in its use phase relative to the production and disposal phases, and the similarity of consumer segments. However, the use of their specific setting on the demand side imposes that PPU and selling yield the same revenue without other distortion on the utility of consumers and the cost for operation and/or production. The mechanism they propose, therefore, can be biased upward or downward and may not predict correctly the impact of PPU on the profitability of the firm.

Closely related to the topic, there exists a strand of the literature on the leasing of durable goods (Desai and Purohit, 1998; 1999; Bhaskaran and Gilbert, 2005; Agrawal et al., 2012). However, studies in the durable goods literature do not provide a suitable framework to study the impact of pay-per-use pricing scheme due to their specific focus on the demand of products rather than of usages.

There exists also a strand of literature on the pricing of digital goods that tackles this pricing structure. Jiang et al. (2008) study the profitability of adopting pay-per-use for a digital good relative to a fixed-price one-time purchase business model. Assuming that consumers' level of usage and marginal utility from usage are uniformly distributed and that pay-per-use imposes an inconvenience cost to consumers, the authors compare the two pricing structures, showing that the possibility of piracy favours pay-per-use over the fixed-price structure. Using a similar framework, Gurnani and Karlapalem (2001) conclude that a hybrid business model, i.e., adding the pay-per-use pricing to the fixed-price business model, is more profitable than adopting any pricing structure exclusively. They show that pay-per-use is more profitable if the cost of in-house development is large and that fixed price is more profitable otherwise. In a more recent paper, Postmus et al. (2009) assume homogeneous marginal utility from usage to study the impact of consumers' in-house development on the choice of the pricing structure of a software vendor. Gilbert et al. (2014) use the same framework, assuming that both the usage level and the marginal utility from usage follow a uniform distribution, proving that selling and renting simultaneously the product is often the optimal strategy of the firm. Balasubramanian et al. (2015) also compare pay-per-use and selling when usage on pay-per-use basis generates a psychological cost for consumers; they show that pay-per-use is more profitable if the psychological cost is low. This strand of the literature, however, is concerned neither with the environmental impact of different strategies nor with the operating cost of products, which is the main characteristics that distinguish physical from digital products.

3. METHODOLOGY

3.1. What is circular economy?

As sketched higher, the IECOMAT project wanted to contribute to the discussion about the definition of CE by formulating a very general theoretical framework, based on social welfare maximization, in which CE indicators can be grounded. This conceptual framework has been published in *Ecological Economics*, see García-Barragán et al. (2019) for full details. Below, a short presentation of the approach is provided.

In contract to the usual assumption in micro economic modelling that consumers derive utility from commodities, we started instead for the idea that consumers care about **functionalities** and that these functionalities require some commodity to be produced. For example, mobility is a functionality which requires bikes, cars or trains as commodities to deliver the mobility services consumer are ultimately interested in. Another example is housing that requires houses and apartments. Technically, we denote the utility function (time indexed and increasing in every argument) as follows:

$$u_t(\hat{c}_{1,t}, \hat{c}_{2,t}, \ldots, \hat{c}_{n,t})$$

Where $\hat{c}_{i,t}$ denotes functionality *i* enjoyed in period *t*. In order to deliver a functionality, commodities or products $c_{i,t}$ are required. We explicitly allow for durable commodities such that a functionality at time *t* can be produced by commodities that were produced in earlier time periods (up to $t - h_i$ where h_i can be interpreted as the expected lifetime of the commodity):

$$\hat{c}_{i,t} = z_t^i \left(c_{i,t}, c_{i,t-1}, c_{i,t-2}, \ldots, c_{i,t-h_i}\right)$$

Commodities are produced using materials and capital (k). We make a distinction between virgin (m) and recycled (r) materials:

$$c_{i,t} = f_{i,t}\left(m_{i,t}^1, m_{i,t}^2 \ldots, m_{i,t}^N, r_{i,t}^1, r_{i,t}^2, \ldots, r_{i,t}^N, k_{i,t}\right)$$

We further assume that, at the end of their lifetime, commodities are taken to recyclers that recover a fraction of the embedded materials which can be re-used in the commodity production process. The non-recycled fraction of materials is send to a landfill which accumulates over time.

Social welfare is defined as the utility of consuming functionalities minus the costs of production and recycling and the cost to society of environmental externalities that are caused by the different materials during their lifetime. The model also includes as physical constraints the evolution of the stock of materials, waste and capital. Maximizing in this model social welfare with respect to the material use gives rise to optimality rules for the use of virgin and recycled materials. In particular, the crucial equation of the paper is:

$$\sum_{s=0}^{h_i} \frac{\partial u_{t+s}^*}{\partial z_{t+s}^*} \frac{\partial z_{t+s}^*}{\partial f_{i,t}^*} \frac{\partial f_{i,t}^*}{\partial m_{i,t}^j} = -\frac{\partial q_{j,t}^v}{\partial m_{i,t}^j} + \lambda_{i,j,t+h_i}^{r^v} \frac{\partial g_{i,t+h_i}^{v,j}}{\partial m_{i,t}^j} - \lambda_{t+h_i}^W - \lambda_t^M$$

The left hand side (LHS) denotes the marginal benefit of using a particular virgin material. The marginal benefit consists of the product of three factors: (1) marginal utility of functionality $\partial u / \partial z$,

(2) marginal productivity of the commodity to produce the functionality $\partial z/\partial f$, and (3) the marginal material productivity to produce the commodity $\partial f/\partial m$. The left hand side refers to marginal costs of material use, in particular environmental externalities, recycling costs, waste accumulation and resource depletion. A very similar equation can be derived for the optimal use of recycled materials.

The marginal benefit of a material is according to the LHS of the formula decomposed into three factors. The first factor $\partial u/\partial z$ denotes the value that consumers attach to an extra unit of consumption of the functionality. In a market context, it reflects the price he or she is willing to pay for an extra unit of functionality (for example an extra passenger-kilometer of mobility). Obviously, some functionality are valued more than others by consumers depending on their preferences. The two other factors of the LHS of the formula refer to technical productivity measures and we can easily think of interventions or policies to increase the value of a material by boosting theses productivities.

- Policies that lead to lower material intensity of products will result in a better marginal material productivity $\partial f/\partial m$. We can think of light weighting of vehicles using strong composite materials.
- And, recalling the importance that we want to attach to sharing and product-as-a-service strategies, these strategies will affect positively the productivity of commodities to produce functionality $\partial z/\partial f$. Car sharing for example will reduce the number of cars necessary to provide mobility functionality to the consumers which is reflected in an increase of $\partial z/\partial f$.

Finally, note that increasing longevity of commodities (hence higher h_i) leads to a higher value of materials as more terms are added to the summation in the formula. Hence life time prolonging strategies are beneficial for the value of materials and the value indicator is sensitive to that.

Using the Formula above, García-Barragán et al. (2019) define optimal recycling and linear activity indicators for material i in sector/commodity j at time t as follows:

$$R^*_{i,j,t} = \left(\sum_{s=0}^{h_i} \frac{\partial u^*_{t+s}}{\partial z^*_{t+s}} \frac{\partial z^*_{t+s}}{\partial f^*_{i,t}} \frac{\partial f^*_{i,t}}{\partial r^j_{i,t}}\right) \alpha^i_{j,t}{}^* \qquad L^*_{i,j,t} = \left(\sum_{s=0}^{h_i} \frac{\partial u^*_{t+s}}{\partial z^*_{t+s}} \frac{\partial z^*_{t+s}}{\partial f^*_{i,t}} \frac{\partial f^*_{i,t}}{\partial m^j_{i,t}}\right)(1 - \alpha^i_{j,t}{}^*)$$

With the endogenous recycling rate defined as the ratio of recycled over total (i.e. virgin plus recycled) material use:

$$\alpha^i_{j,t} = \frac{r^j_{i,t}}{m^j_{i,t} + r^j_{i,t}} \in [0,\, 1]$$

Aggregating these indicators over materials and commodities/sectors, García-Barragán et al. (2019) propose the following circularity indicator:

$$C^*_t = R^*_t - L^*_t$$

This indicator can then be used to unambiguously test if an economy has become more circular over time: if $C^*_{t+s} \geq C^*_t$ for some $s > 0$ it has indeed become more circular. Although the measure has not (yet) been operationalized for particular functionalities (the authors reflect in the paper on how this could be done), it is important to stress the theoretical contribution to the debate on circular economy indicators that has been achieved by the IECOMAT researchers during the BELSPO funded project. This contribution is one of the key elements of the PhD work of KU Leuven PhD student Juan García-Barragán who is expected to publically defend his PhD at KU Leuven in due course.

3.2. Economic modelling of circular economy interactions

Input-Output modelling

The basic Leontief model, expressed by $q = [I - A]^{-1}y$, with q the production output vector, $[I - A]^{-1}$ the Leontief inverse matrix and y the final demand vector represents the manifold and complex interactions between all industries of an economy. Changes in final demand, consumption patterns, production patterns and social or environmental aspects trigger changes in existing global value chains. These exceed the impact on one single-product value chain and national borders. They trigger worldwide production patterns and imply economic, social and environmental impacts. This method has been applied using the latest available and most detailed physical and hybrid Input-Output databases.

General equilibrium modelling

The aim of the newly developed CGE is twofold. First, the model should allow better understanding of the macro-economic consequences of increased circularity, especially for the Belgian case. This kind of understanding can create some clarity for both public and private stakeholders as there is a lack of common agreement on the macro-economic impact of circularity at present (McCarthy, et al. 2018). Second, the CGE model unravels some of the underlying economic mechanisms which can stimulate or hinder the uptake of the CE. This is crucial information for policymakers as this enables them to design tailor-made policies in support of the CE. CGE models in particular struggle to provide meaningful insights given their aggregated sectoral coverage. The IECOMAT research, however, presents a method to introduce a sufficient level of detail in extensive CGE models. The CGE model focusses on Belgium as a small and open economy (which has its consequences for the set-up of the CGE model) which trades with the EU on the one hand, and the Rest Of the World (ROW) on the other hand.

The computable general equilibrium (CGE) model discerns the following types of economic agents:

- Consumers
- Activities
- Government
- Investment
- Enterprises
- European Union (EU)
- Rest of the world (ROW)

In addition, the conventional market balances for the different goods and services, the labor market and the capital services market are introduced in the CGE model.

The households consist of a consumer group with a fixed endowment of capital goods, and a fixed supply of capital services. It is also endowed with a fixed amount of time. The consumer group is assumed to maximize their utility function subject to their budget constraint. The utility function is a nested function with either Cobb Douglas or Modified Constant Elasticity of Substitution (MCES) functions for the different nests. As regards the treatment of transport it should be noted that transport produced by the households themselves is not included in the transport modes, but rather included implicitly in the consumption of the other goods and services.

The utility functions are defined over the so-called excess quantities of consumption, saving and leisure. These are the quantities that exceed the minimum levels or subsistence levels of consumption, saving and leisure. Such minimum levels are introduced in the model to obtain realistic income elasticities. The budget constraint states that the sum of the money costs of consumption and saving and the cost of leisure time cannot exceed full income. Full income is composed of:

- Time income:
    - the total available time minus labour supplied to the EU and ROW multiplied by the net wage rate received by the households
    - the net wage income from labour supplied to the EU and the ROW
- Capital income
- Transfers received from the government
- Net transfers received from the EU and the rest of the world (expressed in local currency)

The domestic activities in the economy are assumed to minimize their production costs subject to their production function. For each activity the aggregate output is assumed to be produced under a constant returns to scale (CRS) technology. The activities are assumed to minimize their costs under the hypothesis of perfect competition.

The production functions are nested functions. All levels of the production function are modelled as MCES functions. The model takes into account that each activity may supply different types of commodities (i.e. goods and services). For each activity and vintage the aggregate output is divided across the different commodities such that revenue is maximized for a given aggregate output level subject to imperfect transformability between the different categories, as represented by a **Constant Elasticity of Transformation (CET) function**.

Following **Armington** (1969) foreign commodities are assumed to be different from domestic commodities, though they might be close substitutes for one another. Homogeneity of domestic and foreign commodities would lead to a tendency towards specialization when coupled with the small country assumption, which is not observed in reality, and would give rise to unrealistic trade elasticities. Therefore, we follow the approach used in many other models and adopt the Armington formulation which allows one to keep aggregative commodity categories across countries but specifies product differentiation by region of origin into the structure of demand.

For each type of commodity, the model considers a representative firm that produces an aggregate or composite commodity with the input of several varieties:

- the variety imported from the EU
- the variety imported from the ROW
- the domestic varieties

Each representative firm is assumed to minimize its costs subjected to a nested production function.

The government and investment sectors are assumed to maximize a utility function subject to their respective budget constraint. In both cases the utility function is a Cobb Douglas function that is defined over the different types of goods and services. In the case of the investment sector it is also defined over the Belgian regions. For this a nested structure is used to allow for imperfect substitutability. The budget constraint for the government imposes that the spending on goods and services cannot exceed the government budget[3]. The budget constraint for the investment sector imposes that the aggregate spending on the investment goods cannot exceed the total investment budget[4].

On the **export side**, remaining faithful to the small-open-country assumption would entail that the export demand by the rest of the world is infinitely elastic. But this is inconsistent with the assumption that products are differentiated by country of origin and imperfect substitutes for one another. This assumption implies less than infinitely elastic demand functions for the country's exports. Based on Dervis et al. (1981) we use a constant elasticity demand function to determine the export demands for each type of goods and services.

The share of the country in world demand of a type of goods and services depends on the world price (assumed to be fixed in real terms), the domestic price and the total foreign demand. The approach follows from the assumption that the foreign sector behaves in a similar way as the domestic country and demands commodities according to the rules of cost minimization subject to a production function for composite commodities. The small country assumption still holds in the sense that a change in domestic price is assumed not to affect the world price, nor the total foreign demand. However, it does have an impact on the country's market share.

The model includes "**enterprises**" as a separate institution. The enterprises receive the remuneration of capital services from domestic and foreign sources, pay income taxes on these revenues and distribute the remaining revenue amongst the households, the government and saving by the enterprises. Enterprises do not consume commodities. The redistribution is done based on exogenous shares, the sum of which should add to zero.

A visual summary of the structure of the model is provided below.

[3] Government budget is composed of tax income from VAT, net tax income from product related taxes (excl. VAT), net tax income from non-product related taxes, net income from import tariffs, tax income from income taxes, net international transfers (in local currency), net capital income of the government, minus government transfers to households, minus government deficit.
[4] Investment budget is composed of household savings, government savings, minus the net value of the change in inventories, current account deficit.

Figure: financial flows in the CGE model

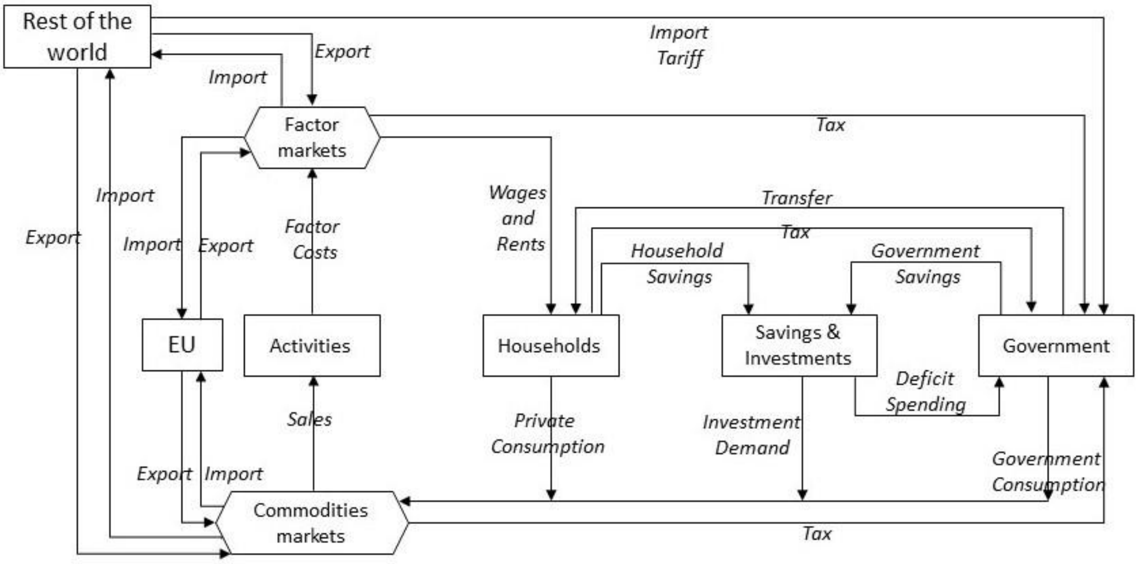
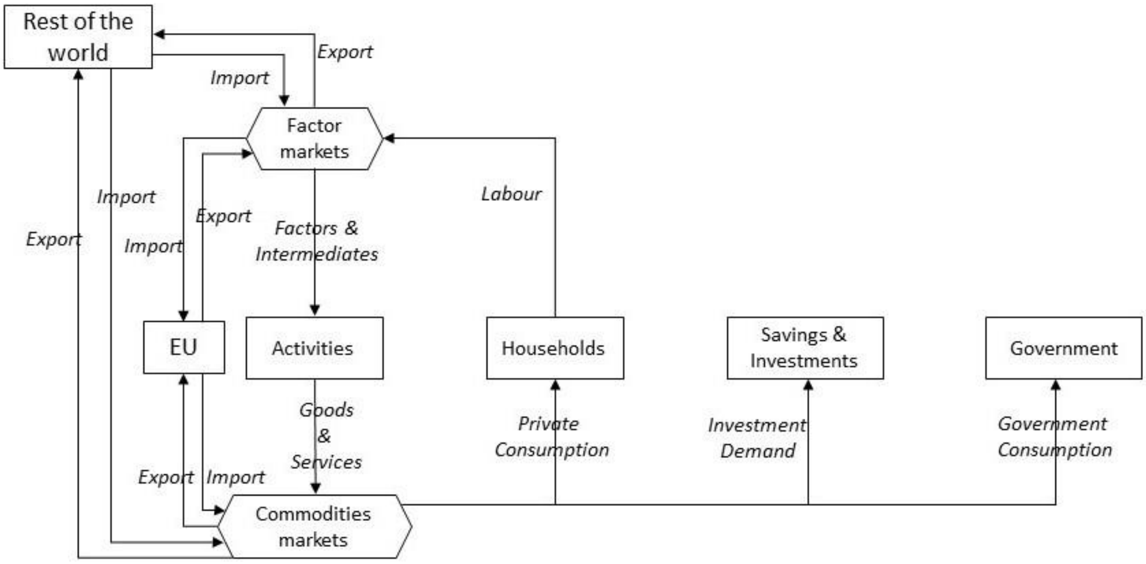


Figure: product, factors and service flows in the CGE model



The model's output allows to report on each of the arrows above in addition to the macro-economic variables which are incorporated in, or determine the outcome of, the CGE model (e.g. GDP, utility…).

The introduction of circularity options in the model requires a number of modification to the original (basic) CGE model. The basic model contains the 12 activities and 12 goods / services presented in the following table.

Table: activities and goods / services present in the basic model

Activities	Goods and services
Agriculture, fishing, forestry	Agricultural products, fish, forestry products
Mining	Mining products
Industry	Industrial products
Energy	Energy products
Construction	Construction products
Trade	Trade services
Land transport	Land transport services
Water transport	Water transport services
Air transport	Air transport services
Logistics & mail	Logistics services & mail
Market services sector	Market services
Non-market sector	Non-market services

Introducing circularity into the CGE model requires two main changes to the basic model's structure. First, additional circular activities, goods and services need to be added to the CGE model as an alternative to the present linear systems. Second, the nested structure of the consumption and production original nested structure of the consumption and production functions need to be restructures. Those two main changes are described below.

Change one: extension of number of activities, goods and services

The circular activity does not exist. Instead, a wide variety of strategies aim to increase circularity, each of these strategies has its own particularities. The 9R model (Potting, et al. 2017) identified no less than ten CE strategies (Refuse raw material use, Rethink, Reduce raw material use, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover energy). This high diversity in circular strategies prevents a one-model-fits-all solution to assess all circular strategies. For each circular strategy, it is necessary to extent the CGE model's number of activities, goods and services. Four possible types of extensions are identified:

- **Extension A: introduce a circular activity which produces a non-differentiable good or service:** In this case, the products/services cannot physically be distinguished from their conventional counterparts. E.g. for energy recovery, material recycling without downgrading, (some cases of) repair;
- **Extension B: introduce a circular activity which produces a differentiable good or service:** Possible circular activities are refurbishment, refuse and reduce raw material use, remanufacture, repurpose, or repair. These activities will provide goods which are alternatives to the purchase of new (linear) goods;
- **Extension C: a conventional (linear) sector which produces a circular good / service:** some by-products and waste streams of conventional activities can directly be introduced as input, intermediate good, or production factor in other circular business cycles;
- **Extension D: Consumer as producer:** once consumers start to produce or supply goods / services themselves, instead of the commercial sector. Distinction is made between the production of non-distinguishable goods and services (e.g. surplus solar energy production by

residential solar panel installations) and distinguishable goods and services (e.g. sharing economy).

Note that, depending on the circular strategy, either one or a combination of these different types of extensions is required to assess the strategy. For each strategy, the modeller needs to consider what type of extensions are activated in the basic CGE model. Subsequently, the newly introduced production and consumption functions need to be specified, and calibrated.

Change two: restructuring of nested production and consumption functions

The introduction of additional activities, goods and services into the model implies modifications to the model's nested structure of consumption and production function. There are two options to include the new activities, goods and services in to the model's nested structures of consumption and production. First, the new activities, goods and services can be added to existing categories of activities, goods and services within the nested structure. This enlarges the size of the existing categories in the basic model.

