“Recycling and natural resource extraction: Insights from monopoly and social planner perspectives”

AUTHORS	Bocar Samba Ba

ARTICLE INFO	Bocar Samba Ba (2025). Recycling and natural resource extraction: Insights from monopoly and social planner perspectives. *Environmental Economics*, *16*(3), 138-147. doi:10.21511/ee.16(3).2025.10
DOI	http://dx.doi.org/10.21511/ee.16(3).2025.10
RELEASED ON	Friday, 10 October 2025
RECEIVED ON	Friday, 28 March 2025
ACCEPTED ON	Wednesday, 09 July 2025

LICENSE	This work is licensed under a Creative Commons Attribution 4.0 International License

JOURNAL	"Environmental Economics"
ISSN PRINT	1998-6041
ISSN ONLINE	1998-605X
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
11	2	0

© The author(s) 2026. This publication is an open access article.

BUSINESS PERSPECTIVES

LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine

www.businessperspectives.org

Bocar Samba Ba (Canada)

RECYCLING AND NATURAL RESOURCE EXTRACTION: INSIGHTS FROM MONOPOLY AND SOCIAL PLANNER PERSPECTIVES

Abstract

The need to understand how recycling can mitigate resource scarcity has been intensified by the accelerating depletion of natural resources, driven by population growth. In this context, the influence of recycling on the dynamics of natural resource extraction is examined. Through a two-period theoretical model, two settings are considered: one in which profit is maximized by a monopolist, and another in which social welfare is maximized by a social planner. In both cases, a perfectly competitive recycling sector is assumed to operate in the second period, and cost interactions between the initial extraction and recycling activities are explicitly incorporated. It is shown that recycling reduces the second period extraction. In the monopoly case, the initial extraction is reduced under incomplete recycling when marginal recycling costs are high, while its effect becomes ambiguous when these costs are low; under complete recycling, the initial extraction is always reduced. In the social planner case, the initial extraction is found to be reduced under incomplete recycling, while under complete recycling, it is observed to follow an inverted U-shaped relationship with the recycling rate. These findings are seen to contribute to the environmental and industrial economics literature by clarifying how recycling efficiency and cost structures shape optimal extraction strategies, offering insights for sustainable resource management and circular economy policies.

Keywords recycling, natural resource, sustainability, welfare, market power

JEL Classification D60, L12, Q01, Q30, Q53

Type of the article: Research Article

Received on: 28th of March, 2025
Accepted on: 9th of July, 2025
Published on: 10th of October, 2025

© Bocar Samba Ba, 2025

Bocar Samba Ba, Ph.D. in Economics, Professor, Center for Research on the Economics of the Environment, Agri-food, Transports and Energy (CREATE); Department of Agricultural Economics and Consumer Sciences, Laval University, Canada.

This is an Open Access article, distributed under the terms of the Creative Commons Attribution 4.0 International license, which permits unrestricted re-use, distribution, and reproduction in any medium, provided the original work is properly cited.

Conflict of interest statement:
Author(s) reported no conflict of interest

INTRODUCTION

An uncontrollable overexploitation of natural resources has been caused by the growth of the global population. This overexploitation is widely regarded as a threat to the future availability of these resources, and the depletion[1] of certain resources – such as gold, uranium, oil, and phosphorus – has been predicted. In response to the anticipated scarcity of these resources, the transition from the traditional linear[2] economy model to a model referred to as the circular[3] economy has been proposed. It is worth noting that the circular economy model is based on several principles, including reduction, reuse, and recycling. Among these, particular attention is given in this paper to the last principle, namely recycling. The role that recycling can play (or can fail to play) in the preservation of a primary natural resource is

1 It should be noted that the notion of natural resource depletion must be nuanced when technological innovations enabling the development of substitutes for primary natural resources are introduced.

2 The linear economy is defined as an economic model in which extraction, manufacturing, consumption, and discarding are involved (Guillard, 2018).

3 The circular economy is defined as a system designed to retain the added value of products for as long as possible and to eliminate waste. Resources are kept within the economy so that end-of-life products can be productively reused, thereby generating new value (EC, 2014).

http://dx.doi.org/10.21511/ee.16(3).2025.10

examined in this paper. More specifically, the following research question is addressed: To what extent is the extraction rate of a primary natural resource affected by recycling? By addressing this question, the conditions under which recycling contributes positively to environmental protection can be identified, as well as those in which unintended negative effects may be generated.

