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Anticipating the location of a waste collection point: an application based on Portugal*

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Abstract. We study the optimal location of a waste facility in a horizontally differentiated duopoly where firms choose their location and price. The policymaker decides the location of a waste facility targeting social welfare maximization. Consistent with the observation of the location decisions of waste facilities in Portugal, we show that the optimal location of a waste facility is never in the city center under partial ex-post regulation. Ex-ante regulation ensures the highest level of social welfare, but from a theoretical point of view, it requires a waste facility located in the city center. A robustness check is then provided to justify that, in actual regulatory practice, a first-mover regulator maximizes social welfare without necessarily imposing the installation of a waste facility in the city center.

Keywords: Waste Management, Spatial Competition, Location, Waste Collection Point, Price Competition.

JEL Classification Numbers: D43, L13, Q53.

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1 Introduction

Waste production results from the use of resources in socioeconomic activities. Regarding its origin, waste has several classifications. This research focuses on municipal solid waste (MSW).[1] Households, industries and services are the main sources of MSW. To ensure the treatment of waste, firms must incur in additional costs to transport it into adequate facilities or waste collection points. In turn, consumers also incur transportation costs traveling from their homes to where firms are located to purchase products. Given the simultaneous presence of two distinct costs, a waste regulator may target various objectives such as allocative efficiency, minimization of transportation costs and environmental protection. This means that firms and waste regulator are subject to several trade-offs. Although firms may have the incentive to be located within a residential area to more easily attract consumers, they are also expected to be environmentally committed which requires, for instance, avoiding dumping and landfilling. From an economic point of view, the waste regulator may have the incentive to support the implementation of a waste collection point within a residential area. However, from an environmental and social standpoint, the perverse effect emerging from the implementation of a waste collection point in that area should not be disregarded. Consequently, the determination of the optimal location of a waste collection point seems to be a critical issue affecting any jurisdiction. In the European Union (EU), it is estimated that a more efficient management of MSW would save 1.4 billion euros of annual imports and would generate 1.6 billion euros in revenues (COM 571 Final 2011). In Portugal, the amount of MSW produced was 4.8 million tonnes in 2012 corresponding to 15% of total national waste. Of these, 12% was referred for multimaterial recovery, 16% for organic recycling, 18% for energy recovery and 54% was sent directly to landfill (APA 2013). Subsequently, an improper management of MSW determines significant environmental costs. The deposition of MSW in Portuguese landfill soils originated greenhouse gas (GHG) emissions of 2.8 million tonnes of CO_2 in 2011 corresponding to 34.1% of waste sector emissions and 4.0% of total national GHG emissions (APA 2013).

In a recent article, Bárcena-Ruiz and Casado-Izaga (2015) use spatial competition to study a High Municipal Solid Waste Management System (HIGH MSWMS) within the linear city model of Hotelling (1929). They investigate a duopoly in the linear city and describe the strategic behavior of producers when the regulator pre-selects the location of a waste collection point. Two different systems are analyzed: a producer-pay-regime (PPR) where the regulator requires firms to pay waste transportation costs, and a consumer-pay-regime (CPR) where the regulator requires consumers to pay waste transportation costs. In a PPR system, Bárcena-Ruiz and Casado-Izaga (2015) conclude that

[1] Waste can be classified as medical, industrial, agricultural and municipal (or Urban) solid waste. According to the Portuguese legislation, article 5, n^o. 1 of Decree law n^o 178/2006 of 5^{th} September 2006, amended and republished in article 3 of Decree law n^o 73/2011 of 17^{th} June 2011, MSW is defined as "waste from households and other waste which by its nature or composition is similar to waste from households".

the waste collection point is always located in the city center. Vitoria-Gasteiz, a city in the north of Spain, is provided as real example where a waste facility located in the city center is observed. They also show that, only in a CPR system under sequential location decision, the waste collection point is biased from the city center. When that is the case, the waste collection point turns to occupy a location closer to the firm with higher market share.

An important and realistic mechanism that may change the location of a waste collection point in a PPR system, not captured in Bárcena-Ruiz and Casado-Izaga (2015), is a setting in which one of the producers is able to select its location before the regulatory decision on the location of the waste collection point. This may occur either explicitly due to the fact that the producer may already be operating before the introduction of waste regulation or implicitly because the producer may anticipate the regulatory decision on where the waste collection point is installed.[2] Assuming that firm A (B) is the leader (follower, respectively) firm in location choice, this means that Bárcena-Ruiz and Casado-Izaga (2015) analyze the case of ex-ante regulation (i.e., the regulator decides the optimal location of the waste collection point before both firms choose the respective locations sequentially), while we focus on the case of partial ex-post regulation (i.e., the regulator decides the optimal location of the waste collection point after the location decision of firm A, but before the location decision of firm B). Thus, the goal of this study is twofold. From the theoretical standpoint, we want to confirm if the result of Bárcena-Ruiz and Casado-Izaga (2015) applied to a PPR system is sufficiently general. In particular, does the transition from ex-ante regulation to partial ex-post regulation modifies the optimal location of a waste collection point? From the practical standpoint, once taking into account that consumers and producers bear transportation costs, we intend to understand which type of regulatory regime ensures social welfare maximization. To meet our objectives, we develop a mathematical framework to analyze the role of a HIGH MSWMS. Although conceptually simple, the linear city is a very powerful and widely adopted model in a wide range of areas, including environmental economics.[3]

The main findings are summarized as follows. Firstly, we find that the centripetal mechanism described in Bárcena-Ruiz and Casado-Izaga (2015) is distorted once changing the timing structure of the game because, despite the centripetal force pushes firms towards the waste collection point, this is no longer located in the city center. If one of the producers commits to a location before the location decision of the waste facility in a PPR system, the optimal location of the waste collection point is never in the city center. This equilibrium result is consistent with the location decisions of waste collection points in Portugal, which is a country characterized by partial ex-post regulation.

