Optimal Municipal Solid Waste Taxation with Waste Picking

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Abstract

In many countries around the world, Municipal Solid Waste (MSW) management is shared between formal and informal sectors. The formal sector (public or private) collects, recycles and disposes of waste, while the informal sector is involved only in the collection and recycling of waste, that is, waste picking. This paper proposes a comprehensive model of the incentive policy whereby MSW is managed by two sectors. We first show that if waste-picking activities are significant and cannot be monitored, the user fee on disposal is inefficient because of illegal dumping. Second, we show that the first-best optimum can be achieved using a Deposit and Refund System policy targeted at the informal sector (informal DRS. The regulator can achieve this optimum by levying tax on consumption goods equal to the marginal social cost of disposal (Deposit), and thus subsidize both waste picking and formal recycling activity (Refunds).

Key words: Municipal Solid Waste Management, Waste Pricing, Deposit and Refund System, Waste Picking, User Fees.

JEL codes: D62, H23, H31, H32, L13

Introduction

How can developing countries finance sustainable MSW management? Over the past few years, this question has increasingly become the central issue in sustainable waste management discussions. Indeed, the World Bank (2012) estimates that by 2020-2025, and at the current

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level of service, the costs required to pursue MSW management will be multiplied three to four times in low- and middle-income countries, versus 1.4 times in high-income countries. Financing through incentive pricing, as has occurred in OECD countries over the past three decades, may be a solution. Incentive MSW pricing is an economic tool, such as the user fee (well known as Pay as You Throw, PAYT), the Extended Producer Responsibility (EPR), or a Deposit and Refund System (DRS).[2] It allows the release of resources in a sustainable way and encourages economic agents in waste reduction and recycling. Unfortunately, the existing studies fail to provide a comprehensive framework within which policy recommendations can be provided to developing countries. The available frameworks do not take into account the fact that MWS management is shared between formal and informal sectors in many developing countries: a phenomenon known as "waste picking".[3]

To date, the literature has mainly studied the optimal, equivalence and complementarity conditions of incentive tools. However, there are two implicit assumptions that underlie their funding: first, all stakeholders in MSW management are formal, that is, taxable, and recognized by the public authority; and second, recycling is free of social cost. Of all authors, only Ino (2011) considers the possibility of illegal dumping by recycling firms. If these two assumptions are plausible in developed countries, this is not in fact the case in developing countries (including transition ones) where the activity of the informal sector[4] is estimated to be between 17.5% and 38.4% GDP (Schneider, Buehn, & Montenegro, 2010).

[2] The PAYT allows for proportional tax on disposal waste. The EPR is a program by which the government assigns the financial or physical responsibility to producers for the treatment or disposal of their products at their end of life. The DRS is a combination of a tax (Deposit) on products due to their disposal cost, and a subsidy (Refund) on recycling as a reward for the avoidance of disposal.

[3] For example, see Dubois & Eyckmans (2014), Ino (2011), Fleckinger & Glachant (2010), Kinnaman (2010), Calcott & Walls (2005), Runkel (2003), Choe & Fraser (1999), Fullerton & Wu (1998), Palmer & Walls (1997), and Fullerton & Kinnaman (1995).

[4] All informal activities together.

Generally, the magnitude of informal activities highlights the pollution phenomena complexity and limits the effectiveness of environmental policies (Mazhar & Elgin (2013); Chattopadhyay, Banerjee & Millock (2011); Baksi & Bose (2010); Chaudhuri & Mukhopadhyay (2006); Blackman (2000)). In terms of MSW management, the incentive MSW policy efficiency has empirically been dependent on the magnitude of waste picking. Even on a small scale, public authorities are required to conduct expensive control activities to ensure the effectiveness of their policies. Despite these activities, waste-picking costs were US$2 and $4.5 million for the Los Angeles and New York recycling programs, respectively, in the 1990s (Mitchell (1995); Anonymous (1995)).[5] More recently, MSW management modernization programs in Cairo (Egypt) and New Delhi (India) were challenged by waste picking (Ezeah, Fazakerley, & Roberts (2013); Wilson et al. 2009)).