From the outset, it should be emphasized that this research question has been the subject of extensive debate in economic literature. Recently, this issue has been explored through the lens of industrial economics and optimal control theory. Within the field of industrial economics, it has been addressed in particular through the works of Ba (2019), Ba and Mahenc (2019), Ba et al. (2020), and Belleflamme and Ha (2024). A common feature in this literature is that two-period models are used to capture the time lag[4] between the initial extraction and subsequent recycling activities. However, the role played by the initial extraction in determining the marginal cost of recycling is not accounted for in this literature. This omission is considered significant, given that a waste stock is generated by the initial extraction and used as input for recycling. Recycling opportunities are inherently enhanced by the presence of a large waste stock, which results in the marginal cost of recycling being reduced (Ba & Soubeyran, 2023). The role of the initial extraction in shaping the marginal cost of recycling has been examined within frameworks based on optimal control theory (Ba & Soubeyran, 2023; Weikard & Seyhan, 2009; Seyhan et al., 2012). The time lag between extraction and recycling activities has not been incorporated in this literature, which is based on dynamic continuous-time models.

The present paper is situated within the tradition of industrial economics models, with the effect of the initial extraction on the marginal cost of recycling being explicitly incorporated. A new perspective on the relationship between recycling and the extraction rate of a natural resource is thus provided by this consideration. More specifically, it is shown that, contrary to previous findings in the industrial economics literature (Ba et al., 2020), the initial extraction is affected by incomplete recycling, through which second period production quantities are subsequently influenced. In doing so, a mechanism that has been overlooked in earlier literature (Ba et al., 2020; Belleflamme & Ha, 2024) is revealed.

1. THEORETICAL BASIS

A sector that extracts a natural resource over two consecutive periods is considered. The first period extraction is denoted by x, with an associated extraction cost given by $(C(x) = x^2/2)$, while the second period extraction is denoted by y, with a corresponding cost specified as $(C(y) = y^2/2)$. A theoretical model of quantity competition is considered, in which two scenarios are analyzed. The first scenario is concerned with the profit maximization of the monopoly, while the second is related to the maximization of social welfare. In both scenarios, it is assumed that the extraction sector is faced with a perfectly competitive recycling sector, in which a portion or the entirety of the waste stock generated during the first period is recycled in the second period. It is considered that the marginal cost of recycling is increased by the recycled quantity r and decreased by the waste stock resulting from the initial extraction (Weikard & Seyhan, 2009; Ba & Soubeyran, 2023). Formally, the marginal cost of recycling[5] is defined $(C^m(x, y) = cr - \beta x)$. In this formulation, $(\beta \in [0,1])$ can be inter-

4 This lag has also been considered in a dynamic discrete-time model, in which the issue of market power held by a monopoly facing a recycling sector behaving as an oligopoly was analyzed by Gaudet and Long (2003).

5 Before proceeding with the analysis, a clarification is warranted to avoid confusion. Although the constrained case is assumed to be defined by (r = βx) (see subsections 2.1 and 2.2), the presence of the term βx n the total marginal cost function is not to be interpreted as an explicit assumption of the constrained case. Instead, the outcome is determined by the structure of the recycling cost function. For instance, if the total recycling cost were assumed to be

$$c\frac{r^2}{2} - \frac{(\beta x)^2}{3\beta}$$

the corresponding total marginal cost would be given by (cr – 2βx/3), and the constrained case expression would not be directly recovered. In such a scenario, the solution would be given by r(x, y) = 1/(c + 1)(10 – y + 2βx/3) differing from the expression in equation (4). Through this alternative cost function, the influence of the initial extraction and recycling efficiency on the marginal cost of recycling is demonstrated.

preted as the efficiency of the recycling technology, and ($c > 0$) as the parameter related to the marginal cost of recycling. The term βx could be interpreted as reflecting economies of scale: an increase in the initial extraction is associated with a reduction in the marginal cost of recycling, due to the greater availability of material to be recycled. It is assumed that used products are made available to the recycling sector by consumers free of charge. This virtuous behavior of consumers[6] may be explained by their pro-environmental attitudes. The recycled quantity and the extracted quantity are considered as perfect substitutes. Consumer preferences are captured by the inverse demand function ($P_1 = (10 - x)$) in the first period and the inverse demand function ($P_2 = (10 - y - r)$) in the second period. The discount factor is assumed to be normalized to one. In both scenarios, the game between the extraction sector and the recycling sector is solved using the backward induction method.