[2] In fact, Queiruga et al. (2012) argue "that firms in some countries began to collect and recycle even before regulations mandated they do so, whereas others took their first steps only after the passage of related legislation. Other countries still have not taken any measures (...) and firms already produce".

[3] See Crew and Heyes (2013) for a literature review and respective description of recent environmental facts worldwide.

Secondly, we compare the equilibrium level of social welfare under ex-ante regulation with the equilibrium level of social welfare under partial ex-post regulation to conclude that social welfare is unambiguously harmed with the transition from ex-ante regulation to partial ex-post regulation. When the relative transportation cost of consumers is sufficiently low, the reduction of social welfare corresponds to the decrease in consumer surplus plus the decrease in producer surplus. When the relative transportation cost of consumers is sufficiently high, the reduction of social welfare corresponds to the reduction of consumer surplus created by the increase in consumers' transportation cost.

This result implies a trade-off in waste regulatory policy because Bárcena-Ruiz and Casado-Izaga (2015) show that the optimal location of a waste facility under ex-ante regulation is the city center, but this equilibrium location is rarely observable in reality. We then provide a robustness check to justify that the waste regulator surpasses the trade-off in real practice, which is tantamount to saying that social welfare can be maximized through the adoption of ex-ante regulation, but without necessarily imposing the city center as the optimal location of the waste facility. This process is developed in two separate steps. First, we highlight the presence of a direct effect under ex-ante regulation that discourages the persistence of a waste facility in the city center. This requires to clarify additional factors forcing the location of the waste facility to alternative places (e.g., peripheral regions) other than the city center under ex-ante regulation. Second, we emphasize the presence of an indirect effect under partial ex-post regulation that reinforces the persistence of a waste facility in a biased location relative to the city center. This requires to confirm that the distortion in the optimal location of the waste facility verified under partial ex-post regulation is resilient or, similarly, that it remains qualitatively valid when the observed heterogeneity between different types of waste facilities is taken into account. If that is the case, the biased location is not influenced by the observed heterogeneity between different waste facilities, thereby making less likely the presence of a waste facility in the city center when the regulatory regime moves towards ex-ante regulation.[4] Needless to say, we find evidence in favor of this conjecture in the case of the Portuguese HIGH MSWMS. Since the biased location of the waste facility under partial ex-post regulation holds generality, its pass through is expected to occur when the regulatory regime moves towards ex-ante regulation. Therefore, the main policy implication from our analysis is the need to consider not only firms' strategic location decisions, but also alternative factors when deciding the optimal location of waste facilities.

[4] From a dynamic point of view, some firms with high maturity may disappear whereas new startups may emerge in a given regional jurisdiction, thereby justifying the transition from partial ex-post regulation to ex-ante regulation. From a static point of view, distinct regulatory regimes may be applied to different waste facilities, that is, either ex-ante regulation or partial ex-post regulation can be applied to different waste facilities, namely if there is heterogeneity between different waste collection points either due to the installation of waste facilities in different regional jurisdictions or due to the fact that a given waste collection point may be located closer to the city center relatively to others being, therefore, subject to tighter regulation.

2 Municipal solid waste management systems in Portugal

The purpose of this section is twofold. Firstly, motivate the assumptions of our model by focusing on the Portuguese HIGH MSWMS and, thenceforward, clarify that Bárcena-Ruiz and Casado-Izaga (2015) are modeling an exception rather than the rule in relation to the optimal location of a waste collection point in a PPR system. The Portuguese MSWMS is organized in two levels or categories. On the one hand, there is a municipal solid waste management category of urban services provided to other management entities, i.e. the HIGH MSWMS. At this macro level, which corresponds to the focus of this research, municipal solid waste costs are paid only by firms constituting, therefore, a PPR system. On the other hand, there is a water and municipal solid waste management category of urban services provided to end users, i.e. the LOW MSWMS. At this micro level, firms and consumers pay waste management costs constituting, therefore, a hybrid consumer-and-producer-pay-regime system. However, even within this category, the Portuguese National Regulatory Authority for Water and Waste Services (ERSAR) documents that firms' activities are the most relevant contributors to the aggregate tax revenue.[5]

Table *I* describes different types of waste collection points per HIGH MSWMS in Portugal. Nowadays, there are 23 HIGH MSWMS in Portugal, being 12 multimunicipal and 11 intermunicipal.[6] The Portuguese HIGH MSWMS are characterized by market discrepancy with respect to the number of municipalities that comprise, area and population covered and socioeconomic conditions of the population served (APA 2013). Moreover, each Portuguese HIGH MSWMS has different waste infrastructures, namely landfills (L), sorting centers (SC), transfer centers (TC), ecocenters (EC), ecopoints (EP), energy recovery centers (ERC), organic recovery centers (ORC) and mechanical biologic treatment stations (MBT). In 2012, 34 landfills, 29 sorting centers, 81 transfer centers, 190 ecocenters, 37971 ecopoints, 2 energy recovery centers, 11 organic recovery fa-

[5] In Portugal, waste management systems are classified with the designations of 'HIGH' or 'LOW', according to territorial criteria and extent of waste treatment, respectively. Within each community, there are waste removing municipal firms whose objective is to guarantee the collection of domestic waste from 'small' collection points. This constitutes the scope of LOW MSWMS. In these micro systems, consumers pay a residual tax through water consumption fees which corresponded, in average, to 4.01 euros per user in 2012 (ERSAR 2014). Moreover, once the domestic waste is collected inside a community, the scope of HIGH MSWMS is to transport the waste collected to 'larger' infrastructures in order to guarantee the corresponding storage, treatment and recovery of waste. HIGH MSWMS are also responsible to directly collect, transport, store, treat and recover specific types of waste. As a result, HIGH MSWMS constitute multimunicipal or intermunicipal macro systems. In the analysis of Bárcena-Ruiz and Casado-Izaga (2015) and in ours as well, the waste collection point corresponds to the large facility composing HIGH MSWMS.