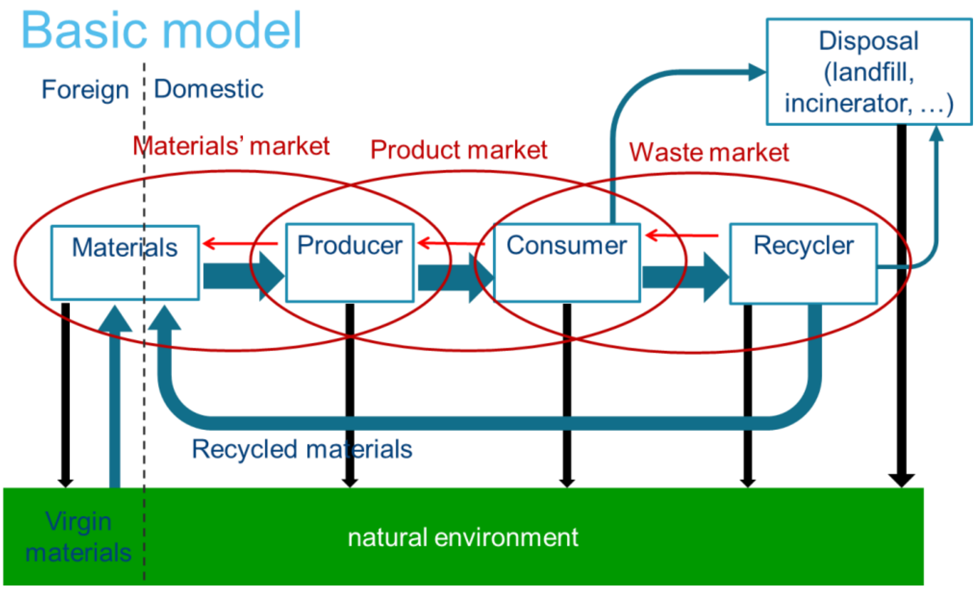
Second, new levels can be added to the nested structures. This increases the number of categories in the CGE model. This requires the separation of some activities, goods and services out of their categories. Subsequently, the separated activities, goods and products are transferred into a newly created category. It is possible to separate activities, goods and services out of the original activities, goods and services (see Table 1) as the original activities, goods and services are aggregates. The twelve activities are summations of several of 98 activities (recorded according to the original NACE codes). Simultaneously, the twelve goods and services are summations out of the same number of goods and services. In theory, if each of the 12 activities and 12 good and products is fully disaggregated, the model would run with 98 sectors and 98 goods and services. However, for computational reasons this is not a preferable situation. Instead, we apply 12 sectors and 12 goods and services, supplemented with some particular sectors, goods, and services (depending on the circular strategy investigated). In case the NACE codes are not sufficient for the identification of circular activities, or circular goods and services, it is possible to further disaggregate the 98 classes based upon other databases (e.g. EXIOBASE, WIOD). All new activities, goods and services need to be calibrated in accordance to the original activities, goods and services (see sections with 'Notes on calibration'). In case this is not possible, the new activities, goods and services need to be specified based upon further literature review of assumption, which is less preferable.

The analysis of circular strategies will typically require the second type of modifications to the nested consumption and production functions. This second modification allows to create devoted categories which include both the linear existing activity, as well as the newly created circular activity (good / service). As such, it is possible to model their interchangeability or substitutability.

Partial equilibrium modelling

In the framework of the IECOMAT project, we have set up a model in which a consumer product is produced using a mix of virgin and recycled material inputs. The producer determines the content of recycled material and material intensity of the product in function of the material prices. The product is sold to consumers that, at the end of life of the product, can sort their waste and or dispose of it legally or illegally. Sorted material is bought by (or sold to) recyclers that recycle valuable materials from the sorted material. The recycled material is sold to producers of the consumer good and the unsorted residual is disposed of in a landfill or incinerator that gives rise to environmental damages. The flow of material and stakeholders in the life cycle of the product are visualized below:

Figure: flow diagram of the life cycle partial equilibrium model



Thick blue arrows denote the flow of materials, black arrows stand for environmental impacts and red arrows for monetary flows. In line with the small open economy nature of Belgium, we think of virgin material being imported from abroad.

Production of the good

The domestic producers choose production level Q, share of recycled input material $\gamma \in [0,1]$ and material intensity reduction $\mu \in [0,1]$ as to maximize profits. Material demand is defined as $[1-\mu]Q$. Without extra effort ($\mu = 0$), one unit of output requires one unit of material. The material intensity of production can be reduced at rate μ but this will increase the unit cost of production by $h(\mu)$. Total material demand can be satisfied by both virgin material (share $1-\mu$) and recycled material (share μ). Without extra effort ($\mu = 0$), no recycled material is incorporated in the output. Profits are given by sales revenue minus total costs which consist of the cost of purchasing virgin material (price p^v) and/or recycled material (price p^r), variable production costs (constant marginal cost c) and the cost of incorporating a fraction $g(\gamma)$ of recycled material and the cost $h(\mu)$ to reduce material intensity by μ. A competitive output market is assumed (price taking behaviour). Regarding the cost functions we assume that incorporating more recycled materials drives up the unit production cost at an increasing rate $g' \geq 0$ and $g'' > 0$. Likewise, it is assumed that reducing material intensity drives up the unit production cost at an increasing rate $h' \geq 0$ and $h'' > 0$. The profit maximization problem of domestic producers can now be written as follows:

$$max_{Q,\gamma\mu}\ \pi = pQ - p^v[1-\gamma][1-\mu]Q - p^r\gamma[1-\mu]Q - cQ - g(\gamma)Q - h(\mu)Q$$

Note that the price of material can be defined as the weighted average of prices of virgin and recycled material: $p^m \equiv p^v[1-\gamma] + p^r\gamma$. The necessary first-order condition for the optimal choice of output (assuming an interior solution $Q > 0$) is given by:

$$p = c + p^m[1-\mu] + g(\gamma) + h(\mu)$$

This is the familiar condition for supply behaviour in a competitive output market: price should be equal to marginal production cost which includes, in addition to the tradition marginal production cost, also material costs and the costs for incorporating recycled material and reducing material intensity.

The optimal choice of recycled content used in production is given by the condition that the marginal cost of the last unit of recycled content equals the corresponding marginal benefit, i.e. the difference in price between virgin and recycled material (taking into account material intensity and assuming that $p^v \geq p^r$): $g'(\gamma) = [p^v - p^r][1-\mu]$.

Increasing recycled content leads to savings in virgin material costs and increasing recycling material costs. The condition reveals that it only makes sense to increase recycled content if recycled materials are less expensive than virgin material. Larger difference in price between virgin and recycled material will lead to more effort to incorporate recycled material ceteris paribus.

Finally, the optimal choice of material intensity is simply determined by the condition that the marginal cost of the last unit of reduction of material intensity equals the corresponding marginal benefit, i.e. the price of material saved: $h'(\mu) = p^m$.

Using the conditions higher, we can define demand for material by domestic producers as $MD^d = [1-\mu]Q$, their demand for virgin material as $VMD^d = [1-\gamma][1-\mu]Q$ and their demand for recycled material as $RMD^d = \gamma[1-\mu]Q$.

Consumers

Consumers choose a level of functionality (i.e. service) F and sorting effort $\alpha \in [0,1]$ as to maximize utility w.r.t. budget constraint. The price of the consumption good is denoted by p. Sorting has an increasing and convex unit cost $s(\alpha)$ with $s' \geq 0$ and $s'' > 0$. Utility is given by an increasing and concave function of consumption of functionality: $U(F)$ with $U' \geq 0$ and $U'' < 0$. We assume a simple linear relationship between the level of functionality and the commodity to produce it: $F = \varphi Q$. The $\varphi > 0$ parameter can be interpreted as the productivity of commodities to produce functionality. A shift towards a sharing business model instead of classical product sales could lead to an increase in the productivity parameter if shared goods are used more intensively than privately owned goods. Unsorted waste can be disposed of at a cost t_d^c while sorted waste can be sold by consumers to recyclers at a price p^s which may be positive or negative (see further in the section on recyclers). The full consumer utility maximization problem can be written as follows:

$$max_{Q,\alpha} \ U(\varphi Q) - pQ - s(\alpha)Q + \alpha Q p^s - [1-\alpha]Q t_d^c$$

The consumers will buy commodities (or better, services of the commodities) up to the point where the **marginal utility of consumption equals the full price**, i.e. its purchasing price plus the sorting effort cost minus (or plus) the revenue (or cost) of sorted material sales and plus the cost of disposing the non-recycled material:

$$\varphi U'(F) = p + s(\alpha) - \alpha p^s + [1-\alpha]t_d^c$$

For later reference we will denote consumer demand for commodities as QD. **Optimal waste sorting efforts** are determined by the condition $s'(\alpha) = p^s + t_d^c$. Hence, the consumer will choose a level of sorting effort such that the marginal cost of the last unit of effort equals the marginal benefit which consists of the price of sorted waste plus the cost of disposal charges saved. From this condition we can infer that consumers will do more recycling effort if the price of sorted waste is high and/or the cost of disposal is high. The supply of sorted waste material (measured in weight units) is given by: $WS = \alpha[1-\mu]Q$.

Note that more complex financial stimuli can be incorporated into this modelling framework. For example, a **deposit-refund** (DRF or *statiegeld* in Dutch) system consist of a tax on the purchase of commodities, combined with a subsidy for proper sorting. Adding $-t_{drf}Q + s_{drf}\alpha Q$ to the consumers' objective function would represent such a disposal refund system.

Recyclers

Recyclers source sorted waste from the consumers and chooses recycling rate $\beta \in [0,1]$ as to maximize their profits. We will express quantities in terms of their material content, hence recyclers buy W tons of sorted waste from the consumers. Profits consists of revenue of selling recycled material at price p^r minus cost of acquiring sorted material at a price p^s. The recycling technology is characterized by an increasing and convex unit cost $r(\beta)$ with $r' \geq 0$ and $r'' > 0$. Recycling residues (i.e. the share of the sorted material that is not recycled) is disposed of at a cost of per unit. The profit maximization problem of the recyclers is therefore given by:

$$max_{W,\beta}\ \pi^r = p^r \beta W - p^s \frac{W}{1-\mu} - r(\beta)W - [1-\beta]W t_d^r$$

The profit maximizing recycling effort choice is characterized by the condition: $r'(\beta) = p^r + t_d^r$. Marginal costs of the last unit of recycling effort should equal the marginal benefits which consist of extra recycled material sales and disposal charges of residues saved. From this condition we can infer that recyclers will recover more valuable material from the sorted waste flow if the price of the recycled material is high and if the disposal charge on recycling residues is high.

Assuming a competitive recycling market (which implies zero economic rents for recycling facilities), we can show that the maximal price recyclers are willing to pay to consumers to buy their sorted waste is $p^s = [1-\mu][p^r\beta - r(\beta) - [1-\beta]t_d^r]$. The higher the price of sorted material, the more recyclers want to pay for sorted waste. High recycling costs and high recycling residue charges tend to reduce the equilibrium price of sorted waste. Note also that the price the recyclers want to pay to consumers for their sorted waste can be negative (so consumers paying recyclers to get rid of their sorted waste) if the price of recycled materials is relatively small compared to the unit cost of recycling and the price of disposal or recycling residues. Whether consumers want to pay for offering sorted waste to the recyclers depends on the costs of the alternative disposal possibilities for the consumers. Clearly, the price recyclers can charge to consumers to get rid of their sorted waste cannot exceed the cost of legal or illegal alternative waste disposal options that consumers can choose from. Finally, we only considered one policy instrument, a charge on disposal of recycling residues, but other instruments can easily be incorporated into the framework. For example, the waste authorities could stimulate high quality recycling by subsidizing net recycled material supply

$RMS = \beta W$. A subsidy on waste treatment activity (so on W) stimulates the quantity of waste processed (and hence increases the price of sorted waste and sorting effort by consumers) but it gives no incentive to recyclers to recover more material from the waste stream (no impact on β).

Equilibrium in the product, waste and material markets

We assume a small open economy facing possible competition of foreign producers. For the foreign producers or clients, we will denote variables with a superscript f. For domestic producers and clients we denote variables without any superscript. For the foreign producers, let c^f denote the constant unit cost of production of the foreign producers which includes all production, material and transport costs to export the good. We do not model their choice of input materials or material intensity but take that as given and equal to the choices made by our domestic producers. If the price is strictly lower than the marginal production cost of the foreign producer, there will be no foreign supply of the good. If there is foreign supply, then the price equals marginal cost. For ease of notation and in line with the literature on mixed-complementarity problems, we will write the supply behaviour compactly as follows: $p - c^f \leq 0 \quad \perp \quad Q^f \geq 0$. Market equilibrium then requires that total domestic demand for commodities is equal to total supply by both domestic and foreign producers: $QD = Q + Q^f$.

As for the market of sorted waste, equilibrium requires that supply of sorted waste by consumers equals demand by recyclers: $WS \geq W$. Regarding the material markets, we start by defining equilibrium in the market for recycled material as $RMS \geq RMD^d + RMD^f$. Besides domestic demand for recycled material, we allow in the model also for the possibility of recycled material exports. We model the export demand behaviour compactly as follows: $p^r - wtpr^f \geq 0 \quad \perp \quad RMD^f \geq 0$. As long as the domestic price of recycled material is higher than the exogenous willingness to pay by foreign recycled material buyers, there will be no exports of it.

Welfare optimum

So far we have looked at a decentralized market equilibrium in which consumers maximize utility and producers and recyclers maximize profits. This is the so-called **descriptive or positive analysis** which we can use to predict how market participants will react to changes in policy instruments. In this section we will look at the **normative analysis**. What is the optimal production, consumption, sorting, recycling, material intensity, uptake of recycled material etc.? In order to characterize the welfare optimum we will **maximize a social welfare function** consisting of (1) consumers' surplus (CS), (2) producers' surpluses (PS) or profits, (3) environmental externalities (EXT), and (4) the government budget (GB). Externalities can arise at all stages of the life cycle: in the extraction and production of virgin material stage, in the production stage, in the consumption stage, in the recycling stage and during end of life or disposal. For each of these phases, the model framework foresees the possibility of a specific marginal external damage. Hence, the total externalities over the entire life cycle are given by: $EXT = e^v VMD^d + e^p Q + e^c Q + e^{cd}[1-\alpha][1-\mu]Q + e^r W + e^{rd}[1-\beta]W$.

A question arises with respect to the geographic scope of the welfare function. We mainly focus on domestic or regional welfare but foreign externalities (for example of virgin material extraction abroad) can be considered by an appropriate formulation of the externalities' equation.

In the section of scientific results, we will illustrate the possibilities of the modelling framework by comparing, for a particular parameterization of the model, the welfare optimum with market outcomes with different policy instruments.

3.3 Micro economic incentives and business models

Business models: game theoretical analysis

Since we are interested in the strategic interaction between the new firms or types of market with the incumbents in the industry (between the recycling firm and the primary producer or between the peer-to-peer sharing market and the manufacturing firm of durable goods), we adopt game-theoretical, stylized models in all three studies of this task. This approach allows us to isolate and identify fundamental interactions between firms and to conduct comparative static exercises so as to identify the conditions under which the new business models (or new firms with more sustainable business models) can be both profitable and more environmentally friendly. In the following sections, we present the basic setting of the models built for the three studies.

Impacts of an improvement in the collection of scraps for recycling on the interaction between primary producers and recycling firms

We consider a two-period model in which a virgin producer competes with a recycling firm that enters in the second period. The virgin producer produces goods from virgin material (or extract the virgin material itself) while the recycling firm relies on a collected proportion of end-of-life products produced by the primary producer as input for its reprocessing. The timeline is as follows: at time zero, the government sets a commitment for the collection rate $\alpha \in [0,1]$; after observing this information, in the first period, the primary producer produces a quantity of primary product, anticipating the entry in the second period of a recycling firm with an unknown recycling cost. By the end of the first period, all products in use wear out. The revealed proportion of the end-of-life products are collected for recycling while the rest is disposed of. The recycling firm then enters, reveals the true recycling cost and use the scraps collected as input to compete with the virgin producer à la Cournot.

For the sake of simplicity, we normalize the production cost of the virgin producer to zero and assume that the recycling firm bears the cost of buying scraps from the collection sector, sorting and reprocessing old scraps to produce recycled products. The recycling cost function $C(c, r)$ depends on the efficiency parameter c and the quantity of recycling r. $C(c, r)$ strictly increases and is twice differentiable in $r \geq 0$. The marginal recycling cost $C'(r)$ increases with $c > 0$ and equals zero if $c = 0$. We assume that recycling is at least as expensive as virgin production, i.e. $c \geq 0$, and that c is unknown to the virgin producer until the entry of the recycling firm. Prior to that, the virgin producer expects that c is distributed uniformly over $[0, \bar{c}]$ with $\bar{c}$ the maximum c above which the recycling firm cannot profitably enter the market. On the demand side, we assume that demand is constant over time with the inverse demand function $P = P(Q)$ being strictly decreasing, twice differentiable in R+ and reaching zero at a finite value of Q, and where $Q = v + r$ is the total quantity of virgin (v) and recycled (r) products in each period. Denoting P' and P'' the first and second derivatives of the demand function with respect to Q, we also assume that $P'(x) < C''(x)$ for all $x \geq 0$ and that the marginal revenue declines with Q, i.e. $P''(Q)Q + P'(Q) < 0$ for all $Q > 0$. Under these assumptions, the best-response functions are downward sloping, and there exists a unique and locally stable Cournot equilibrium in which per-firm outputs decrease with the number of firms if firms are symmetric. Using the Cournot model for homogeneous products with no discount factor, we put the virgin producer in the worst-case scenario as far as entry is concerned. If products were (horizontally or vertically) differentiated or if the virgin producer had a stronger preference for the present, entry would be less of a threat, so these assumptions would not alter the results in any meaningful way (it would just reduce the threat of entry).

Implications of peer-to-peer sharing and second-hand markets on the manufacturing of a durable good

Following Anderson and Ginsburgh (1994), we propose a steady-state framework to model the interaction between a manufacturing monopolist, a second-hand market for used goods and a sharing platform. Specifically, we consider a manufacturer producing physical products that last for two periods. After two periods, they are worthless to everybody. However, after the first period, they can be sold and bought as 'used' products. Compared to a new unit of the product, the used unit is depreciated by a factor $\delta \in [0,1]$. For the sake of simplicity, we normalize the quality of the product to 1 and assume that the durability level is the probability that the product functions properly without failure in the second period of its lifetime.

Thus, a new unit of product is assumed to function without any failure with probability one while a used unit of the product only function properly with probability δ, which is considered as the durability of the product. It depends on the type of the product and the incentive to improve or reduce the durability level of the manufacturing firm. To avoid the complication of the cost structure on the analysis, we assume that the cost of production is zero, and we investigate only the incentive of the firm to change the durability level based on its impacts on the revenue of the firm.

On the demand side, there is a measure one of consumers who vary in the valuation that they attach to the quality of the product that they own or use. The valuation is denoted by $v \in [0, 1]$, with higher values of v denoting individuals who enjoy higher surplus from every time they use the product. Hence, a consumer whose valuation for quality is v will enjoy a surplus of v if she owns (and uses) a new unit of product and a surplus of δv if she owns a used unit product (as a used unit only functions properly with a probability δ). We assume that v follows a uniform distribution between zero and one.

Beside using the product purchased, the owners of the product (used or new) have the option to rent the product out on a P2P market and earn money from the rental activities. On the demand side of the P2P market, renters also enjoy a surplus v and pay a fee f for each time she can rent the product. On the supply side, we assume for simplicity that the owners of a new unit of product can rent it out with a probability $\alpha \in [0, 1]$, while the owner of a used unit can only rent it out with a probability $\delta \times \alpha \in [0, 1]$. That is, in this setting, α characterizes the capacity of the P2P market to match the owners and renters for the rental activities; α depends not only on the institution that organizes the P2P market (platforms such as GetAround or Airbnb) but also on the properties of the product. For instance, products that spend most of their time being idle (such as cars or drills) are relatively more available for sharing (and thus have a larger capacity α) than products that are used continuously (such as glasses) or may be needed any time (such as medical equipment). The case that $\alpha = 0$ indicates that the product cannot be shared at all and is used as the benchmark case where only the second-hand market exists. The interpretation of δ as the probability that the used product can function is pretty intuitive here. Since the new product always functions, it can be rented out with probability α. Meanwhile, a used product with failure rate δ can only be rented out with probability $\delta \times \alpha$.

Since the model is in steady state, consumers who buy the new (or used) product in one period will repeat the purchase every period. Likewise, consumers who do not buy the product and rent it on the P2P market will also repeat this pattern of consumption in all periods. Therefore, in the steady-state period, the options available to a consumer are:

- N: Sell the used unit of product that she owns on the second-hand market, buy a new unit, use it and rent it out on the P2P market;
- U: Buy a used unit on the second-hand market, use it and rent it out on the P2P market;
- R: Do not buy any product and rent on the P2P market;
- O: Do not participate in the market, use the alternative with utility normalized to zero.

Denoting by p_N , p_U and f the price of a new product, the price of a used product on the second-hand market, and the rental fee on the P2P market, the utility functions of a consumer of type v under the four options are given by:

- N: $U_N = v + \alpha f - p_N + p_U$;
- U: $U_U = \delta(v + \alpha f) - p_U$;
- R: $U_R = \alpha(v - f)$;
- O: $U_O = 0$.

Throughout the basic model, we assume that the second-hand and the P2P markets are perfectly competitive. That is, the price of used products p_U and the rental fee f are endogenously determined as the market-clearing prices (i.e., the prices at which supply equals demand on each market).

In each steady-state period, the timeline of the model is as follows. In the first stage, the manufacturing firm fixes the price of new units p_N. In the second stage, consumers who own a used unit of product from the previous period sell the used unit on the second-hand market and buy a new unit from the manufacturing firm. In the third stage, consumers who own a used unit that reaches it end-of-life get rid of it and buy a used unit of the product on the second-hand market. In the last stage, the P2P market opens for non-owners to rent the products; then the second-hand and the P2P markets are cleared. The model is solved backward to get the subgame-perfect Nash equilibrium: we first solve the equilibrium of the sharing and second-hand markets then the equilibrium of the market for new products.

Motivations of a manufacturing firm to adopt pay-per-use business models and conditions for the business model to be win-win

Unlike the previous two models that focus more on the production side of a product, this study stresses the characteristics of the demand side that affect the profitability and the resulting aggregate usage of servitisation compared to selling. To do that, we propose a framework in which a monopolistic manufacturer faces consumers who experience distinct instances of needs for the good at random utility level.

On the demand side, consumers are identified by their usage rates α - the proportion of time that a consumer needs to use the product: at the extremes, a usage rate $\alpha = 0$ characterizes a consumer who does not need to use the product at all, while $\alpha = 1$ characterizes a consumer who needs the product all the time. At a particular instance of need, a consumer derives a random utility level V. The key assumption is that a consumer only learns about the utility level that she derives from each usage instance just before the moment that it is realized. By this assumption, the consumer who considers purchasing the product has to form an expectation of her utility over the future usage of the product. In contrast, if a pay-per-use (PPU) scheme is available, the consumer can decide whether she will rent the product after having learned about the utility that she can derive of that precise usage instance.