This section will be divided into two subsections. In the first scenario, the case in which the extractor behaves as a monopoly and thus maximizes its profit is examined. In the second scenario, the case in which social welfare is maximized is considered.

1.1. Maximization of the extractor's profit

In this subsection, the influence of recycling on the equilibrium extraction quantities is analyzed under the assumption that the extractor behaves as a monopolist. As the game is solved through backward induction, the analysis is initiated with period 2, in which the reaction functions of both the extractor and the recycling sector are determined, before proceeding backward to period 1.

In period 2, the profit of the extractor is expressed as follows:

$$\pi_2 = (10 - y - r)\, y - \frac{y^2}{2}. \tag{1}$$

The reaction function of the extractor, as derived from equation (1) is given by:

$$y(r) = \frac{10 - r}{3}. \tag{2}$$

In this period, the following profit function is maximized by the recycling sector, which operates as a perfectly competitive sector:

$$\pi_r = P_2 r - C(r, x), \quad \frac{S}{C} \cdot r \le \beta x. \tag{3}$$

The program (3) is solved under the assumption that the recycling sector behaves as a perfectly competitive sector, leading to the following reaction function:

$$r(x; y) = \begin{cases} \dfrac{10 - y - \beta x}{c + 1}, if\ r < \beta x \\ \beta x, otherwise. \end{cases}. \tag{4}$$

Two Nash-Cournot equilibria in period 2 are obtained from the intersection of equations (2) and (4). To distinguish these two types of equilibrium, the case where ($r < \beta x$) is considered the unconstrained case (incomplete recycling), while ($r = \beta x$) is regarded as the constrained case (complete recycling):

1) In the unconstrained case, the equilibrium quantities are given by:

$$y^{nc} = \frac{10c - \beta x}{3c + 2}, \tag{5}$$

and[7]

$$r^{nc} = \frac{3\beta x + 20}{3c + 2}. \tag{6}$$

The exponent "*nc*" is used to denote the "non-constrained" term, with the condition ($10c - \beta x > 0$) required for ($y^{nc} > 0$).

2) In the constrained case, the equilibrium quantities are given by:

6 The participation of consumers in the recycling process could be modeled by assuming that used products are sold to the recycling sector at a positive price. Such a transaction would be represented as an additional cost for the recycling sector, which would then be incorporated into its production decision. For the sake of simplicity, this aspect is not considered here. For an analysis in which this factor is included, see Hoogmartens et al. (2018).

7 It can be easily observed that

$$\frac{\partial r^{nc}}{\partial \beta} = \frac{3x}{3c + 2} > 0$$

which is intuitive, as an increase in the recycling rate is associated with an increase in the recycled quantity.

http://dx.doi.org/10.21511/ee.16(3).2025.10

$$y^c = \frac{10-\beta x}{3}, \tag{7}$$

and

$$r = \beta x. \tag{8}$$

The exponent "c" is used to denote the "constrained" term, with the condition $(10 - \beta x > 0)$ required for $(y^c > 0)$. Now, the quantity extracted in the first period is analyzed. In that period, the profit over the two periods is maximized by the monopoly through its choice of x. Here, a distinction between the unconstrained case and the constrained case is made.

1.1.1. Unconstrained case

The monopoly's profit over the two periods is given by:

$$\pi^{nc} = \left(10 - x^{nc}\right)x^{nc} - \frac{\left(x^{nc}\right)^2}{2} + \left(10 - y^{nc} - r^{nc}\right)y^{nc} - \frac{\left(y^{nc}\right)^2}{2}. \tag{9}$$

The following equilibrium quantity extracted in the first period is yielded by the maximization of (9), taking into account (5) and (6)

$$x^{nc} = \frac{30c\left(3c+4-\beta\right)+40}{27c^2+36c+3\left(2-\beta\right)\left(\beta+2\right)}. \tag{10}$$

It is important to note that the second-order condition (SOC) associated with (9), after considering (5) and (6) is given by

$$\frac{\partial \pi^{nc}}{\partial x^{nc}} = -\frac{27c^2+36c+3\left(2-\beta\right)\left(\beta+2\right)}{\left(3c+2\right)^2}. \tag{11}$$

This condition is satisfied negatively if $(27c^2 + 36c + 3(2 - \beta)(\beta + 2) > 0)$, which holds true given the assumption $(\beta \in [0,1])$. Thus, the profit function is considered concave in x.