[6] A distinctive factor within HIGH MSWMS is the legal form of management. In multimunicipal management systems, a state concession is granted to private companies. In intermunicipal management systems, municipalities transfer the management system to associations of municipalities, intermunicipal companies that are fully or partially public and/or private concessions.

cilities and 7 MBT stations compose the total number of waste collection points in Portugal.

Table I: Different waste collection points per HIGH MSWMS in Portugal.

HIGH MSWMS	L	SC	TC	EC	EP	ERC	ORC	MBT
Valorminho	1	1	1	2	470	-	-	-
Resulima	1	1	1	2	912	-	-	-
Braval	1	1	1	2	1131	-	-	-
Resinorte	5	4	8	15	3282	-	1	-
Lipor	1	1	-	21	3565	1	1	-
Ambisousa	2	3	2	8	756	-	-	-
Suldouro	1	1	-	4	1489	-	1	-
R. Nordeste	1	-	4	14	580	-	-	1
Valorlis	1	1	3	4	984	-	-	1
Ersuc	3	2	6	7	3557	-	-	1
Ecobeirão	1	1	3	19	1334	-	1	1
Reisistrela	1	1	8	14	625	-	1	-
Valnor	2	1	7	13	1346	-	1	-
Valorsul	2	2	6	8	5537	1	1	-
Ecoleziria	1	-	2	4	366	-	-	-
Resitejo	1	1	3	9	1201	-	1	-
Tratolixo	1	-	3	2	4406	-	-	1
Amarsul	2	2	1	7	2378	-	1	-
Gesamb	1	1	4	7	652		-	1
Ambilital	1	1	4	7	505		-	-
Amcal	1	1	2	4	111		-	1
Resialentejo	1	1	4	5	380		-	-
Algar	2	2	8	2	2404		2	-
Total	34	29	81	190	37971	2	11	7

Source: APA (2013) and ERSAR (2014)

As explained in Bárcena-Ruiz and Casado-Izaga (2015), "(...) we consider just a waste collection point and not a landfill as a landfill generates negative externalities and because of these effects it would be located outside the residential area". Hence, we disregard landfills in addition to ecocenters and ecopoints due to their reduced dimension to ensure that both studies are aligned and, consequently, we only focus on large sanitary waste facilities. It is now important to stress out that none of the relevant waste facilities is located in the middle of a Portuguese city. Moreover, some regional jurisdictions already had firms operating before the construction of the respective waste facility and the Portuguese legislation establishes that producers are the entities responsible to pay waste management costs.[7] Summarizing, simple observation of the Portuguese HIGH

[7] We also exclude ecocenters and ecopoints since these do not constitute large waste facilities. For details on the Portuguese legislation, see Article 5, n^o. 1 of Decree Law 178/2006 of 5^{th} September 2006, amended and republished in Article 3 of Decree Law 73/2011 of 17^{th}

MSWMS indicates that Bárcena-Ruiz and Casado-Izaga (2015) are modeling an exception rather than the rule in terms of the optimal location of a waste facility in a PPR system.

The remainder of the paper is organized as follows. Section 3 presents the model. Section 4 describes the main results. Section 5 compares our results with those of Bárcena-Ruiz and Casado-Izaga (2015). A robustness check is exposed in Section 6. Section 7 concludes.[8]

3 Model

Consider a duopoly with horizontally differentiated firms dealing with two types of decision: short-term (i.e., price) and long-term (i.e., location). The goal is to confirm the following claim.

Claim 1. *In a PPR system, the location of a waste collection point is not restricted to the center of a city.*

On the demand side of the market, an unitary density of consumers is uniformly distributed along the interval $[0, 1]$.[9] Consumers inelastically demand one unit of product and incur a quadratic transportation cost relatively to distance td^2, where t measures the transportation cost of consumers per unit of distance,[10] $t > 0$ and d^2 is the squared distance travelled by a single consumer from its home (x) to one of the two possible locations (a if attending to firm A or b if attending to firm B, respectively). Each consumer derives surplus from consumption, gross of price and transportation cost, denoted by v which is assumed sufficiently large to ensure full market coverage.

On the supply side of the market, two producers indexed by i, $i = \{A, B\}$, are respectively located at a and b, $\{a, b\} \in \mathbb{R}$. Note that $a < b \cup a > b$ holds,

June 2011. The exception occurs in the management of municipal waste whose daily output does not exceed 1100 liters per producer. Transcribing this to the Portuguese classification of MSWMS, HIGH MSWMS are responsible to daily outputs exceeding 1100 liters per producer, ensured inside and outside municipalities and constituting a PPR. LOW MSWMS are responsible to daily outputs not exceeding 1100 liters per producer, ensured inside communities by waste removing municipal firms. As a result, Portugal constitutes a good proxy to support our research. On one hand, it constitutes an adequate case-study where a PPR system has been implemented. On the other hand, none of large waste collection points is located in the center of a city.

[8]For the sake of brevity, we relegate to the Online Appendix the formal analysis of the PPR system and respective proofs, we present additional factors in favor of the implementation of waste collection points in peripheral zones under ex-ante regulation and expose the statistical exercise confirming that the equilibrium location of the waste facility under partial ex-post regulation is resilient to the observed heterogeneity between different HIGH MSWMS in Portugal.

[9]This interval corresponds to the ex-ante product space of characteristics occupied by consumers. Alternatively, in the traditional sense of location theory, it can be interpreted as the residential area of consumers.

