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Exploring the impact of circular economy on welfare and market power in oligopolistic markets

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HIGHLIGHTS

- We explore the effects of circular economy on social welfare and markup.
- Nonlinear Cournot model with isoelastic demand.
- Three policy regimes: no-policy, waste taxation, and circular economy.
- Welfare under circular economy is larger in more (less) concentrated markets when demand elasticity is low (high).
- Markup is lower under the circular economy regime.

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ABSTRACT

This paper examines the effects of circular economy policies on social welfare and average markup in an oligopolistic market using a Cournot model characterized by isoelastic demand and the production of scrap materials. We evaluate the implications of a circular economy based on recycling, comparing it with scenarios of no policy and waste taxation. Our findings reveal that the circular economy becomes increasingly preferable to waste taxation in concentrated markets with high price elasticity of demand. Furthermore, we observe that the average market power, as measured by the average Lerner index, is lower under a circular economy regime compared to both no policy and waste taxation scenarios. These results suggest that implementing circular economy practices not only enhances social welfare but also diminishes the market power of oligopolistic producers, thereby fostering a more competitive environment. This research contributes to the understanding of how circular economy policies can effectively balance economic growth and environmental sustainability within oligopolistic frameworks, providing valuable insights for policymakers aiming to promote sustainable practices in industry.

1. Introduction

In March 2020, the European Commission launched the Circular Economy Action Plan (CEAP), a key pillar of the European Green Deal designed to drive sustainable growth by shifting the EU towards a circular economy. The CEAP introduces a broad mix of legislative and non-legislative measures aimed at transforming production and consumption through enhanced recycling, reuse, and waste prevention. By focusing on resource-intensive sectors like electronics, plastics, and packaging, the plan seeks to extend the lifecycle of materials, reduce environmental impact, and support the EU's ambitious target of climate neutrality by 2050 while protecting biodiversity (European Commission, 2023).

The industrial sector plays a central role in this transition, with the Green Deal providing both incentives and regulatory frameworks to foster sustainable practices across all value chains, including energy-intensive industries. The EU's industrial strategy emphasizes competition, innovation, open markets, and a streamlined single market, positioning the Union as a facilitator and regulator of this green transformation. These efforts are complemented by coordinated policies on climate, energy, transport, and taxation aimed at cutting greenhouse gas emissions by at least 55% by 2030 relative to 1990 levels.

However, the economic consequences of these policies, particularly their effects on production costs, pricing, firm profitability, and consumer welfare, remain uncertain. Additionally, while recycling is prioritized, alternative approaches such as waste taxation could, in some scenarios, deliver greater social welfare gains. Therefore, evaluating the impact of circular economy policies on social welfare and average markup is essential. Comparing a recycling-focused circular

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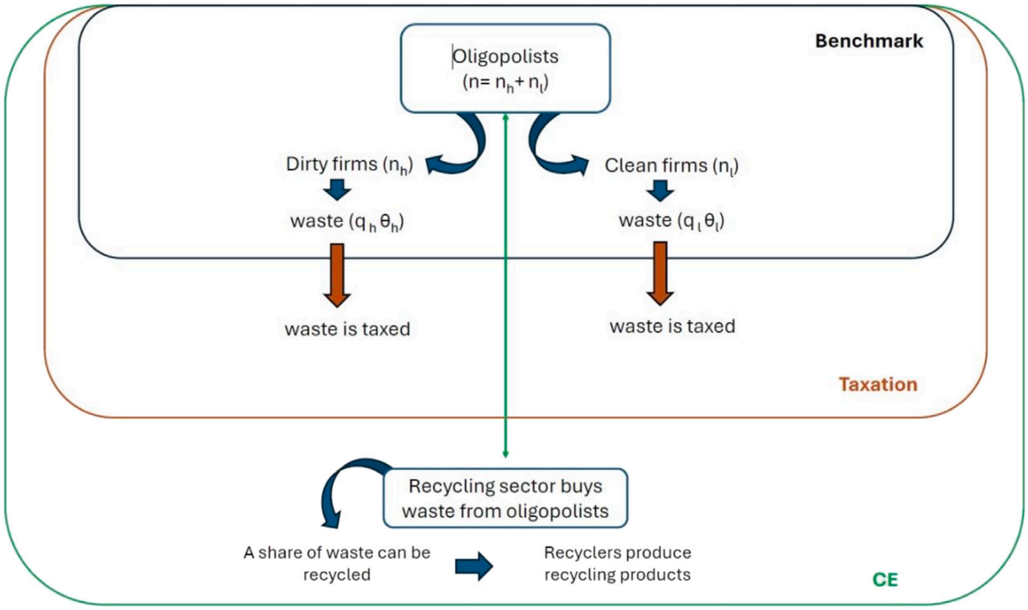


Fig. 1. Graphical representation of the production process of the model under different regimes.

economy with no-policy and waste taxation scenarios offers critical insights into their relative economic and social outcomes, guiding more effective and balanced policy design for sustainable development.

Recent literature has increasingly highlighted the potential economic and environmental costs associated with implementing manufacturing systems grounded in the circular economy, which in some cases may offset or even nullify the anticipated environmental benefits (Jaeger and Upadhyay, 2020; Greer et al., 2021; Geissdoerfer et al., 2017). For example, recycling processes can inadvertently lead to overproduction, escalating energy consumption and production costs, while also introducing complexity and inefficiencies into supply chains (Lieder and Rashid, 2016; Bocken et al., 2016). From an economic perspective, circular economy initiatives may alter firms' market power dynamics; although a reduction in market power can enhance consumer welfare through lower prices and increased competition, it may simultaneously diminish firms' incentives to invest in circular innovations and sustainable production practices (Murray et al., 2017; Hobson and Lynch, 2016). These complex trade-offs underscore the need for nuanced policy design that carefully balances environmental goals with economic and social considerations.

Building on the considerations discussed above, we develop a Cournot oligopoly model with iso-elastic demand to examine social welfare and market power within a circular economy framework. Two key factors will underpin the focus of this analysis: price elasticity of demand and market structure. These elements play a critical role in determining the degree of competition, market concentration, and firms' pricing strategies, thereby significantly influencing the efficacy of environmental policies such as recycling initiatives. In our study, the recycling activity takes place at the end of the production process and involves waste materials that cannot be reused by the firm. However, such waste constitutes raw material for another production sector specialized in recycling and reusing these materials. This ensures the circularity of the production process, as the waste is reintroduced into the production cycle instead of being sent to landfill, as happens in the traditional production model. Fig. 1 provides a graphical representation of the entire production process of the model in the benchmark, taxation, and circular economy regimes.

Fig. 1 clearly shows the difference between a linear production scheme and a circular one. A "linear production model" follows a traditional process where natural resources are extracted, transformed into products, used, and ultimately discarded as waste, without significant recovery or recycling. In contrast, the "circular production model" aims to reduce waste and use resources more efficiently by keeping materials in circulation for as long as possible. Essentially, this model creates a closed system where waste is minimized or reintroduced into the production cycle.

It is worth noticing that we are assuming no direct competition between the recycling sector and the original production sector. Real examples where our hypothesis can be applied include:

- *Food by-products and industrial liquid waste*, where specific waste materials are not directly replaced by new products but are valorized as secondary resources without competing in the main market of original products (Caponio et al., 2022; Poritosh et al., 2023; Correani et al., 2023).
- *The sector of valorization of organic or chemical company waste*, where specific wastes (for example, rice cake production residues, polystyrene scraps, gypsum sludge, used isopropanol) are reused or recycled in a way that does not directly compete with primary production, but rather creates a complementary virtuous cycle. These wastes become resources for other processes or products in other sectors like food, construction and chemical (Laadila et al., 2021; Chavan et al., 2022).
- *Textile recycling from post-industrial waste* where fabric scraps or production offcuts are collected and recycled separately from the production of new textiles, these recycled materials often enter different markets (e.g., insulation materials, stuffing, or lower-grade fibers) rather than directly competing with new fabric production (Ibrahim et al., 2025; Sanchis-Sebastia et al., 2021; Ferreira et al., 2025).
- *Glass cullet recycling for specialty glass products*: glass waste collected from specific industrial processes (like lab glass or certain bottle types) may be recycled into specialty or secondary glass products rather than replacing the production of standard new glass containers, thus operating in a complementary, non-competing market niche (Barbato et al., 2024; Silva et al., 2017; Baek et al., 2025).
- *Electronic waste (e-waste) recycling focused on rare metals*: the recycling of electronic scrap to recover precious metals (gold, palladium, rare earths) occurs largely separately from the manufacturing of new consumer electronics, often carried out by specialized facilities, without market substitution between recycled

materials and virgin raw materials at the product level (Ding et al., 2019; Sanchez Moran et al., 2024).

- *Wood waste recycling into biochar or composite materials*: wood scraps or sawdust from manufacturing can be recycled into biochar, mulch, or wood-plastic composites, industries that usually do not compete with primary timber or lumber production but rather create value-added products in different markets (Olszewski et al., 2023; Leone et al., 2025; Papageorgiou et al., 2021).
- *Industrial chemical waste recovery for niche chemical feedstocks* where certain industrial liquid or solid chemical wastes are processed and purified to re-enter chemical supply chains as specialty feedstocks, which are typically distinct from the chemicals produced anew by primary manufacturers, thus avoiding direct market competition (Dresher and Kienberger, 2022; Kusenberg et al., 2022).

Given ongoing questions about the full effectiveness of a circular economy regime, we evaluate its viability by comparing its outcomes with those of a no-policy scenario and a waste taxation regime. This study therefore addresses three main research questions: (1) Does the circular economy improve social welfare? (2) How does the transition to a circular economy affect firms' market power? (3) Under what economic conditions is a circular economy regime more advantageous than alternative policies such as waste taxation?

While our theoretical model provides a robust framework for understanding the implications of waste taxation and circular economy policies on business waste generation, it is crucial to connect these findings to real-world policy instruments, even if the specific policy designs do not perfectly align with the assumptions of our model. By analyzing existing policies and their observed effects, we can better understand the practical meaning of our theoretical results and identify the nuances of real-world application. The focus of our theoretical model on a direct tax on waste output finds a strong real-world parallel in landfill taxes. This policy is a key instrument used globally to discourage waste disposal and incentivize alternative waste management practices. Landfill taxes are levies imposed on each ton of waste sent to a landfill. By increasing the cost of disposal, they make recycling and other forms of waste diversion more economically attractive for businesses. For example, the United Kingdom's Landfill Tax, introduced in 1996, has been progressively increased over the years. This steady increase has created a powerful financial signal for businesses to reduce their waste and seek out more sustainable solutions. The tax has stimulated the development of a commercial waste management market, where companies compete to offer innovative recycling and waste-handling services to businesses looking to minimize their tax liability (Ipsos and UCLC, 2025).

The other policy regime analyzed in our paper, which is based on circular economy principles, is most closely embodied by the Extended Producer Responsibility (EPR) scheme (Kripalani et al., 2025; Li et al., 2023; Gupt and Sahay, 2015). EPR is recognized as a fundamental waste management policy instrument that supports the implementation of the European waste hierarchy. As a central policy framework within the EU, EPR has significantly contributed to improving the collection and recycling of waste streams containing plastics. Additionally, it is widely acknowledged that EPR plays a vital role in helping to meet both the existing EU waste targets and the more ambitious goals set forth in the EU Circular Economy Package (Filho et al., 2019). These policies shift the financial and/or physical responsibility for a product's end-of-life from municipalities to the producers. EPR policies have spurred producers to redesign their products and packaging to be more resource-efficient. For instance, companies have reduced the weight of packaging or switched to more easily recyclable materials to lower their fees under EPR schemes. The fees collected under EPR programs provide a stable funding source for recycling infrastructure, leading to higher collection and recycling rates for covered materials.