Normalizing the outside option to zero, V can represent the relative value of using the manufacturer's product compared to outside options. A high level of V indicates poor alternatives to the product investigated. In cities where public transports are in bad conditions, for example, it is likely that people will often find it relatively highly satisfying to use cars. In contrast, in cities where public transports are well organized, the relative level of satisfaction of taking a car compared to taking public transport will be lower. A low level of V can also indicate that there are many substitutes for the product, while the opposite indicates that consumers do not have a real choice other than the manufacturer's product. Also, the relative level of satisfaction may vary across people at the same instance of time. Even though public transport is poorly organized, some user may find it more interesting to go by bus when the commuting is convenient while another user does not. In another situation, the preferences of the two users may be completely reversed. Since the level of satisfaction of each usage depends on many external factors (such as the weather, traffic conditions, etc.), a consumer cannot predict perfectly her utility level for each usage prior to the instance of time that she needs to use the car. Therefore, characterizing the utility level of usage V as a random variable allows us to describe in a relevant way different situations or different industries in the economy without standardizing the alternative to every consumer in the economy.

For the sake of tractability, we assume that there are two segments of size one of consumers in the market: high-usage and low usage consumers, identified by their usage rates $\alpha_i \in \{\alpha_L, \alpha_H\}$. At each moment that a consumer needs to use the product, she may derive, with equal probabilities ½, a high utility v_H or a low utility v_L. The manufacturer knows how the usage rates and the utilities of each use are distributed $(\alpha_H, \alpha_L, v_H, v_L)$ but cannot directly observe the level of use of a consumer or the utility level that the consumer derives from each use. Because of this, the manufacturer cannot apply first-degree price discrimination under both selling and PPU. Hence, there is one unique selling price p under selling and one unique per-use fee f under PPU.

Business models: case studies

In addition to the theoretical analysis of business models, the IECOMAT project explicitly aimed at testing empirically the willingness of consumers and producers to adopt more circular business models.

To determine barriers and drivers for consumers, an empirical approach, namely discrete choice experiments, was used to identify the importance of product characteristics in consumers' adoption decisions and to determine consumer groups with different preferences for circular activities. A discrete choice experiment (DCE) is a quantitative, survey-based, technique that is used for eliciting individual preferences (Louviere & Hensher, 1982; Louviere & Woodworth, 1983). It is especially apt to deal with multidimensional choices and has been used in a variety of settings. In a DCE, respondents select their preferred option out of a predetermined set of alternatives, which are described by their main characteristics (Johnston et al., 2017). DCE can be used to recover respondents' preferences, the relative importance of specific business model characteristics, and the willingness-to-pay for these characteristics.

Two specific case studies were selected to study consumers' attitudes towards circular activities and business models in more detail: leasing of **smartphones** (Rousseau, 2019) and circularity in **clothes consumption** (Rousseau & Carmen, 2019). Both case studies focus on young consumers ('millennials'). For the smartphone case we focus on anyone living in Flanders or Brussel aging between 15 and 30 in 2016 and as on anyone living in Flanders or Brussel aging between 15 and 35. Millennials have interacted with technology since birth and are thus much more digitally literate than previous generations; they are thought to be more concerned about the environment, more global in their thinking, less brand-loyal, and to have a low tolerance for delays in technology services (Hanks et al., 2008; Harris et al., 2011). These people are the consumers of the future and previous studies have shown that, although they are more environmentally conscious, they are reluctant to change their consumption patterns. For example, ThredUp (2018) conclude that millennials are, on the one hand, wasteful impulse buyers who wear clothes only a couple of times, and on the other hand, hate to waste as they care most about environmentally conscious brands and buy second hand for environmental reasons. This contradictory behaviour makes it interesting to study millennials' attitudes towards circular activities and business models.

To determining barriers and drivers for companies to create a business in circular economy in practice, CLIMACT has followed a four-step approach. Firstly, the scope of study was defined based on review of relevant documents and meetings with Thuc Huan Ha. Secondly, an inventory of good practices through different networks was created. Thirdly, several business cases are described based on interviews with eight businesses: Cambio, Interface, Cirkle, Billybike, Cycad, Usitoo, Tournevie, Textiflore. Fourthly, after a feedback session with the project consortium and follow-up committed, the findings are consolidated in a presentation.

4. SCIENTIFIC RESULTS AND RECOMMENDATIONS

4.1. What is circular economy?

The novel theoretical framework to ground CE indicators was described in detail in section 3.1 higher.

4.2. Economic modelling of circular economy interactions

Input-Output modelling: CE potential for the (open) Belgian economy

Trade relations

The trade relations with other countries are traditionally summarized in one index : the openness index (sum of import value and export value divided by GDP) . Generally a high openness index is considered positive for further economic development. For the CE potential it is essential to consider import and export share in the openness index separately as they show different potentials for or impacts from more CE domestically or abroad (Geerken et al., 2019)).

Openness index

From the table below it can be concluded that Belgium is a country with a very high openness index:

Table: Openness Index for a selection of countries (2015). (Eurostat, 2016; World Bank, 2016)

	Openness Index (% of GDP)	export (in % of GDP)	import (in % of GDP)
Belgium (BEL)	164	83	81
The Netherlands (NLD)	154	71	82
Germany (DEU)	86	47	39
France (FRA)	61	30	31
China (CHN)	41	22	19
United States (USA)	28	13	15
Brazil (BRA)	27	13	14

One relationship between the openness of a country and the potential for CE is that a country with a high import percentage, like **Belgium** with 81%, is **highly dependent on other countries for importing natural resources, (semi-finished) goods and services** as an input to its own economy. A stronger domestic circular economy, assuming the same final demand, will reduce those imports and dependency. Another consequence of a high import percentage for the potential of a domestic CE is that many products are not produced locally, which may have consequences for the potential for strengthening domestic re-use and repair strategies, for example, due to a lack of product knowledge, Intellectual Property Rights (IPR) and spare part availability. The severity of these consequences will be lower for generic widely used products that already have many international suppliers for (spare) parts and use an international network of repair actors, such as cars, compared to a very specific product containing high-tech knowledge, IPR and only a few suppliers providing spare parts, such as a dedicated medical imaging device.

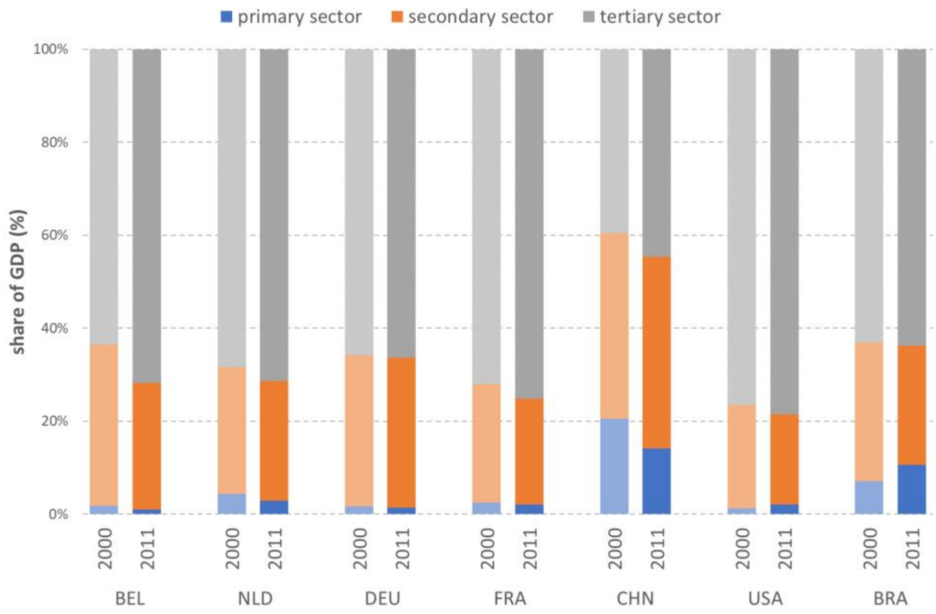
A country with a high export percentage, like Belgium with 83%, will have less control over the destinations at the end-of-life phase of goods exported abroad. A country with a high export percentage is also more vulnerable to stronger CE activities abroad, as this may reduce export activity.

Availability of spare parts, easy flow of re-usable products across borders help realizing the potential for CE worldwide but the consequences for the domestic economy will vary depending on its trade relations.

Economic structure

In most countries the service sector (tertiary sector) keeps growing, whereas the primary sector is declining in economic importance.

Figure: Sector composition for a selection of countries (2015). (Eurostat, 2016; World Bank, 2016)



The (non-)existence of primary sectors is relevant for the strategy of closing material loops domestically. A relatively small (like Belgium compared to other countries) share of primary sectors shows limited vulnerability for increased CE activities, either domestic or abroad. On the other hand, if a country wants to raise secondary material production, skills and technologies to produce primary and secondary materials can be very similar and production often takes place in an integrated way (e.g. steel, aluminium). Relatively large secondary sectors are positive for having industrial competences for CE activities like re-use, remanufacturing, repair but can also pose a risk when combined with high export percentages, due to increasing CE activities abroad. Both conclusions apply to Belgium. The existing trend of a decreasing primary sector (in Belgium and other EU countries) will be amplified by having more CE activities in secondary/tertiary sectors.

Competitiveness and CE potential

Balassa index

The revealed comparative advantage (RCA) is used in international economics for calculating the relative strength or weakness of a certain country in a certain class of goods or services as evidenced by trade flows. It can be measured by the Balassa Index, defining the specialisation in exports of a certain product if a country's market share in that product is higher than the average in a reference area. A country reveals comparative advantages in products for which this indicator is greater than 1, showing that its exports of those products are more than expected based on its importance in total exports by the reference area.

Table: Balassa Index of a selection of sectors in Belgium relevant to the circular economy (between brackets is a reference to NACE Rev. 2). Source: own calculations based on EXIOBASE v3.4.

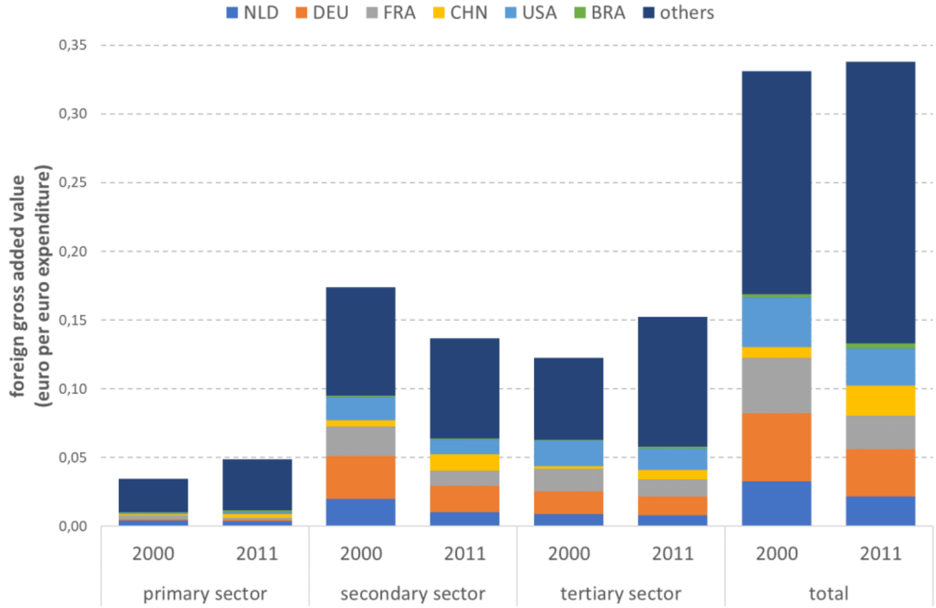
Sector	2000	2011
mining and quarrying (B)	0.16	0.21
manufacture of textiles, wearing apparel and leather products (C13-15)	2.11	1.34
manufacture of wood and of products of wood and cork, except furniture (C16)	3.27	1.75
manufacture of paper and paper products (C17)	0.98	0.59
manufacture of coke and refined petroleum products (C19)	2.24	1.71
manufacture of chemical and chemical products (C20)	0.55	0.65
manufacture of rubber and plastic products (C22)	1.63	1.18
manufacture of other non-metallic mineral products (C23)	2.23	1.57
manufacture of basic metals (C24)	2.23	2.05
manufacture of fabricated metal products, except machinery and equipment (C25)	1.79	0.94
manufacture of computers, electronic and optical products (C26)	0.52	0.51
manufacture of electrical equipment (C27)	1.13	0.65
manufacture of machinery and equipment n.e.c. (C28)	0.77	0.52
manufacture of motor vehicles, trailers and semi-trailers (C29)	1.10	0.66
manufacture of other transport equipment (C30)	0.35	0.17
manufacture of furniture; other manufacturing (C31-32)	1.19	0.53
wholesale trade, except of motor vehicles and motorcycles (G46)	0.52	1.81
retail trade, except of motor vehicles and motorcycles (G47)	0.55	0.26
land transport and transport via pipelines (H49)	1.29	2.86
water transport (G50)	0.89	1.73
air transport (G51)	0.54	0.60
warehousing and support activities for transportation (G52)	1.07	4.79

The competitive advantage of Belgium in logistics is found in warehousing, water and road transport, while Belgium has a competitive disadvantage in air transport and retail. A further increase of the economic activity of providing services instead of selling goods can be evidently achieved by actors in tertiary sectors (using goods from secondary sectors), as well as by secondary sectors themselves extending their offerings. Belgium has a decreasing share in secondary sector contributions to GDP and its competitiveness in most industries is lower than in its surrounding countries. This potentially makes Belgium vulnerable to outsourcing. Investing and extending the principles of CE could help to break this trend.

Value chain analysis

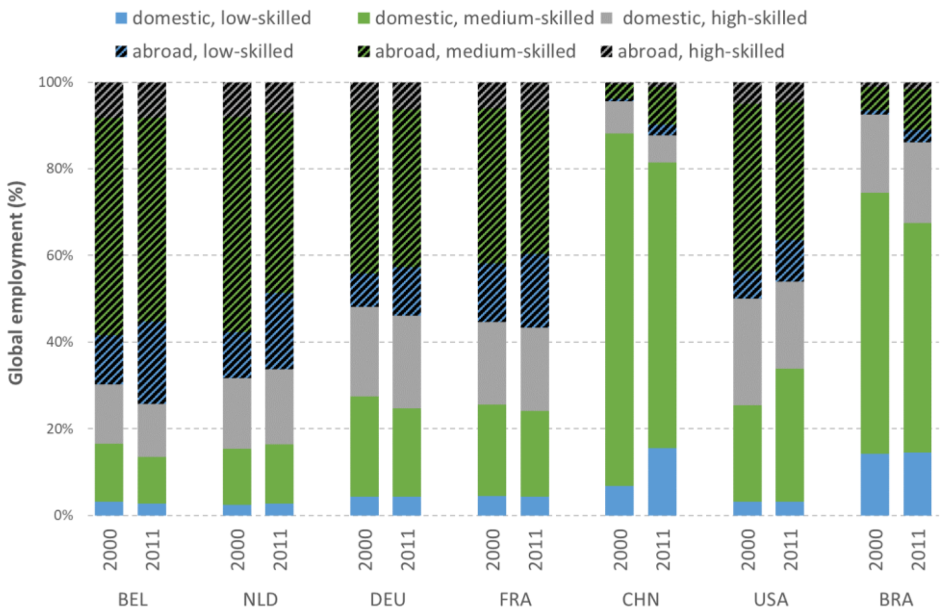
The world is globalizing and so is Belgium. Value chains are getting longer and new trade partners further away from Belgium are producing resources, intermediate and final products for Belgium's final demand (see fig below) . This causes transport at world level to grow faster than world GDP. Belgium is strong in logistics and warehousing so this maybe an asset in the circular economy where repair and reverse logistics play a growing role.

Figure: Foreign contribution of value added by spending one euro of final demand by Belgium in 2000 and 2011 (own calculation based on EXIOBASE 3.4).



Final demand in Belgium also creates a lot of jobs abroad, which may be partially lost when domestic Belgian CE activities increase. It also means that for example domestic repair activities have to be competitive with the alternative of producing new products with often cheaper labour in global value chains. Lower domestic labour cost on repair may shift the balance “repair vs buy new” and save natural resources globally.

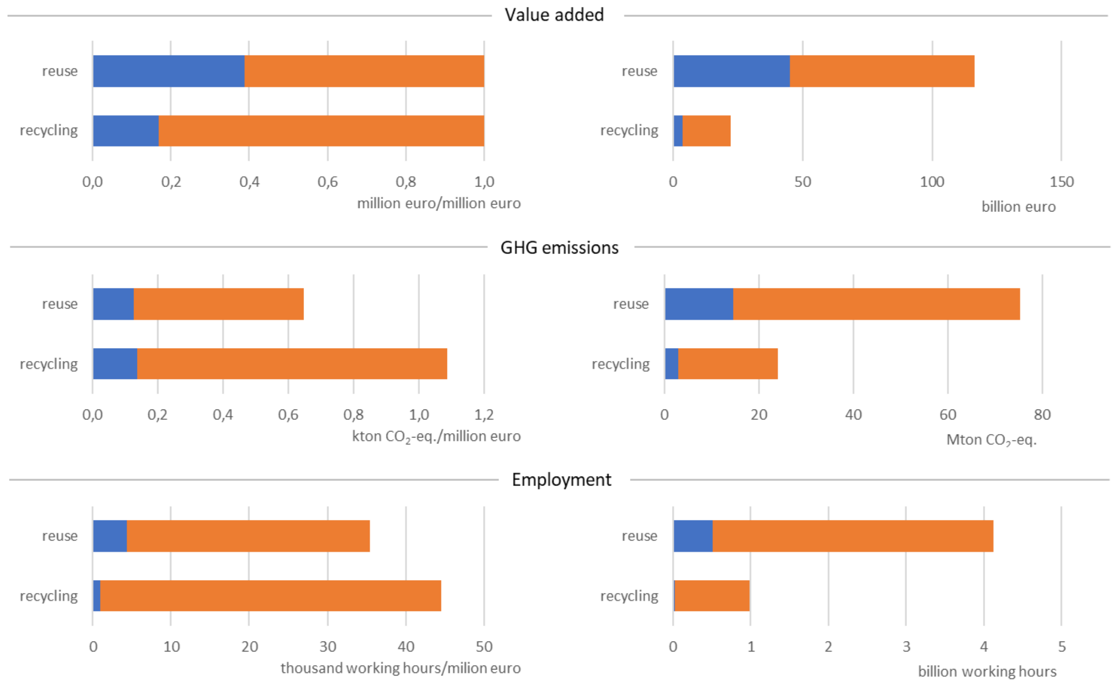
Figure: Employment triggered by country final demand in 2000 and 2011. Source: own calculations based on EXIOBASE v3.4.



Substitution potential for Sustainable Material Management strategies

In this method (see Christis et al., 2015) the gross maximum potential in terms of value added, GHG emissions and employment (domestically and abroad) is assessed for strategies like recycling and re-use, by assessing the current economic activities that will be replaced by new CE activities (that are hard to quantify at macro level).

Figure: Expected decrease in value added, greenhouse gas emissions and employment in the current economy for every million euros of substitution (left) and absolute values (right) through re-use and recycling (own calculations based on EXIOBASE). Blue : domestic share. Orange : share abroad

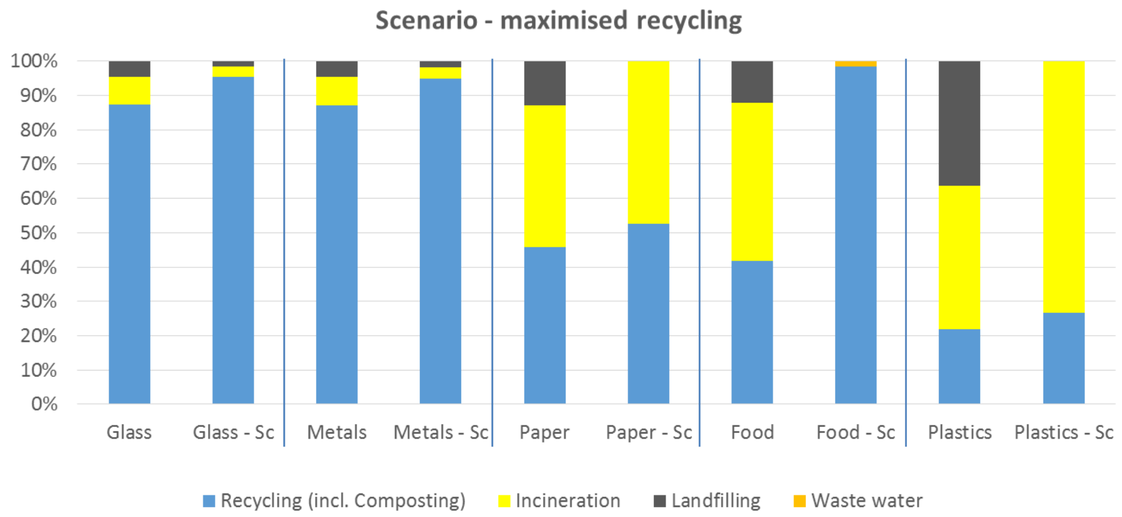


The figure shows that the re-use strategy compared to the recycling strategy is associated with more potential value, GHG savings and jobs. It also shows that recycling may save relatively more GHG emissions per Euro. The share abroad of the maximum substitution potential is always larger than the domestic share , indicating the global character of value chains contributing to Belgian demand.

Waste treatment scenarios and their GHG emission reductions based on physical and hybrid IO analysis

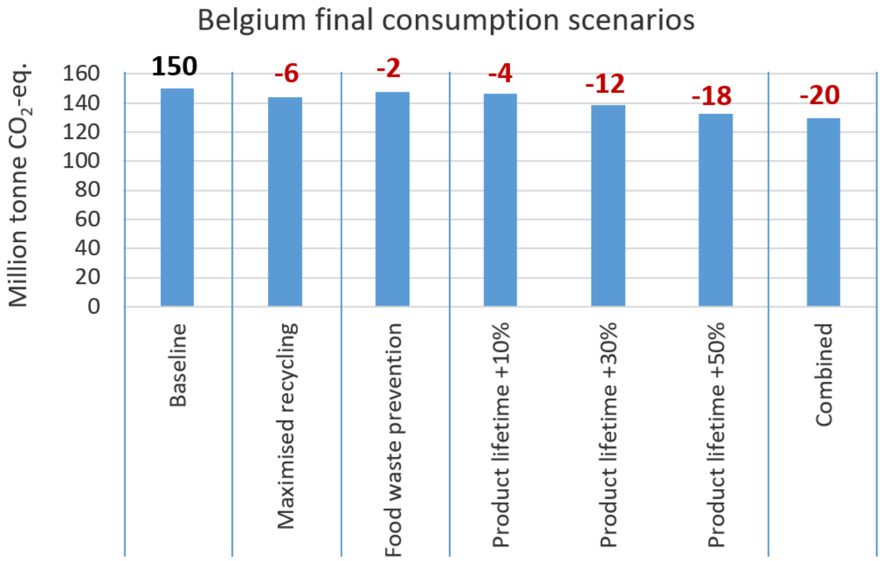
This method starts from current practice in waste treatment for landfill, incineration, biogas, compost, recycling etc. for waste fractions like food, manure, textile, paper, plastics, glass steel, aluminium, construction materials etc. In a second step for recycling a maximised scenario for the year 2035 is defined based on a previous EU FP6 Forwast project to raise current recycling percentages to higher levels based on past trends, options for recycling, policies in place. A food waste reduction scenario leading to 50 % reduction of food waste in industries and households is assumed to be achieved without additional material , energy and transport, so mainly by behavioural change in households and technological development targeting extending shelf life, more consumer information. For extending product lifetimes the effect of different percentages (10 % , 30 %, 50 %) is calculated leading to reducing inputs of all durable products maintaining the mass balances and avoiding double counting. For this method the recent EXIOBASE v3.3.11 database was used that includes data on the flows of products and waste in an economy.