[10]Variable t introduces product differentiation in one dimension: distance between consumers' location and firms' location. This distance is materialized in transportation costs incurred by consumers that can be direct (e.g., fuel cost, bus ticket) and/or indirect (e.g., time required to travel). Hence, t can be interpreted as an inverse measure of the degree of market competitiveness such that the lower t is, the fiercer is competition between firms.

i.e. leader A chooses location a and then follower B chooses location b that may be at the right or at the left of A's location. Locations a and b measure the distance of both firms from the left endpoint of the city.[11]

In what follows, let us present the model for $a < b$. Nevertheless, a simple relabeling allows to describe demands, profits and surpluses for $b < a$. Assume that, once each firm chooses the respective location, this cannot be changed in the future. Both firms produce the same identical good, differentiated in the eyes of consumers by the location and price of producers.

The indirect utility of a generic consumer located at $x \in [0,1]$ choosing to buy from A is given by

$$u^A(x) = v - p^A - t(x-a)^2, \tag{1}$$

while the indirect utility of the same consumer choosing to buy from B is given by

$$u^B(x) = v - p^B - t(b-x)^2, \tag{2}$$

where $p^i \geq 0$ is the price of firm i. Without loss of generality, we normalize firms' marginal cost to zero.

Following Bárcena-Ruiz and Casado-Izaga (2015) assume that the waste collection point is located at $r \in \mathbb{R}$. Moreover, assume that the production of the good involves the generation of waste that must be transported from each firm to the waste collection point. Consequently, if a firm is located at a positive distance from the location of the waste collection point, then the firm will incur in waste transportation costs. The waste transportation costs are quadratic with respect to the distance travelled from each firm to the waste collection point and proportional to the amount of market share. Formally, the waste transportation cost of firm A and B is given by

$$\begin{cases} M^A = g(a-r)^2 D^A; \\ M^B = g(b-r)^2 D^B, \end{cases} \tag{3}$$

where g represents the positive cost or effort of waste transportation assumed to be equal between firms, $g > 0$.[12] The location of the indifferent consumer is given by

$$u^A(\widetilde{x}) = u^B(\widetilde{x}) \Rightarrow \widetilde{x}(p^B, p^A, b, a) = \frac{a+b}{2} + \frac{p^B - p^A}{2t(b-a)}. \tag{4}$$

[11] In contrast, Hotelling (1929) and the vast majority of related frameworks consider that locations a and b measure the distance of firms from the left and right endpoints of the city, respectively.

[12] High g means that the amount of waste generated per unit of good produced is very costly, which implies higher effort on firms' side once transporting this kind of waste to the collection point (e.g., inflammable waste, hazardous waste). Low g or, in limit, $g \to 0$ means that transporting the waste is not too costly or, in limit, free (e.g., lower transportion effort is applied to biodegradable waste). Moreover, g can be interpreted as the time spent by firms on waste disposal. This variable represents an inverse measure of the degree of market competitiveness such that the lower g is, the fiercer is competition between firms.

Consumers located to the left of $\widetilde{x}$ prefer to buy from A, while consumers located to the right of $\widetilde{x}$ prefer to buy from B. Demands are then given by

$$D^A(p^B, p^A, b, a) = \begin{cases} 1, \ \widetilde{x} > 1; \\ \widetilde{x}(p^B, p^A, b, a), \ 0 \leq \widetilde{x} \leq 1; \\ 0, \ \widetilde{x} < 0, \end{cases} \tag{5}$$

and

$$D^B(p^B, p^A, b, a) = \begin{cases} 0, \ \widetilde{x} > 1; \\ 1 - \widetilde{x}(p^B, p^A, b, a), \ 0 \leq \widetilde{x} \leq 1; \\ 1, \ \widetilde{x} < 0. \end{cases} \tag{6}$$

The profit of firm i is given by

$$\pi^i = p^i D^i - M^i. \tag{7}$$

Consumer surplus (CS) is given by

$$CS = v - p^A D^A - p^B D^B - \int_0^{\widetilde{x}} t(x-a)^2 dx - \int_{\widetilde{x}}^1 t(b-x)^2 dx, \tag{8}$$

where $\widetilde{x}$ is the location of the indifferent consumer between buying from A or B. The regulator defines the location r of the waste collection point targeting social welfare maximization. Social welfare (W) consists in the sum of producer surplus and consumer surplus

$$W = \pi^A + \pi^B + CS. \tag{9}$$

Social welfare does not depend on prices since these correspond to a mere transfer from consumers to producers. The timing structure of the game is motivated by the arguments exposed in Section 2 and given as follows. In the first stage, leader A chooses location a to maximize π^A. In the second stage, regulator R decides location r of the waste collection point to maximize W or, similarly by duality, to minimize total transportation costs (TTC). In the third stage, follower B decides location b to maximize π^B. In the last stage, both firms engage in price competition. The game is solved through the backward induction method.

4 Analysis

4.1. Subgame perfect Nash equilibrium

After solving the game, the presence of two 'symmetrically asymmetric' equilibria is verified depending on whether $a < b$ or $b < a$ is assumed. For ease of exposition, we do not present both location equilibria in the main text since these correspond to mirror images of each other. In what follows, let us focus on the equilibrium holding for $a < b$.