1.1.2. Constrained case

The monopoly's profit over the two periods is given by:

$$\pi^c = \left(10 - x^c\right)x^c - \frac{\left(x^c\right)^2}{2} + \left(10 - y^c - r^c\right)y^c - \frac{\left(y^c\right)^2}{2}. \tag{12}$$

The following equilibrium quantity extracted in the first period is obtained from the maximization of (12), considering (7) and (8):

$$x^c = \frac{10}{\beta+3} \tag{13}$$

The recycled[8] quantity derived from equation (13) is then given by:

$$r^c = \frac{10\beta}{\beta+3} \tag{14}$$

It can be easily demonstrated that the second-order condition applied to (12), after considering (7) and (8), is given by $(1/3(\beta - 3)(\beta + 3) < 0)$, which indicates that concavity is exhibited by the profit function in x.

1.2. Maximization of the social welfare

As in the monopoly case, the effect of recycling on the equilibrium extraction quantities is examined in this section. The analysis is initiated with period 2, where the extracted and recycled quantities are determined, before proceeding backward to period 1 to establish the extraction for that period.

In period 2, the social welfare function is defined as follows:

$$\widehat{w_2} = 10\left(y+r\right) - \frac{\left(y+r\right)^2}{2} - \frac{y^2}{2} - \left(c\frac{r^2}{2} - \frac{\left(\beta x\right)^2}{2\beta}\right). \tag{15}$$

8 It can be easily shown that

$$\frac{\partial r^c}{\partial \beta} = \frac{30}{\left(\beta+3\right)^2} > 0$$

The following expression is obtained from the maximization of (15) by the social planner:

$$y(r)=\frac{10-r}{2} \tag{16}$$

As perfect competition is always assumed in the recycling sector, the reaction function of the recycling sector is given by:

$$r(x;y)=\begin{cases}\dfrac{10-y-\beta x}{c+1} & ,\ if\ r<\beta x.\\ \beta x, otherwise\end{cases} \tag{17}$$

The distinction between the unconstrained case and the constrained case is also made.

1.2.1. Unconstrained case

The equilibrium quantities are given by:

$$\hat{y}^{nc}=\frac{10c-\beta x}{2c+1} \tag{18}$$

And

$$\hat{r}^{nc}=\frac{2\beta x+10}{2c+1} \tag{19}$$

1.2.2. Constrained case

The equilibrium quantities are given by:

$$\hat{y}^{c}=\frac{10-\beta x}{2} \tag{20}$$

And

$$\hat{r}^{c}=\beta x \tag{21}$$

Now, the initial extraction is examined. The social welfare is maximized by the social planner over the two periods. A distinction between the two cases is also made:

1.2.3. Unconstrained case

The social welfare function over the two periods is written as follows:

$$\begin{aligned}\hat{W}^{nc}=&10\left(\hat{x}^{nc}\right)-\frac{\left(\hat{x}^{nc}\right)^2}{2}-\frac{\left(\hat{x}^{nc}\right)^2}{2}\\&+10\left(\hat{y}^{nc}+\hat{r}^{nc}\right)-\frac{\left(\hat{y}^{nc}+\hat{r}^{nc}\right)^2}{2}-\frac{\left(\hat{y}^{nc}\right)^2}{2}\\&-\left(c\frac{\left(\hat{r}^{nc}\right)^2}{2}-\frac{\left(\beta\hat{x}^{nc}\right)^2}{2\beta}\right).\end{aligned} \tag{22}$$

The equilibrium quantity extracted in the first period is obtained from the maximization of (22), after considering (18) and (19):

$$\hat{x}^{nc}=\frac{220c+110}{2(2c+1)-\beta^2\left(2c^2+c-2\right)}. \tag{23}$$

It is important to note that the second-order condition associated with (22), after considering (18) and (19), is given by

$$\frac{2\beta x}{2(2c+1)}\left(2c^2+c-2\right). \tag{24}$$

The condition is satisfied negatively if ($2c^2 + c - 2 < 0$), which must hold for the social welfare function to be concave in x.