Germany and France provide two notable yet different examples of EPR implementation. Their distinct approaches and historical contexts offer valuable insights into the policy's effectiveness. Germany, a pioneer in this field, launched its "Green Dot" system in 1991. This competitive, market-oriented model established a parallel, private collection and sorting infrastructure. By charging producers fees based on packaging weight and material, the system directly incentivized material reduction and the use of more recyclable materials. This approach has led to some of the highest recycling rates for plastic packaging in Europe and fostered a mature recycling industry. France, while also an early adopter, has followed a more centralized, regulatory path. Initially managed by a single eco-organization, France's system has evolved significantly with recent laws like the 2020 AGEC Act, which expanded EPR to a wider range of products. Producer fees are now increasingly tied to a product's environmental performance, rewarding eco-design and penalizing non-recyclable materials. This framework uses strong regulatory oversight to push for broader circular economy goals, including reuse and repair (Preuss and Garrett, 2025.)

Our simulations indicate that the circular economy generates higher welfare than taxation, especially when market is concentrated and price elasticity of demand is high. A second important finding relates to the effect on average market power, which decreases with the implementation of a circular economy policy.

The remainder of this paper is organized as follows. Section 2 provides a discussion of the related literature emphasizing the main recurring and documented effects of circular economy. The model is developed in Section 3, distinguishing the circular economy case from no policy and waste taxation regimes. Results are presented and discussed in Section 4. Finally, our argument are summarized in Section 5.

2. Literature review

A review of the literature reveals three relevant aspects concerning the effects of the circular economy on production, prices, and market power. These studies enhance our understanding of the potential impact of the circular economy on total welfare, particularly in comparison to alternative policies such as waste taxation. Accordingly, we begin by discussing the literature regarding each of the three key aspects, before extending the discussion to the effects on welfare, an area that has only recently begun to be explored.

Recent studies suggest that embracing of a circular business model may have the potential to ensure that resource consumption (material footprint) and production growth become decoupled, leading to reduced pollution without hindering economic growth (Chi-Ang Lin, 2020). This aligns with the European Commission's perspective that achieving a 30% increase in resource productivity by 2030 could result in nearly a 1% growth in GDP.

For instance, positive impacts of the circular economy on economic growth have been noted in China, though primarily in the long term (Chen et al., 2020). Applying a DID model to a panel of 163 Chinese cities, it appears that the circular economy has a negative impact on GDP growth in the short term, due to its implementation costs; however, the economic downturn gradually improves over time, showing that once the circular economy becomes structured, it begins to positively influence economic activity keeping pollution levels low.

Along this line of research, Vuta et al. (2018) examine how the implementation of circular economy practices, particularly recycling, affects the economic growth of the 28 EU member states from 2005 to 2016. Their findings indicate that recycling initiatives positively influence the real GDP growth rate by enhancing resource productivity. These results are confirmed by Busu and Lenuta Trica (2019) for 27 EU countries, during the time frame 2010 to 2017.

According to the recent analysis of Chen and Pao (2022), a 1% increase in the rate of waste recycling and a 1% increase in circular economy investment are associated with 0.200% and 0.280% increases in GDP, respectively.

While the preceding discussion highlights the potential of the circular economy to achieve decoupling between economic growth and environmental pollution, a substantial body of research presents a more skeptical view, questioning whether such decoupling is truly attainable. Bauwens (2021) points out that a genuinely circular economy may not be compatible with the growth of production, due to its significant implementation costs and the resulting decrease in resource consumption. Moreover, the development of a circular business model has to overcome many barriers that can hinder economic growth, including economic barriers such as uncertain profits, technological barriers due to the necessary conversion of traditional linear system of production, and socio-cultural barriers mainly linked to the rigidity of consumers habits and behaviors Corvellec et al. (2021), De Jesus and Mendonca (2018), Skene (2018). Circular economy may actually lead to increased production and consumption of energy and materials, reinforcing the existing linear production model by generating an overabundance of waste materials (Schultz et al., 2024; Ferrante et al., 2024). In this case, the recycling industry acts as a new business sector that can encourage many companies to increase production in order to have more waste material to sell as raw material; this necessarily leads to an increase in both energy consumption and emissions. This phenomenon has been referred to as the "Waste-Resource Paradox". Proponents of this view contend that the proliferation of waste, even if some of it is recycled or repurposed, could still result in significant social and environmental harm (Greer et al., 2021). In a similar vein, the idea of the *circular economy rebound* (Zink and Geyer, 2017) suggests that recycling waste materials could result in a substantial increase in supply due to higher demand driven by the recycling industry, which may ultimately undermine any environmental benefits achieved.

Another relevant aspect that emerges from the literature is the reduction of the market price when a circular economy system is implemented. There are at least two general mechanisms by which a circular economy based on recycling waste material can lead to market price reduction. The first has to do with the activity of recycling sector. The production of secondary goods and materials from recycling can have a negative impact on prices, both because it is, generally, of lower quality and therefore sold at lower prices and because it increases the aggregate supply of goods and materials with the consequent price reduction even for better quality but substitutable goods and materials (Zinck and Geyer, 2017). It is important to note that this result holds under specific assumptions, such as the presence of a competitive market structure where multiple firms offer varying quality levels; a heterogeneous consumer base with differing preferences and willingness to pay; some degree of substitutability between low- and high-quality products; increasing production costs with improving quality that justify price differentiation; and consumer sensitivity to price relative to quality as well as variations in income distribution influencing purchasing behavior across quality segments.

The second has to do with the effect of recycling on the marginal costs of primary production. Recycling of waste materials allows companies to reduce costs either through increased revenues from their sale or through reuse in production processes. Recent empirical evidence of this is provided for the Italian tanning industry by Dainelli et al. (2024). Waste hides, salt and water used in processing are reused in the production process with clear benefits in terms of lower production costs. Depending on the circular economy innovation adopted, cost savings range from 23% to 54% confirming how circular economy can increase firms' competitiveness and make them more resilient to price fluctuations. Similarly, significant cost reductions stemming from the adoption of circular economy practices are observed in the large textile industry (da Silva et al., 2021), cement industry (Strazza et al., 2011) and the sector of refinery (Cabello-Eras et al., 2013). In general, cost reductions makes firms more competitive allowing to reduce the price of primary goods and increase demand. However we cannot exclude the opposite effect of an increase of final prices of products as a result of the increased environmental quality (Zeng et al., 2010) or product quality (Correani et al., 2023). In our model, price reductions occurs because the circular economy maintains product quality while enabling companies to sell some of their waste materials, resulting in lower production costs.

Finally, a third important aspect concerns the market power of firms involved in the implementation of the circular economy. Many authors have focused on the erosion of market power due to recycling (Martin, 1982; Zhou and Smulders, 2021; Hoogmartens et al., 2018). According to this literature, recycling can negatively impact firms' markups because of competition in the market for recycled goods and materials. Consequently, firms tend to adopt specific strategies to mitigate this phenomenon, such as limiting the substitutability between virgin and recycled materials (Suslow, 1986) or reducing the supply of scrap material to the recycling sector. This second strategy has been highlighted by several authors, including Grant (1999) and Ba (2022), in relation to the well-known Alcoa case from 1945, as well as by Ba and Soubeyran (2023) regarding the general case of exhaustible resource supply, and more recently by Watkins (2024) in the context of the U.S. paper industry. Along this line of research, Gaudet and Van Long (2003) propose a model featuring a single firm producing a primary good alongside a recycling sector comprised of N symmetric Cournot oligopolists. They demonstrate that the market power of the primary producer diminishes as the delay between primary production and recycling increases. The intuitive explanation is that this time delay reduces competitive pressure from the recycling sector, prompting the producer to increase its current production and lower prices. Paradoxically, while recycling increases the profits of the primary producer, its Lerner index declines.

Selling scrap materials provides firms with an additional revenue stream. The income generated from these sales can help reduce production costs, which in turn lowers the marginal costs associated with manufacturing (Correani et al., 2023; Normal, 2019). When this effect is universally applied to all producers, as illustrated in our model, we may observe a decrease in prices and market power, accompanied by increased profits due to a rise in demand.

The aforementioned aspects allow us to compare the alternative policy of taxing waste in order to evaluate the differing effects on welfare. Recent research has suggested that imposing taxes on waste materials can be viewed as an effective strategy for fostering the development of a circular economy (Conrad, 1999; Milios, 2021; Freire-Gonzales et al., 2022; Chenavaz and Dimitrov, 2024). In this context, taxation exerts a negative impact on production, leading to increased prices and reduced demand. Although it facilitates pollution reduction, it may adversely affect welfare through declines in both consumer surplus and profits (Correani et al., 2023). Consequently, taxing waste can stimulate the development of a production system that values recycling and reuse by offsetting the higher costs associated with taxation through revenue generated from the sale of waste materials. Positive effects of recycling on consumer surplus and welfare are highlighted in a recent study by Johari and Hosseini-Motlagh (2019), who propose a Stackelberg–Cournot model to examine the coordination of a sustainable closed-loop supply chain. In a similar vein, Ba and Mahenc (2019) develop a two-period model in which an exhaustible resource produced by an extractor can be recycled by a competing firm. They demonstrate that maximizing social welfare is associated with higher recycling activity. More recently, Belleflamme and Ha (2024) analyze the strategic interaction (Cournot competition) between two competing firms using primary and recycled materials as their inputs. They observe that consumer surplus increases with recycling activity, whereas social welfare rises only at sufficiently high recycling rates.

In line with these findings, we should expect the circular economy to enhance social welfare more than taxation. However, despite its potential to improve social welfare, the transition to a circular economy is often hindered by significant financial and economic obstacles that must be carefully addressed.

The implementation costs of circular economy systems pose significant challenges, particularly due to high upfront investments and market inefficiencies. Gafström and Aasma (2021) emphasize that economic barriers, such as the elevated costs of recycled materials compared to virgin resources and the substantial initial capital requirements for CE infrastructure, can impede adoption. These financial hurdles are compounded by weak economic incentives and a lack of tools to quantify long-term benefits, as noted in studies of European and Spanish SMEs (Ting et al., 2023). For instance, Kirchherr et al. (2018) found that 40% of EU firms view high investment costs as a critical barrier, while Ormazabal et al. (2018) highlight how Spanish SMEs struggle with limited access to financing for CE transitions.

The viability of CE projects is further threatened by market dynamics. Zink and Geyer (2016) argue that "green" products often fail to account for rebound effects, where efficiency gains lead to increased consumption, offsetting environmental benefits. This paradox underscores the need for systemic economic restructuring rather than isolated product-level changes. Furthermore, the higher production costs of circular materials-up to 30% more expensive in some sectors-reduce competitiveness against linear alternatives unless supported by policy interventions like carbon pricing or subsidies (Rao et al., 2025).

While long-term analyses, such as a 30-year cost–benefit study of CE projects, show positive net present values through resource efficiency and emission reductions, short-term financial risks deter private-sector adoption (Gigli et al., 2019). Successful implementation therefore requires coordinated fiscal policies-including tax rebates, CE-specific funding programs, and penalties for linear practices-to align economic incentives with sustainability goals. Without such measures, the upfront cost burden risks stalling CE transitions despite their long-term environmental and economic potential.