Figure: Illustration of waste treatment/recycling for the waste fractions involved in the maximised recycling scenario (-Sc)



In the maximised scenario recycling will go up and landfilling will be almost phased-out.

Figure: GHG emissions relating to Belgian final demand in 2011 (baseline) compared with Belgian final demand for the three scenarios and a combination of the three. The combined scenario used the product lifetime +30% figures.



Raising current recycling rates to higher levels may reduce the GHG emissions with 6 million tonnes Reducing food waste with 50 % may reduce the GHG emissions with 2 million tonnes. Assuming a 30 % extension of product life time this may reduce GHG emissions with 12 million tonnes.

Recommendations

- When developing CE policies it is recommended to take the full global value chain into account, including winners and losers either domestically or abroad, , and to help preparing the losers for the change.
- Further research is recommend to develop and improve scenario-based methods (f. e. the use of equilibrium models) that can handle the effects of complex changes in open

economies in the context of CE, including the potential rebound effects. As noted by recent review work (OECD, 2017) the transition to a more circular economy and increased efficiency in the use of material resources will involve multiple interactions between different sectors and countries, and will take place in parallel with other trends like digitalisation and automation. To model the potential of CE, the same source recognizes three types of assumptions that should drive modelling results: assumptions on future efficiency improvements, assumptions on the degree of substitutability between primary and secondary materials and assumptions on changes in the future structure of the economy and consumption patterns. Assumptions are also needed on the extent to which these will take place in the absence of policy drivers.

General equilibrium modelling

We described higher the general equilibrium modelling framework developed to include more detailed CE aspects. As an illustration of the capabilities of that CGE modelling framework, the IECOMAT consortium decided to examine the case of **household appliances** in detail. There are two options in case a household appliance breaks down. Its owner can repair the appliances, or the owner can dispose the appliance and replace it by a new appliance. The repair option is the circular strategy in these circumstances. In case we want to introduce these two options in the CGE model, this requires that we must distinguish and introduce new activities as well as new commodities / services into the CGE model.

In addition to the activities part of the basic CGE, the following activities are added to the new CGE:

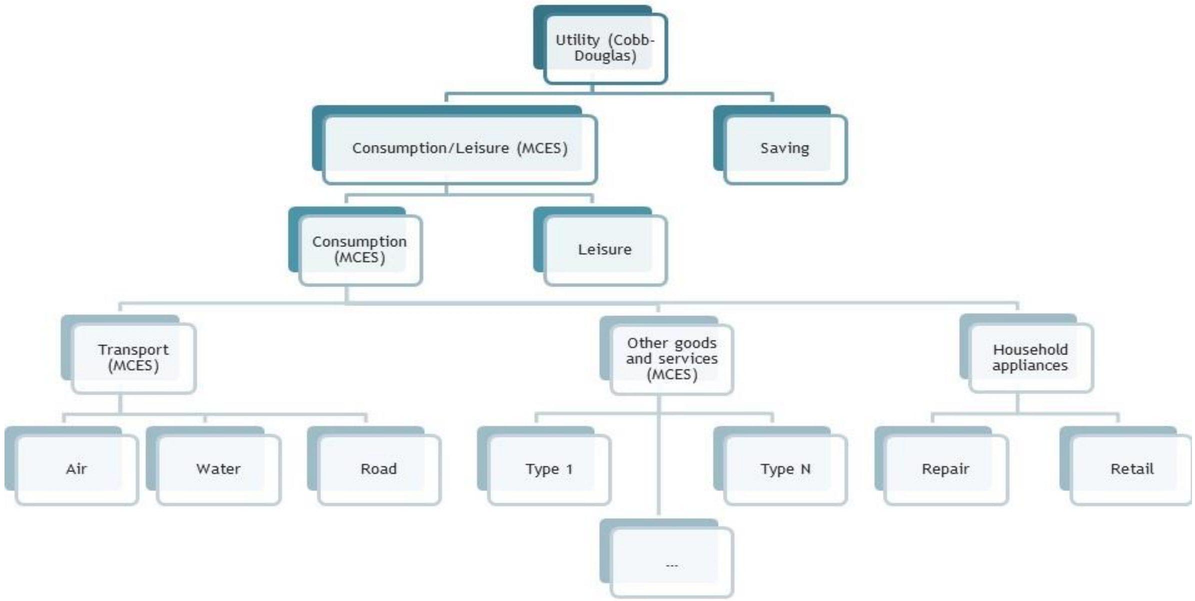
- Retail of household appliances;
- Repair of household appliances.

In the basic model, those two activities were part of one of the original 12 activities. So, the introduction of two new activities entails the shrinkage of some of the original activities. The newly introduced retail and repair activities make use of, or produce, specific commodities / services. Also, these specific commodities / services introduce need to be separately introduced in the CGE model. The following commodities / services are added to the 12 original commodities / services:

- Household appliances;
- Spare parts for household appliances;
- Repair services.

It is necessary to distinguish household appliances as a separate commodity, as increased repair of these commodities is expected to decrease the number of household appliances which circulate in the CGE's economy. Also, the number of sold new household appliances is likely to decrease in case of increased repair of broken household appliances. As an alternative to the purchase of new household appliances, the possibility to opt for repair services is introduced as additional service in the CGE model. Since this service is expected to make intense use of spare parts for household appliances, also these goods are separately introduced in the CGE model.

Figure: Structure of the consumers' utility functions, introducing circular repair strategy

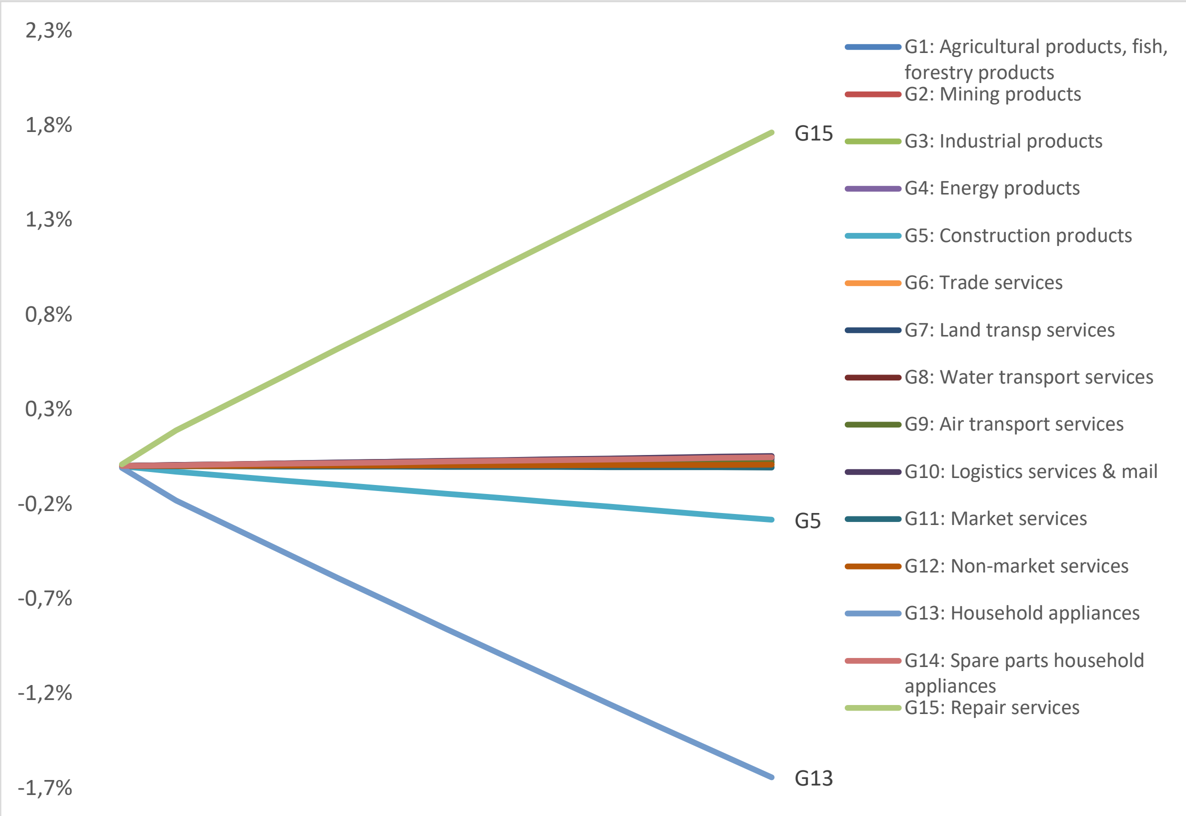


These additional activities and commodities / services can all be separately distinguished out of the same I/O tables provided by the Federal Planning Bureau. Hence, they are disaggregated out of the 12 original activities and commodities & services. Subsequently, all the new CGE model's activities and commodities & services are calibrated in accordance with the original activities and commodities & services. As demonstrated above, the new CGE model now has a repair sector of household appliances which competes with the retail of new household appliances. To analyse the uptake of the repair activities, we need incentivize this activity in the CGE model. Fiscal policies are used to do so. The following sections describe a number of fiscal policies, and their impact.

Example: Fiscal policy - increase the taxes on new household appliances

The Belgian government can try to encourage repair of household appliances by making the purchases of new household appliances less attractive. This is achieved by increasing the product related taxes for household appliances. This scenario is re-run 15 times in order to analyse an incremental increase of these taxes (each step stands for a +1% increase of the original tax level). The results of this incremental increase are displayed in the figure below.

Figure: Percentage change in traded volume of commodities and services compared to the baseline situation following an incremental increase of the product related taxes for household appliances.

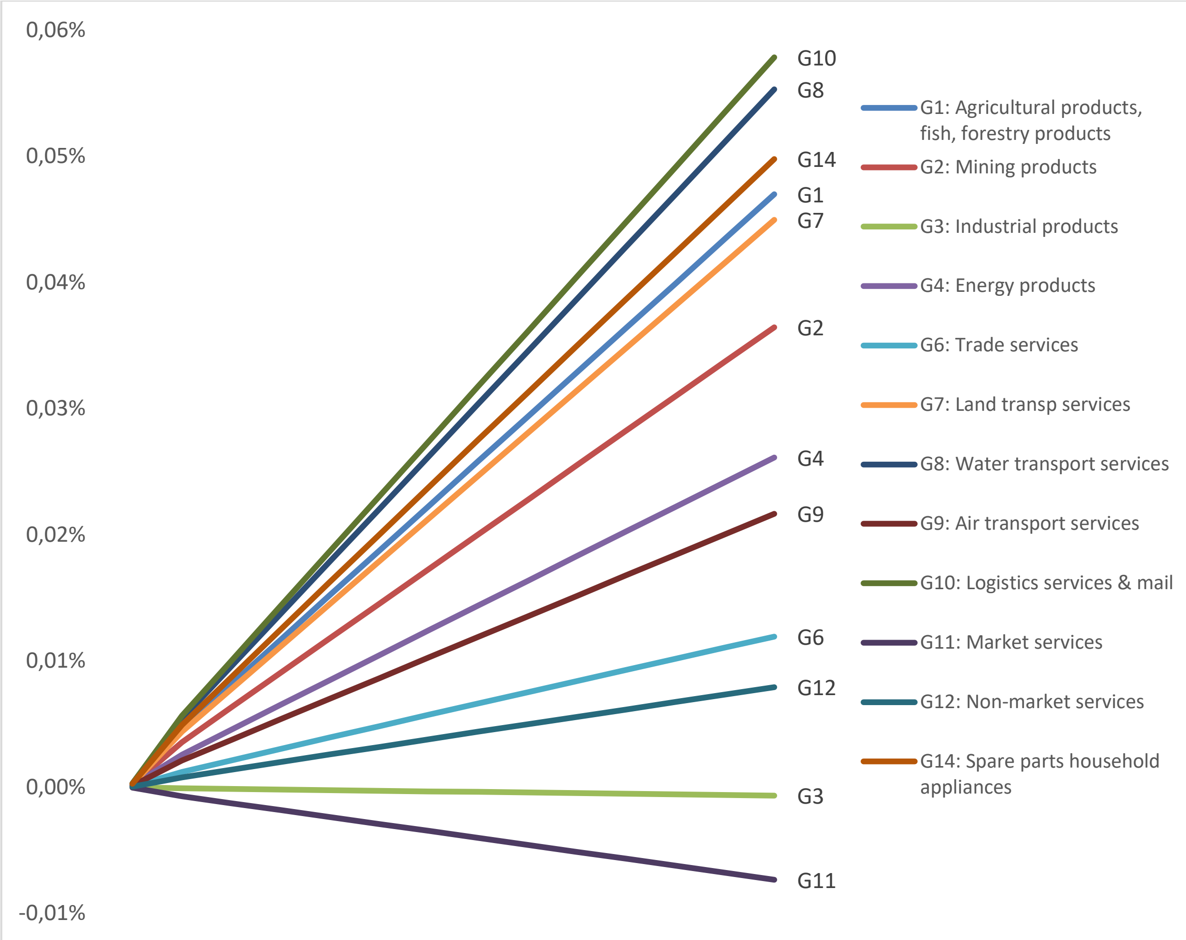


NOTE.- the tax rate increases from 0 to 15% and is displayed on the x-axis, the percentage change in the outcome variable is displayed on the Y-axis.

This figure clearly indicates that increased tax level increases the level of repair services (G15) required in the Belgian economy at the expense of the volume of new household appliances traded within Belgium (G13). The new CGE model also allows to investigate how all other sectors react to this evolution. This is displayed in the following figure which clearly demonstrates that the different sectors might react very differently to the tax increase. The Belgian economy needs less Industrial products (G3) and less Market services (G11). Also construction products are traded less intensively. The decreasing retail activities negatively impact the need for construction products. This decrease is not (fully) compensated by an increased demand for construction products following increased repair activities as those repair activities require less construction in comparison to retail activities.

All other goods are traded more intensively. Worth mentioning is the uptake of the trade in spare parts for household appliances, as well of the increased trade in logistics services & mail and water transport services. The uptake of trade in spare parts is straightforward, as the spare parts serve as an input for the repair services. However, sending the defect household appliances back and forth to repair professionals, or sending the spare parts seems to require and entail more transport activity as well.

Figure: Percentage change in traded volume of commodities and services compared to the baseline situation following an incremental increase of the product related taxes for household appliances.



NOTE.- the tax rate increases from 0 to 15% and is displayed on the x-axis, the percentage change in the outcome variable is displayed on the Y-axis.

Except for the level of traded commodities and services within Belgium, there are numerous variables to report on, depending on the interest of the audience or particular research question. The following paragraphs discuss a selection of the variables to report on.

Import dependency

It is often claimed that the level of circularity is inversely related to the level of import dependency. This claim is further investigated for Industrial products (G3) as this is a highly relevant product group for Belgium for several reasons:

- It is the most important product group in terms of traded value (not volume);
- The production of industrial products ranks 4th in terms of demand for labour as input factor;
- The production of industrial products ranks 5th in terms of demand for logistics services as input factor

This part of the analysis allows the maximum increase of product-related taxes (+15%).The outcomes for this situation are compared with the baseline situation to check the evolution of variables.

We noticed that the traded volume of Industrial products decreased by 0.0073% following the tax increase. This indicates that we cannot solely consider the volume of imported Industrial products to analyze the import dependency since the decreased overall trade in Industrial products within

Belgium is likely to decrease the import levels as well. Instead, we consider the origin of the traded Industrial products. Table presents the percentage changes of traded volumes of Industrial products per origin (i.e. the EU, the Rest of the World, and Belgium). This table clearly indicates that Belgium is indeed importing less Industrial products from both the EU and the Rest of the World. This is in line with the earlier findings that less Industrial products are traded within Belgium in general. However, more Industrial products originate from Belgium itself. Following this rationale, Belgium has indeed become less import dependent for Industrial products.

Table: Percentage change of traded volume of Industrial products in Belgium, per origin, compared to baseline scenario

Origin of the traded Industrial products	Percentage change traded volume
EU	-0.0607%
Rest of the World	-0.0634%
Belgium	+0.0615%

This analysis can be repeated for each commodity or service of interest.

Factor input requirements – example of labour

Each production process requires input factors and input of commodities and/or services. Hence, the CGE model can list the labour requirement per type of activity. Again, we compare the baseline situation with the maximum tax increase situation. As we already noticed increasing and decreasing importance at product level, hence we can expect comparable evolution in the sectoral labour demand.

The evolutions are presented in Table. This table indicates that most activities face increased labour demands. Therefore, also the total Belgian labour demand increased by 0.01% following the tax increase for the taxes on new household appliances. The repair activities experience the most considerable increase in labour demand (+6.93%), while the increases for the other activities are much more moderate (i.e. not surpassing the +1% level). Notice that also the labour demand of Industry has increased, despite the declining importance of the traded volume of Industrial products. This follows the analysis on import dependency for the Industrial products which demonstrates that, despite the declining importance, more Industrial products originate from Belgium. Only two sectors face a declining need for input of labour: the construction sector and the retail sector. This again indicates that the retail sector is more closely interlinked to the construction sector compared to the linkages between repair activities and the construction sector.

Table: Percentage change in labor demand per sector compared to baseline scenario

Sector	Percentage change labor demand
S1: Agriculture, fishing, forestry	+0.11%
S2: Mining	+0.50%
S3: Industry	+0.08%
S4: Energy	+0.12%
S5: Construction	-0.29%
S6: Trade	+0.04%
S7: Land transport	+0.10%
S8: Water transport	+0.13%
S9: Air transport	+0.12%
S10: Logistics & mail	+0.09%
S11: Market services sector	+0.03%
S12: Non-market services sector	+0.02%
S13: Retail	-1.66%
S14: Repair	+6.93%
Total	**+0.01%**

Accordingly, this analysis demonstrated a decreased need for investments, indicating that capital goods and labor are substitute factors.

Other relevant findings

The changes above are the result of a tax increase for the new household appliances. This tax increase also has an impact on some macro-economic indicators. The Belgian GDP for example declined by 0.046%. This is a straightforward observation as increased taxes in equilibrium models typically result in suboptimal solutions. Also the households utility level decreased (by 0.040%). Notice however that this model only provides a purely economic analysis. These evolutions provide no insights in the environmental gains of the tax increase for example, but it provides tools to do so:

In the context of the Circular Economy it is therefore also interesting to investigate what the increased level of repair activities exactly stands for. Therefore, the database with the outcome of the new CGE model was discussed with stakeholders in the field of household repairs. This research managed to couple the database of the labour needs of the repair sector in the Walloon and Brussels region with the CGE model's outcome. Based upon the number of hours spend on repair activities, this data coupling first allows to estimate the total number of repairs completed, which is 95,596. Ex-post calculations indicate that this number of repairs managed to avoid 603,369 kg of waste generation. Also the latter calculation is the result of consultation with the Walloon repair federation.

Sensitivity analysis

In the above analysis, the cross price elasticity between retail and repair of household appliances is set at 0.99 (close to one, but not equal to one to avoid divisions by 0). However, this cross price elasticity is uncertain, as no good estimate for the elasticity was found in literature. A sensitivity analysis on uncertain parameters (such as the cross price elasticity) can demonstrate the robustness of the CGE model.

With this purpose, the incremental tax increase is re-run on the same CGE model, but for different cross price elasticities. The results of these different runs are displayed in Table. This overview demonstrates that the magnitude of the cross price elasticity has an impact on the magnitude of the decrease in traded volume of household appliances. However, this impact remains limited, and the model's outcomes for the quantity of household appliances traded is comparable. This demonstrates the robustness of the CGE model's outcomes.

Table: Impact of the incremental tax increase on the traded quantity of new household appliances for different cross price elasticities

Cross price elasticity	Impact of incremental tax increases (+1% to + 7%) on quantity of new household app							
	+1%	+3%	+5%	+7%	+9%	+11%	+13%	+15%
0.99	-0.01%	-0.32%	-0.59%	-0.82%	-1.12%	-1.38%	-1.64%	-1.75%
1.5	-0.01%	-0.32%	-0.59%	-0.86%	-1.13%	-1.39%	-1.64%	-1.77%
3.0	-0.01%	-0.32%	-0.60%	-0.87%	-1.14%	-1.41%	-1.67%	-1.80%

NOTE.- cross price elasticity between the retail of new household appliances (G13) and the repair of household appliances (G15)

The impact of the cross price elasticity's magnitude on the responsiveness to tax changes of other quantity and price variables is very comparable to the analysis presented above. In fact, the magnitude of the cross price elasticity is less important for the responsiveness of the other variables, all relative changes among the different 'cross price elasticity scenarios' are less distinct in comparison to the changes displayed in the table above.

Other policies

The above analysis describes what happens in case a fiscal policy which aims to discourage the consumption of new household appliances. However, governments can also try to encourage consumption of sustainable products and services by lowering the taxes on these products and services, or by granting subsidies. The following paragraphs describe the impact of a **subsidy on the repair activities**. Again, an incremental increase of the subsidy is modelled, increasing the subsidy in a step-wise process by 1% each time. This analysis demonstrates that the subsidy and the tax entail completely different price mechanisms, leading to different outcomes for the Belgian economy.

First, the subsidy manages to convince a considerable number of consumers to opt for the repair of their defect household devices (G15). This increased demand for repair services also boosts the need for spare parts of the household appliances (G14). This is presented in Table. The increased repair activities also manage to achieve a higher number of repairs compared to the tax-scenario, as well as avoid more waste (Table).

However, the price decrease initiated by the subsidy is partially compensated by the increased demand for the repair services. The latter reasoning can be observed by comparison of the consumer purchase prices of the repair services and the Armington composite prices. The Armington price composite is the price before taxes, subsidies and trade margins.