Proposition 1. *Let $\{a,b\} \in \mathbb{R}$, $\{t,g\} \in \mathbb{R}_+$ and $a < b$. The subgame perfect Nash equilibrium (SPNE) with partial ex-post regulation is described as follows.*

$\forall \frac{t}{g} \in \left(0, \frac{5}{27}\right]$:

$$\begin{cases} (a^*, b^*, r^*) = \left(\frac{7}{6} - \frac{11t}{3(g+t)}, -\frac{141}{30} + \frac{81t}{30g} + \frac{176g}{30(g+t)}, \frac{7}{6} - \frac{75t}{20g} + \frac{81t^2}{20g^2}\right); \\ \left(p^{A*}, p^{B*}\right) = \left(\frac{t^2(5g+27t)\left(605g^3 - 111g^2t - 729gt^2 + 2187t^3\right)}{3600g^3(g+t)^2}, \frac{t^2(5g+27t)^2\left(73g^3 - 102gt + 81t^2\right)}{3600g^3(g+t)^2}\right); \\ \left(D^{A*}, D^{B*}\right) = \left(\frac{5}{6} - \frac{9t}{10g}, \frac{1}{6} + \frac{9t}{10g}\right); \\ \left(\pi^{A*}, \pi^{B*}\right) = \left(\frac{(25g-27t)^2t^2(5g+27t)}{4500g^3(g+t)}, \frac{t^2(5g+27t)^3}{4500g^3(g+t)}\right); \\ CS^* = v - \frac{t(9500g^4 - 63625g^3t + 301725g^2t^2 - 360855gt^3 + 255879t^4)}{18000g^3(g+t)}; \\ W^* = v - \frac{t(1900g^4 - 15325g^3t + 50625g^2t^2 - 54675gt^3 + 19683t^4)}{3600g^3(g+t)}. \end{cases}$$

$\forall \frac{t}{g} \in \left[\frac{5}{27}, +\infty\right)$:

$$\begin{cases} (a^*, b^*, r^*) = \left(\frac{1}{2} + \frac{g}{9(g+t)}, \frac{3}{2} - \frac{8g}{9(g+t)}, \frac{11}{18}\right); \\ \left(p^{A*}, p^{B*}\right) = \left(\frac{t^2(109g+108t)}{81(g+t)^2}, \frac{2t^2(59g+27t)}{81(g+t)^2}\right); \\ \left(D^{A*}, D^{B*}\right) = \left(\frac{2}{3}, \frac{1}{3}\right); \\ \left(\pi^{A*}, \pi^{B*}\right) = \left(\frac{8t^2}{9(g+t)}, \frac{2t^2}{9(g+t)}\right); \\ (CS^*, W^*) = \left(v - \frac{t(31g+423t)}{324(g+t)}, v - \frac{t(31g+63t)}{324(g+t)}\right). \end{cases}$$

Proof. Consult the Online Appendix.

To maintain consistency in the terminology throughout the manuscript, let us designate the transportation cost of consumers t as transportation cost or product differentiation and the transportation cost of firms g as waste cost. The strategic interpretation of the model is explained by three main effects: demand or market size effect pushes both firms towards the city center due to the expectation of increasing membership through the reduction of consumers' transportation cost; price or competitive effect induces each firm to locate further away from the rival to soften price competition; waste cost reducing effect induces both firms to locate next to the waste collection point to obtain cost savings. The first two strategic effects are standard in linear city models. The third one reflects that an increase in waste cost implies a reduction of productive efficiency or, similarly, an increase in cost inefficiency. Consequently, both firms may have the incentive to reduce the waste cost by moving towards the location of the waste facility under specific circumstances.

Proposition 1 highlights two facts. First, the waste cost reducing effect is referred as a centripetal effect in Bárcena-Ruiz and Casado-Izaga (2015). This effect, however, is no longer centripetal in our game given that the waste collection point is located between firms' locations but never in the city center, thereby implying that Claim 1 cannot be rejected. Second, the leader faces tougher competitive pressure for a sufficiently strong relative sensitivity of consumers towards product differentiation, i.e. the greater is t/g. When both firms are predominantly concerned on fighting for additional revenue rather than ensuring cost savings only the follower can internalize the location of the waste collection point, which allows it to take advantage of the observed information to skimp on the cost structure. The regulator is second-mover rather than first-mover, however, despite being influenced by the firm A's location decision, the regulatory decision also takes into account consumer preferences and future strategic interaction. Although follower B is able to effectively reply to the leader's location by internalizing the waste cost reducing effect, the standard Stackelberg outcome unambiguously holds in equilibrium such that the leader firm charges higher price, holds larger market share and obtains greater profit than the follower firm:

$$p^{A*} > p^{B*}, \quad D^{A*} > D^{B*}, \quad \pi^{A*} > \pi^{B*}.$$

4.2. Comparative statics

Let us explain the variability of the equilibrium locations, prices, market shares, profits, consumer surplus and social welfare in the domain of the relative transportation cost of consumers, t/g. Before that, we should interpret the meaning of this variable. This ratio corresponds to the transportation cost per unit of distance incurred by consumers in relation to the transportation cost per unit of distance incurred by firms. In the differentiation perspective, t/g below (above) one means that consumers' sensitivity towards product differentiation is lower (higher, respectively) than firms' sensitivity towards waste cost. In the physical or material perspective, t/g below (above) one means that the price per liter of diesel for consumers is lower (higher, respectively) than that for firms. In the temporal perspective, t/g below (above) one means that consumers' sensitivity towards the time spent on purchasing a differentiated product is lower (higher, respectively) than producers' sensitivity towards the time spent on waste disposal. If a low (high) ratio t/g means that transportation cost is excessively low (high) relatively to waste cost, then firms should give additional attention to their cost (revenue) structure as $t/g \to 0$ ($t/g \to \infty$) reflecting therefore fierce competition to save costs (acquire revenue, respectively).

4.2.1. Locations

Figure 1 shows the equilibrium location of the leader, waste collection point and follower in the domain of the variable t/g. We identify a monotonic relationship between the leader's location and ratio t/g, whereas a non-monotonic relationship between the follower's location and ratio t/g is observed.

FIG 1 [HERE]

Fig. 1. Equilibrium locations of the leader (black line), waste collection point (red line) and follower (blue line) in the domain of the variable t/g.