The purpose of this paper is to complete the previous literature on optimal MSW management policy by adapting Ino's (2011) analytical framework to the context of developing countries where formal recycling firms and waste pickers coexist. We formalize formal and informal (waste pickers) recycling firms that differ in productivity, where the regulator can raise taxes or subsidize the formal firms only. In addition, the regulator cannot monitor informal firms, in either recycling or in waste disposal. We study the optimal conditions in "perfect" competitive markets by considering the dualist and the structuralist formal-informal relationship.

Our results show that if waste-picking activities are significant and cannot be monitored, there is an optimal policy to deal with both MSW environmental concerns and informal recycling. In particular, we show that a user fee is inefficient because of the illegal dumping carried out by informal firms. Second, we show that the first-best optimum can be matched by using a Deposit and Refund System policy targeted at the informal sector (informal DRS). The regulator can do

[5] Cited by Medina (2001).

this by levying a tax on consumption goods equal to the social marginal cost of disposal (Deposit), and can subsidize both waste picking and formal recycling activity (Refunds). The regulator then sets the formal recycling refund equal to the Deposit and the waste-picking refund equal to the Deposit, less its marginal social cost.

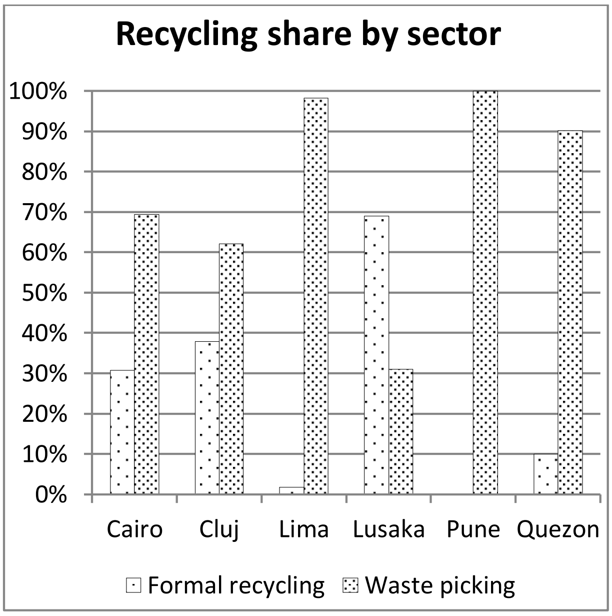
The rest of this paper is organized as follows. In Section 1, we provide a brief description of waste picking in developing countries. Section 2 introduces the model's assumptions. Section 3 then characterizes the market equilibria and Section 4 provides the optimal conditions of the Informal Deposit and Refund System. Section 5 concludes.

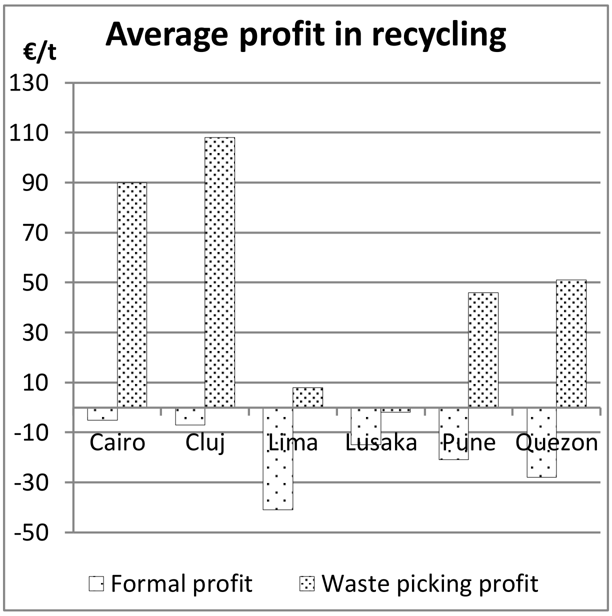
1. Waste-picking activities in developing countries