While the consumer purchase price decreases due to the subsidy, the Armington composite price increases for the repair services, indicating the increased demand for this service. In contrast, following the taxes on retail, the Armington price composite for repair services decreased. Because of this Armington composite price increase for repair services, the purchase of new household appliances remains quite attractive in relative terms, especially in comparison to the tax-scenario. Hence, the decrease of sales of new household appliances is not as big as expected based upon the increase in repair services. As the retail activity is impacted less, it can be observed that the construction sector is not damaged by the decreased retail activity. Instead, the increased repair activities (albeit this remains a small sector) also boost construction.

Table: Impact of subsidy for the repair of household appliances services, per commodity & service, and for different cross price elasticities between repair and retail of household appliances

Variable	Cross price elasticity	
	0.99	3.0
G1: Agricultural products, fish, forestry products	-0.004%	-0.005%
G2: Mining products	-0.004%	-0.004%
G3: Industrial products	0.000	0.000%
G4: Energy products	-0.003	-0.003%
G5: Construction	+0.030%	+0.030%
G6: Trade services	-0.002%	-0.002%
G7: Land transport services	-0.005	-0.005%
G8: Water transport services	-0.006	-0.006%
G9: Air transport services	-0.003	-0.003%
G10: Logistics services & mail	-0.006	-0.007%
G11: Market services	0.000	0.000%
G12: Non-market services	-0.001	-0.001%
G13: Retail household appliances	-0.006	-0.146%
G14: Spare parts household appliances	+3.461%	+4.000%
G15: repair household appliances	+10.519%	+37.220%

All other sectors experience limited decreased activities however. This is explained by the competitive nature of the need for input among the activities. Because of the subsidies, the repair activities generate an increased rent, allowing a higher remuneration for labour. Hence, the repair sector manages to attract additional labour (Table). Again, the closely linked spare parts sector follows this evolution. All other sectors are facing decreased availability of labour forces however, in combination with increasing prices, this compels the sectors to decrease their level of activity. At economy-wide level this is not dramatic however as the entire Belgian demand for labour increases. Finally, also the GDP increases following the subsidies, in contrast to the decreasing GDP in case of the taxes.

Table: Examples of impact by an incremental subsidy increase for repair services of household appliances (for max increase scenario +15%)

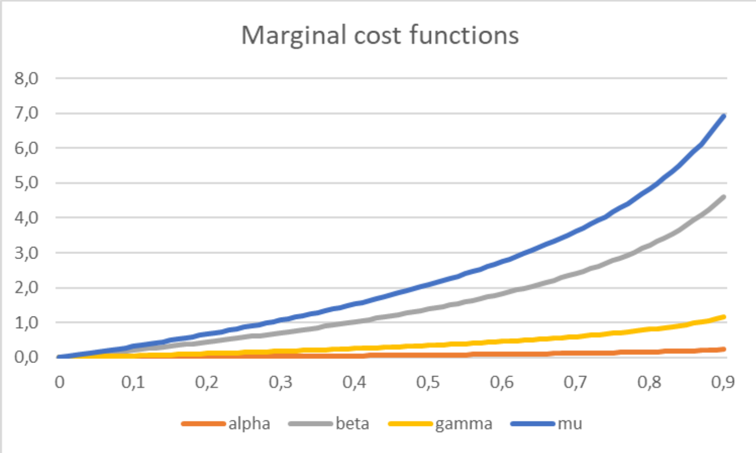
Variable		Percentage change
Labor requirements per sector	S1: Agriculture, fishing, forestry	-0.012%
	S2: Mining	-0.056%
	S3: Industry	-0.008%
	S4: Energy	-0.014%
	S5: Construction	+0.028%
	S6: Trade	-0.004%
	S7: Land transport	-0.011%
	S8: Water transport	-0.014
	S9: Air transport	-0.014
	S10: Logistics & mail	-0.010
	S11: Market services sector	-0.003
	S12: Non-market services sector	-0.002
	S13: Retail	+0.133%
	S14: Repair	+36.808%
	Total	+0.001%
GDP		+0.004%
Number of repairs		113,468
Avoided waste		716,166 kg

The analysis above considers repair activities for household activities. However, the calibration of the functions related to these activities is based upon the official I/O data provided by the Belgian Federal Planning Bureau. This data only captures the all professional repair activities in the different sectors. However, the repair activities in the CGE model do not capture the informal repair activities. It misses out on, for example, repair cafés without remuneration or repair by consumers themselves. As such, the model is likely to underestimate the real number of repaired household appliances. Nevertheless, the small changes per sector, or in labour requirements are the result of a very narrow targeted fiscal policy (only repair of a specific devise is considered). Hence a more holistic policy could create even more impact.

Partial equilibrium modelling

We illustrate the possibilities of the partial equilibrium modelling framework described higher by comparing, for a particular **parameterization of the model**, the welfare optimum with several market outcomes that differ with respect to the policy instruments that are applied. We start with an illustration of an economy in autarky, hence no imports of products and no exports of recycled material. In a second example we allow for imports of goods and exports of recycled material. We assume an iso-elastic utility function $U(Q) = [1/[1-\varepsilon]]Q^{1-\varepsilon}$ with $\varepsilon = 1.5$. The unit cost of production of the consumption good is set equal to $c = 2.0$, the price of virgin material is normalized to one $p^v = 1$ and we assume that only the disposal of consumer waste causes externalities $e_d^c = 0.1$. Furthermore, the functional form of the marginal cost functions is given by $y = \theta ln(1-x)$ with $\theta = -0.1$ for sorting effort α, $\theta = -2.0$ for recycling effort β, $\theta = -0.5$ for the share of recycled content γ, and $\theta = -3.0$ for material intensity reduction μ. We choose parameters for the different marginal cost functions reflecting the idea that it is relatively easy for consumers to sort waste and for producers to include recycled materials in their products. But recycling and reducing material intensity were chosen to be relatively more expensive. Of course, other choices are possible, this is only a stylized parameterization to show the possibilities of the modelling framework. The resulting marginal cost functions are traced out below.

Figure: Marginal cost functions for material intensity, recycled content, recycling and sorting efforts

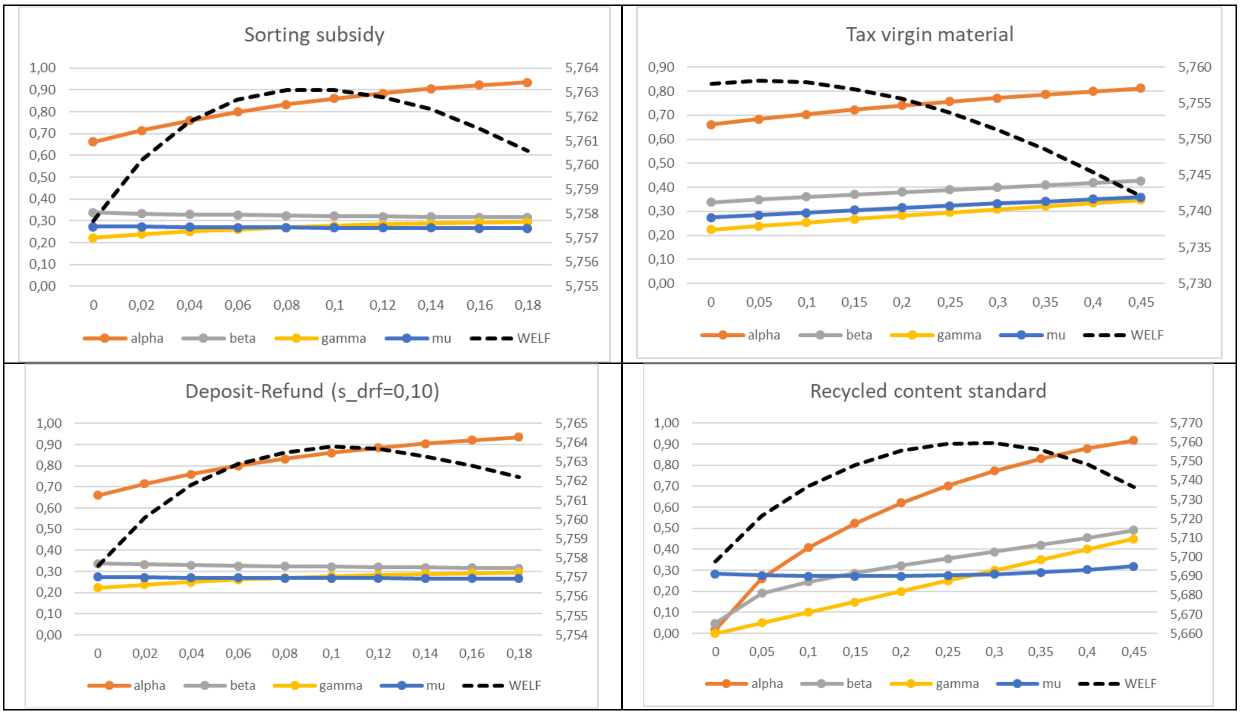


For this parameterization, we consider four well-known policy instruments: (1) a **sorting subsidy**, (2) a **tax on virgin material imports**, (3) a **deposit-refund system**, and (4) a **recycled content standard**. In environmental economics, an extensive body of literature has investigated the pros and cons of waste management policy instruments, see Dubois and Eyckmans (2014) for an overview. The purpose of our illustrative simulation exercises is to check whether the partial equilibrium simulation model is flexible enough to capture the sensitivity of consumer and producer decisions with regard to these classic policy instruments.

The sorting subsidy is a financial reward given to the consumer that sorts waste properly. Recalling the methodology section, the subsidy is implemented by adding $+s_{drf}\alpha Q$ to the consumer's budget constraint such that the consumer gets more money if he or she sorts more (higher α). The tax on virgin material is to be paid by the producer and is modelled as an excise tax. We augment the price of virgin material with the tax: $p^v + t^v$. The deposit-refund system is a combination of a sales tax on the commodity and a refund on the sorted waste. We therefore add $-t_{drf}Q + s_{drf}\alpha Q$ to the consumer's budget restriction. Finally, the recycled content standard is implemented by forcing a fixed value for the share of recycled material to be used by the producer in the input material mix: $\gamma = \bar{\gamma}$. For each of these instruments, we varied the policy parameter monotonically and we plot the resulting corresponding values of the social welfare (the dotted black line denoted by WELF in the graphs below), sorting effort (alpha), recycling rate (beta), share of recycled content in total material supply (gamma), and material intensity (mu).

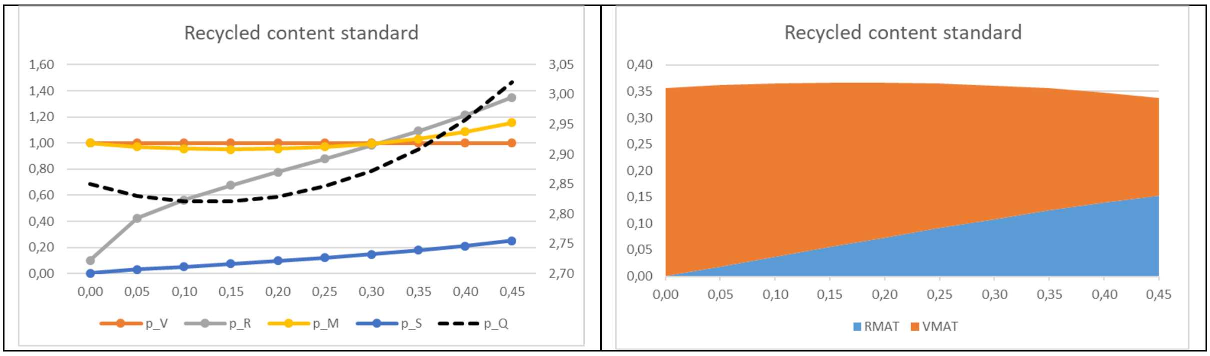
For example, looking at the **recycled content standard case**, we forced the recycled content (hence the gamma parameter) gradually up from zero to 45% (0.45) with steps of 5% (0.05). Welfare increases along this path and peaks at around 30% (0.30). As the recycled content increases, demand for recycled material goes up and therefore, supply has to follow. The increase in supply requires higher recycling and sorting rates. For a recycled content standard of 45%, the market model implies that consumers should sort approximately 90% or their waste and recyclers recover 50% of material from it. Note that in autarky (without imports / exports), equilibrium in the market for recycled material requires that $\alpha\beta = \gamma$. The supply of recycled material is given by the recycled share of sorted waste (βW) and sorted waste is equal to the sorting effort times the (end of life) consumption quantity ($W = \alpha[1 - \mu]Q$). For the market to clear, this full amount should be incorporated by producers in their input material mix ($\gamma[1 - \mu]Q$). In the market equilibrium, the price of recycled material (p^r) is such that this supply of recycled material exactly equals the demand for it. Note also that consumer oriented policies (sorting subsidy and deposit-refund) hardly affect choices of producers to use recycled content or the lower material intensity. Only the recycled content standard has strong impact on the producer's choices of the product quality aspects.

Figure: Comparison of four different policy instruments in terms of welfare and effort levels



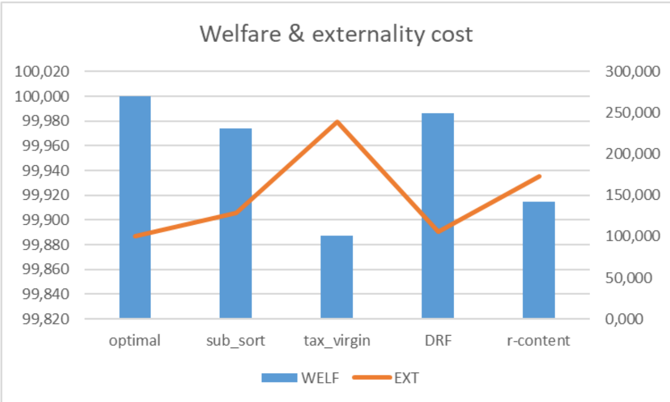
Zooming in on the recycled content case, we show below the evolution of prices and material quantities. As the recycled content standard increases, the price of recycled material (grey line p_R) and, to a lesser, extent of sorted waste (blue line p_S), increase markedly. The price of the product (black dotted line p_Q, secondary axis) first decreases and then increases. This results in first rising and then falling consumption and hence demand for materials (right panel). Obviously, the share of recycled material (blue area denoted by RMAT) in total material use is increasing when the recycled content standard goes up.

Figure: Recycled content standard: welfare and prices (left) and material shares (right)



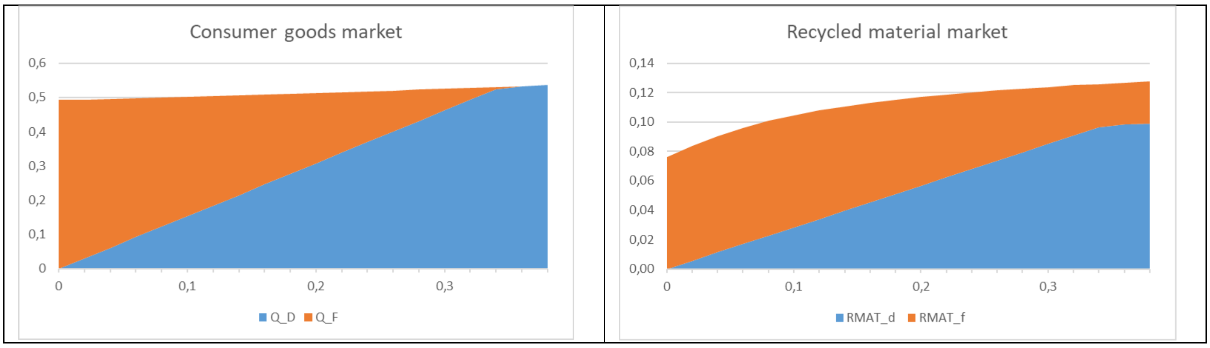
But how do these different instruments compare to the welfare optimum for the parameters we picked? In order to obtain a consistent comparison we picked the policy parameter level corresponding to the peak of the welfare line. For that **optimized level of the policy instrument** we compare welfare (blue bars denoted by WELF) and environmental externalities (line denoted by EXT, secondary axis) to the welfare optimal levels. As can be seen from the graph below, all policy instruments, even at their optimized level, fail to achieve the welfare level of the welfare optimum (normalized to 100). In particular the tax on virgin material imports and the recycled content standard perform relatively poor compared to the welfare optimum. From a theoretical perspective, this is not surprising. The externality cost is dominated by externalities of disposal and both the recycled content standard or virgin material import tax do not target this problem directly. The sorting subsidy and deposit-refund system are more closely connected to the disposal externality than the other instruments. The **best performing instruments in terms of welfare are the deposit-refund and the sorting subsidy**. The simulation model therefore confirms the theoretical result by Palmer and Walls (1997) regarding the superiority of deposit refund systems and the analysis by Söderholm (2011) regarding the problems with virgin material or extraction taxes. We also compared the environmental externalities across all cases and we observe that again, the virgin material tax and recycled content standard perform poorly compared to the welfare optimum.

Figure: Comparison of four different policy instruments in terms of welfare and externalities



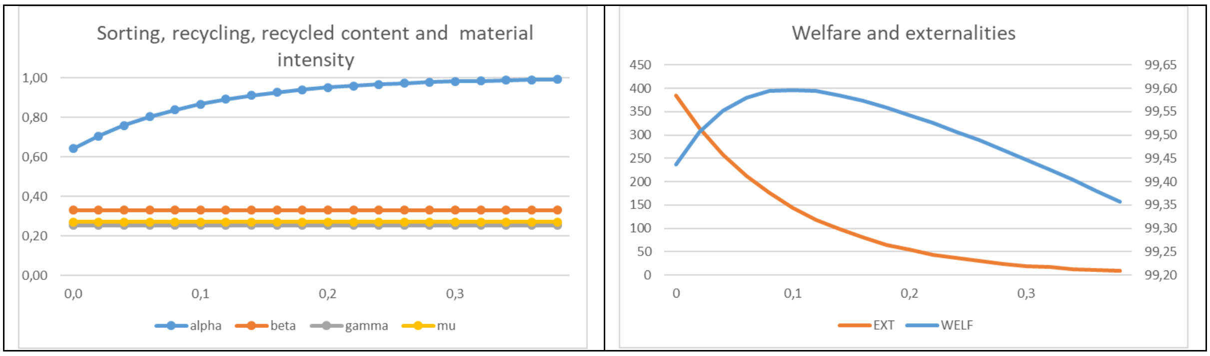
We also describe a second, more sophisticated, example in **which imports of consumer goods and exports of recycled material** are activated in the model. In particular we assume that marginal production cost of consumer goods by foreign producers is equal to $c^f = 2.831$ and the reservation price for waste material exports is given by $wtp_r^f = 0.8$. As a policy instrument we consider a deposit-refund system with $t_{drf} = 0.1$ and varying rate of subsidy $s_{drf} = 0 \rightarrow 0.4$. The graphs below depict the split between domestic and foreign producers in the consumer and recycled material markets.

Figure: Deposit-Refund in an open economy: consumer good (left) and recycled material (right)



Initially, for relatively low sorting subsidy rates, the consumer goods market is dominated by foreign producers. Domestic producers struggle to capture market share. A similar picture applies the recycled material market. Waste of consumption is sorted and recycled and most of the recycled material is bought by foreign. Sorting efforts go up when sorting is subsidized stronger (see alpha in left hand graph below) and approaches almost 100% for subsidy rates higher than 0.3. Note that the sorting subsidy has no impact whatsoever on the choices made by producers regarding material intensity and recycled content, nor on the recycling effort. This is due to the fact that international prices dominate the virgin and recycled material market. The extra supply by our small open economy does not cause international prices to move. Finally, we observe from the right hand side graph below that welfare peaks at a subsidy rate of approximately $s_{drf} = 0.1$ and externalities (measured relatively to the social welfare optimum) decrease and even fall below the first best optimal level once the subsidy rate supersedes $s_{drf} = 0.15$.

Figure: Deposit-Refund in an open economy: effort rates (left) and welfare and externalities (right)



Recommendations

- From the policy simulations with the autarky model we have learned that environmental externalities in the life cycle of a good should be tackled by policy instruments that target decisions very close to where environmental effects originate. If the aim is to curb negative externalities from waste disposal (or prevent illegal disposal and exports) we clearly found that taxing virgin material in the beginning of the life cycle clearly inferior to policies that boost sorting efforts directly like a sorting subsidy, or even better, a deposit refund system.
- As a general conclusion from the simulation experiments with international trade linkages for products and recycled materials, we can say that domestic policies have substantial impact on domestic externalities of disposal but the product quality choices like material intensity and

recycled content are to a large extent driven by prices that are internationally determined. Hence, the circular economy policy manoeuvring space is strongly restricted in a small open economy like the Belgian one.

- We are aware of the fact that these are only very first conclusions based on a stylized simulation exercise. The next step is to calibrate the model to a real world example of a product and test a wider range of policy interventions. The calibration of the model is however challenging as it requires information on cost of sorting, recycling, incorporation of recycled content and reduction of material intensity of products. This is typically private information of companies and there are no statistics on these costs. Therefore, any future research will have to rely on expert judgement and strong hypotheses regarding the primitive parameters of technologies and preferences.

4.3 Micro economic incentives and business models

Business models: game theoretical analysis

Impacts of an improvement in the collection of scraps for recycling on the interaction between primary producers and recycling firms

Under the assumption that recycling is no cheaper than virgin production and the cost of recycling is unknown to the virgin producer, our two-period model shows that increasing the collection of scraps for recycling does not reduce monotonically virgin production. This result holds as long as a unique and stable Cournot equilibrium exists, which requires a minimum set of assumptions on the demand function.

In our model, if the initial collection rate is low, virgin production decreases with the collection rate as the virgin producer strategically reduces prior-production to increase her chance to control the production of the recycling firm in the second period. However, if the initial rate is high enough, increasing the collection rate leads to an *increase* in virgin production from its initial level. When the collection rate is high, the virgin producer finds it too costly to reduce production in the first period in order to maintain the probability of controlling the recycling firm. Consequently, he relaxes the reduction of prior production when the collection rate increases and maintains the monopolistic prior production when the collection rate is higher than a certain threshold.

Our result suggests a revision on our ambitious targets to reach the circular economy. Because consumers always benefit from an increase in the collection rate, increasing the collection rate to attain the threshold that minimizes virgin production can increase consumers surplus and hurt the environment in the same time. But if the collection is higher than that threshold, increasing the collection rate will still favour consumer surplus but will lead to an increase in virgin production, which leads to an increase in the environmental impacts of the economy from its minimum level. Furthermore, once the recycling firm is saturated, improving the collection rate, which is costly for society, will have no further impact on virgin production. Therefore, improving the collection rate from a low initial level can be a win-win situation but pushing the collection rate too high may make the economy deviate from its first-best situation and needs to be considered carefully.