Three cases should be highlighted from a static point of view. When $t/g \to 0$, both firms exhibit an extremely high concern with cost reduction. Moreover, the waste collection point is located outside the residential area, which lessens the fear of social dissidence. This justifies the birth of industrial zones in peripheral regions since the equilibrium is characterized by *minimum differentiation outside consumers' residential area*

$$(a^*, r^*, b^*) = \left(\frac{7}{6}, \frac{7}{6}, \frac{7}{6}\right).$$

When $t/g \to 5/27$, consumers' sensitivity is still lower than firms' sensitivity. Interestingly, the follower chooses to be positioned in a location that maximizes social welfare in standard models of location choice. The waste collection point is located close to the leader's location, but further away from the city center. The equilibrium is characterized by *symmetric differentiation inside consumers' residential area.*

$$(a^*, r^*, b^*) = \left(\frac{19}{32}, \frac{11}{18}, \frac{3}{4}\right).$$

When $t/g \to +\infty$ or $g/t \to 0$, both firms exhibit an extremely high concern with revenue acquisition. Consequently, the leader firm has no incentive to move away from the city center, while the follower firm has the incentive to be located further away from the leader's location. Firms differentiate maximally such that A is located in the city center, while B is located outside the residential area to fully exploit product differentiation. Moreover, the regulator is not influenced by the leader's decision since this would harm social welfare due to the decrease in consumer surplus. The equilibrium is characterized by *asymmetric differentiation with the leader (follower) located in the city center (outside consumers' residential area, respectively).*

$$(a^*, r^*, b^*) = \left(\frac{1}{2}, \frac{11}{18}, \frac{3}{2}\right).$$

Let us now focus on the evolutionary perspective of t/g. Firm A is leader in location choice, which allows it to benefit from a first-mover advantage. Two conclusions should be then highlighted. First, the equilibrium location of firm A is inversely related to t/g. Second, a permanent fixation of the leader firm within a given city is justified by the fact that $t > g$ is frequently observed in reality (e.g., due to fuel supply discount cards for businesses). In turn, the location of the waste collection point is influenced by the firm A's location decision. The equilibrium location of the waste facility is adaptive for $t/g < 5/27$, while remaining constant otherwise. The regulator installs the waste facility in a biased location outside (inside) the residential area for a sufficiently low (high, respectively) t/g that neither corresponds to the city center nor collapses with firm A's location except if $t/g \to 0$ or $t/g = 1/9$. The waste collection point occupies a position to the right (left) of the city center for $a < b$ ($b < a$, respectively). Accordingly, it follows that the product space of characteristics occupied by the leader outweighs (does not outweigh) the product space of characteristics occupied by the follower for $a < b$ ($b < a$, respectively). Firm A is unambiguously located closer to the city center, while firm B is located further away from the city center, though not excessively, given that only firm B internalizes the waste cost reducing effect being therefore sufficiently differentiated from the rival, but positioned in a location sufficiently close to the waste collection point. This implies that firm B replies by positioning itself in a location closer (further away) from the city center for a sufficiently low (high, respectively) t/g.

4.2.2. Prices and market shares

Figure 2 shows the equilibrium price and market share of both firms in the domain of the variable t/g. In a static perspective, the price of the leader is unambiguously higher than the price of the follower and both firms charge above marginal cost: $p^{A*} > p^{B*} > 0$, $\forall t/g > 0$. In a dynamic perspective, the price gap between firms unambiguously increases in t/g: $\partial\left(p^{A*} - p^{B*}\right)/\partial(t/g) > 0$, $\forall t/g > 0$. In fact, the price charged by the leader is twice the price charged by the follower if the relative transportation cost of consumers converges to infinity: $p^{A*} = 2p^{B*}$ if $t/g \to \infty$.

Moreover, the leader firm unambiguously conquers the largest market share. However, the gap between market shares is decreasing in t/g as long as the relative transportation cost of consumers is sufficiently weak: $\partial\left(D^{A*} - D^{B*}\right)/\partial(t/g) < 0$, $\forall t/g < 5/27$. Otherwise, market shares remain constant such that $D^{A*} = 2D^{B*}$ holds, $\forall t/g > 5/27$. This suggests that the strategy pursued by the follower firm for $t/g > 5/27$ (i.e., to be located further away from the leader) ensures the persistence of a niche market.

FIG 2 [HERE]

Fig. 2. Equilibrium price and market share of the leader (black line) and follower (blue line) in the domain of the variable t/g.

4.2.3. Profits

Figure 3 shows the equilibrium profit of both firms in the domain of the variable t/g. A firm's profit increases by two means: either increasing the degree of horizontal differentiation or decreasing the waste cost. In a static perspective, the profit of the leader is unambiguously greater than the profit of the follower: $\pi^{A*} > \pi^{B*}$, $\forall t/g > 0$. In a dynamic perspective, the profit gap between firms unambiguously increases in t/g: $\partial\left(\pi^{A*} - \pi^{B*}\right)/\partial(t/g) > 0$, $\forall t/g > 0$.

FIG 3 [HERE]

Fig. 3. Equilibrium profit of the leader (black line) and follower (blue line) in the domain of the variable t/g.

In fact, the profit enjoyed by the leader is four times greater than the profit enjoyed by the follower if the relative transportation cost of consumers converges to infinity: $\pi^{A*} = 4\pi^{B*}$ if $t/g \rightarrow \infty$. Being a leader in location choice is extremely desirable under this circumstance because the price effect and demand effect vary positively such that the leader charges a sufficiently high price, while it acquires additional market share by moving towards the city center. In turn, the follower is forced to accommodate the leader's strategy by moving further away from the city center and waste facility in a location outside the residential area to continue serving a niche market, thereby ensuring no market exclusion and positive profit.