1.2.4. Constrained case

The social welfare function over the two periods is given by:

$$\begin{aligned}\hat{W}^{c}=&10\left(\hat{x}^{c}\right)-\frac{\left(\hat{x}^{c}\right)^2}{2}-\frac{\left(\hat{x}^{c}\right)^2}{2}+10\left(\hat{y}^{c}+\hat{r}^{c}\right)\\&-\frac{\left(\hat{y}^{c}+\hat{r}^{c}\right)^2}{2}-\frac{\left(\hat{y}^{c}\right)^2}{2}-\left(c\frac{\left(\hat{r}^{c}\right)^2}{2}-\frac{\left(\beta\hat{x}^{c}\right)^2}{2\beta}\right).\end{aligned} \tag{25}$$

The following equilibrium quantity extracted in the first period is obtained from the maximization of (25), after considering (20) and (21):

$$\hat{x}^{c}=\frac{10\beta+20}{\beta^2+4}. \tag{26}$$

It should be noted that the second-order condition associated with (26), after considering (20) and (21), is given by

http://dx.doi.org/10.21511/ee.16(3).2025.10

$$-\frac{1}{2}\beta^2 - 2 < 0, \quad (27)$$

indicating that the social welfare function is concave in x.

2. RESULTS

In the following, the results will be presented by distinguishing between the two scenarios: profit maximization by the monopolist and social welfare maximization by the social planner.

2.1. Maximization of the extractor's profit

Condition (4) indicates that recycling is reduced by an increase in the second period extraction and is increased by a higher initial extraction. Simple comparative statics applied to (5) and (7) show that, in both the unconstrained and constrained cases, the second period extraction is reduced by recycling, as expressed by

$$\frac{\partial y^{nc}}{\partial \beta} = -\frac{x}{3c+2} < 0, \quad and \quad \frac{\partial y^{c}}{\partial \beta} = -\frac{x}{3} < 0, \quad (28)$$

respectively. With respect to the first period, the results are found to differ depending on whether the case is constrained or unconstrained. In the unconstrained case, the following derivative is obtained through a comparative static applied to (10):

$$\frac{\partial x^{nc}}{\partial \beta} = -10\frac{(3c+2)^2(3c-2\beta)+3c\beta^2}{3\left(9c^2+12c-\beta^2+4\right)^2}, \quad (29)$$

This result indicates that the effect of recycling on the initial extraction is influenced by the marginal recycling cost parameter c. More specifically, when c is relatively high (i.e., $c > 2/3\beta$), a reduction in the initial extraction is induced by recycling. Conversely, when c is relatively low (i.e., $c \leq 2/3\beta$), the effect of recycling on the initial extraction is rendered ambiguous, as it depends on two opposing forces. The relationship between the initial extraction and recycling, as shaped by different values of c, is illustrated in Figure 1.

It is shown that for the relatively high value of c (c = 1.1), represented by the black curve, a decrease in the initial extraction is induced by recycling. In contrast, for the relatively low value of c (c =1/6), represented by the light gray curve, an increase in the initial extraction is observed.

In the constrained case, it is shown through a comparative static applied to (12) that a reduction in the initial extraction is induced by recycling, as expressed by

$$\frac{\partial x^{c}}{\partial \beta} = -\frac{10}{(\beta+3)^2} < 0. \quad (30)$$