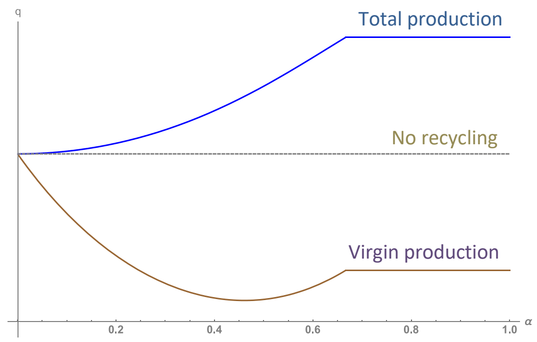


Figure: Evolution of virgin production and total production with respect to the capacity of scrap collection (α), compared to the benchmark case of no recycling.

We can observe a rebound of the volume of virgin production if the collection rate α *increases above a certain level. Also, if the collection rate* α *is too high, it has no more impact on the both the virgin and total production.*

Implications of the peer-to-peer sharing and secondhand markets on the manufacturing of a durable good

The P2P and the second-hand markets share some similarities regarding how they affect the manufacturing firm. Both cause a “cannibalization effect” on the manufacturing firm by eating parts of demands on the primary market. But they also create a “value effect” by favouring the “liquidation” of the product by allowing owners to sell the used product on the second-hand market or to rent the product on the P2P market, which affects positively the profitability of the manufacturing firm by increasing the consumers’ willingness-to-pay for new products.

However, there exist a fundamental difference between the second-hand and P2P markets. In a second-hand market, the ownership of the products is transferred from one individual to the other, usually followed by the former owner of the product purchasing another new product to satisfy her needs. The second-hand market, therefore, exists when individuals who have high valuation for usage of the product resell it to individuals who have lower valuations for the usage of the product. Conversely, the peer-to-peer (P2P) marketplaces allow an owner to rent her products to a renter during a short period of time for a small payment without the transfer of ownership from the former to the latter. The opening of a P2P market, hence, allows owners to rent out products in their idling time for extra revenues while still satisfying their needs of using the product without the need to buy another one. The transaction, therefore, may be conducted not only from an individual with high valuation to an individual with lower valuation for the product but also in the reverse direction: individuals with low valuation for the usage of the product rent the product to individuals who have a higher valuation.

Furthermore, since both new and used products can be rented on the P2P market for a fee (with different probabilities), the “value effect” of the P2P market can be larger than the “value effect” of the second-hand market, in which it is created only once when products turn old and are sold from one individual to another. Particularly, if the capacity to match supply with demand on the P2P market is high enough, so that middle-end consumers prefer renting the product on the P2P market over buying the used product on the second-hand market, owners can expect to rent the product with a high fee and hence, are willing to pay more for both new and used products.

When the two markets co-exist, there must also be an interaction between them. On the one hand, the P2P market creates a “value effect” that increases the willingness-to- pay for the used product.

But since this "value effect" increases the number of owners (the supply of the P2P market), while it reduces the volume of non-owners (the demand of the P2P market), it will bring down the market-clearing rental fee, which, in turn, can reduce the "value effect" that the P2P market generates for used goods. On the other hand, since consumers can now rent the product instead of buying it, there also exists a "cannibalization effect" between the two markets.

As a result of the two effects above, the manufacturing firm does not always lose from the emergence of the P2P market. More precisely, the manufacturing firm can earn more profit with the P2P market than without it if the matching capacity of the P2P market is higher than a certain threshold. In this case, consumers with low valuations for the usage of the product buy used units of the product on the second-hand market, while consumers with medium valuations for the usage of the product rent it on the P2P market. This threshold of the sharing capacity, however, increases with the durability level of the product if the latter is high and decreases with the durability level otherwise. As a consequence, if the nature of the product dictates a high initial durability level, the manufacturing firm may have incentives to decrease the level of durability of the product so that the P2P market has better chances to have the sharing capacity higher than the threshold above which the manufacturing firm is better off. On the contrary, if the nature of the product dictates a low initial durability level, the manufacturing firm will want to increase the durability level of the product to have better chances to earn more profit from the P2P market. Products like cars, for example, are easy to share and can attain a high matching probability on the P2P market. Cars manufacturers may even earn more profit with the existence of the P2P market by favouring the sharing of cars instead of considering the latter as a threat to their business.

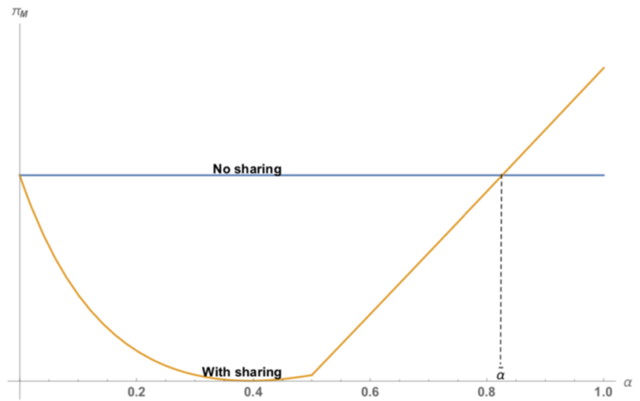


Figure: Profit of the manufacturing firm with and without the P2P sharing market

While an improvement of the sharing capacity α from an initially low level harms the profit of the manufacturing firm, the latter can profit from the improvement of α if the initial level is high enough. If α is higher than a certain level $\tilde{\alpha}$, the manufacturing firm is actually better off with the sharing market.

Recently, General Motor launched the very first peer-to-peer sharing platform supported by a manufacturing firm. However, GM only allows cars not older than the 2015 models to be shared on the platform. Even though we do not have enough data to judge the correctness of this strategy, from the model, we can still shed some light on its impacts on the profitability of the firm. Such a policy encourages consumers to buy the new product and is more profitable to the manufacturing firm compared to the case that all new and used products can be shared if the matching capacity of the P2P market is low. However, if the capacity of the P2P market is high enough, the share-new-only policy yields a lower value effect on the profitability of the firm. Therefore, the firm only profits from this policy if the sharing capacity is not too high; if the sharing capacity is high enough, the manufacturing firm profits the most if everybody can join, with both new and used product be shared on the P2P market.

Concerning the environmental impact of the sharing economy, the ownership level in the economy decreases with an increase in the capacity of the P2P market. The intensity of resource usage, which measures the total usage rate per unit of product existing in the economy, also increases with the capacity of the P2P market if the initial level of durability is low but might increase or decrease with the capacity of the P2P market otherwise. When the firm reacts to the P2P market by endogenising the choice of durability, it can be the case that the firm may want to reduce the durability level if the latter is initially higher than a certain threshold. In this case, the variation of the index with respect to the capacity of the P2P market is unclear. Hence, improving the sharing economy increases the efficiency of resource usage for products that have low durability level, but the effect is not clear for products which are already somewhat durable.

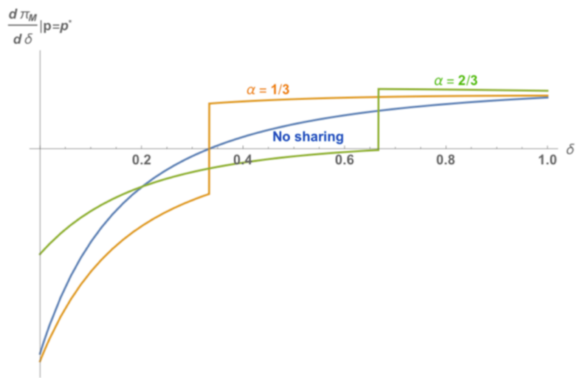


Figure: marginal profit of the manufacturing firm with respect to the durability level for the three cases: no sharing, with sharing of capacities α = 1/3 and α = 2/3.

Compared to the case without the P2P market, the manufacturing firm, when there is the P2P market, may have high or lower marginal profit with respect to the durability level higher or lower motivation to increase the durability level of the product.

There are, however, some limitations in this setting. We assume that the second-hand and the sharing markets are perfectly competitive with no transaction costs. The assumption of no transaction costs simplifies the computation and imposes that all used units of products are sold on the second-hand market. Anderson and Ginsburgh (1994) show that the positive transaction costs on the second-hand market give rise to consumers who buy a new product and keep it until its end-of-life instead of selling it on the second-hand market. Since the possibility to rent the product out on the P2P market increases the price of used products on the second-hand market and the probability of renting out a new unit of product is higher than for a used one, the existence of the P2P market encourages the owners to sell the used product more than in the case without sharing. On the demand side of the second-hand market, since acquiring a used product is now more expensive due to the transaction cost, renting the product on the P2P market can now be more interesting for the consumers. Therefore, positive transaction costs on the second-hand market may reduce the supply and increase the demand on the P2P market. Further research is necessary to shed light on this matter.

Motivations of a manufacturing firm to adopt pay-per-use business models and conditions for the business model to be win-win

In this study, we compare the pay-per-use (PPU) business model with the traditional selling on two aspects: the revenue of the firm and the resulting aggregate usage as a proxy for the environmental impact caused by the business. We address these issues under the key assumption that consumers are uncertain about the utility that they can derive from each usage instance when making decision to buy the product under selling while they can learn about the utility derived from a specific usage instance when deciding whether to rent the product under PPU.

Under this assumption, the impact of PPU (relative to selling) on the revenue of the firm can be separated into two effects: the “market-expansion” and the “surplus-extraction” effects. By charging consumers a per-use fee for every time they use the product only, the firm can give access to usage to some of those consumers who would remain inactive under selling due to the fixed selling price. Unless the firm can cover the whole market under selling by charging a low selling price, PPU can always expand the market to the low-usage consumers and, thereby, generate some revenue from them. PPU, hence, creates a non-negative “market-expansion” effect that can increase the revenue of the firm.

Also due to the pricing structure, under PPU consumers self-select into different types and pay differently according to their types. In case the firm has to charge a low selling price under selling, it does not extract all the surplus of the high-usage consumers. In this situation, the firm can earn more from PPU by extracting a larger share of the surplus of these consumers. However, because the firm has to set the per-use fee higher than the operating cost and consumers use the product only if they derive a utility higher than the cost they pay (the per-use fee under PPU or the operating cost under selling), PPU may reduce the usage of these consumers. As a consequence, these consumers have a lower willingness-to-pay under PPU than under selling. Thus, the sign of the “surplus-extraction” effect is ambiguous, and the firm earns higher revenue under PPU only if the “market-expansion” effect can compensate for the loss from the “surplus-extraction” effect if the latter is negative.

The negative “surplus-extraction” effect is due to the decline in usage of consumers when they switch from purchasing the product to renting it by a per-use payment. Empirical studies such as Peter Muheim & Partner (1999) for example, estimates that people in Switzerland who previously owned cars but sold them when they switched to carsharing reduced their average vehicle miles traveled by 18%. Shaheen et al. (1999) report even a larger reduction, about 33 to 50% in Switzerland, 37% in the Netherlands and 58% in Germany. Even though the magnitude of the reduction vary greater among studies, it is likely that the switch from ownership to a renting pay-per-use system makes consumer mindful of the cumulative costs of driving, which makes them “appear to have become more judicious and selective when deciding whether to drive, take public transit, walk, bike, or even forgo a trip” (Cervero et al., 2007).

If PPU leads to market expansion, since the “market-expansion” effect is positive, a not-to-small negative “surplus-extraction” effect is sufficient for PPU to yield higher profits to the manufacturing firm. Therefore, it is easier for PPU to yield higher revenue if it can lead to market expansion. In case that the firm already covers the whole market under selling, PPU can yield higher revenue only if the operating cost is high enough so that only high-utility usage instances are realized and that consumers maintain the same usage levels under both business models. In this case, the firm earn higher revenue by having consumers self-selecting and the high-usage consumers paying more than the price they would pay under selling. However, if the operating cost is low, the firm under PPU faces a trade-off when setting the per-use fee. If the per-use fee is low, the firm cannot extract all the surplus from high-utility usage instances while the firm under selling partially does. In this case, PPU yields higher revenue than selling only if the operating cost is low enough so that the firm can earn more revenue from serving the low-utility usage instances of the high-usage consumers. Since the firm earns less revenue from the low-usage consumers, the more significant is this segment compared to the high-usage segment, the harder it is for PPU to dominate selling.

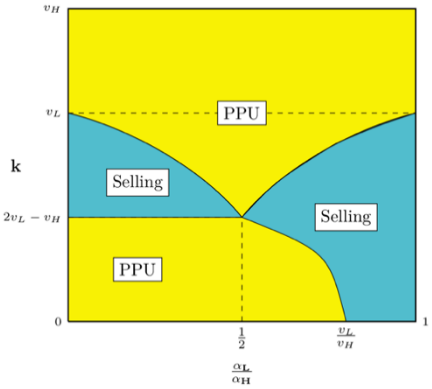


Figure: more profitable business model with different values of operating cost and segmentation of the market.

PPU is more profitable in the yellow zones while selling is more profitable in the blue zones. The vertical axis represents the operating cost of the product relative to the utility derived from using the product. The horizontal axis represents the relative value of the low-usage segment of consumer to the value of the high-usage segment: on the left of the graph, the firm only sells to high-usage segment under selling; on the right its sells to both segments under selling.

This result sheds light on another channel for PPU to be more profitable than selling besides its capacity to expand the market: the capacity to have consumers pay differently according to their usage rate and pay higher than the price under selling. This paper, hence, provides some enrichment for other existing papers. In Agrawal and Bellos (2015) and Orsdemir et al. (2019), the concavity of the utility function imposes that, without other distortions in the operating and production costs, PPU and selling yield the same profitability since the "market- expansion" and the "surplus-extraction" effect cancel each other out perfectly. In their setting, under PPU the consumer with the highest valuation for the usage of the product pays exactly the price that she would pay under selling. As a consequence, all other consumers pays less under PPU than under selling, the "surplus-extraction" effect is therefore negative. So, it is only by the form of the utility function that the "market-expansion" effect can compensate perfectly this loss. Therefore, Orsdemir et al. (2019) conclude that the advantage in operating the product (so that the operating cost is lower) is necessary for PPU to the more profitable while in Agrawal and Bellos (2015) the advantages of PPU is yielded by the pooling capacity of the product, which leads to lower production cost and hence, higher profit for the firm.

The setting used in Balasubramanian et al. (2015) and Postmus et al. (2009), for example, can be considered as special cases of this paper: when the utility derived from the usage instances is constant, consumers maintain the same usage level under both selling and PPU. Without the effect of a negative “surplus- extraction” effect, in their setting, PPU is more profitable than selling by design since both the "surplus-extraction" and the "market-expansion" effects are positive.

The model also helps to shed some light on the properties of the market that can make PPU a win-win business model, i.e., a business model that can make the firm more profitable while reducing the level of aggregate usage. If the operating cost is high, so that consumers only use the product if they derive a high utility level of usage under both business models, PPU is more profitable than selling but it can result in a higher level of aggregate usage if it leads to market expansion. If the operating cost is lower than a certain threshold, PPU is more profitable if it leads to market expansion. In this case, it also results in a higher level of aggregate usage. Therefore, PPU can be a win-win business model only if the operating cost is between a range of value relative to the utility levels that consumers derives from usage. In this case, PPU reduces the usage level of consumers who are willing to buy the product under selling. So even though it leads to market expansion, since the new consumers still use the product less than existent consumers, PPU can still reduce the level of aggregate usage while increasing the profits of the firm.

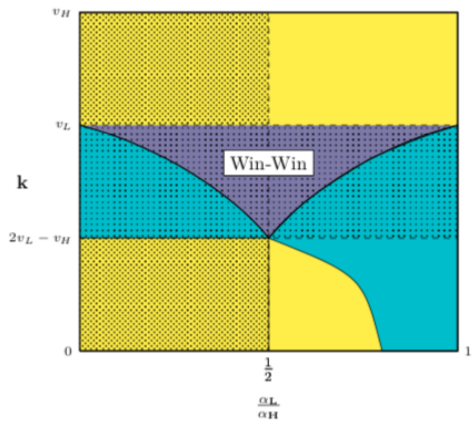


Figure: Conditions for PPU to be a win-win business model

PPU can increase the revenue of the firm and reduce the level of aggregate usage only in the zone in purple. In other cases that PPU can increase the revenue of the firm, it results in at least as high level of aggregate usage as selling.

Even though the setting is this paper is for a monopolist manufacturing firm, it can also provide some insights about the profitability of PPU in case there is competition among firms. Because the profitability of PPU depends on the "market-expansion" and the "surplus-extraction" effect, we can rely on how competition influences these two effects to predict how PPU will perform in a competitive context. If the profitability of PPU depends significantly on the "market-expansion" effect, PPU will encounter problems to be profitable since the firm has to compete with other competitors. The "surplus-extraction" effect can also be lower under competition as consumers may switch to other suppliers if they are sensitive to the higher payment under PPU. However, we must also count the switching cost of changing to other suppliers, particularly in case of sophisticated systems of products that require high knowledge and competences to operate. In this case, the supplier can certainly extract the surplus from these consumers as long as the high payment is still lower than the switching cost. Therefore, we can expect that if PPU is more profitable thanks to a "surplus-extraction" effect that outweighs the "market- expansion" effect, the firm may be better off under competition compared to the other case - when the "market-expansion" effect drives the profitability of the business model. This is the reason why in Balasubramanian et al. (2015), PPU makes the firm better off if in monopoly setting but worse off in duopoly setting. In their setting of competition, since only low-usage consumers use the product via PPU, the surplus-extraction effect must be low or even negative. Furthermore, since the PPU firm encounters the competition from the selling firm and it already reach market coverage, the market-expansion effect is also null.

Business models: case studies

Case 1: Leasing of smartphones

Motivation

The current study focuses on millennials' preferences for leasing smartphones in Flanders (Belgium). The global market for smartphones is one of the most rapidly growing in the world (OECD, 2015). Moreover, the market of smartphones is characterized by a rapid replacement of older devices. For example, Suckling and Lee (2015) report a typical lifetime of two to three years for smartphones. Besides the high turnover rate, devices are often not discarded in a responsible manner. According to a consumer study done by Nokia in 2011, 40% of discarded mobile phones were kept as spares, 27% were re-used, and only 12% were collected or returned for recycling (Tanskanen, 2013). These trends lead to a possible irretrievable loss of resources since smartphones contain many rare and precious (earth) metals such as indium, gallium and neodymium (Tanskanen, 2013). Besides material use, energy use is another important impact of smartphone production and use (Suckling & Lee, 2015).

Description sample

The online survey was distributed to a non-probabilistic sample in March 2016 via the Qualtrics software. Finally, 362 individuals started the survey leading to 325 useable responses. Our sample consisted of 47% male and 53% female respondents. Unsurprisingly, a large fraction of the respondents was still studying for their high school or higher degree. The respondents were between 15 and 30 years old with an average of 22.5 years. Some 92% of respondents currently owned a smartphone. The most popular brand among respondents was Apple (36%) followed by Samsung (24%), Huawei (11%), OnePlus (8%), and Sony (5%). None of the respondents owned a Fairphone. Only 2% of the sample received a company phone from their employer and some 13.4% bought their phone in a package deal with their communication providers.

Main results

More than 80% of the respondents currently owned a phone that was less than two years old (Figure 1) and some 37% had already owned four or more phones. So, in line with previous research, a high turnover rate for smartphones is found for this sample. In addition, the second-hand market for smartphones does not seem to be flourishing (Table 1). Only some 12% of respondents currently owned a second-hand phone: 8% received the phone for free from family or friends, while only 4% actually bought a used phone. Looking at the disposal of respondents' used phones, we see that only 15% offered the phone for re-use: 9% gave it away for free, while 6% sold it. Further, in line with past studies, we find that the disposal of used smartphones is problematic: some 73% kept it as a spare, while only 6% disposed their used phone in a way that recycling or re-manufacturing would be possible (Table 1). This low level of recycling is in line with the information provided by Recupel (n.d.), which estimates that some 5% of all smartphones in Belgium are currently recycled.

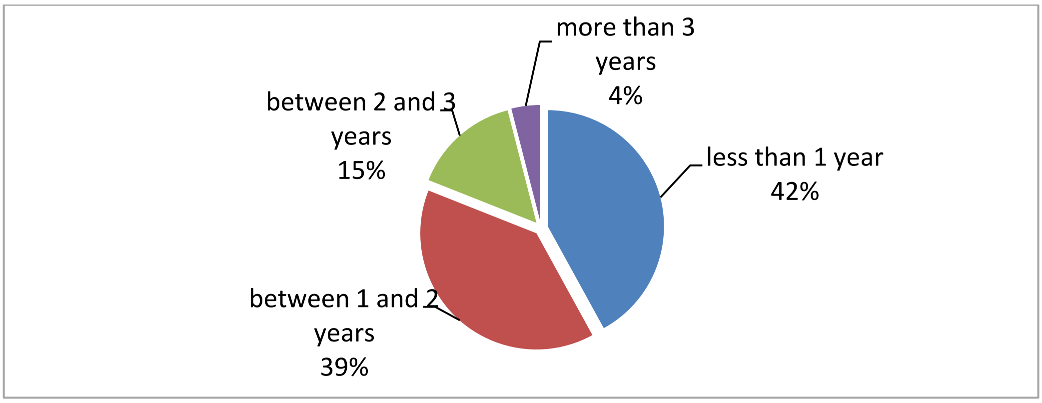


Figure: Age of respondents' current smartphone

Table: Smartphone purchase and disposal

Current smartphone	%	Disposal of old smartphone/mobile	%
new online	25	kept on a shelf at home	73
new in shop	52	sold as used	6
new from friends or family	8	given away for free	9
new from employer	2	disposed in recycling park or collection point	4
used bought	4	disposed in shop when buying new phone	2
used from friends or family	8	other (e.g. stolen, lost… but also in bin)	6
other	1		

Looking at the Discrete Choice Experiment (DCE in the sequel), the main effects model shows that respondents have a preference for Apple and Samsung over the other brands. Moreover, respondents prefer newer models over older models. Respondents also prefer phones with more available memory and with a higher quality battery. Regarding the length of the warrantee period, respondents' preferences seem less clear cut. Still they seem to prefer some warrantee over no warrantee. Finally, as expected, they dislike higher prices.

A latent class model allowed us to distinguish three different respondent classes. The first class has clearly ranked brand preferences: Apple and Samsung are valued highest and the Windows phone least. They prefer newer models, more memory and a better performing battery. However, they do not seem to care about the warrantee conditions. The second class has marked anti-Apple preferences and is indifferent between the other brands with a slight preference for the Fairphone. They prefer newer models, more memory, a better performing battery and also a longer warrantee period. This second class seems to be more price sensitive than the first class. The third class prefers an Apple or Samsung phone and is indifferent between the other brands. This class also prefers newer models, more memory, a better performing battery and to some extent a longer warrantee period. It is also more price sensitive when it comes to the rent price, but not with respect to the buy price. Thus the main differences between the different classes focus on brand preferences, warrantee preferences and price sensitivity.