4.2.4. Consumer surplus and social welfare

Figure 4 clarifies that consumer surplus and social welfare are monotonic in t/g. For $t/g < 5/27$, the leader charges an increasing price and sustains a decreasing market share in t/g. Despite the follower holds an increasing market share, it also charges an increasing price in t/g. Since consumer surplus is negatively influenced by prices, it unambiguously decreases in t/g. Market shares remain constant, while both prices rise for $t/g > 5/27$. Hence, consumer surplus also decreases for this parameter space. Moreover, social welfare follows a similar pattern to consumer surplus. This is because the loss in consumer surplus unambiguously dominates the gain in producer surplus in the domain of the variable t/g: $|\partial CS/\partial\left(t/g\right)| > \partial PS/\partial\left(t/g\right)$, $\forall t/g > 0$. The level of social welfare for $a < b$ is similar to that holding for $b < a$. If $a < b$ becomes $b < a$, then the leader's product space of characteristics dominates the follower's product space of characteristics. However, this change corresponds to a neutral action on prices and market shares, which implies that producer surplus and consumer surplus remain unchanged. As a result, similar is applied to social welfare.

FIG 4 [HERE]

Fig. 4. Equilibrium consumer surplus and social welfare in the domain of the variable t/g.

5 Socially optimal waste regulatory regime

Our market environment corresponds to partial ex-post regulation, while the Bárcena-Ruiz and Casado-Izaga (2015)'s market environment corresponds to ex-ante regulation. In what follows, we aim to conclude which regulatory regime is most beneficial to society.[13]

Proposition 2. *Ex-ante regulation is unambiguously socially desirable in the Portuguese high municipal solid waste management system. Formally*

$$W^* < W^*_{BR\&CI(2015)}, \quad \forall t/g > 0.$$

Proof. Consult the Online Appendix.

Relevant conclusions can be inferred. Firstly, the transition from ex-ante regulation to partial ex-post regulation permanently harms social welfare. The reason is straightforward and summarized as follows. When the relative transportation cost of consumers is sufficiently high, producer surplus is unchanged. However, consumer surplus is reduced and, consequently, social welfare decreases in proportion to the reduction of consumer surplus. When the relative transportation cost of consumers is sufficiently low, producer and consumer surpluses are both reduced, hence, similar applies to social welfare. Secondly, there is a welfare loss in the aftermath of a regulatory policy accommodating private leadership regardless of whether consumers' transportation cost is similar to firms' waste cost. Therefore, regulatory leadership should always be considered to avoid the undesirable effect on social welfare. Thirdly, private leadership does not enhance the competitive pressure and toughness of price competition. Fourthly, the follower should always explore the informational advantage under private leadership since the correct internalization of the waste cost reducing effect may improve its profit. Fifthly, the necessity of finding an ideal location to waste facilities is currently a critical concern in national and transnational jurisdictions given the widespread willingness to satisfy the targets of the 2030 Agenda for Sustainable Development presented by the United Nations High Level Political Forum on 18 July 2017. In the Portuguese case, the sustainable development goals number 4 (Quality Education), number 5 (Gender Equality), number 9 (Industry, Innovation and Infrastructures), number 10 (Reducing Inequalities), number 13 (Climate Action) and number 14 (Protecting Maritime Life) constitute the main national priorities. Proposition 2 reveals that ex-ante regulation corresponds to the best regulatory practice to ensure the fulfillment of target 13. The waste regulator should always be first-mover in long run decisions, thus, permanently anticipating firms' strategic location or variety decisions to ensure that social welfare maximization is not compromised. If unable to do it, alternative forms of ex-ante regulation should be considered (e.g., imposition of minimum quality standards on waste treatment processes) given that a preemptive regulatory behavior is unambiguously beneficial for society.

[13] For the sake of brevity all the formal proofs, economic intuition and comparison of locations, prices, market shares, profits and consumer surplus between the two regulatory regimes are relegated to the Online Appendix.

Finally, Proposition 2 reveals a trade-off in waste regulation policy. The waste regulator ensures the highest level of social welfare if becoming first-mover, but from a theoretical point of view, ex-ante regulation requires to install the waste facility in the city center (Bárcena-Ruiz and Casado-Izaga 2015). Therefore, the paradox stems from the fact that a waste collection point located in the city center is rarely observable in reality, while ex-ante regulation applied to the waste industry is frequently observed as a means of ensuring the highest level of social welfare. More surprising yet, it is the delay in the regulatory decision on where to install the waste facility, which may be the result of regulatory uncertainty or inertia in the formulation of the waste policy, the driving force inducing the waste collection point to be located outside the city center. However, an intriguing observation is the recognition that the identified trade-off is often surpassed by the waste regulator in actual regulatory practice. Consequently, a robustness check should be provided to demonstrate that a first-mover regulator can maximize social welfare without necessarily imposing the city center as the optimal location of the waste facility.