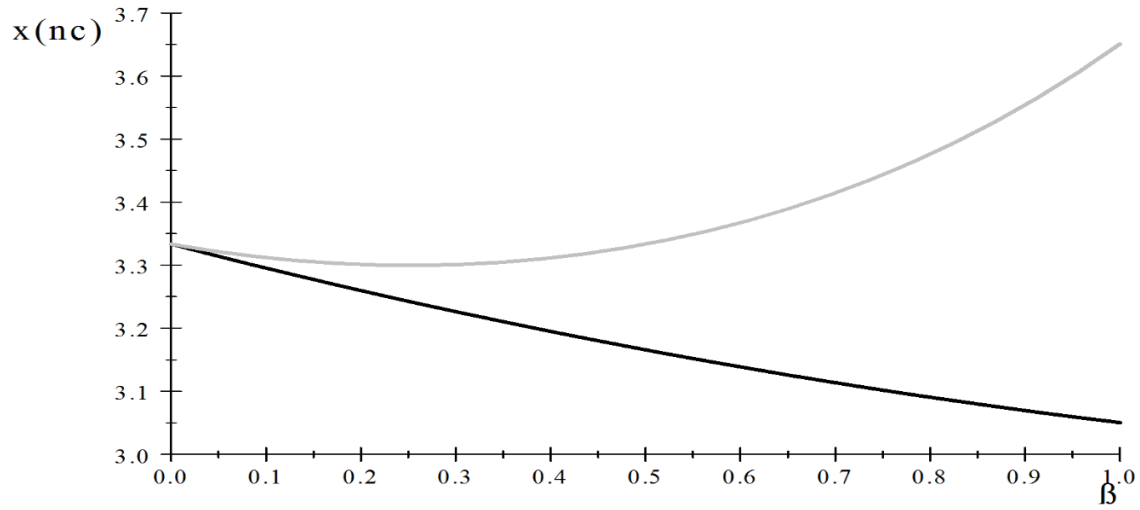

Figure 1. Role of recycling on the initial extraction in the unconstrained case and the profit maximization scenario, depending on the values of c

2.2. Maximization of the social welfare

In the second period, it is shown through simple comparative statics applied to (18) and (20) that the extraction is reduced by recycling in both the unconstrained and constrained cases, as indicated by

$$\frac{\partial \hat{y}^{nc}}{\partial \beta} = -\frac{x}{2c+1} < 0, \quad \text{and} \quad \frac{\partial \hat{y}^{c}}{\partial \beta} = -\frac{x}{2} < 0, \quad (31)$$

respectively. Regarding the first period, the results are found to vary depending on whether the case is constrained or unconstrained. In the unconstrained case, it is indicated by a comparative static applied to (23) that the initial extraction is reduced by recycling, as shown by

$$\frac{\partial \hat{x}^{nc}}{\partial \beta} = -\frac{2\beta(220c+110)(2c^2+c-2)}{(-2c^2\beta^2 - c\beta^2 + 4c + 2\beta^2 + 2)^2} < 0, \quad (32)$$

given that $2c^2 + c - 2 < 0$. In the constrained case, it is shown by a comparative static applied to (25) that

$$\frac{\partial \hat{x}^{c}}{\partial \beta} = -\frac{10(\beta^2 + 4\beta - 4)}{(\beta^2 + 4)^2} < 0. \quad (33)$$

The sign of this derivative depends on the expression ($\beta^2 + 4\beta - 4$), which is negative for $0 < \beta < 0.8$ and positive for $0.8 < \beta < 1$. It is then indicated that the effect of recycling on the initial extraction depends on the level of the recycling rate: a reduction in the initial extraction is caused by recycling at high recycling rates, whereas an increase is caused at relatively low recycling rates. This result is illustrated in Figure 2.

3. DISCUSSION

Several important insights into the interplay between the resource extraction sector and a perfectly competitive recycling sector are offered by the theoretical results derived above.

In both the profit-maximization and welfare-maximization scenarios, it is demonstrated that when recycling is incomplete, it is jointly influenced by the extraction in both the first and second periods. Specifically, the recycling activity is tended to be reduced by the extraction in the second period due to the perfect substitutability between extracted and recycled materials. In contrast, recycling is enhanced by the extraction in the first period through a scale effect. The dampening effect of the second period extraction on recycling has been well established in the economic literature (Belleflamme & Ha, 2024; Ba et al., 2020). However, to the best of our knowledge, the positive influ-