Our model builds upon and integrates the existing literature discussed above by proposing an analysis inspired by the works of Cerqueti et al. (2023) and Correani et al. (2025). These studies respectively introduce a dynamic and a static Cournot oligopoly framework to compare various environmental policies. Following their conceptual foundation, we adopt a similar Cournot oligopoly approach to juxtapose the circular economy with waste taxation. Our contribution extends the current theoretical literature in four key directions:

1. The predominant studies are based on the premise that primary producers, whether monopolists or oligopolists, engage in direct competition with recyclers (see Belleflamme and Ha, 2024; Gaudet and Van Long, 2003). In contrast, our approach to the circular economy encompasses scenarios in which a producer generates waste materials that serve as inputs for entirely different sectors, thereby mitigating the competitive dynamics between producers and recyclers. Examples of this framework are provided by Correani et al. (2023) who explore a circular economy model applied to food waste, and by Greer et al. (2021) who provide real life examples of such non-competitive behavior between manufacturers and recyclers.
2. We assume that producers have identical marginal production costs, despite their heterogeneity regarding the quantity of waste material generated and sold to the recycling sector. This assumption has been introduced by Cerqueti et al. (2023) within a different theoretical context that compares environmental taxes with cap-and-trade policies.
   The choice of symmetric marginal costs in our model is motivated primarily by the need to enable a clear and direct comparison between alternative policy scenarios without interference from exogenous differences in technology or production costs. Notably, both waste tax and recycling policies examined in the paper introduce asymmetry in firms' marginal costs, but in an endogenous manner: under the waste tax regime, marginal costs increase proportionally with the amount of waste produced, whereas under recycling, marginal costs decrease as the share of recyclables sold increases. Thus, any resulting asymmetry in marginal costs across firms is generated "ex post" by the waste management policy itself, rather than being imposed "ex ante" due to inherent differences in technology or production processes. Nonetheless, we recognize the importance of exploring the implications of initial cost asymmetries. Therefore, we have added an Appendix section extending the model to allow for higher marginal costs for less polluting (clean) firms prior to the implementation of waste management policies. While this extension introduces analytical challenges that somewhat affect the model's tractability, the qualitative results remain robust and are not significantly altered compared to the baseline with symmetric marginal costs.
3. We examine the economic impact of the circular economy in comparison to waste taxation, according to different levels of price elasticity of demand. This is a significant aspect that, to the best of our knowledge, has not yet been explored in the literature. For instance, our analysis demonstrates that the effects of the circular economy on welfare can vary dramatically as the responsiveness of demand to price changes. Although in both scenarios the firms compete in the Cournot sense, meaning they simultaneously decide the quantities to produce in order to maximize their profits, some substantial differences emerge. In the circular economy scenario, firms not only sell their main product but also recover part of their production waste by selling it as reusable or secondary materials. This mechanism provides an additional revenue opportunity and encourages more efficient resource management and reduced environmental impact. Recycling lowers the amount of waste to be disposed of, potentially affecting costs and production decisions. In contrast, in the scenario with waste taxation, firms do not recycle. The waste they produce is taxed and sent to landfill. The tax represents an additional cost firms must bear for each unit of waste produced, thus increasing total production costs. This scenario reflects a linear resource management approach, with negative incentives for waste production but no material recovery.
4. Our model treats the restrictions imposed by authorities on permissible pollution levels as binding constraints. Consequently, through equilibrium mechanisms, the aggregate output of oligopolistic firms yields the same volume of non-recycled waste materials, regardless of the policy implemented. What differs is the distribution of pollution among various types of firms. This approach allows us to account for both the current severity of environmental policies enforced by the EU and to emphasize the key economic components of welfare, specifically profits and consumer surplus, which, in contrast to aggregate pollution levels, vary depending on the policy adopted.

3. The model

In this section we describe the model setup, distinguishing the case with no environmental policy (benchmark model) from the cases where a policy is implemented. Following Fanti et al. (2015) and Askar–Alnowibet (2016) we consider a Cournot oligopoly with isoelastic demand function and assume a homogeneous product market with a population of $n = n_l + n_h$ firms, where n_h and n_l are respectively the number of dirty and clean firms. Each firm i of type $s \in \{h, l\}$ sets a quantity $q_{i,s}$ according to the demand function

$$p = \left[\sum_{i=1}^{n_h} q_{i,h} + \sum_{j=1}^{n_l} q_{j,l} \right]^{-1/\eta}, \qquad (1)$$

where $\eta > 1$ denotes the constant price elasticity of demand.

The isoelastic demand function is widely used in the literature due to its analytical tractability and the ability to study the effects produced by changes in consumers' price sensitivity, making it easier to study firms' pricing and output (Askar and Alnowibet, 2016;

Fanti et al., 2015). It is a useful approximation for all sectors where consumers would not have a clearly defined reservation price. This is particularly evident in the luxury goods sectors, which spans many different industries such as woodworking, glass, textiles, and metals. Moreover, products like cigarettes or other addictive goods often have a strongly isoelastic and inelastic demand. Habitual consumers are not very sensitive to price changes, meaning a percentage change in price leads to a much smaller percentage change in the quantity demanded. This behavior is persistent, making the price elasticity of demand relatively constant over a wide range of prices. A similar reasoning is applicable to markets of goods with high brand loyalty and those with high entry barriers (i.e. chemical industry) where companies may have some market power and be able to influence prices without causing large changes in the quantity demanded.

We will make the simplifying assumption that firms are ex ante symmetric in the sense that they have the same constant marginal cost $c \geq 0$. However, firms show differences in pollution they generate by producing the homogeneous product. The assumption of constant marginal costs corresponds to a linearly homogeneous production function, meaning that input usage scales proportionally with output, keeping marginal costs fixed regardless of production scale. Under these conditions, we recognize that any barriers to market entry cannot be explained by natural economic factors such as increasing returns to scale or fixed costs embedded in production. Consequently, such entry barriers must be understood as politically imposed constraints, which may be justified (for example, in sectors like health) or result from rent-seeking behaviors intended to shield incumbent firms from competition.

We assume that every unit of output $q_{i,s}$, generates θ_l units of pollution if output is produced by a clean process, and θ_h units of pollution if output is produced by a dirty process. Obviously, $\theta_h > \theta_l$. Then, the total amount of pollution is

$$Poll = \sum_{i=1}^{n_h} q_{i,h}\theta_h + \sum_{j=1}^{n_l} q_{j,l}\theta_l. \quad (2)$$

Pollution is characterized as waste that, under a conventional environmental taxation regime, would typically be disposed of in landfills. Conversely, within a circular economy framework, this waste can be repurposed as a productive input for a burgeoning recycling sector, thereby generating revenue streams for the firm responsible for its generation.

In dealing with different policy regimes, we set a target emission level corresponding to a share α of the emissions $Poll_B$ that would occur under a no-policy scenario (Benchmark model). Both the recycling regime and the waste taxation policy achieve this target via endogenous determination of key parameters: a tax rate in the case of waste taxation and the recycling rate along with the price of recycled waste in the circular economy scenario. Consequently, despite differences in production technology that may characterize the two scenarios, the level of emissions—and thus their impact on welfare—is the same under both policies. This approach aligns with recent studies (Cerqueti et al.; Correani and Morganti, 2025) and reflects the constraints imposed by current European environmental regulations, which primarily focus on achieving strict waste reduction targets rather than immediate welfare optimization. By imposing a common emission constraint across both regimes, the analysis can focus on the efficiency of the two policies in achieving the same environmental target. For instance, under a waste taxation regime, brown firms tend to reduce their production to lower their tax burden. In contrast, under a circular economy system, these firms increase production to maximize revenues from the sale of recycled waste. Therefore, even with identical final pollution levels, the higher production under the circular economy regime leads to lower prices and greater consumer surplus. This, in turn, results in a more pronounced increase in overall welfare compared to the taxation regime. Removing this assumption would lead to different pollution levels under the two policy regimes (likely higher in the circular economy due to the rebound effect) with varying welfare impacts; however, it would provide no information on the optimal tax rates or recycling rates needed to achieve the waste reduction targets set by authorities, which our model endogenously determines and which drive the automatic adjustment of firms' strategies towards environmental goals.

The following sections elaborates on the four different versions of the model. First, it analyzes the scenario without environmental policy (Section 3.1). Then, it differentiates two versions of the model based on the specific environmental policies considered: environmental tax (Section 3.2), and circular economy (Section 3.3). For each model we compute equilibrium quantities and prices, firms' profit, consumer surplus and total welfare.

3.1. Benchmark model

As a benchmark, we are considering a scenario where firms do not adhere to any emissions constraint. Consequently, the regulator does not impose any additional costs (such as emissions taxes) on firms to achieve a specific policy target. This implies that without environmental policies the model boils down to a standard nonlinear Cournot oligopoly in which all firms have to maximize the following profit function with respect to $q_{i,s}$

$$\pi_{k,s} = \left[\left(\sum_{i=1}^{n_h} q_{i,h} + \sum_{j=1}^{n_l} q_{j,l}\right)^{-\frac{1}{\eta}} - c\right] q_{k,s}, \qquad s \in \{h, l\}. \quad (3)$$

Profits maximization by both type of firms yields the following implicit reaction function where $Q = \sum_{i=1}^{n_h} q_{i,h} + \sum_{i=1}^{n_l} q_{i,l}$

$$\frac{\partial \pi_{i,h}}{\partial q_{i,h}} = 0 \Longleftrightarrow Q^{-\frac{1}{\eta}} - \frac{q_{i,h}}{\eta} Q^{-\frac{1+\eta}{\eta}} - c = 0, \quad (4)$$

$$\frac{\partial \pi_{j,l}}{\partial q_{j,l}} = 0 \Longleftrightarrow Q^{-\frac{1}{\eta}} - \frac{q_{i,l}}{\eta} Q^{-\frac{1+\eta}{\eta}} - c = 0. \quad (5)$$

Assuming symmetry among firms of the same type, i.e. $q_{ih} = q_h$ and $q_{jl} = q_l$ for any i and j, we obtain the equilibrium quantities

$$q_h^* = q_l^* = q_B^* = \frac{Q_B^*}{n_h + n_l}, \quad (6)$$

where the subscript B means *benchmark model* and $Q_B^* = \left[\frac{\eta(n_h+n_l)-1}{\eta c(n_h+n_l)}\right]^{\eta}$ is the aggregate quantity. The adoption of different abatement technologies does not affect the strategic choices of the firms, leading them to produce the same amount of output. Then, the equilibrium price and profits are $p_B^* = (Q_B^*)^{-\frac{1}{\eta}}$ and $\pi_B^* = \left(p_B^* - c\right) q_B^*$ whereas consumer surplus is

$CS_B^* = \int_0^{Q_B^*} Q^{-1/\eta} dQ - p_B Q_B = \frac{1}{\eta-1}(Q_B^*)^{\frac{\eta-1}{\eta}}$ which is positive for $\eta > 1$. Finally, we derive the specification of social welfare by adding firms' profit to consumer surplus and subtracting pollution ($Poll_B = (\theta_h n_h + \theta_l n_l) q_B^*$), which is a negative externality (see Belleflamme and Peitz, 2010, p. 25; Belleflamme and Ha, 2024)

$$W_B^* = CS_B^* + (n_h + n_l)\pi_B^* - Poll_B = Q_B\left(\frac{\eta Q_B^{-1/\eta}}{\eta - 1} - \frac{n_h\left(c + \theta_h\right) + n_l\left(c + \theta_l\right)}{n_h + n_l}\right). \quad (7)$$

The welfare concept we use is common in industrial economics and measures consumer welfare as the difference between the amount consumers are willing to pay and the actual price they pay, which corresponds to the area between the demand curve and the price level. Producer surplus, reflected by profits, is then added to this consumer surplus. This basic welfare measure is adjusted by adding positive externalities, such as increased tax revenues from waste taxation, or subtracting negative externalities, like pollution, created by the economic agents involved in the decision-making process.

$$W_T^* = CS_T^* + n_h\pi_{T,h}^* + n_l\pi_{T,l}^* - (1-\tau)\alpha Poll_B =$$
$$Q_T\left(\frac{\eta Q_T^{-1/\eta}}{\eta-1} - \frac{n_h\left(c^2+\tau\left(2\theta_h\left(c+\eta\tau\theta_l n_l\right)+\theta_h^2\left(\tau-\eta\tau n_l\right)-\eta\tau\theta_l^2 n_l\right)\right)+n_l\left(c+\tau\theta_l\right)^2}{n_h\left(c+\tau\theta_h\right)+n_l\left(c+\tau\theta_l\right)}\right)+$$
$$\frac{\alpha(\tau-1)Q_B\left(\theta_h n_h+\theta_l n_l\right)}{n_h+n_l}, \tag{14}$$

Box I.