6 Robustness

The robustness check process is developed in two separate steps. The complete analysis is relegated to the Online Appendix for the sake of brevity, but we briefly summarize it here. On the one hand, we highlight the presence of a direct effect under ex-ante regulation that discourages the persistence of a waste collection point in the middle of a city. This requires to provide an extensive look of additional factors (e.g., ex-ante environmental impact assessment, uncertainty, multi-criteria analysis and past experiences, heterogeneity of municipal plants) boosting the change in location of waste facilities to peripheral regions and a comprehensive review of the main appropriate methods and key economic, environmental and social aspects helping the design and selection of optimal areas for waste collection points. We conclude that all these extra attributes force the location of large waste facilities to alternative places other than the city center under ex-ante regulation. On the other hand, we emphasize the presence of an indirect effect under partial ex-post regulation that reinforces the persistence of a waste collection point in a biased location relative to the city center, thus, indirectly making less likely the presence of a waste collection point in the middle of a city if there is a transition from partial ex-post regulation to ex-ante regulation. This requires to confirm that the distortion in the optimal location of the waste collection point verified under partial ex-post regulation is resilient to the observed heterogeneity between different types of waste collection facilities or, similarly, that it remains qualitatively valid when the observed heterogeneity between different types of waste collection facilities is taken into account. If that is the case, the optimal biased location with representative or homogeneous waste collection point holds generality, thereby making less likely the presence of a waste collection point in the city center under ex-ante regulation due to the transmission of the biased location verified under partial ex-post regulation. Note that, in the benchmark analysis, HIGH MSWMS is treated as if holding a single representative waste collection point or, similarly, as if being composed by a set of homogenous waste collection points. However, waste collection points may be heterogeneous within a given HIGH MSWMS and each type of waste collection point may have different characteristics or distinct components across different HIGH MSWMS. This may be due to the fact that waste collection points are established in different locations, existence of different types of waste or implementation of distinct innovation processes within each HIGH MSWMS. The overall objective of this extension was reached and the methodology employed is summarized as follows. Firstly, we identify the main source of heterogeneity between the different Portuguese HIGH MSWMS by showing that the unique variable holding statistically significance to explain the observed heterogeneity is the "annual variation in the amount of R&D investment". Secondly, we conclude that the observed heterogeneity between the different Portuguese HIGH MSWMS does not influence the equilibrium location of the waste facility clarified in Proposition 1 due to the weak and statistically insignificant correlation between variable "annual variation in the amount of R&D investment" and variable "distance of the different waste collection points held by each Portuguese HIGH MSWMS with respect to the city center".[14] This implies the discovery of evidence that the biased location of a representative or homogeneous waste collection point is resilient to the observed heterogeneity between different HIGH MSWMS. Consequently, the equilibrium location of a representative or homogeneous waste collection point in a country characterized by partial ex-post regulation holds generality, thereby validating that the respective biased location is applied to a broader market environment and allowing to infer that the pass through of the biased location is likely to persist when the regulatory regime moves from partial ex-post regulation to ex-ante regulation, thus, making less likely the presence of a waste facility in the city center when the welfare maximizer regulator is first-mover.

7 Conclusions

This study shows that the location of a waste collection point is not restricted to the middle of a city in a PPR system. This result is consistent with the observation of the location decisions of waste collection points in Portugal. The result emerges from the fact that a certain firm may already be operating before the introduction of waste regulation or, alternatively, due to the anticipation of the regulatory decision on where the waste collection point is installed. This research also contributes to Industrial Organization literature, in particular to the topic of horizontal product differentiation with sequential location decisions between private firms and regulator. When a private firm assumes the role of first-mover, the analysis reveals the existence of negative effects on consumer

[14] The first step requires the use of hierarchical cluster analysis (HCA) and analysis of variance (ANOVA), while the second step results from the observation of Pearson's correlation matrix for each cluster found.

surplus, producer surplus and social welfare. This finding assumes significant relevance in cities where consumers are unprotected due to legal loopholes.[15] In this sense, the aim of this research is not to propose a decision model for the location problem. Instead, we identify a potential market failure problem in policymaking. The inability to credibly commit to a location by acting as first-mover limits the ability of a regulator to achieve an efficient geographic configuration of the market. If location commitment is not achievable, the policymaker should consider alternative forms of ex-ante regulation to avoid perverse effects on social welfare. Finally, we identify a trade-off in waste regulation policy which consists of observing that the highest level of social welfare requires ex-ante regulation, but from a theoretical point of view, this regulatory regime requires the implementation of a waste collection point in the city center. We then demonstrate that a first-mover regulator surpasses the imminent paradox in actual regulatory practice.

Two extensions should deserve future consideration. Firstly, the introduction of incomplete information. The cost structure of a firm is largely influenced by waste costs. Usually, a firm is uninformed about rival's time spent on waste disposal. Imagine that a firm has private information about its waste marginal cost. The rival internalizes the information gap, while the informed firm internalizes the lower information observed by the rival. This requires to solve a static Bayesian game to find a Bayesian-Nash equilibrium. In the traditional setting exposed in Tirole (1988), we should solve a game where, say firm B, truly knows its waste cost g, while firm A believes that firm B has marginal waste cost g^H with probability $1-\lambda$ or marginal waste cost g^L with probability λ, $g^L < g^H$. Note that, if we assume that firm B is first-mover, then it will never benefit from the cost reducing effect because the regulator is second-mover. Subsequently, follower A internalizes this outcome meaning that one expect that incomplete information may not play a significant change in our main finding. However, if we assume that follower B is third-mover, then leader A turns to be worried with the role of incomplete information. In a Bertrand game with strategic complements, incomplete information may increase (reduce) equilibrium prices if the informed firm is high-cost (low-cost, respectively). Moreover, an increase in the probability of follower B being low-cost may reduce equilibrium prices irrespective of whether the firm is low-cost or high-cost. Hence, incomplete information may or not be against the centripetal force described in Bárcena-Ruiz and Casado-Izaga (2015). Secondly, the analysis of different types of regulatory behavior. In our model the regulator is second-mover, but also naive in the sense that the perverse effect on social welfare is not anticipated. A sophisticated regulator may develop an adequate zoning policy to anticipate it. Finally, the present analysis relies on a rather stylized model as it has the main goal to infer the relation between ideal timing of the waste regulatory decision, optimal location of the waste facility and social welfare maximization. To meet this ob-

[15] If a legal loophole exists, by definition, the policymaker cannot "manipulate the timing of the location game and force simultaneous choice when is very concerned with firms' profits or a sequential choice when is very concerned about the consumer surplus" (Bárcena-Ruiz and Casado-Izaga 2015).

jective in the clearest possible way, we took a partial equilibrium analysis and, consequently, a number of other relevant issues was neglected, in particular the fact that waste disposal may be subject to certain activities that may cause harsh environmental damage (e.g., illegal dumping). As such, keeping in mind the simplifying assumptions and the limitations of our approach, it seems interesting to take this concern in future research by introducing a representative variable of environmental damage in the social welfare formula.[16]

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[16] We thank an anonymous reviewer for pointing out this important fact to us.