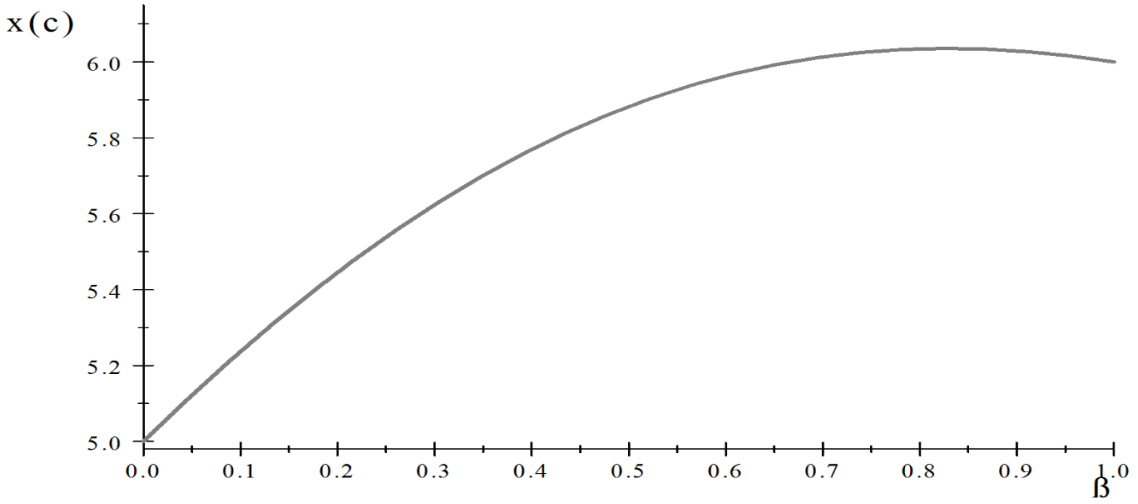

Figure 2. Role of recycling on the initial extraction in the constrained case and the social welfare maximization scenario

http://dx.doi.org/10.21511/ee.16(3).2025.10

ence of the first period extraction on the marginal cost of recycling has not yet been addressed in this industrial economics literature, in this context.

It is demonstrated by the present analysis that, regardless of the scenario (monopoly or social planner) and the degree of recycling (incomplete or complete), a decrease in the extraction in the second period is induced as recycling increases. The explanation for this result is provided as follows. A reduction in the second period extraction is caused by recycling due to the perfect substitutability between recycled and extracted products. Extraction is adjusted downward by the monopoly in response to the increased recycled quantity so that a high resource price is maintained. This result is found to be consistent with findings established in the industrial economics literature (Belleflamme & Ha, 2024; Ba et al., 2020).

To further explore the effects of recycling on the initial extraction, a distinction is made between the two strategic frameworks: profit maximization and social welfare maximization.

3.1. Maximization of the extractor's profit

When recycling is incomplete, it is shown that the effect of recycling on the initial extraction is dependent on the level of the marginal recycling cost parameter c. Indeed, when c is high, a reduction in the initial extraction is caused by recycling. The intuition behind this result is explained by the reduction of the initial extraction level by the extractor, as it is anticipated that this reduction will limit recycling opportunities. A signal is also sent to the recycling sector by this behavior, indicating that the second period extraction might be increased by the monopoly, which could lead to a lowering of the resource price in that period and a discouragement of the recycling sector. Conversely, when c is relatively low, the effect of recycling on the initial extraction is rendered ambiguous. When recycling is complete, a reduction in the initial extraction is caused. As mentioned above, this behavior is adopted by the monopolist to limit the possibilities of recycling.

3.2. Maximization of the social welfare

When recycling is incomplete, a reduction in the initial extraction is caused. This result contrasts with the finding of Ba and Mahenc (2019), by which the initial extraction would be increased by a social planner maximizing social welfare to encourage recycling activity. Two major elements are considered to explain the difference between these two results. First, the effect of the initial extraction on the marginal cost of recycling is not considered by Ba and Mahenc (2019). Second, the assumption is made that the resource is completely depleted in period 2. Since perfect substitutability exists between recycling and the second period extraction, a reduction in the second period extraction is caused by an increase in recycling. This reduction mechanically results in an increase in the initial extraction, as anything not extracted in one period will be extracted in the other period. When recycling is complete, the effect on the initial extraction is rendered ambiguous, depending on the level of the recycling rate. Indeed, a decrease in the initial extraction is induced by recycling at high recycling rates, whereas an increase is induced at relatively low recycling rates. A possible explanation for this result can be formulated as follows. On the one hand, when a high recycling rate is anticipated, a reduction in the initial extraction may be favored by the social planner, as the rate may be considered sufficiently high already. On the other hand, when a relatively low recycling rate is anticipated, an increase in the initial extraction may be encouraged by the social planner to stimulate recycling. As a result, an inverted U-shaped pattern is followed by the extraction in this period. To the best of our knowledge, this result has not been documented in the recycling literature from an industrial economics perspective.

CONCLUSION

In this paper, the impact of recycling on natural resource extraction and its role in promoting or hindering environmental sustainability has been examined. Two scenarios were considered: profit maximization by a monopoly and welfare maximization by a social planner, both with a competitive recycling

sector entering in the second period. It is shown that recycling always reduces the second period extraction. Its effect on the first period extraction, however, depends on the scenario and conditions. Under the monopoly case, incomplete recycling leads to the reduced initial extraction when recycling is costly, but the effect is unclear when recycling is cheap. With complete recycling, the initial extraction is always reduced. Under the social planner case, the initial extraction is reduced when recycling is incomplete, but with complete recycling, it may rise or fall depending on the recycling rate, following an inverted U-shaped pattern.