3.2. Taxation

The introduction of environmental taxation alters the firms' profit maximization process by adding the cost of pollution which depends on the amount of output produced. More precisely, firms are subject to an additional cost, levied by authorities, which is dependent on the quantity of waste generated during the production process. More efficient firms (those with a lower θ) will incur a smaller cost, thereby gaining a competitive advantage that enables them to increase output for a given price. The simplest way to incorporate this into the model is to introduce a tax proportional to the waste produced, which reduces the firm's profits. Formally, the profit function for firm k of type s becomes

$$\pi_{k,s} = \left[\left(\sum_{i=1}^{n_h} q_{i,h} + \sum_{j=1}^{n_l} q_{j,l}\right)^{-\frac{1}{\eta}} - c\right] q_{k,s} - \tau\theta_s q_{k,s}, \qquad s \in \{h,l\}. \tag{8}$$

where τ is the amount of tax that each firm pays for a unit of pollution.

From the first-order condition of profit maximization we obtain the final output produced, respectively, by dirty $(q_{T,h})$ and clean $(q_{T,l})$ single firm (the subscript T means taxation):

$$q_{T,h}^* = Q_T\frac{\eta n_l\tau\left(\theta_l-\theta_h\right)+c+\tau\theta_h}{n_h\left(c+\tau\theta_h\right)+n_l\left(c+\tau\theta_l\right)} \tag{9}$$

$$q_{T,l}^* = Q_T\frac{\eta n_h\tau\left(\theta_h-\theta_l\right)+c+\tau\theta_l}{n_h\left(c+\tau\theta_h\right)+n_l\left(c+\tau\theta_l\right)}, \tag{10}$$

where the aggregate quantity is $Q_T = \left(\frac{\eta(n_h+n_l)-1}{\eta\left(n_h\left(c+\tau\theta_h\right)+n_l\left(c+\tau\theta_l\right)\right)}\right)^{\eta}$. To meet the policy target $Poll = \alpha q_B^*(\theta_h n_h + \theta_l n_l)$, government has to set a τ such that

$$\alpha q_B^*(\theta_h n_h + \theta_l n_l) = n_h\theta_h q_{T,h}^* + n_l\theta_l q_{T,l}^*. \tag{11}$$

The equilibrium profits for both type of firms are respectively given by

$$\pi_{T,h}^* = \frac{Q_T\left(c+\tau\theta_h+\eta\tau n_l\left(\theta_l-\theta_h\right)\right)\left(-c-\tau\theta_h+Q_T^{-1/\eta}\right)}{n_h\left(c+\tau\theta_h\right)+n_l\left(c+\tau\theta_l\right)}, \tag{12}$$

and

$$\pi_{T,l}^* = \frac{Q_T\left(c+\eta\tau n_h\left(\theta_h-\theta_l\right)+\tau\theta_l\right)\left(-c-\tau\theta_l+Q_T^{-1/\eta}\right)}{n_h\left(c+\tau\theta_h\right)+n_l\left(c+\tau\theta_l\right)}. \tag{13}$$

Finally, total welfare is (see equation given as in Box I.) where $CS_T^* = \frac{1}{\eta-1}(Q_T^*)^{\frac{\eta-1}{\eta}}$ and the term $\tau\alpha Poll_B$ represents the positive effect of revenues from taxation.

3.3. Circular economy

To implement a circular economy, a new industry must be established that utilizes the waste products of other companies as raw materials for its own operations. Oligopolistic firms can sell their waste to the recycling sector at price $\hat{p}$. However, only a share $0 < \delta < 1$ of waste can be recycled, whereas the remaining part flows into the landfill and represents the pollution produced by companies. As the value of the parameter δ approaches 1, an increasing proportion of waste can be reused, which indicates a higher efficiency of the recycling sector. In contrast to a taxation scheme, a recycling system offers firms an additional source of revenue. This revenue is proportional to the quantity of waste recycled and is valued at $\hat{p}\delta\theta q_i$. Formally, this increased income reduces marginal costs, potentially encouraging firms to expand their output and thus creating a rebound effect. Thus, profit of firm k of type s is

$$\pi_{k,s} = \left[\left(\sum_{i=1}^{n_h} q_{i,h} + \sum_{j=1}^{n_l} q_{j,l}\right)^{-\frac{1}{\eta}} - c\right] q_{k,s} + \hat{p}(\delta\theta_s q_{k,s}), \qquad s \in \{h,l\} \tag{15}$$

where the last term in (15) represents the revenue resulting from the sale of production waste.

Regarding the recycling sector we keep the analysis as simple as possible, and assume the following production function $Y = (R)^{\beta}$ where Y denotes the new output generated through the utilization of recycled waste R, derived from the production activities of oligopolistic companies, and $0 < \beta < 1$ is the elasticity of output respect to the input. Denoting the market price of R by $\hat{p}$, we can write the profit of recycling sector as $\pi_R = (R)^{\beta} - \hat{p}R$ from which we derive the demand of recycled waste $R = (\beta/\hat{p})^{1/1-\beta}$. Without loss of generality we assume that the price of output Y is equal to 1.

Note that oligopolists and recycler do not compete with each other; rather, recycler serve a different market using waste as input. Numerous examples of this kind of circular business model are documented and discussed in the literature. Among the others, Greer et al. (2021) report the interesting cases of *QMilk*, a recycler producing textile products using surplus milk generated by the dairy industry, and *Spaak* which extract limonene, pectine and citrus oil from orange peels produced by the industry of food and restoration.

Maximizing profits (15) with respect to $q_{k,s}$ we obtain the equilibrium quantities (CE means "circular economy")

$$q_{CE,h}^* = Q_{CE}\frac{\eta n_l\hat{p}\delta(\theta_h-\theta_l)+c-\hat{p}\theta_h\delta}{n_h(c-\hat{p}\theta_h\delta)+n_l(c-\hat{p}\theta_l\delta)}, \tag{16}$$

$$q_{CE,l}^* = Q_{CE}\frac{\eta n_h\hat{p}\delta(\theta_l-\theta_h)+c-\hat{p}\theta_l\delta}{n_h(c-\hat{p}\theta_h\delta)+n_l(c-\hat{p}\theta_l\delta)}, \tag{17}$$

where $Q_{CE} = \left(\frac{\eta(n_h+n_l)-1}{\eta\left[(c-\hat{p}\theta_h\delta)n_h+(c-\hat{p}\theta_l\delta)n_l\right]}\right)^{\eta}$ is the aggregate quantity.

The efficiency δ of recycling sector and the market price $\hat{p}$ of reusable waste can be derived solving the following system of equations, representing the constraints of this industry

$$(1-\delta)(\theta_h q_{CE,h}^* n_h + \theta_l q_{CE,l}^* n_l) = \alpha(\theta_h n_h + \theta_l n_l)q_B^*, \tag{18}$$

$$\delta(\theta_h q_{CE,h}^* n_h + \theta_l q_{CE,l}^* n_l) = \left(\frac{\beta}{\hat{p}}\right)^{\frac{1}{1-\beta}}. \tag{19}$$

Expression (18) is the environmental constraint, that guarantees the equality between pollution produced by firms in a regime of circular economy with efficiency δ and the target to be reach, whereas (19) represents the equilibrium between supply and demand of reusable waste which gives the market clearing price $\hat{p}$.

$$\begin{aligned} W^*_{CE} =& CS^*_{CE} + \pi^*_{CE,h} n_h + \pi^*_{CE,l} n_l - \alpha Poll_B + \pi_R = \\ & - p\left(\frac{\beta}{\hat{p}}\right)^{\frac{1}{1-\beta}} + \left(\frac{\beta}{\hat{p}}\right)^{\frac{\beta}{1-\beta}} - \frac{\alpha Q_B\left(\theta_h n_h + \theta_l n_l\right)}{n_h + n_l} + \\ & Q_{\mathrm{CE}}\left(\frac{\eta Q_{\mathrm{CE}}^{-1/\eta}}{\eta - 1} - \frac{n_h\left(c^2 - \delta\hat{p}\left(2\theta_h\left(c - \delta\eta\hat{p}\theta_l n_l\right) + \delta\hat{p}\theta_h^2\left(\eta n_l - 1\right) + \delta\eta\hat{p}\theta_l^2 n_l\right)\right) + n_l\left(c - \delta\hat{p}\theta_l\right)^2}{n_h\left(c - \delta\hat{p}\theta_h\right) + n_l\left(c - \delta\hat{p}\theta_l\right)}\right). \end{aligned} \tag{22}$$

Box II.

The equilibrium profits are given by

$$\pi^*_{CE,h} = \frac{Q_{\mathrm{CE}}\left(-c + Q_{\mathrm{CE}}^{-1/\eta} + \delta\hat{p}\theta_h\right)\left(c + \delta\hat{p}\left(\theta_h\left(\eta n_l - 1\right) - \eta\theta_l n_l\right)\right)}{n_h\left(c - \delta\hat{p}\theta_h\right) + n_l\left(c - \delta\hat{p}\theta_l\right)}, \tag{20}$$

$$\pi^*_{CE,l} = \frac{Q_{\mathrm{CE}}\left(-c + Q_{\mathrm{CE}}^{-1/\eta} + \delta\hat{p}\theta_l\right)\left(c - \delta\hat{p}\left(\eta n_h\left(\theta_h - \theta_l\right) + \theta_l\right)\right)}{n_h\left(c - \delta\hat{p}\theta_h\right) + n_l\left(c - \delta\hat{p}\theta_l\right)}, \tag{21}$$

whereas consumer surplus is $CS^*_{CE} = \frac{1}{\eta-1}\left(Q^*_{CE}\right)^{\frac{\eta-1}{\eta}}$. Total welfare is (see equation given as in Box II.) Note that the implementation of a circular business model involves costs related to technology, infrastructure, employee training, institutional barriers, energy consumption and cultural acceptation. These initial costs can be substantial, especially for small and medium-sized enterprises, often acting as barriers to widespread adoption (Marek and Krejza, 2023). A major component of these costs relates to product and process redesign. Companies must invest in sustainable design that enables products to be repaired, reused, or recycled, often requiring higher-quality or specialized materials and new supply chains. Additionally, systems for collecting, sorting, and processing end-of-life products add operational and logistical expenses. Scarcity of high-quality recycled materials and the need to build local recycling capacity further increase initial costs, complicating the transition for less-resourced organizations. To fully assess the financial impact, life cycle cost models (C-LCC) have been developed to evaluate both costs and benefits of circularity. These models show that although upfront investments are higher, cumulative savings from reduced material, waste, and energy costs can outweigh initial expenditures, especially when circular principles are integrated from the design phase. For example, in construction, circular economy practices have led to measurable cost reductions and improved resource efficiency over infrastructure lifespans. However, realizing these benefits is not automatic. The transition period may involve higher operational costs and market barriers, such as limited markets for secondary materials and uncertainties about product quality and supply. Policy interventions, financial incentives, and industry collaboration are often necessary to support organizations during early phases and accelerate the shift.