MSW management is a public economy activity where the informal sector is extremely active in developing countries. Since the 2000s, the magnitude of this activity has led to the development of descriptive studies. Waste picking as an occupation is a well-known phenomenon, with waste pickers known in various countries as, for example, Zabbaleen (Egypt), Cartoneros (Argentina and Brazil), Chifonye (Haiti), Kacharawala (India), Tokai (Bangladesh) Kabaris (Pakistan), Pepenadores or Catroneros (Mexico), Basuriegos or Traperos (Colombia), Boujouman (Senegal), Kaya Bola (Ghana), and Pemulung (Indonesia). Waste picking is identified as referring to the collection, sorting and reusing of waste material recovered by individuals (or family groups), or by collectors who are not recognized by municipalities. This phenomenon is characterized by intensive labor, low technology, low-paid, unregistered and unregulated work. It is largely the result of economic and social factors, such as poverty, social exclusion, rural migration, immigration, long-term unemployment, unskilled labor, and a lack or absence of legal collection[6] (Ezeah, Fazakerley and Roberts (2013); Wilson,

6 In the Middle East and North African (MENA) countries, for example, MSW legal collection is estimated to be about 40-100% in urban areas and about 5-90% in rural areas (Arif, 2010).

Velis and Cheeseman (2006)). The graphs below indicate the formal recycling and waste-picking activities estimated by CWG[7] and GIZ[8] in the cities of some developing countries. Waste picking has the same environmental benefits as formal recycling; that is, it reduces virgin materials and energy consumption, minimizes waste disposed of, and so on. In addition, it has economic benefits, which mainly include providing jobs and income to poor populations. About 0.5%-2% of urban populations gain their livelihood from this activity (Wilson et al. (2012), Medina (2008; 2000)). In addition, waste picking avoids external costs for MSW management in developing countries, which is estimated to be about 2.4-7.3 million Euros in six cities[9] (Gunsilius, Chaturvedi, & Scheinberg, 2011).





Source: Gunsilius, Chaturvedi, & Scheinberg, (2011)

Figure 1: Formal recycling and the share and profit of waste picking

However, the informal character of waste picking provides the opportunity for illegal dumping, the use of dirty technologies with significant risks to public health and the environment, and the exposure of workers to occupational hazards. In this regard, the recycling of electronic waste

[7] Collaborative Working Group on Solid Waste Management in Low- and Middle-income Countries
[8] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.
9 Cairo (Egypt), Lima (Peru), Lusaka (Zambia), Cluj-Napoca (Romania), Pune (India) et Quezon (Philippines)

is critical. Rudimentary dismantling techniques,[10] although efficient, can release harmful substances into the air (for example, lead, cadmium, mercury, and GHG), and contaminate the soil and groundwater. Waste pickers are the first to be exposed to such health risks. The risk of injury, parasitic, infectious and respiratory diseases are 2-10 times more prevalent in these workers than for the rest of the population (UN-HABITAT (2010a-2010b); Cointreau (2006)). In addition, child labor is common. Ultimately, waste pickers have no social security, and work between 6-10 hours a day, on average (Asima et al, (2012); Gunsilius (2012), Medina (2008) UN-HABITAT (2010b); Fahmia & Sutton (2006)). Waste picking is desirable for both economic and environmental benefits however, it is undesirable in terms of the social cost of emissions, health and social risks.

The current picture of MSW management in most developing countries is similar to the France of M. Poubelle (1884),[11] where the formal sector coexists with waste picking. Waste pickers can operate autonomously (for example, collecting, recycling, and selling on the local or international markets), and are therefore in competition with formal recycling firms. On the other hand, both informal and formal sectors have the possibility of cooperating, whereby formal recycling firms would play an intermediary role between waste pickers and the local or international Secondary Raw Materials (SRM) markets. Waste pickers are said to be the basis of a hybrid pyramid scheme where informal and formal activities are dynamically linked (Oteng-Ababio, Arguello & Gabbay (2013), Tirado-Soto & Zamberlan (2013) and Wilson Velis, and Cheeseman (2006)).

[10] It is customary to open burnt electronic waste in order to recover valuable metals, such as copper, steel and aluminum (UNEP 2009).
[11] M. Eugène Poubelle is the prefect of Paris who invented the trash.