At least two main contributions are made to the industrial economics literature. First, it is shown – contrary to earlier studies – that the initial extraction can decrease even with incomplete recycling. Second, the initial extraction affects second period quantities by altering the marginal cost of recycling, challenging prior assumptions.

Although the analysis remains theoretical, several practical implications are offered for policymakers and stakeholders in resource management and recycling. It is suggested that improving recycling efficiency can, under certain conditions, reduce extraction and align environmental with economic goals. However, it is emphasized that recycling policies should be preceded by a careful assessment of market structure and context to avoid unintended, counterproductive effects.

Future research may be guided by an extension of this approach. While the impact of recycling on resource extraction and environmental quality has been emphasized in this paper, it is acknowledged that certain resources are difficult or nearly impossible to recycle. In such cases, it is suggested that recycling be integrated with other core principles of the circular economy – such as source reduction and product reuse – within a unified analytical framework, through which their interactions can be examined and their combined influence on extraction dynamics assessed.

AUTHOR CONTRIBUTIONS

Conceptualization: Bocar Samba Ba.
Formal analysis: Bocar Samba Ba.
Investigation: Bocar Samba Ba.
Methodology: Bocar Samba Ba.
Validation: Bocar Samba Ba.
Visualization: Bocar Samba Ba.
Writing – original draft: Bocar Samba Ba.
Writing – review & editing: Bocar Samba Ba.

REFERENCES

1. Ba, B. S. (2019). Taxe, subvention et coût fixe d'entrée: Oligopole de Cournot avec entrée endogène [Tax, subsidy and fixed entry cost: Cournot oligopoly with endogenous entry]. *Revue d'Economie industrielle – Industrial Economics Review, 165,* 117-134. (In French). https://doi.org/10.4000/rei.7935
2. Ba, B. S., & Mahenc, P. (2019). Is recycling a threat or an opportunity for the extractor of an exhaustible resource? *Environmental and Resource Economics, 73,* 1109-1134. https://doi.org/10.1007/s10640-018-0293-1
3. Ba, B. S., & Soubeyran, R. (2023). Hotelling and recycling. *Energy and Resource Economics, 72,* Article 101358. https://doi.org/10.1016/j.reseneeco.2023.101358
4. Ba, B. S., Combes-Motel, P., & Schwartz, S. (2020). Challenging pollution and the balance problem from rare earth extraction: How recycling and environmental taxation matter. *Environment and Development Economics, 25*(6), 634-656. https://doi.org/10.1017/S1355770X20000054
5. Belleflamme, P., & Ha, H. (2024). Improving recycling: How far should we go? *Environmental and Resource Economics, 87,* 1993-2033. https://doi.org/10.1007/s10640-024-00880-z
6. EC. (2014). *Towards a circular economy: A zero waste programme for Europe.* Brus-

http://dx.doi.org/10.21511/ee.16(3).2025.10

sels. Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:50edd1fd-01ec-11e4-831f-01aa75ed71a1.0001.01/DOC_1&format=PDF

7. Gaudet, G., & Long, N. V. (2003). Recycling redux: A Nash-Cournot approach. *Japanese Economic Review, 54*(4), 409-419. https://doi.org/10.1111/1468-5876.t01-1-00067

8. Guillard, V. (2018). D'une économie linéaire à une économie circulaire [From a linear economy to a circular economy]. *Economie et Management – Economics and Management, 168,* 22-29. (In French). Retrieved from https://hal.science/hal-01891422/file/economie-lineaire-a-une-economie-circulaire.pdf

9. Hoogmartens, R., Eyckmans, J., & Passel, S. V. (2018). A Hotelling model for the circular economy including recycling, substitution and waste accumulation. *Resources, Conservation and Recycling, 128,* 98-109. https://doi.org/10.1016/j.resconrec.2017.09.015

10. Seyhan, D., Weikard, H. P., & Ierland, E. V. (2012). An economic model of long-term phosphorus extraction and recycling. *Resource, Conservation and Recycling, 61,* 103-108. https://doi.org/10.1016/j.resconrec.2011.12.005

11. Weikard, H., & Seyhan, D. (2009). The distribution of phosphorus resources between rich and poor countries: The effect of recycling. *Ecological Economics, 68*(6), 1749-1757. https://doi.org/10.1016/j.ecolecon.2008.11.006