At the moment, expression (22) does not explicitly include these exogenous costs, which instead will be considered and discussed in the next section to analyze the welfare gap between circular economy and waste taxation.

4. Results

The primary objective of our research is to evaluate the comparative efficacy of the circular economy approach versus a more traditional environmental policies based on taxing waste. This inquiry can be approached from both a social and private perspective. From a social perspective, we aim to investigate the impact of these environmental policies on social welfare. This involves analyzing the distributional effects of these policies on the overall well-being of society, including the potential benefits and drawbacks for firms and consumers. From a private perspective, we will examine the effects on the market power of companies involved.

Table 1
Parameters and variables.

Parameters	Value	Description
η	> 1	price elasticity of demand
α	0.45	abatement parameter
c	0.5	firm's marginal cost
θ_h	1	waste per unit of output - dirty firm
θ_l	0,9	waste per unit of output - clean firm
β	0.5	output elasticity in recycling sector
n	≥ 2	total number of firms: $n_h + n_l$
n_h	≥ 1	number of dirty firms
n_l	≥ 1	number of clean firms
Variables		**Description**
q_{ik}		output of firm i of type $k \in (h, l)$
Q		aggregate quantity
p		market price
τ		tax per unit of pollution
$\hat{p}$		price of reusable waste
δ		share of recyclable waste
CS		consumer Surplus
π_{ik}		profit of firm i of type $k \in (h, l)$
W		total welfare

The analysis is conducted through numerical simulations based on standard parametrization reported in Table 1, in accordance with the existing literature on oligopoly modeling and environmental policy.

In the context of oligopolistic markets, we are examining firms that produce a homogeneous good. The distinguishing feature among these firms lies in the intensity of pollution they generate. However, this difference cannot be too pronounced, as it would lead to horizontal product differentiation and varying marginal production costs (i.e. $c_h \neq c_l$ instead of c for both types of firms). To account for these considerations, we set the parameters θ_l and θ_h equal to 0.9 and 1 respectively.

In line with the EU's target of reducing pollution and waste at least 55% by 2030, we set the parameter α equal to 0.45 (European Parliament, 2021).

We adopt the value of marginal cost $c = 0,5$ as specified by Fanti et al. (2015). The price elasticity of demand coefficient, denoted as η, is a crucial parameter in the model. We investigate various situations by varying the value of η from 1.1, which represents an inelastic demand, up to 6, which indicates a highly elastic demand (we move η around the value of 2 adopted in Fanti et al. (2015)). Additionally, we assume an output elasticity (β) in the recycling sector of 0.5. Given that $0 < \beta < 1$, we are assuming that the recycling sector is characterized by decreasing returns to scale. This assumption finds confirmation in recent studies for both Italy (Abrate et al., 2014) and Japan (Chifari et al., 2017). For Italy, empirical analyses of local recycling systems have observed decreasing returns to scale, particularly at lower output levels, indicating that as recycling inputs increase, the output grows less than proportionally. Similarly, in the Japanese context, while recycling technologies and policies have advanced, the sector overall still faces limits to value creation and sectoral expansion, consistent with decreasing returns to scale. Based on this evidence, in our model we adopt a central value $\beta = 0.5$, and in the final part of this section, we consider variations around this value to assess their impact on the model results.

4.1. Output and price

As Greer et al. (2021) pointed out, a circular economy may induce an increase of production because of the new demand of recyclable materials, but it is not clear whether this phenomenon generate more or less pollution. Our model supports the prediction of increased output in a circular economy context. However, as a result of adjustments in the price of reusable materials, $\hat{p}$, and share δ, the final level of pollution (measured by the amount of non-recycled material) decreases in accordance with the policy target indicated by α (see equilibrium conditions (18) and (19)).

Result 1. Circular Economy is characterized by higher output and lower market price:

$$Q_T^* < Q_B^* < Q_{CE}^* \quad \textit{and} \quad p_{CE}^* < p_B^* < p_T^*. \tag{23}$$

In a circular economy framework, oligopolistic firms benefit from additional revenue generated by selling reusable materials; this generate the same effect of a marginal cost reduction inducing firms to increase production and reduce market price. The opposite effect is obtained by taxing waste; marginal cost increases due to the additional cost represented by the tax rate τ.

4.2. Welfare

In recent studies, it has been highlighted that the adoption of a circular economy model can be costly due to technological, cultural, market, and institutional barriers that may hinder its successful implementation (Gafstrom and Aasma, 2021; Kirchherr et al., 2018; Ormazabal et al., 2018). Moreover, pollution stemming from the recycling sector may offset its reduction in oligopolistic sector, thus nullifying the environmental benefits of a circular economy system (Zink and Geyer, 2016). At this regard, Greer et al. (2021) provide examples of existing circular economy models implying increasing pollution dues to overproduction, higher energy consumption and hazard for human health. All these factors are not explicitly considered by the model but may dramatically affect the total welfare in a circular economy regime. We can indirectly take into account of these factors by denoting the implementation costs with C_{CE} and affirm that

Statement 1: *Let us define $\Delta W_T = W_{CE}^* - W_T^*$ then, a circular economy regime provides a higher social welfare than waste taxation if*

$$\Delta W_T \geq C_{CE}. \tag{24}$$

The welfare gap delineates the threshold beyond which a circular economy approach loses its comparative advantage in terms of cost-effectiveness relative to conventional environmental policy tools. This condition has to be tested for different levels of price elasticity of demand and market structures (number of firms and their distribution).

Figs. 2(a) and 2(b) illustrate the welfare gap between different policy regimes as the number of firms increases from a duopoly to an oligopoly with 10 firms; we assume that $n_h = n_l$. This assumption will be removed in a second step, as reported in Fig. 3.

The results show that welfare under a circular economy is always higher than welfare under taxation: $W_{CE} - W_T > 0$. The main argument is that waste taxation introduces market distortions by increasing the prices faced by consumers and reducing aggregate quantity. Consequently, consumer surplus and aggregate profits will be lower respect to a circular economy regime. However, this negative effects on welfare are mitigated when demand is inelastic, which in turn explains the low welfare gap $W_{CE} - W_T$. The gap narrows further when considering the positive effects of competition following an increase in the number of companies (Fig. 2(a)).

Market distortion of waste taxation are more relevant when demand is elastic. In this case, W_{CE} is much larger than W_T and the positive effects of competition are not strong enough to significantly reduce the gap. (Fig. 2(b)). Figs. 2(a) and 2(b) also provide insights into the welfare effects of waste taxation compared to a no-policy regime. The black line in the figure shows that waste taxation is always welfare-improving compared to the no-policy case, regardless of the price elasticity of demand. The benefits of waste taxation grow as the degree of competition between companies increases. This is because as the number of firms in the market increases, the goal of reducing waste can be achieved with gradually decreasing levels of taxation.

Similar results are reported in Fig. 3 where we measure the welfare gap $\triangle W_T$ for different distributions of clean and dirty firms. The matrix plots in Fig. 3 illustrate the relationship between welfare gap ($\triangle W_T$), market structure (number of firms), and price elasticity of demand. A circular economy becomes increasingly preferable to taxation as the market structure approaches a duopoly (yellow box in the bottom left-hand corner of both matrix plot). This suggests that circular economy can generate higher welfare gains compared to taxation in less competitive markets. Welfare gap tends to be higher when price elasticity of demand increases The contrast between the two matrix-plots highlights the importance of considering both market structure and price elasticity of demand when evaluating the welfare implications of circular economy policies relative to taxation (see Fig. 3).

These considerations lead us to the second result of the model.

Result 2. For a given implementation cost C_{CE}, a circular economy is increasingly preferable to taxation (welfare gap $\triangle W_T$ increases) in more concentrated markets and as price elasticity of demand increases.

For instance, suppose that the cost of implementation is $C_{CE} = 4$; according to simulations reported in Fig. 2(a), we have $\triangle W_T > C_{CE}$ only in oligopolies characterized by high price elasticity of demand. In the other cases, taxation will be preferable to circular economy.

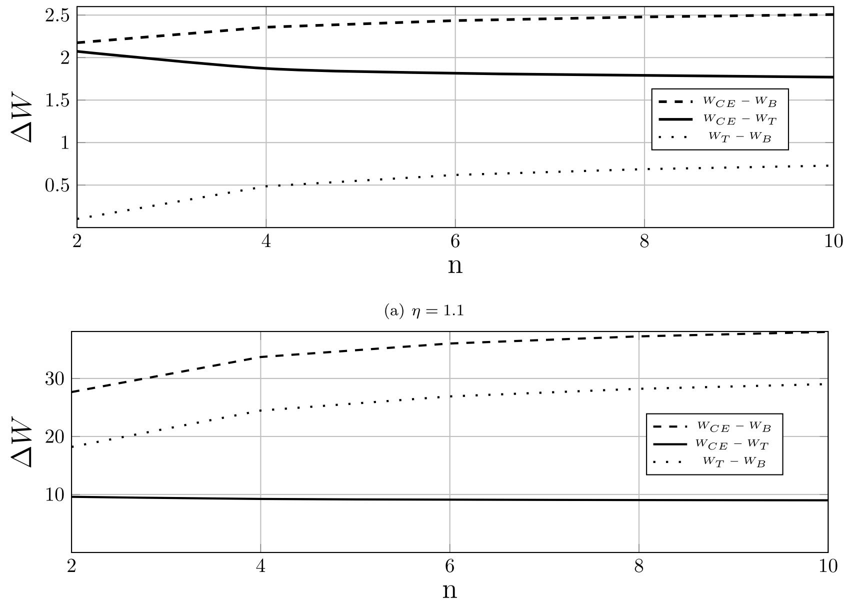
Even when accounting for the costs of recycling, the results still hold true. However, there is a notable difference — total welfare is lower compared to a scenario where recycling has no associated costs. To illustrate this point further let us assume that the recycling sector incurs a cost c_r for each unit of production that is recycled. This cost can be expressed as a proportion of the share of production which is recycled, as shown in the following formula:

$$c_r = \gamma \delta^2 \qquad \gamma > 0. \tag{25}$$

Increasing recycling costs reduces both demand R and price $\hat{p}$ of waste material inducing oligopolistic firms, mainly the more polluting, to reduce their production. Market price P_{CE} will be higher with negative impact on consumer surplus and social welfare. In Table 2 is reported the price of waste material and the welfare gap for an increasing recycling costs and different market structure; we study the case with low price elasticity of demand, $\eta = 1,1$. As explained, for a given number of firms, both price and welfare gap decrease as recycling becomes more costly, making circular economy less attractive respect to waste taxation. The parameter γ is chosen so as to ensure a positive equilibrium price $\hat{p}$. In fact, as gamma increases, the demand for reusable materials, $R = \left(\frac{\beta}{\hat{p}+\delta\gamma}\right)^{1/(1-\beta)}$ decreases (shifting to the left) and the equilibrium price $\hat{p}$ could become negative.

For higher γ a positive equilibrium price requires greater elasticity β

Moreover, making production of the recycling sector more elastic (increasing β) leads to higher demand of reusable waste, contrasting the market failure generated by a negative price.



(a) $\eta = 1.1$

(b) $\eta = 6$

Fig. 2. Welfare gap for increasing number of firms ($n = n_h + n_l$ with $n_h = n_l$) and different levels of price elasticity of demand η.