Besides the DCE, respondents were also asked directly whether they would consider leasing a smartphone. The results of this direct question reveal that a significant group seemed hesitant to consider a lease contract: with 31% saying they would 'certainly not' and 41% saying they would 'probably not' consider leasing. Less than 30% indicated that they would be willing to lease a smartphone rather than buy one, of which only a small fraction (3%) was certain that they would enter in such a contract and a larger part (25%) would consider it.

When asked in an open-ended question about the main motivations for this answer, respondents revealed several reasons which can be classified as drivers or barriers towards leasing smartphones. These arguments were coded and categorized according to three dimensions: consumer characteristics, product characteristics and use characteristics (Table 2). The most stated barriers relate to financial impact, lack of control and perceived risks, while the most stated drivers relate to financial impact, convenience and flexibility.

Table: Arguments used by respondents as drivers or barriers towards leasing smartphones

Focus		Stated drivers (# resp.)	Stated barriers (# resp.)
Consumer	Environmental attitudes	5	0
	Innovativeness (latest model)	9	0
	Risk perception	1	34
	Lack of control	2	64
	Extended self (own my phone)	1	28
	(In)stability of income and cost flows	5	2
Product	Fast innovation cycle	8	0
	Environmental impact	1	0
Use	Convenience & flexibility	12	4
	Variety – more choice	7	0
	Duration of use	9	6
	Environmental impact	9	1
	Financial impact	40	74
	Safety (data security, privacy)	0	8
	Uncertainty (reduction of)	9	12
	Habits (no benefits from change)	0	8

Discussion

At first glance, the results seem to reveal some contradictory findings. Looking at the average implicit discount rate (IDR) over the complete dataset, the high average IDRs (21% for two-year life span; 46% for three-year life span) imply that respondents seem to be quite willing to consider leasing rather than buying smartphones, as future lease payments are heavily discounted and do not weigh greatly on current decisions to obtain a smartphone. However, these results are not confirmed by the results of asking respondents directly whether they would consider leasing a smartphone as less than 30% indicated that they would be willing to consider this. This reluctance to consider leasing a smartphone for a large part of the sample is in line with the findings from qualitative studies for two of Belgium's neighbouring countries: the Netherlands (Poppelaers et al., 2018) and the UK (Hobson et al.; 2018).

These contradictory results disappear when we investigate a more detailed picture emerging from the latent class estimation. The presence of consumer classes with significantly different preferences is in line with the findings of Mashhadi et al. (2019) for smartphones, and has been found for many other sustainable consumption choices. While class 1 seems open to leasing (based on the high positive IDRs) and class 3 does not seem to be open to leasing (based on the negative IDRs), class 2 reveals a more ambiguous picture. Depending on the expected life span of the smartphone, respondents in class 2 can be seen as being open to leasing for a life span of three years, or as being averse to leasing for a life span of two years. So less than 50% of the sample (class 1) seems willing to select a leasing contract, approximately 20% (class 2) might consider leasing if the use period of their smartphone is sufficiently long, and approximately 30% (class 3) does not want to consider leasing. The importance of duration of use on the adoption decision of PSS confirms previous findings from, among others, Mont (2004), Edbring et al. (2016), and Mashhadi et al. (2019).

The pattern of answers according to the respondent class to a direct question regarding buying versus leasing confirms that class 3 is clearly the most averse towards leasing a smartphone: with 50% stating they would ‘certainly not’ consider leasing compared to 21% in class 1 and only 11% in class 2. However, class 2 is now revealed as being the most open to leasing a smartphone: with 46% ‘certainly yes’ or ‘maybe yes’ answers compared to 37% in class 1 and 10% in class 3. These findings suggest that respondents in class 2 expect a use period of more than two years for their smartphone.

Some concluding remarks

The evidence collected among 15 to 30 year old Flemish consumers shows that support for leasing smartphones cannot be taken for granted. On the one hand, the results from the choice experiments indicate that, on average, respondents are quite willing to opt for lease contracts to acquire their preferred phones. Nevertheless, looking at different respondent classes, these averages cover some very different preferences. Three consumer classes had significantly different brand preferences and attitudes towards warrantee schemes, but also their willingness to accept leasing contracts turned out to be very different. In the end, slightly less than half of the sample seemed open to leasing, while the other half was much more cautious and refusing.

Looking at the main arguments underlying the attitude towards leasing a smartphone provided additional insight into the main drivers and barriers. Respondents indicate that they are not willing to take the risk of leasing a smartphone because of the uncertainty regarding the consequences of such a decision. They fear that unexpected costs will occur when phones need to be repaired, that phones will not be replaced when these are lost or stolen, that their privacy may no longer be sufficiently protected or that they will not receive the most trendy model. Moreover, smartphones have become part of the self-identity of young consumers, which makes the adoption of leasing schemes even more difficult. Therefore, in order to develop the market for leasing contract it seems important to eliminate as many of these uncertainties as possible. However, environmental concerns, financial considerations and a desire to own the latest model were stated as possible drivers of adopting a product-service system in this context.

Case 2: Circularity in clothes consumption

Motivation

Several negative environmental and social outcomes are associated with the production, usage, maintenance, and disposal of clothes (Roos et al. 2016). The most common fibres used for clothes are synthetic fibres (mostly coal- and petroleum-based) and cotton (Maldini et al. 2017, WRAP 2017). As synthetic fibres are usually non-renewable and have a negative impact on climate change, and as traditional cotton-growing uses excessive amounts of water, pesticides, and fertilizers, the industry is actively searching for alternatives (Muthu 2018). The current, problematic global material flow starts with hazardous chemicals that are used to transform the raw materials into textiles and clothing, such as phthalate use in artificial leather or polybrominated diphenyl ethers used to fireproof textiles (Van Der Velden et al. 2014, Kant 2012). Next, the clothes may have to be transported over a long distance to get to the consumer, resulting in a wide variety of negative externalities such as congestion, air pollution and accident risks. During the use and maintenance phase, washing the clothes requires water, electricity, and possibly hazardous detergents. During washing, synthetic fibres release micro-fibres which are a real threat to marine environments (Cesa et al. 2017, De Falco et al. 2018). Lastly, there are major ethical concerns about the way the clothing industry operates. Scandals about child labour, low wages, abuse, and accidents (like the one in Rana Plaza in 2013) are rampant and the Belgian government is lagging behind when it comes to forcing industry to take responsibility (Goethals and Knockaert 2018). Unfortunately, it appears that consumers are hardly aware of these issues (Goworek et al. 2012) and Morlet et al. (2017) show that clothes sales doubled from 50 to 100 billion units per year between 2000 and 2015. It is therefore no surprise that sustainability of textiles and fashion is on the agenda of, for instance, WRAP in the UK (WRAP UK 2018), ECAP in Europe (ECA 2018) and the Ellen MacArthur Foundation (Morlet et al. 2017).

The objective of this study is to obtain insight into whether young consumers in Flanders are open to circular business models and ideas in the clothing industry and to what extend traditional sustainable practices such as repair are still being used. To this end, a survey is used to learn about current use of and attitudes towards sustainable business models for clothes. This survey also includes a discrete choice experiment (DCE) focusing on the relative importance of specific product characteristics in forming consumers' preferences for T-shirts.

Description sample

The online survey was distributed to a non-probabilistic sample in March 2018 via the Qualtrics software. In total, the dataset contains 747 respondents between 15 and 35 years old living in Flanders or Brussels. 76% of respondents are female, while 24% are male. The job and financial situation of the respondents is also biased; 59% are students and only a minority (6%) indicates that they are financially struggling to make ends meet.

Respondents were questioned about their typical shopping behaviour (Figure 2) and which features they find important when buying clothes. The high streets are the most popular shopping location, although online shopping is equally popular for frequent shoppers (i.e. those who went shopping more than five times in two months). Swapping and second hand markets offer consumers an opportunity to extend the lifetime of clothes, but these options are far less popular. Price, comfort, and fit are considered most important when buying clothes; social and environmental impact and the country of production are least important. The fact that clothing choice is not an altruistic choice has also been pinpointed by experts in the textile industry as a big hurdle for the necessary changes in consumers' clothing decisions (Harris et al. 2016).

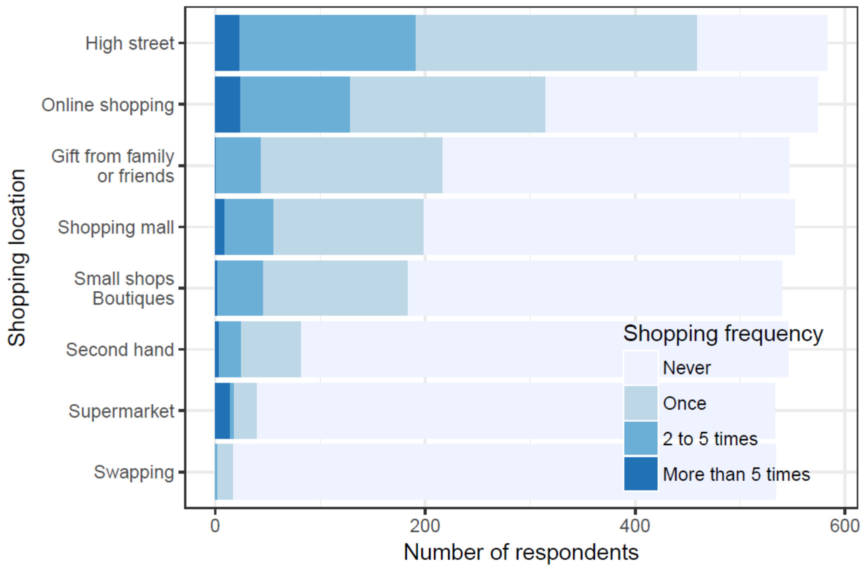


Figure: Where and how frequently respondents went shopping in January and February 2018

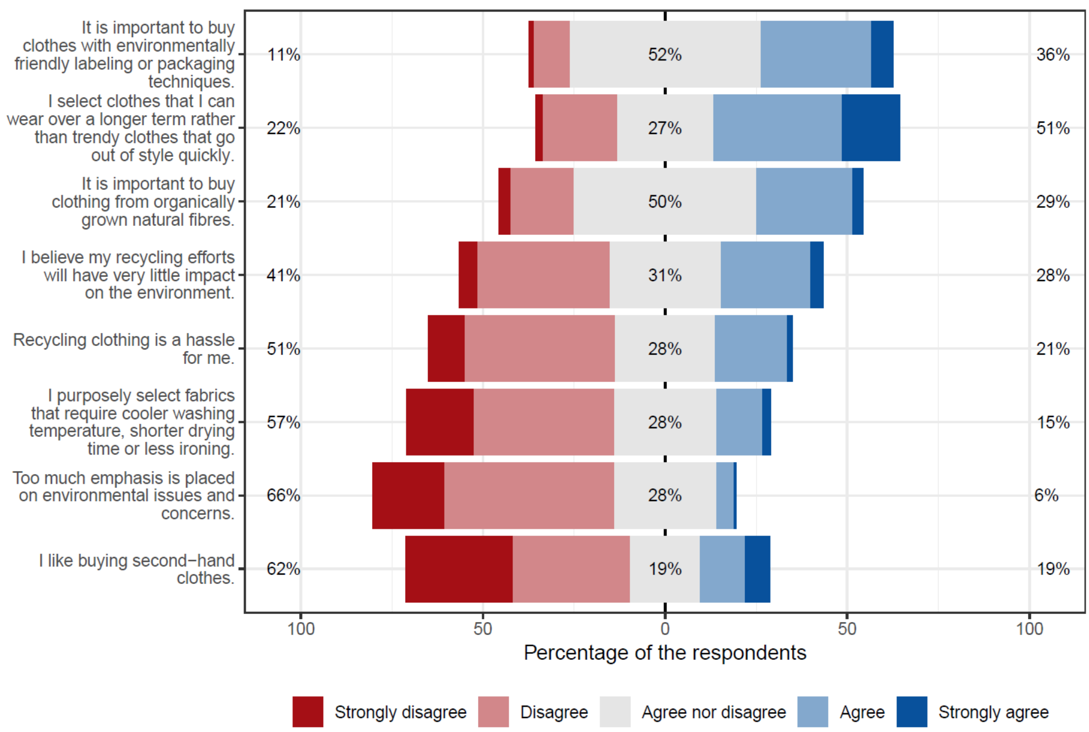


Figure: Respondents' attitudes

Main results

In this section the respondents' attitudes towards sustainable business models and their familiarity with several such business models in the fashion industry are discussed. Several statements were presented to the respondents and their answer patterns reveals quite a lot of heterogeneity (Figure 3). Opinions on several matters are diverging. For example, while approximately 40% of the respondents disagreed with the statement that their recycling efforts will have very little impact on the environment, 30% was indifferent and 30% agreed. In addition, Figure 3 shows that durable clothing is appreciated. Figure 3 also shows that half of the respondents are neutral when it comes to ecolabels or organically produced fibres; they do not really seem to care about. Similarly, second-hand clothes or low maintenance fabrics are chosen by only 19 and 15 percent respectively.

Figure 4 shows that most respondents never used new business models like clothing libraries (Zamani et al., 2017) and fashion leasing (97% and 94% never use it respectively). Even phone applications for sustainable fashion such as Good on you or Vinted are rarely used (92%). In contrast, traditional repair services as well as buying durable clothes that last longer are still frequently used approaches to extend the product lifetime (only 18% never use traditional repair services).

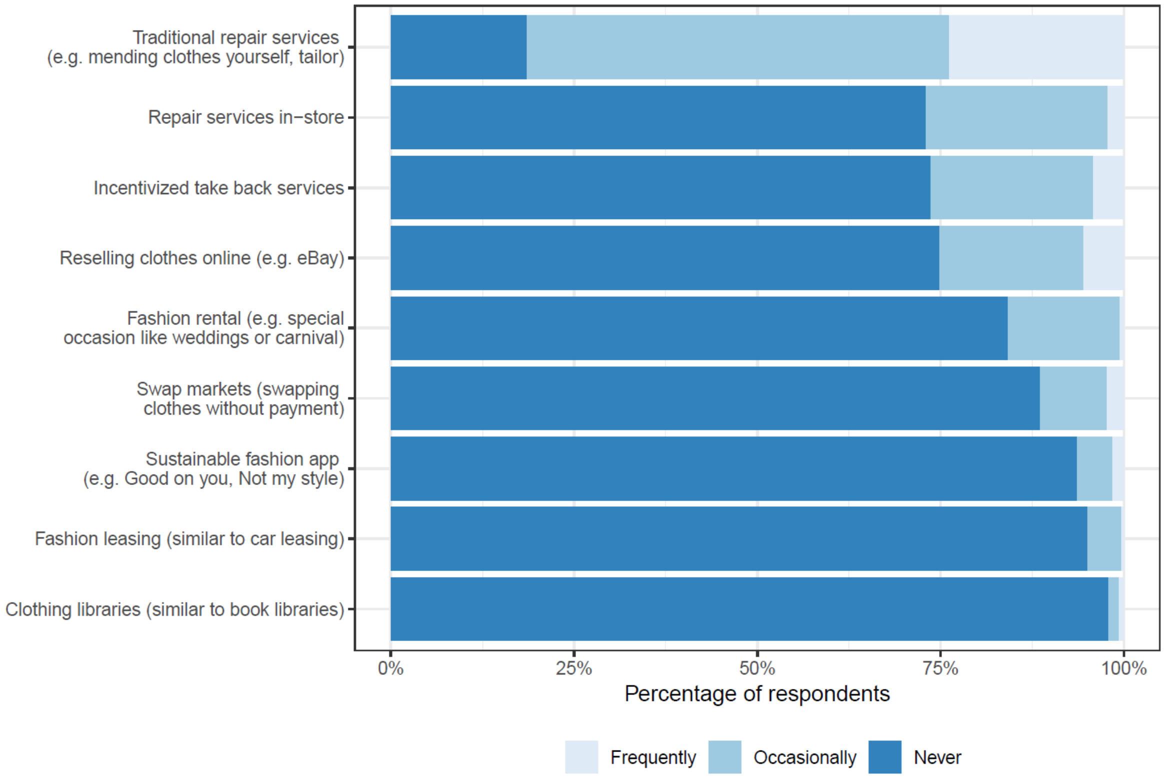


Figure 4: Familiarity with circular business models

As Belgium has been one of the top recycling countries for decades (Eunomia 2017), it is no surprise that very few respondent indicate that they would simply discard a T-shirt after use and most keep the average T-shirt for at least one year.

As expected, the DCE reveals that respondents dislike higher prices and they have an outspoken preference for new T-shirts that have a longer lifetime. For fibres, new polyester gets the lowest and cotton the highest valuation compared to recycled polyester. It is interesting to see that, while the willingness to pay for recycled cotton is slightly lower than new cotton, the opposite is true for recycled and new polyester. Lastly, the respondents had about the same positive willingness to pay for ecolabels as for locally-produced (instead of Asian) T-shirts.

A latent class models reveals three distinct respondent classes and that the largest share of people belong to the third class. The most striking thing about class 1, is that price is irrelevant for these consumers. They value durability, ecolabels, recycled cotton, locally-produced T-shirts, and second hand T-shirts. This class can be labelled as `sustainable consumers' due to their appreciation for the more sustainable attributes of T-shirts. Class 2 consumers are the most price sensitive, care the least about durability, and want new clothes made of new cotton fibres. While ecolabels do not interest them, they prefer EU-produced over Asia-produced clothing and a generic brand over a designer brand. This class can be labelled as `pragmatic consumers' as they seem to focus on getting the best value for money when selecting a T-shirt. The biggest class, class 3, have a clear preference for cotton and attach moderate value to locally and ecologically produced T-shirts. This class is the only class which positively values designer brands and they attach the greatest value to clothes being new. This class can be labelled as `mainstream consumers'.

Discussion and some concluding remarks

The survey results and their analysis show a similar reluctance among Flemish millennials to use and support sustainable business models in the fashion industry. In this sample, that is biased toward highly educated millennials, nine out of ten has never used clothing libraries, fashion leasing, or sustainable fashion apps (Figure 4). Slightly more popular are new business models that are not only more sustainable, but also provide monetary benefits such as incentivized take back systems and selling clothes that are no longer wanted. Approximately one third of the sample has experience with these win-win opportunities. However, in line with Paras et al. (2017), it seems that effort and time costs are strong deterrents when it comes to clothes disposal. A large majority of the respondents opts to donate clothes to charities and second-hand shops. It is perceived as an easy, convenient and ethical option. In addition, traditional alternatives to extending the life span of clothes, i.e. repair services, are clearly more established and most respondents are familiar with this sustainable practice (Figure 4). Thus, it seems appealing to consider reviving traditional, yet sustainable, business models rather than stimulating new business models to increase the sustainability of consumers' clothing choices. Companies may use this knowledge and turn it into a sustainable business model through, for example, clothing repair cafés, workshops, or online learning platforms. In line with past literature (Kozar and Connell 2013), survey responses reveal an attitude-behaviour gap. Over half of the sample reveals pro-environment and sustainable attitudes based on Figure 3, while a much smaller group uses sustainable business models, cares about sustainable labels (organic agriculture, ecolabel), about societal impact, or shops in second-hand clothes shops. Trendiness, comfort and price still seem to be the dominant determinants for many consumers when it comes to selecting clothes.

The results of the DCE focusing on preferences for T-shirt attributes are in line with the other survey results. On average, respondents have a strong preference for new T-shirts, and, to a lesser extent, for durable T-shirts. The other attributes such as country of production, fibres and ecolabel, are clearly less relevant to respondents when selecting a T-shirt. The relatively small size of the group of sustainable consumers in this study shows the difficulty of facilitating a transition towards a more sustainable consumption system. On a positive note, some traditional business practices such as clothes repair and making durable clothes deserve additional attention as they can be labelled as sustainable (prolonging life spans) and seem to be more acceptable to consumers.

Business models: results from interviews (subcontracted to CLIMACT)

Based on interviews and other documents, eight business cases are studied in more detail in order to gain insight into the main barriers and drivers of adoption of circular business models with a focus on servitisation and sharing models. The key features of each case are summarized below.

Table: Description business cases

Companies	**Key features by case**
Cambio (company)	« Traditional » business model (strong collaboration with authorities, 3 years to prepare the business plan, etc.) Limits : use of non-sustainable materials
Interface (company)	Big company with a sustainable approach internally & externally Limit to the EC business model : • good at ecodesign but recycling service not very successful in France • Rental service of carpet did not work in France (regulatory barrier)
Tournevie (association)	Limits: • Use of material resources • Financial
Textifloor (company)	Fulfils a gap in the market (in connection with Interface)
Usitoo (cooperative – test phase)	2 circles Long process of development Financial uncertainties
Billy bike (company, test phase)	Pragmatic business model: very successful Limits : use of unsustainable material (electricity & bike materials)
Cycad (company)	Significant network Few costs
Cirkle (company)	Financial concerns (no profitability since they start in 2011): market competitive & lack of money to invest in marketing

The analysis of these cases resulted in several insights into the factors that stimulate or discourage the adoption of circular business models.

Two important drivers are identified. Firstly, the entrepreneurs and CEO’s are usually driven by a strong conviction and willingness to have a positive impact on society through environmental, social and economic changes. Secondly, guidance to companies and public incentives very useful to start. For example, Cambio has benefited from strong collaboration with public authorities since the beginning. Also, good networks and relationships with banks, public authorities and others are felt to be important.

However, several barriers have also been identified. Firstly, respondents mention a need of adaptation in the regulation for these new business models. Some general barriers are faced by all companies starting their business in Belgium in sensitive areas (e.g. environmental, food): such as, administrative complexity and burden to create the business structure and the challenge to hire employees. Some specific barriers are also mentioned. For example, access to a public space for a private company and changes in traffic regulation are needed for the implementation of Cambio’s business model. As another example, Usitoo and Impulse mentioned to lack of an adapted NACE code or official classification for their business. Secondly, the market seems not yet ready mainly because of behavioural obstacles. Changes in consumers' behavior are necessary. For example, Interface and Textifloor state that consumers are not ready to buy an ecological/ecodesign product that is more expensive than the market price or to use recycling processes more expensive than waste landfilling. A lack of awareness and a lack of demand is felt to slow down the widespread adoption of circular business models. Thirdly, specific financial characteristics of these new business models can be restrictive as they are often misunderstood by banks. A significant initial outlay is needed to generate a continuous stream of 'small' payments. Follow-up of these payments require regular invoicing making service models more burdensome than selling. Finally, the business models without product ownership seems more risky in terms of rebound effects. When companies remain owner, consumers' money savings can be used for other harmful activities. When consumers are owners (e.g. Airbnb, Uber, Deliveroo), users take the risk and they have no incentive to prolong the service life of products or to provide high quality service.