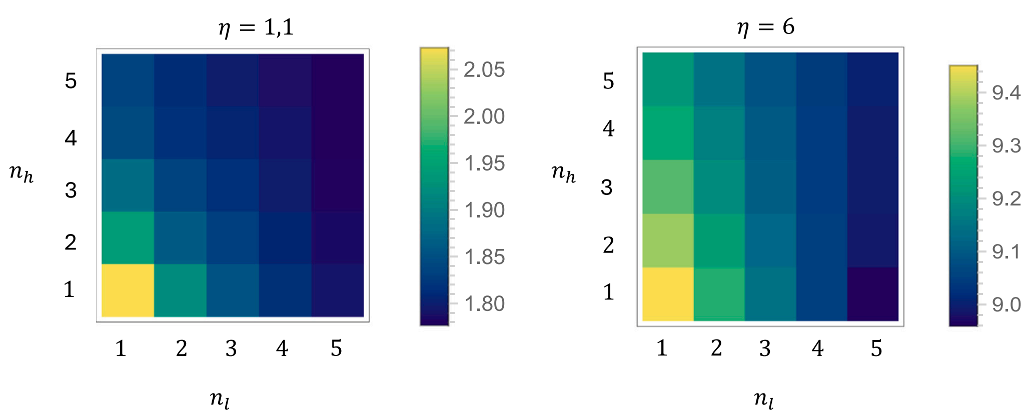


Fig. 3. Welfare gap $\triangle W_T$ for different distributions of firms: $1 \le n_h \le 5$ and $1 \le n_l \le 5$.

Table 2
$\triangle W_T$, $\hat{p}$, $\eta = 1, 1$.

γ	$n = 2$		$n = 4$		$n = 6$		$n = 8$		$n = 10$	
	$\hat{p}$	$\triangle W_T$	$\hat{p}$	$\triangle W_T$	$\hat{p}$	$\triangle W_T$	$\hat{p}$	$\triangle W_T$	$\hat{p}$	$\triangle W_T$
0	0.34	2.07	0.31	1.87	0.3	1.81	0.29	1.79	0.29	1.77
0.1	0.31	1.85	0.28	1.67	0.27	1.62	0.26	1.60	0.26	1.58
0.5	0.22	1.4	0.19	1.26	0.17	1.22	0.17	1.20	0.17	1.18
1	0.14	1.13	0.1	1.02	0.09	0.98	0.08	0.96	0.08	0.94

4.3. Markup

The implementation of waste management policies can have a direct influence on the marginal costs and pricing decisions of the companies involved in the waste management industry. This, in turn, can lead to significant variations in the market power of the sector, depending on the specific policy instruments employed. Following Belleflamme and Peitz (2010), we measure the average market power of the oligopolistic firms by the average Lerner index

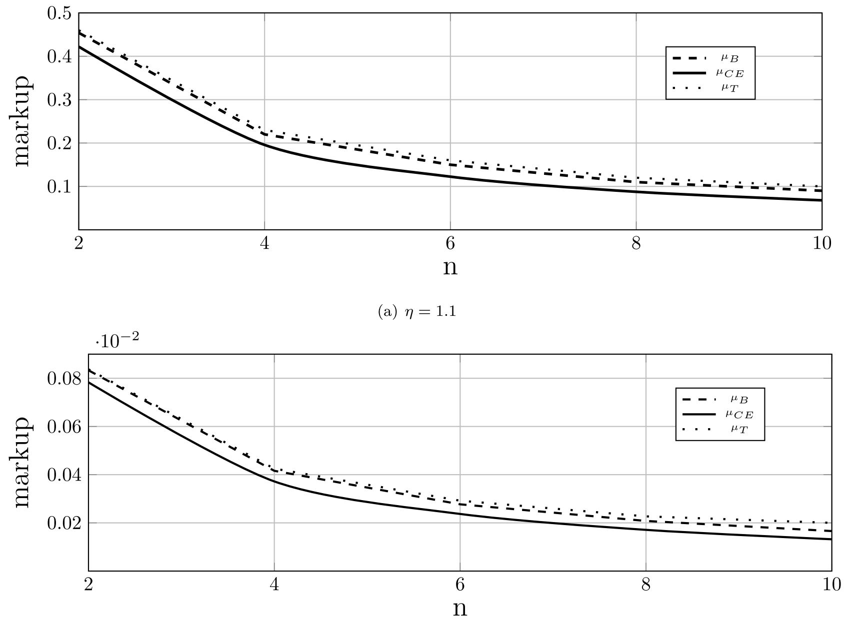
$$\mu = \frac{p - \sum_{i=1}^{n_h} \alpha_i MC_{i,h} - \sum_{j=1}^{n_l} \alpha_j MC_{j,l}}{p} \tag{26}$$

where p is the market price, α_i is firm $i's$ market share and $MC_{i,k}$ the marginal cost of firm i of type $k \in \{h, l\}$. Under a circular economy regime, the average markup becomes

$$\mu_{CE} = \frac{p^*_{CE} - n_h(c - \hat{p}\theta_h\delta)\frac{q^*_{CE,h}}{n_h q^*_{CE,h} + n_l q^*_{CE,l}} - n_l(c - \hat{p}\theta_l\delta)\frac{q^*_{CE,l}}{n_h q^*_{CE,h} + n_l q^*_{CE,l}}}{p^*_{CE}}; \tag{27}$$

whereas, with taxation, we have

$$\mu_T = \frac{p^*_T - n_h(c + \tau\theta_h)\frac{q^*_{T,h}}{n_h q^*_{T,h} + n_l q^*_{T,l}} - n_l\left(c + \tau\theta_l\right)\frac{q^*_{T,l}}{n_h q^*_{T,h} + n_l q^*_{T,l}}}{p^*_T}. \tag{28}$$



(a) $\eta = 1.1$

(b) $\eta = 6$

Fig. 4. Markup in different policy regimes and for increasing number of firms; $n_h = n_l$.

Table 3
Rate of recycling δ for different number of firms and price elasticity of demand.

η	$n = 2$	$n = 4$	$n = 6$	$n = 8$	$n = 10$
$\eta = 1.1$	0.810	0.788	0.780	0.773	0.770
$\eta = 6$	0.768	0.752	0.747	0.745	0.743

Table 4
Rate of recycling δ for different number of firms, price elasticity of demand and β.

		$n = 2$	$n = 4$	$n = 6$	$n = 8$	$n = 10$
$\eta = 1.1$	$\beta = 0.1$	0.620	0.607	0.602	0.600	0.593
	$\beta = 0.7$	0.917	0.893	0.892	0.890	0.881
$\eta = 6$	$\beta = 0.1$	0.573	0.565	0.563	0.562	0.561
	$\beta = 0.7$	0.768	0.752	0.747	0.745	0.743

Note that in the case of perfect symmetry among firms, i.e. $\theta_h = \theta_l$, we have $\mu_{CE} = \mu_T = H/\eta$ where H denotes the Herfindahl index and there is no markup difference between the two policy.

Fig. 4 reports average markup for increasing number of firms and different levels of price elasticity of demand.

As expected, average markup (and thus market power) decreases as the number of firms increases. This is a well-established economic principle, as greater competition among a larger number of firms leads to lower markups. Interestingly, circular economy regime yields lower markup with both more and less elastic demand and regardless of the number of oligopolists. This indicates that the circular economy framework is effective in reducing market power and promoting more competitive pricing, even in concentrated market structures. The reason is that a circular economy system reduces the marginal costs of oligopolistic firms while taxation increases them. Consequently, under a waste taxation regime, price level will be higher and aggregate quantity lower than in a circular economy, with positive effect on average markup. This explains the negative impact on consumer surplus when a waste taxation system is implemented, as the higher markups and prices associated with the taxation regime come at the expense of consumer well-being.

Result 3. The average markup under a circular economy regime is lower than under a waste taxation regime

In Section 5, we provide empirical evidence supporting this result for Italy. We highlight how the average markup in certain industrial sectors involved in recycling activities (glass, wood, chemical and textile) is higher in regions of central and southern Italy, where circular economy systems are less developed, and waste management primarily relies on taxation.

4.4. Recycling rate analysis

This section examines how well the recycling rate produced by the model aligns with existing empirical data, offering insights into the model's practical applicability. The values of the percentage of waste recycled by firms vary significantly depending on the sector, geographic area, and type of waste treated. Based on the parametrization chosen for our model, a recycling rate value emerges that ranges between 74% and 81%, as shown in Table 3. These values are consistent with recent data on the Italian industry, where the share of industrial waste actually recycled hovers around 70%–75%, with variations depending on material type and sector. More specifically, for the industrial packaging sector, a recycling rate of approximately 75.2% is forecast for 2025, with growing volumes of recycled materials and specific recycling percentages by category: over 85% for paper and cardboard, over 80% for steel, 70% for aluminum, and over 81% for glass (Ispra, 2025; Sustainable Development Foundation, 2024; Correani and Morganti, 2025).

However, at the European level, the recycling rate varies greatly from one country to another, depending on sector, geographic area and type of waste treated, ranging from values above 80% in Italy and Belgium to levels around 10% in Romania and Finland (Correani and Morganti, 2025). Our model allows for taking these differences into account through recalibrations of the main parameters, such as the elasticity of output in the recycling sector, β. This parameter measures the ability of the sector specialized in recycling to transform waste into finished products and therefore depends on various key factors such as technology, operational and managerial processes, and local system characteristics. Table 4 reports the rate of recycling for different

Table 5
Welfare gap $W_{CE} - W_T$ for different number of firms, price elasticity of demand and β.

		$n = 2$	$n = 4$	$n = 6$	$n = 8$	$n = 10$
$\eta = 1.1$	$\beta = 0.1$	1.526	1.389	1.343	1.320	1.305
	$\beta = 0.7$	3.070	2.845	2.803	2.800	2.810
$\eta = 6$	$\beta = 0.1$	3.060	2.858	2.745	2.676	2.628
	$\beta = 0.7$	33.876	34.111	34.286	34.518	34.780

Table 6
Markup gap $\mu_{CE} - \mu_T$ for different number of firms, price elasticity of demand and β.

		$n = 2$	$n = 4$	$n = 6$	$n = 8$	$n = 10$
$\eta = 1.1$	$\beta = 0.1$	−0.005	−0.006	−0.008	−0.009	−0.011
	$\beta = 0.7$	−0.080	−0.064	−0.043	−0.021	−0.001
$\eta = 6$	$\beta = 0.1$	−0.0010	−0.0012	−0.0016	0.0021	−0.0025
	$\beta = 0.7$	−0.013	−0.010	−0.008	−0.006	−0.003

values of β and price elasticity of demand. As expected, a high β results in increased recycling rates. To complete the analysis we provide simulations for welfare gap (Table 5) and markup gap (Table 6) for different values of β. Table 5 confirms that circular economy increases welfare respect to taxation, especially with high price elasticity of demand. However, we also observe that higher β is associated to a larger welfare gap as competition increases. Our simulations reveal that the circular economy delivers higher social welfare than waste taxation in concentrated markets when price elasticity of demand is low, highlighting the potential for CE policies to boost economic resilience and competitiveness in oligopolistic sectors—a key objective emphasized in the EU's Clean Industrial Deal and the upcoming Circular Economy Act (WBCSD, 2020; European Parliament, 2024). Conversely, recycling is more advantageous in competitive markets only when price elasticity of demand and β are high, suggesting that market structure, technological efficiency of recycling sector and consumer responsiveness critically shape policy effectiveness. A notable example in this field is Germany's Extended Producer Responsibility system for household packaging. This approach operates within a competitive market where consumers are highly aware and responsive. The demand for recycled materials is encouraged by regulations that set minimum recycled content requirements and by deposit-return schemes, which increase consumer sensitivity towards recycled products. This competitive environment, combined with elastic demand and advanced recycling technologies, has made recycling both economically viable and efficient.