Proposed solutions range from adapting the regulation and procedures, over educating the public on new ways of consuming, to creating a signal price on raw materials. The main impact of these circular business models are felt to be a reduction of material flows in the economy while maximizing service output or user satisfaction. Social, environmental and economic impacts matter.

Business models: stakeholder workshop June 21, 2019

On June 21, 2019, the IECOMAT team organized a stakeholder workshop in Brussels about business models. Results from the game theoretical analysis and case studies were presented by the academic researchers of VITO, KU Leuven and UCL. In addition, two business representatives (Bruno Vermoesen of B/S/H Home Appliances and Mia Van Daele of Quares real estate & Jade Synergies) gave brief presentations about their real world experiences with new business models. The full program of the workshop can be found in appendix. At the end of the stakeholder workshop, a **policy discussion** was held of which the main conclusions are listed below.

What are the financing difficulties for you? Should the government help? Is finance the biggest issue?

> BV: No, financing is not the biggest issue, we're not calling for support from the government. Only financing the devices will cost millions if we scale up this model. Management wouldn't approve… so financing is a problem. But if the management is also convinced of the social and circular benefits, then it would be possible to release the funds from the management.

Is the biggest reward in the cost benefit of a newer installation?

> MVD: There's still a lot of evolution in the technology, it becomes cheaper but we still need to be creative to get the financing. We have to convince the financial institutions of the business case.

> BV: The fact that you created Jade synergies separately already shows that it's too big of a risk.

Banks are also thinking hard on how to service the companies who come to them and how they can alter their risk estimates for the new models. About regulation; it's still very tailor-made for linear models. For example energy flows cannot be shared. The legal bottlenecks seems to be very specific for all of the sectors. Can we fix all of the bottlenecks with one solution or will we need sector-specific actions?

MVD: One thing that definitely needs to change is that responsibilities are currently tied to one company. Sharing responsibilities is currently very difficult. They should definitely make sharing easier.

BV: Lack of organization of European legislation across member states. Transferring a business model from one country to another is thus sometimes simply impossible. F.e.: leasing in the Netherlands is limited to 7 years and therefore we have to limit the washing machine lease to 6 years and we cannot simply replicate the Papillion model to the Netherlands.

Products are standardized but services not at all across member states. Consumer awareness also appears to be a big issue as well. Sometimes they are simple not aware of the issues, sometimes they only care about the financial gains and not at all about the environmental gains. Who should do the awareness building?

BV: That is clearly a task of the regulator, e.g. the European Commission. They should put their blue flag with yellow stars on clothes or other things that are better for the environment. Also, consumers often say what they want to do but they don't always do what they say.

MVD: Awards might also help. But of course, with financial incentives, everything will go faster

BV: We also need to internalize more negative environmental externalities. The externalities should be more visible and better recognizable for consumers that have to choose between suppliers and business models.

5. GENERAL CONCLUSIONS

- The many definitions and conceptualizations of CE hamper perhaps the mainstreaming of it towards actual policy making, but at the same time, they are an indication of the depth and breadth of the concept. The IECOMAT research illustrates that CE is about a whole lot more than closing circles. Complex interactions between, at least, connected markets, rebound effects, environmental impacts, strategic business incentives and consumer attitudes are to be taken into account for a proper understanding of the desirability and incentivisation of a transition towards a more circular economy. The notion of "preserving the value of materials and products" and the notion of "functionality" should be central in CE research according to the IECOMAT research team.
- There exists a multitude of modelling approaches for CE, but none of them currently captures endogenously and comprehensively the shift from a linear to a more circular economy. For the moment, a complementary set of modelling tools best serves the purpose, each of them tailored to specific research and policy questions. The IECOMAT project has contributed substantially to the methodological development and empirical application of different modelling tools for Belgium, but additional investments in methodological and empirical research are definitely needed.
- The Input-Output and Computable General Equilibrium models demonstrates that the CE will have an economy-wide impact. The input-output model results show the importance of taking the very high level of openness of the Belgium economy into account, when designing policies. The application of the CGE to repair of household appliances shows how some sectors will be impacted through direct intersectoral linkages with the circular activities while other sectors will be impacted indirectly. Some sectors may be positively impacted, while other sectors may be negatively impacted. The bottom line remains that these intersectoral linkages are considerable and should be taken into account properly while designing policies in support of the CE in order to limit or prevent unintended consequences. In addition to their impact at the sectoral activity levels, different policy types will also differently impact other macroeconomic parameters (e.g. import dependency, overall welfare & GDP, labour requirements, capital-intensity of production etcetera).
- Modelling the full global value chain, both domestically and abroad, is crucial for a comprehensive modelling of CE transitions in a small open economy like Belgium. The partial equilibrium framework developed under the IECOMAT project shows that environmental externalities in the life cycle of a good should be tackled by policy instruments that target decisions very close to where environmental effects originate. Also, given the interconnection of markets, a combination of policy instruments (for example deposit-refund systems) will be necessary to align all stakeholders' incentives with maximum social welfare including environmental effects while avoiding negative rebound effects and illegal behaviour.
- Regarding the producers' perspective, the IECOMAT project investigated theoretical models of the strategic incentives of companies to engage in more circular business models like sorting and recycling, Peer-to-Peer (P2P) and Pay-per-Use (PPU). The analysis shows that the possible adoption of CE business models is driven by the interplay of different incentives like "market-expansion" (attracting new customers), "surplus-extraction" (charging more to existing customers) and "value" (the owner earning money by sharing his goods) effects. There are win-win situations possible in which firms switch to CE business models because they are more

profitable and at the same time beneficial for the environment. However, this is not always the case so that additional incentives remain necessary to achieve the desired transition.

- IECOMAT's research on business drivers for CE through a series of interviews with businesses revealed that many circular economy start-ups in Belgium are driven by personal conviction and their desire to have a positive impact on society through environmental, social and economic changes. In spite of this positive driver, the interviewees mentioned a strong need for smarter regulation and price signals that internalize the social costs of materials in order to achieve a more level playing field for circular business models.
- Regarding the consumer perspective on CE business models, the IECOMAT research demonstrates that there is a large heterogeneity among consumers in their willingness to switch away from conventional linear and ownership-based consumption models. Legal uncertainty, loss of status effects of ownership, the high perceived total cost of ownership etcetera seem to hold back even young consumer segments from switching towards more circular business models for clothing and smartphones. Only improved repair options (prolonging the life time of products) seem a more established and acceptable CE strategy to consumers for these product types. Overall, more elaborate use of smart monetary incentives will be required to incentivize the transition towards a more circular economy. A better understanding of the perceived consumer barriers can also help innovative companies to develop new, fashionable business models that can seduce consumers into more circular modes of consumption.

6. DISSEMINATION AND VALORISATION

- 2015/09/14, Rousseau, S., participated to business diner on "Circular Economy" organized by the Ambassador of the United States Mission to the European Union Anthony L. Gardner in honor of Ms. Lisa Jackson (Vice President for Environment, Policy and Social Initiatives, Apple and Former Administrator at the U.S. Environmental Protection Agency (EPA) in the presence of Mr. Karmenu Vella EU commissioner for the Environment, Brussels, Belgium (by invitation only)
- 2015/10/11-14, Geerken, T., participated in several Workshops at World Resource Forum, Davos, Switzerland. The overall theme of this year's conference was "Boosting Resource Productivity by adopting the Circular Economy"
- 2015/10/24, Rousseau, S., participated to Expert Workshop on the role of environmental taxes in the circular economy organized by Plan C, 'Steunpunt' TRADO and 'Steunpunt' SuMMa, KU Leuven, Belgium (by invitation only)
- 2015/11/26, Bréchet, T., co-chairman of Commission 3 « Croissance et environnement » of the Congrès des économistes belges de langue française édition 21, Université de Liège, Belgium
- 2015/11/26, Eyckmans, J., Congrès des économistes belges de langue française édition 21, Université de Liège, Belgium : *L'économie circulaire sous l'angle de l'économie environnementale*
- 2016/01/21, Vercalsteren, A., Christis, M., Geerken, T., participated in the Final Conference of the European project DESIRE, Brussels, Belgium
- 2016/01/29, Eyckmans, J., 8th Belgian Environmental Economics Day BEED, Université de Mons, Belgium: *How Far Should EPR Reach? Exports of Used Goods to Developing Countries*
- 2016/02/15-16, Mayeres, I., participated in the Final Conference of the EU PolFree/Dynamix Projects in Brussels, Belgium
- 2016/03/18, Ha, T.H., participated in the 2nd workshop on Industrial Organization in the digital economy, UCL, Louvain-La-Neuve, Belgium
- 2016/04/25, Geerken, T., Boonen, K., participated in an event Industrial Ecology: Science, the Environment and the Circular Economy, organized by ISIE, International Society for Industrial Ecology, Brussels, Belgium
- 2016/06/15, García-Barragán, J.F., participated in the STOA Workshop Waste Management Key player in the transition to a circular economy, European Parliament, Brussels
- 2016/08/22-26, Ha, T.H., participated in the PhD Summer School in Circular Economy of the EIT Raw Materials organized by 4 partners of the EIT KIC Raw Materials: KU Leuven, Ghent University, RWTH Aachen University and University of Liege, Geetbets, Belgium
- 2016/10/9-10, Geerken, T., Dams, Y., participated in the third European Resource Forum, organized by UBA (Umweltbundesambt), Berlin, Germany
- 2016/10/21, García-Barragán, J.F., CEDON seminar, KU Leuven, campus Brussels, Belgium: *Optimal Taxation for a Fully Circular Economy Model*
- 2016/11/02, Ha, T.H., CORE Brown Bag seminar, UCL, Louvain-La-Neuve, Belgium: *Scrap collection for recycling, how good is good?*
- 2016/11/25, García-Barragán, J.F., CEDON seminar, KU Leuven, campus Brussels, Belgium: *Optimal Taxation for an Open Circular Economy*
- 2016/12/02, Ha, T.H., Doctoral Workshop 2016, Université de Namur, Belgium: *Scrap collection for recycling, how good is good?*
- 2016/12/05-06, Ha, T.H., participated in the 6th FAERE Thematic Workshop on Green Innovation, French Association of Environmental and Resource Economists, Paris, France
- 2017/02/2-3, García-Barragán, J.F., 31th Belgian Conference on Operations Research, KU Leuven, campus Brussels: *On the economics of circular economies*
- 2017/02/24, García-Barragán, J.F., 10th Belgian Environmental Economics Day BEED, KU Leuven, campus Brussels: *On the economics of circular economies* (Poster)
- 2017/02/24, García-Barragán, J.F., 10th Belgian Environmental Economics Day BEED, KU Leuven, campus Brussels: *A fully integrated model for a small open circular economy*

- 2017/02/24, Ha, T.H., 10th Belgian Environmental Economics Day BEED, KU Leuven, campus Brussels: *Scrap collection for recycling, how far should we go?*
- Ha, T.H., 10-11/03/2017, Liège, participated in the 3rd Workshop on Industrial Organization in the Digital Economy
- 2017/03/12-03, Ha, T.H., participated in the 2nd Belgian-Japanese Public Finance Workshop, Louvain-la-Neuve, Belgium
- 2017/05/30-2017/06/01, Ha, T.H., ECORES 2017 Summer School, Louvain-la-Neuve, Belgium: *Scrap collection for recycling, how far should we go?* (poster)
- 2017/06/05-16, Ha, T.H., Trento Summer School in Adaptive Economic Dynamic, New Thinking on the firm, Trento, Italy: *Servitization as sustainable business model*
- 2017/06/20-22, Ha, T.H., 24th Ulvön Conference on Environmental Economics, Ulvön, Sweden: *Scrap collection for recycling, how far should we go?*
- 2017/06/25-29, Geerken T. Christis M, Boonen. K., 9th International Conference on Industrial Ecology ISIE2017, Chicago, USA: *Potential for Circular Economy in open economies: Case of Belgium*
- 2017/06/28-2017/07/01, García-Barragán, J.F., Rousseau, S., Eyckmans, J., 23th annual meeting of the European Association of Environmental and Resource Economists EAERE 2017, Athens, Greece, *A fully integrated model for a small open circular economy*
- 2017/07/03-07, Ha, T.H., 2017 EAERE-FEEM-VIU European Summer School in Resource and Environmental Economics, Venice, Italy: *Scrap collection for recycling, how far should we go?*
- 2017/09/07, Ha, T.H., European Doctorate in Economics - Erasmus Mundus EDEEM Jamboree, Bonn, Germany: *Scrap collection for recycling, how far should we go?*
- 2017/09/12, Ha, T.H., 4th Annual Conference of the French Association of Environmental and Resource Economists FAERE, Nancy, France: *Scrap collection for recycling, how far should we go?*
- 2017/09/22, Rousseau, S., International Workshop on Choice Modelling. KU Leuven, Belgium *Towards a Circular Economy: Millennials' Attitudes Concerning Leasing Smartphones*
- 2017/11/30-2017/12/01, García-Barragán, J.F., FSR Climate Annual Conference on the Economic Assessment of European Climate Policies, Florence, Italy: *On the economics of recycling and small open circular economies*
- 2018/01/31, Rousseau, S., 11th Belgian Environmental Economics Day BEED, KU Leuven, campus Brussels: *Towards a Circular Economy: Millennials' Attitudes Concerning Leasing Smartphones*
- 2018/04/10-13, García-Barragán, J.F., XIXth International Conference On Economic And Social Development, Moscow, Russia: *The small open circular economy*.
- 2018/04/18, Huan Ha Thuc, 16th Annual International Industrial Organization Conferences (IIOC) - Hilton Indianapolis Hotel, Indiana, USA: *Scrap collection for recycling, how far should we go?*
- 2018/05/04, Huan Ha Thuc, International conference on environmental economics, a focus on natural resources, University of Orleans, Orleans, France: *Scrap collection for recycling, how far should we go?*
- 2018/05/04, Eyckmans, J., Consumer Protection in a Circular Economy conference, Faculty of Law, KU Leuven, Belgium: *Circular Economy, an economic perspective* (keynote)
- 2018/05/31, García-Barragán, J.F., CORE PhD day, Louvain-la-neuve, Belgium: *The power of the circular economy*.
- 2018/06/3-7, García-Barragán, J.F., Sustainable Resource Use and Economic Dynamics conference SURED 2018, July, 2018. Ascona, Switzerland: *The small open circular economy*.
- 2018/06/07, Huan Ha Thuc, Public Economic Theory conference PET 2018, Hue University, Hue, Vietnam: *Servitization as a sustainable business model, an economic analysis*
- 2018/06/11-12, Huan Ha Thuc, Vietnam Economist Annual Meeting, Foreign Trade University, Hanoi, Vietnam: *Servitization as a sustainable business model, an economic analysis*

- 2018/06/19, Eyckmans, J., Workshop on the Economics of the Circular Economy, Centraal Plan Bureau CPB, Den Haag, the Netherlands: *A Hotelling model for the circular economy including recycling, substitution and waste accumulation* (keynote)
- 2018/06/25-29, García-Barragán, J.F., 6th World Congress of Environmental and Resource Economists WCERE, Gothenburg, Sweden: *The small open circular economy*.
- 2018/08/27, Huan Ha Thuc, European Economic Association – Econometric Society European Meeting EEA-ESEM, Cologne University, Cologne, Germany: *Scraps collection for recycling, how far should we go?*
- 2018/08/31, Huan Ha Thuc, 45th European Association for Research in Industrial Economics meeting EARIE, Athens, Greece: *Scraps collection for recycling, how far should we go?*
- 2018/11/26-27, García-Barragán, J.F., FSR Climate Annual Conference on the Economic Assessment of European Climate Policies, Florence, Italy: *The circular economy, international trade, and the sectoral composition of economies*
- 2019/02/01, García-Barragán, J.F., 12th Belgian Environmental Economics Day BEED, University of Antwerp, Belgium: *The circular economy, international trade, and the sectoral composition of economies*
- 2019/02/01, Huan Ha Thuc, 12th Belgian Environmental Economics Day BEED, University of Antwerp, Belgium: *Servitization as a sustainable business model, an economic analysis*
- 2019/03/26, Eyckmans, J., "IMPAKT van circulaire economie", lecture series organized by Post Universitair Centrum PUC, KULAK, Openbare bibliotheek Kortrijk (public library of the city of Kortrijk), Belgium: *Nieuwe business modellen voor circulaire economie, opportuniteiten en beperkingen* (public lecture)
- 2019/04/23, Eyckmans, J., VOKA Business Club Product-as-a-Service 2019, VOKA, Kortrijk, Belgium: *Nieuwe business modellen voor circulaire economie, opportuniteiten en beperkingen* (lecture on invitation only)
- 2019/05/20, Ha, T.H., Doctoral Workshop 2019, Université Catholique de Louvain, Belgium: *Peer-to-peer Sharing vs. Secondhand Market: Implications on the Manufacturing Firm of Durable Goods*
- 2019/06/18-20, Ha, T.H., 26th Ulvön Conference on Environmental Economics, Ulvön, Sweden: *Peer-to-peer Rental vs. Secondhand Market: Implications on the Manufacturing of Durable Goods*
- 2019/07/7-11, Brusselaers J, Dams Y, Christis M, Geerken T., 10th International Conference on Industrial Ecology ISIE2019, Beijing, China: *Macro-economic modelling of material flows in the circular economy*
- 2019/07/8-11, Ha, T.H., Public Economic Theory 2018 Conference, Strasbourg, France: *Pay-per-use as sustainable business model, a focus on revenue and aggregate usage level*
- 2019/09/05-06, Ha, T.H., the JEL, Madrid, Spain: *Peer-to-peer Rental vs. Secondhand Market: Implications on the Manufacturing of Durable Goods*
- 2019/09/12-13, Ha, T.H., 16th European Network on the Economics of the Firm ENEF workshop, WIFO, Vienna, Austria: *Peer-to-peer Rental vs. Secondhand Market: Implications on the Manufacturing of Durable Goods*

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Boulanger, P.M., and Bréchet, Th. (2015). Croissance et environnement: une présentation des travaux de la Commission 3, in: De Keuleneer et al. (eds), *La croissance: réalités et perspectives*, Congrès des économistes édition 21, Liège, 26 Novembre 2015 (Editions Université Ouverte, Charleroi), 412-426.

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De Jaeger, S. & Eyckmans, J. (2015). From pay-per-bag to pay-per-kg: The case of Flanders revisited, *Waste Management and Research* **33**, 1103 –1111

Dubois, M. & Eyckmans, J. (2015). Efficient waste policies and strategic behavior with open borders. *Environmental and Resource Economics* **62**, 907-923

Eyckmans, J. (2015), L'économie circulaire sous l'angle de l'économie environnementale, in: De Keuleneer et al. (eds), *La croissance: réalités et perspectives*, Congrès des économistes édition 21, Liège, 26 Novembre 2015 (Editions Université Ouverte, Charleroi), 519-532.

Eyckmans, J. (2019), Circular Economy, an Economist's Perspective, in: Keirsbilck, B. and Terryn, E. (eds), *Consumer Protection in a Circular Economy* (Intersentia, Mortsel, Belgium)

Eyckmans, J., García Barragán, J.F. and S. Rousseau (2019). A general model for sorting, recycling and green design (working paper)

García Barragán, J.F., Eyckmans, J. and S. Rousseau (2019). Defining and measuring the circular economy: A mathematical approach. *Ecological Economics* **157**, 369-372

García-Barragán, J.F., (2019), The small open circular economy (working paper)

García-Barragán, J.F., Zelity, B. (2019), Large scale recycling and international trade (working paper)

Geerken, T., Schmidt, J., Boonen, K., Christis, M., Merciai, S. (2019), Assessment of the potential of a circular economy in open economies - Case of Belgium. *Journal of Cleaner Production* **227,** 683-699

Ha, T. H. and Belleflamme, P. (2018). Scraps collection for recycling, how far should we go? (working paper)

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8. ACKNOWLEDGEMENTS

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ANNEXES

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Program Workshop Circular Business Models

IECOMAT workshop on circular economy business models

FRIDAY, June 21 2019, afternoon

Half day workshop on circular economy business models in which IECOMAT results are presented and a dialogue with stakeholders (policy makers, business) is organized.

Program

- **Welcome and sandwiches** [12:45]
- **Introduction** [13:30-13:40]
- ***Business models and circular economy***
  Tom Rommens (VITO) [13:45 – 14:10]
- ***From ownership to access, what opportunities and/or threats for manufacturing firms?***
  Huan Ha Thuc (Université Catholique de Louvain) [14:10 – 14:35]
- ***A T-shirt is a T-shirt – sustainable business models for fashion***
  Raïsa Carmen (KU Leuven) [14:35 – 15:00]
- **Coffee break** [15:00 – 15:20]
- **Business case I**
  Bruno Vermoesen (B/S/H Home Appliances) [15:20 – 15:40]
- **Business case II**
  Mia Van Daele (Quares) [15:40 – 16:00]
- **Round table** on policies for circular business models [16:00 – 16:30]
- **END [16:30]**

Venue: KU Leuven, Faculty of Economics and Business, campus Brussels,
Hermes building, 6th floor, room 6303
(entrance via Warmoesberg 42, 1000 Brussels)

Registration: LINK

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Belgian Research Action through Interdisciplinary Networks

Thematic axis 5: Major societal challenges
Resource-efficient society: Circular economy

KU LEUVEN   vito   UCL Université catholique de Louvain   LOUVAIN School of Management

Program Closing Conference

IECOMAT closing conference

THURSDAY, September 19 2019, afternoon

Half day conference on Integrated Economic Modeling of Material Flows IECOMAT.

Program

- Meeting follow up committee [11:30-12:30] (by invitation only)
- **Welcome and sandwiches** [12:30-13:00]
- **Introduction** [13:00-13:05]
- **Session 1:** System analysis and macro modeling (VITO) [13:05-13:55]
- **Session 2:** Micro economic modeling of product value chain (KU Leuven) [13:55-14:45]
- **Coffee** [14:45-15:15]
- **Session 3:** Micro economic analysis and business cases (UCL) [15:15-16:00]
- **Key note:** The next big thing in the circular economy is the Economy
  Ken Webster (University of Exeter and formerly Ellen MacArthur Foundation)
  [16:00-17:00]
- **Closing discussion** [17:00-17:30]
- **End** [17:30]

Venue: KU Leuven, Faculty of Economics and Business, campus Brussels,
Hermes building, 6th floor, room 6306
(entrance via Warmoesberg 42, 1000 Brussels, follow the signs on the street)

Registration: free but compulsory via this link

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Thematic axis 5: Major societal challenges
Resource-efficient society: Circular economy

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