Table 6 reports the markup gap between the circular economy and taxation regimes across different levels of β. The main finding – that market power is reduced under the circular economy scenario – is confirmed. We observe that the gap tends to widen with higher values of β since the price $\tilde{\beta}$ of recycled waste increases as β rises. This incentivizes oligopolists to produce more (aggregate production Q_{Ce} increases), which consequently leads to a reduction in the price p_{CE} and, therefore, a decrease in their market power. Clearly, based on the logic of the Lerner index, this effect becomes more pronounced as consumers become more price-sensitive.

5. Empirical evidence

This section aims to provide real-data validation of the results derived from our theoretical model. However, this empirical validation should be regarded as exploratory, intended to offer preliminary evidence and hypotheses for further investigation through more rigorous and focused research. A more in-depth investigation exceeds the scope of this article and will be addressed in future studies. Our simulations conducted in the theoretical model indicate that an increase in recycling activity is correlated with a rise in overall production. This prediction is supported by real data observed across the 27 EU countries. Fig. 5 plots the average values for real GDP per capita and the Circular Material Use Rate (CMUR) for the period 2010–2023. The CMUR is an indicator measuring the share of recycled materials reintegrated into the economy, with higher values denoting a reduction of the dependence on the extraction of primary raw materials. The data, sourced from Eurostat, highlight a positive correlation between higher rates of circular material use and greater levels of real GDP per capita in EU countries. The underlying hypothesis is that countries with low recycling rates – and therefore with limited implementation of circular economy principles and methods – tend to focus more heavily on waste taxation policies. While such policies can incentivize waste management and reduction, they may also reflect a lower effectiveness or willingness to adopt circular material approaches, potentially limiting production growth through sustainable channels (see Figs. 5 and 6).

Regarding welfare, our theoretical model predicts that welfare tends to increase with the implementation of a circular economy system. The transition towards circularity, by promoting sustainable resource use and recycling, is expected to generate positive welfare effects through environmental benefits and enhanced economic efficiency. However, measuring welfare is inherently complex because it requires extensive microeconomic data, including detailed information on prices and quantities produced across different sectors. Such granular data are often not readily available or consistent, making direct welfare measurement challenging. Due to these difficulties, welfare is frequently assessed using composite indices that integrate multiple dimensions of wellbeing. For example, certain composite welfare indices discussed in the literature aim to capture broader quality of life aspects beyond pure economic metrics (e.g., Adler, 2019). In this regard, we employ the Life Satisfaction indicator, provided by Eurostat, as a proxy for welfare, ranging from 0 (completely dissatisfied) to 10 (completely satisfied). Life satisfaction is a widely recognized subjective well-being measure that reflects individuals' overall evaluation of their quality of life. We note that, although firms' profits are not directly reflected in this indicator, it is reasonable to assume that higher profits lead to greater life satisfaction, as they typically result in higher remuneration for employees and employers. The data for the 27 EU countries show a clear positive correlation between higher levels of life satisfaction and elevated recycling rates. This relationship confirms the model's prediction that circular economy practices, through their environmental and economic impacts, are associated with increased welfare.

Regarding the effects on markups, we choose to focus the empirical analysis on recycling in Italy due to the country's distinctive position as one of Europe's most virtuous cases in the development of a recycling system inspired by the principles of the circular economy. Italy stands out within the European context not only for achieving high recycling rates but also for its ability to integrate innovation, policy frameworks, and public participation in fostering a sustainable waste management infrastructure (Correani and Morganti, 2025). By examining the Italian experience, we seek to provide empirical evidence confirming the main outcomes of the model, namely the negative impact of the circular economy on firms' markup. It is important to highlight that despite Italy being one of the most virtuous examples of circular economy development in Europe, the implementation of a fully developed circular system is still incomplete. Significant disparities remain between the northern regions, which are more organized and efficient in recycling activities, and the central and southern regions, where recycling infrastructures and operational capacity are less developed. This discrepancy is confirmed in Table 7, which reports recent data on the number of recycling plants and their treatment capacity by geographic area, underlying the pronounced gap between the North and the rest of Italy:

Moreover, in regions where circular economy systems exhibit greater development and sophistication (i.e. Lombardia, Veneto, Piemonte, Emilia Romagna), local governments implement substantial

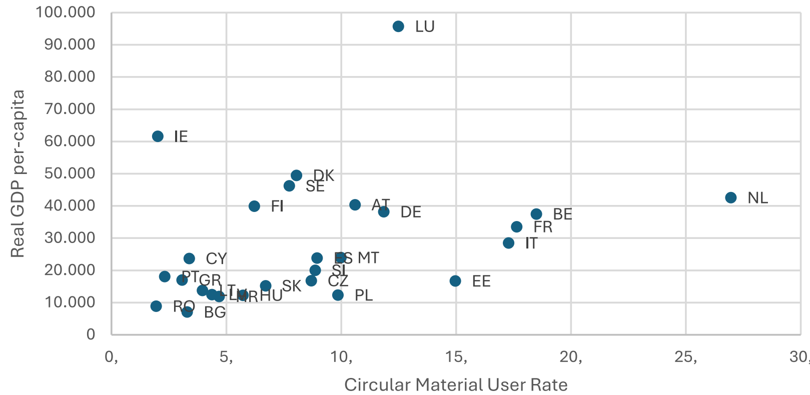


Fig. 5. Real GDP per-capita and Circular Material User Rate.
Source: Eurostat, 2010–2023.

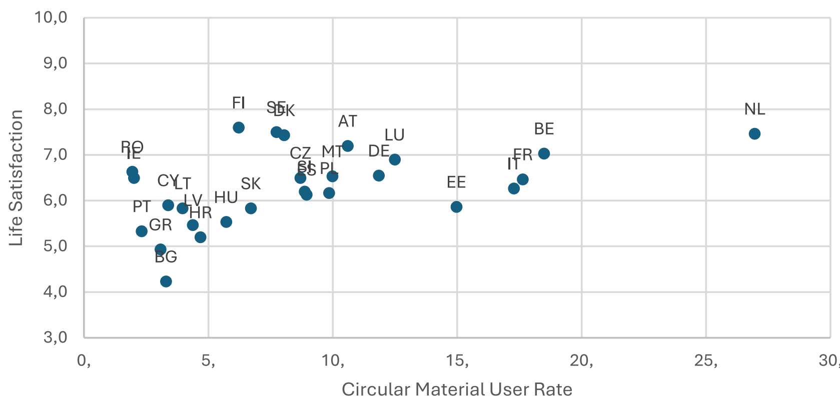


Fig. 6. Life satisfaction and Circular Material User Rate.
Source: Eurostat, 2010–2023.

Table 7
Number of plants grouped by type and geographic area in Italy (2023).
Source: Ispra (2025).

	Material recovery plants	Material recovery plants at production facilities	Storage facilities
North	2576	773	967
Center	693	228	273
South	1281	222	414

reductions in waste-related taxes (TARI) for enterprises demonstrating high recovery and recycling capacities. This policy approach effectively facilitates a progressive transition from conventional waste taxation frameworks to models incentivizing recycling outcomes. Following the evidence presented and according to the predictions of our theoretical model, we should observe that firms located in Northern Italy and operating within sectors engaged in circular economy systems exhibit, on average, lower markups compared to similar firms situated in the Central and Southern regions. This difference is expected to reflect the more advanced development and integration of circular practices in the North, which likely enhances operational efficiencies and competitive dynamics, thereby exerting downward pressure on firms' pricing power. According to the Sustainable Development Foundation (2024), some of the most important sectors involved in recycling activities include glass, wood, chemical, and textile. A distinctive characteristic of these sectors is that the industrial waste generated during their production processes is often sold to other companies as raw materials. Importantly, these purchasing firms do not compete with the original producers, enabling a symbiotic relationship that supports material recovery and reuse within the circular economy framework. Table 8 presents the average markup of firms engaged in the recycling process, differentiated by sectors and geographical areas. The data have been extracted from the Aida Bureau Van Dijk database and cover a ten-year period from 2015 to 2024. We consider medium to large-sized enterprises (with more than 50 employees), as they exhibit characteristics more consistent with an oligopolistic industrial structure. The markup is calculated following the method proposed by (Griffith et al., 2010), defined as the ratio between value added and production costs. The results align with the model's predictions, indicating a lower average markup for firms in the North, which are more involved in a circular economy system, compared to firms located in the central and southern regions.

6. Limitations and research prospects

Our model exhibits certain limitations that also shape directions for future research.

Primarily, the static nature of the framework limits the analysis to a single-period perspective, precluding an examination of dynamic

Table 8
Average markup distinguished by material type and geographic area in Italy (2015–2024).
Source: Our elaboration on Aida data.

	Glass	Wood	Chemical	Textile
North	31%	27, 3%	21, 5%	28, 5%
Center	34, 2%	32, 8%	27, 7%	30, 3%
South	34, 6%	27%	26, 7%	37, 3%

strategic adjustments by firms over time. Incorporating a dynamic setting, potentially through differential games as in Cerqueti et al. (2023), could provide richer insights into firms' evolving responses to environmental policies. Although this type of framework (differential game) allows for the study of the behavioral evolution of firms across different scenarios, it entails several technical challenges related both to the increased complexity of the mathematical structure and to the time inconsistency of equilibrium strategies, which can be avoided only by imposing strong assumptions on the objective functions and the dynamic constraint (see Cerqueti et al., 2023). Additionally, while our current focus is on a Cournot oligopoly structure, extending the analysis to alternative market forms – such as sequential-move oligopolies à la Stackelberg (Feng et al., 2024; Wang et al., 2019), price competition à la Bertrand (Matsui, 2023), or markets characterized by product differentiation à la Hotelling (Ba and Soubeyran, 2023) - would enhance the generalizability and depth of the findings. In highly competitive markets, a Bertrand oligopoly—where firms engage in strategic price-setting—may be more appropriate, potentially leading to substantial price reductions under a circular economy regime, thereby intensifying competition and significantly enhancing overall welfare. A sequential Cournot framework (à la Stackelberg) is more applicable in markets dominated by one or more leading firms, typically characterized by a first-mover advantage manifested in higher output levels relative to followers. However, the implementation of a circular economy system could invert this advantage if recycling activities enable follower firms to achieve greater marginal cost reductions than leaders. Additionally, modeling the market as a Hotelling oligopoly allows for the incorporation of both vertical and horizontal product differentiation. Within this framework, firms may strategically position their circular products to appeal to distinct consumer segments with heterogeneous preferences for sustainability and quality. Such product differentiation can result in price dispersion and diminished direct price competition, reflecting the market power derived from product positioning. The net effect on welfare remains ambiguous, as gains from improved product quality and sustainability may be offset by welfare losses arising from enhanced market power.

Secondly, the assumption that the difference in marginal costs between the two types of firms is sufficiently small is a plausible assumption for an oligopolistic industry with homogeneous products as represented in our framework (see the Appendix). However, this assumption presents an opportunity for further refinement of the analysis, particularly by extending it to oligopolistic industries with heterogeneous production costs. Such heterogeneity may arise from factors like vertical differentiation (varying product quality offered to consumers) or technological gaps in production and recycling processes. Incorporating the recycling sector within this extended framework could help reduce the market power that often intensifies with greater product and technological differentiation.

Thirdly, the model assumes that the price elasticity of demand is always greater than 1, which is a necessary condition to ensure that consumer surplus is well-defined. A possible extension of the model could involve using a different demand function, such as a linear form $p = a - b(n_h q_h + n_l q_l)$, where variations in the parameter b would allow for the assessment of the effects of higher or lower price elasticity of demand. However, in this case as well, additional assumptions would be needed regarding the market size parameter a, which must be sufficiently large to ensure positive quantities produced by the firms.

An additional limitation is that our approach focuses on a single market, consistent with the typical framework in industrial organization. Firm strategies and policy decisions influence market outcomes such as prices and quantities within this market. While these outcomes may affect other markets and generate feedback effects, we explicitly define the relevant market for our analysis and do not consider cross-market interactions. As a result, our model operates within a partial equilibrium framework, treating costs, prices in other markets, and income as fixed. In contrast, a general equilibrium approach would determine these variables endogenously. Nonetheless, this setup could be extended to a more complex general equilibrium environment featuring multiple interconnected oligopolistic markets and recycling sectors. It is important to highlight that the literature presents only two established approaches for consistently modeling imperfect competition within a general equilibrium framework: the earlier GOLE model developed by Peter Neary, 2002, 2010, 2016), and the more recent methodology advanced by Stauvermann and Kumar (2021, 2024), Stauvermann et al. (2025)). This second approach would be particularly effective for analyzing the effects of waste management policies on income redistribution from the younger to the older generation, especially in contexts where oligopolistic markets interact with competitive markets. Extending the model to a general equilibrium framework would constitute a significant advancement. Although this approach would introduce greater analytical complexity to the model's structure, it represents a natural next step in the theoretical research on the effects of the circular economy. Such an extension would provide valuable insights into the implications that a comprehensive recycling system could have across diverse but interconnected industries, particularly in terms of access to production factors and final markets, collaboration in research and development, and marketing strategies.

We also assume that the recycling sector does not directly compete with the original oligopolistic industry. Although there are multiple settings where such a model is validly applicable, the theoretical analysis can be extended to cases where the implementation of a circular economy system alters the market and competitive structure by introducing new competitors into the oligopolistic market offering differentiated products. The effect on the markup appears ambiguous at first glance, as product differentiation generated by recycling may increase market power, while the presence of a greater number of firms tends to reduce it. Regarding total welfare, however, an increase can be reasonably expected, driven both by the availability of differentiated products and by intensified competition. The implementation costs of the circular economy are not explicitly accounted for in the simulations, reflecting a limitation due to the difficulty of accurately quantifying these costs, which vary widely across different institutional and market contexts and are hard to integrate into a purely theoretical framework. However, the difference in welfare levels between the two policy regimes effectively establishes an upper bound on the implementation costs, beyond which the circular economy would no longer be preferable to a waste taxation regime. Therefore, our analysis provides a useful benchmark for future empirical research aimed at comparing the efficiency of different waste management policies (recycling versus taxation), once the difficulties in measuring both welfare and implementation costs can be overcome.

Finally, although the model offers important insights, a more extensive analysis would be required to thoroughly examine its predictions across diverse contexts. A thorough empirical analysis of these predictions goes beyond the scope of the paper, which is purely theoretical in nature. The model provides a criterion grounded in solid theoretical foundations for comparing different waste management policies. However, there is currently a lack of reasonably sufficient data on market concentration, price markups, prices, quantities, and similar metrics, while welfare remains a theoretical concept that is difficult, if not impossible, to capture through empirical indicators. The empirical evidence we present is preliminary precisely because it is not exhaustive; nevertheless, it offers a promising direction by using proxies for welfare and markup, for which we have data only for Italian firms. These data provide initial support for the model's predictions. A comprehensive and conclusive empirical study should therefore be the subject of future research.

7. Conclusions

The transition from a linear production model to a circular economy constitutes a critical objective within the framework of the European Green Deal. However, there remains a lack of consensus among scholars and policymakers regarding the potential implications of this transition for social welfare and market power dynamics of the firms involved. While the circular economy aims to reduce waste and pollution through recycling and reuse, it may also inadvertently reduce social welfare due to potential issues such as overproduction, increased energy consumption, and resistance from firms experiencing diminished market power. These complexities highlight the need for a comprehensive analysis of the conditions under which a circular economy can deliver net benefits, rather than relying solely on alternative policy measures like waste taxation.

To address these issues, we develop a Cournot model with isoelastic demand, where firms differentiate themselves by producing varying levels of waste materials that are subsequently recycled and sold as inputs to another production sector. This modeling approach aligns with the European Green Deal's CEAP, which promotes sustainable product design, waste reduction, and the extended use of materials across sectors such as electronics, packaging, and textiles—industries responsible for significant resource consumption and waste generation. We also analyze an alternative waste reduction policy based on taxing scrap materials generated by manufacturers, reflecting ongoing EU regulatory efforts to incentivize waste prevention alongside recycling. Our simulations demonstrate that the circular economy yields higher welfare than taxation, particularly in concentrated markets characterized by high price elasticity of demand. Another key finding is that average market power decreases following the implementation of a circular economy policy, which supports the EU's ambition to level the playing field for secondary raw materials and enhance supply chain autonomy by reducing dependence on virgin inputs from third countries. These results remain robust even when accounting for the endogenous costs associated with recycling, heterogeneous marginal costs and different values of the elasticity β, underscoring the importance of integrating economic incentives with regulatory frameworks to foster innovation and investment in circular business models.

By embedding these policy insights and market realities, our study contributes to understanding how the EU's ambitious circular economy agenda can be operationalized to achieve both environmental and economic goals.

The model presented here serves as a foundational framework that can be extended in several promising directions. One potential extension involves modeling the recycling sector as a direct competitor to producers of the original product, thereby intensifying competition and prompting oligopolists to strategically reduce their own output to limit recyclers' advantages. A second avenue could explore the combined effects of waste taxation and recycling policies to assess how these instruments complement each other. Third, it would be valuable to investigate how consumer preferences for recycled versus virgin materials evolve under different policy regimes.

Exploring these research directions promises to yield valuable insights into the complexities of implementing circular economy practices within oligopolistic markets, while providing actionable guidance for policymakers striving to balance economic growth with environmental sustainability.

CRediT authorship contribution statement

Luca Correani: Writing – review & editing, Writing – original draft, Software, Methodology, Conceptualization. **Patrizio Morganti:** Writing – review & editing, Writing – original draft, Software, Methodology, Conceptualization. **Cecilia Silvestri:** Writing – review & editing, Writing – original draft, Supervision.

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Declaration of competing interest

There is no conflict of interest at disclose.

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Appendix

In this appendix, we examine the welfare and markup differences between the two waste management policies under the assumption of asymmetric marginal costs. Recognizing that clean technologies typically entail higher fixed or operating expenses, we model clean firms as having higher marginal costs, i.e. $c_l > c_h$. The ensuing sections present the relevant quantities corresponding to each scenario.

No Policy

$$Q_B = \left[\frac{\eta(n_h + n_l) - 1}{\eta(c_h n_h + c_l n_l)}\right]^{\eta}, \tag{29}$$

$$q_{B,h} = Q_B \frac{c_h + \eta(n_l c_l - n_l c_h)}{c_h n_h + c_l n_l}, \tag{30}$$

$$q_{B,l} = Q_B \frac{c_l + \eta(n_h c_h - n_h c_l)}{c_h n_h + c_l n_l}. \tag{31}$$

Observe that if $c_l > c_h$, then

$$\eta < \frac{c_l}{n_h(c_l - c_h)} \tag{32}$$

should hold to guarantee that production $q_{B,l}$ is positive.

Waste Taxation

$$Q_T = \left[\frac{\eta(n_h + n_l) - 1}{\eta(n_h(c_h + \tau\theta_h) + n_l(c_l + \tau\theta_l))}\right]^{\eta}, \tag{33}$$

$$q_{T,h} = Q_T \frac{c_h + \tau\theta_h + \eta n_l \tau(\theta_l - \theta_h) + \eta n_l(c_l - c_h)}{n_h(c_h + \tau\theta_h) + n_l(c_l + \tau\theta_l)}, \tag{34}$$

$$q_{T,l} = Q_T \frac{c_l + \tau\theta_l + \eta n_h \tau(\theta_h - \theta_l) + \eta n_h(c_h - c_l)}{n_h(c_h + \tau\theta_h) + n_l(c_l + \tau\theta_l)}. \tag{35}$$

Circular Economy

$$Q_{CE} = \left[\frac{\eta(n_h + n_l) - 1}{\eta(n_h(c_h - \hat{p}\theta_h\delta) + n_l(c_l - \hat{p}\theta_l\delta))}\right]^{\eta}, \tag{36}$$

$$q_{CE,h} = Q_{CE} \frac{(c_h - \hat{p}\theta_h\delta) + \eta n_l \hat{p}\delta(\theta_h - \theta_l) + \eta n_l(c_l - c_h)}{n_h(c_h - \hat{p}\theta_h\delta) + n_l(c_l - \hat{p}\theta_l\delta)}, \tag{37}$$

$$q_{CE,l} = Q_{CE} \frac{(c_l - \hat{p}\theta_l\delta) + \eta n_h \hat{p}\delta(\theta_l - \theta_h) + \eta n_h(c_h - c_l)}{n_h(c_h - \hat{p}\theta_h\delta) + n_l(c_l - \hat{p}\theta_l\delta)}. \tag{38}$$

Table 9
$W_{CE} - W_T$. $c_l = 0.5$, $c_h = 0.49$.

η	$n = 2$	$n = 4$	$n = 6$	$n = 8$	$n = 10$
$\eta = 1.1$	2.086	1.88	1.83	1.81	1.80
$\eta = 6$	9.82	9.72	9.71	9.77	9.84

Table 10
$\eta_{CE} - \eta_T$. $c_l = 0.5$, $c_h = 0.49$.

η	$n = 2$	$n = 4$	$n = 6$	$n = 8$	$n = 10$
$\eta = 1.1$	−0.031	−0.027	−0.021	−0.016	−0.010
$\eta = 6$	−0.002	0.001	0.003	0.006	0.009

Condition (32) reduces the tractability of the analysis compared to the case with symmetric marginal costs, restricting the study of the model to cases characterized by low price elasticity of demand, a limited number of polluting firms, and a small difference in marginal costs $c_l - c_h$. Accordingly, Table 9 reports a simulation which considers two scenarios characterized by low and high price elasticity of demand respectively, and asymmetric marginal costs.

Simulations confirm that the circular economy becomes increasingly preferable to waste taxation as price elasticity of demand rises. However, we also observe that at higher elasticity levels, the welfare gap $W_{CE} - W_T$ tends to be higher in more competitive markets. The intuition behind this phenomenon is that in both policy regimes, welfare decreases as the number of firms increases due to greater pollution. However, the lower marginal costs of dirty firms and the greater demand sensitivity imply lower prices and therefore, a higher consumer surplus, mitigating the reduction in W. This effect is more evident under a circular economy regime, in which there is an additional reduction in marginal costs related to the sale of waste.

Table 10 reports the markup gap $\eta_{CE} - \eta_T$ in the case of asymmetric marginal costs. As in the symmetric case, circular economy is characterized by a lower average markup respect to waste taxation ($\eta_{CE} - \eta_T < 0$) when price elasticity of demand is low. On the contrary, if elasticity is high the markup gap becomes positive and increasing with the number of firms.

This phenomenon arises because the average markup in a circular economy decreases to a lesser extent compared to that under a taxation regime as the number of firms increases. This outcome is attributable to the fact that 50% of firms benefit from lower marginal costs, which enhances their market power relative to the remaining 50%, thereby mitigating the overall reduction in average markup associated with an increasing number of firms. In contrast, this mitigating effect is diminished under taxation, as firms incur higher marginal costs due to taxes imposed on each unit of waste generated.

Data availability

Data will be made available on request.

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