Since the 1990s, several international organizations[12] have promoted Integrated and Sustainable Waste Management (ISWM) towards the improvement of MSW management in developing countries. ISWM desires that all stakeholders in MSW management, including waste pickers, are involved in MSW management strategy, which prompts the following questions: how can waste pickers be involved in MSW strategy, such as an incentive pricing policy? and, what are the consequences of such a policy on the size and relationship between formal recycling firms and waste pickers? Analyses in the following sections aim to provide some answers to these questions.

2. The model

2.1. Consumers

A small and open economy is composed of m $(k = 1, 2 \ldots, m)$ representative households[13] with a utility function: $U_k(x_k^d) + y_k$ Where x_k^d represents household k's demand for homogeneous goods exchanged in the market and y_k represents household k's demand for numeraire. $U_k\colon \mathbb{R}_+ \longmapsto \mathbb{R}$ strictly increase and are strictly concave. To restrict our focus, we consider that the consumption of y does not generate waste and, contrary to Ino (2011), compliant households do not illegally dump waste.[14] We assume a material balance[15] for the consumption of x: household k can provide the amount r_k^s to recycling firms and earn $P_r \in \mathbb{R}$[16] after having sorted its wastes with cost $Cr\colon \mathbb{R}_+ \longmapsto \mathbb{R}_+$ that is strictly increasing and strictly convex; or can legally

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[12] Collaborative Working Group on Solid Waste Management in Low- and Middle-Income Countries, World Bank, UN-Habitat, Sweep-net.
[13] Households alternatively demand consumption goods x and supply recyclable materials r. The superscripts d and s mean households' demand and supply, respectively.
[14] This is a common assumption in the literature. The legal disposal cost τ can be kept low in order to discourage illegal waste disposal. Being rational and having a concave utility function, it is assumed that households do not illegally dispose of waste when τ is lower than the average fine for illegal disposal. This allows us to put aside the monitoring problem that is already considered in Ino (2011).
[15] The material balance hypothesis is common in optimal MSW policy literature. It assumes that one unit of good generates one unit of residuals after consumption; see Kinnaman (2010), Aalbers & Vollebergh (2008), and Palmer & Walls (1997).
[16] Households can pay recycling firms to avoid paying the user fee. In this case P_r is negative.

eliminate the amount z_k and pay for $\tau \in \mathbb{R}_+$, such as $x_k^d = r_k^s + z_k$. The representative household program is defined as follows:

$$\begin{cases} \max_{x_k^d, y_k, r_k^s, z_k} U_k(x_k^d) + y_k \\ \quad s.t. P_x x_k^d + y_k + \tau z_k + Cr_k(r_k^s) \leq I_k + P_r r_k^s \\ \quad x_k^d = r_k^s + z_k \end{cases}, \tag{1}$$

where I_k is household's income, P_x and P_r are the market price of goods and Recyclable Materials (RM). First-order conditions for representative household are defined by:

$$U_k'(x_k^d) = P_x + \tau \tag{2}$$

$$Cr_k'(r_k^s) = P_r + \tau. \tag{3}$$

On the same grounds as Ino (2011), we assume $0 < r_k^s < x_k^d$. Therefore, the aggregate demand for goods and the aggregate supply of residuals (RM) are defined with the inverse functions:

$$x_k^d(P_x; \tau) = U_k'^{-1}(P_x + \tau) \tag{4}$$

$$r_k^s(P_r; \tau) = Cr_k'^{-1}(P_r + \tau) \tag{5}$$

$$X^d(P_x; \tau) = \sum_{k=1}^{m} U_k'^{-1}(P_x + \tau) \tag{6}$$

$$R^s(P_r; \tau) = \sum_{k=1}^{m} Cr_k'^{-1}(P_r + \tau). \tag{7}$$

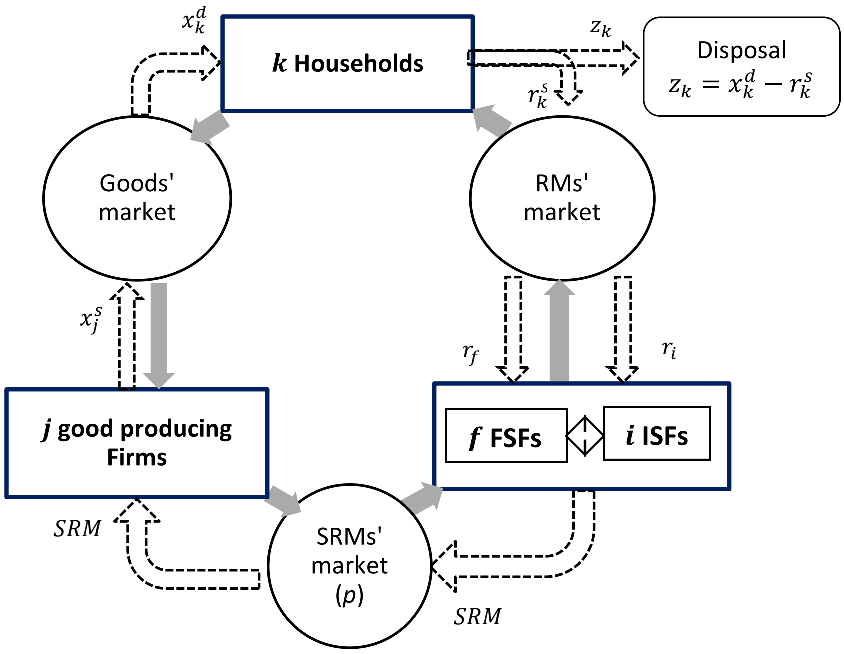
Suppose that $X^d(P_x; \tau)$ and $R^s(P_r; \tau)$ are differentiable in a relevant range. Note that the demand for goods (X^d) and supply of RM (R^s) depend on prices (P_x and P_r) and the marginal cost of legal disposal (τ).

2.2. Firms

There are three types of homogenous firms: p $(j = 1,2 \ldots, p)$ firms producing homogeneous consumption goods; n^f $(f = 1,2 \ldots, n^f)$ formal; and n^i $(i = 1,2 \ldots, n^i)$ informal firms reprocessing Recyclable Materials (RM). These firms and households participate in three competitive markets. On the first market, m $(k = 1, 2 \ldots, m)$ households and p $(j = 1,2 \ldots, p)$ firms exchange the goods x at the price P_x. On the second market, m $(k = 1, 2 \ldots, m)$ households, n^f $(f = 1,2 \ldots, n^f)$ formal and n^i $(i = 1,2 \ldots, n^i)$ informal firms exchange MR at the price P_r. On the third market, p $(j = 1,2 \ldots, p)$ firms, n^f $(f = 1,2 \ldots, n^f)$ formal and/ or n^i $(i = 1,2 \ldots, n^i)$ informal firms exchange Secondary Raw Materials (SRM) at the price p (Fig.2). We assume that informal firms operate only in the MSW management. This allows us to ignore policies directed at improving allocative efficiency and to focus solely on environmental issues.

The representative firm j produces x_j^s according to a strictly increasing and convex cost function, $Cx_j(x_j^s): \mathbb{R}_+ \longmapsto \mathbb{R}_+$. Its program is defined as follows, with t a marginal tax on products:

$$\max_{x_j^s}\left[(P_x - t)x_j^s - Cx_j(x_j^s)\right]. \tag{8}$$



Note: RM: Recyclable Materials; SRM: Secondary Raw Materials; ISF: Informal Sector Firms; FSF: Formal Sector Firms.

Figure 2: Model with two recycling sectors

While formal and informal recycling firms (Formal Sector Firms 'FSFs' and Informal Sector Firms 'ISFs') earn from processing RM in Secondary Raw Materials (SRM) a strictly concave profit[17] $B_f;\ B_i\colon \mathbb{R}_+ \longmapsto \mathbb{R}$, respectively, with $B_s'(0) > 0$ and $\lim_{r_s \to \infty} B_s'(r_s) = -\infty$ and $s \in \{f, i\}$. The whole RM demand for the representative formal and informal firms is noted r_{fi}^d with $r_{fi}^d = r_f + r_i$. The n^f FSFs receive a marginal subsidy s for recycling. We assume that FSF's RM demand (r_f) is to be completely processed, that is, the FSF does not illegally dispose a part of its demand.[18] This hypothesis is more realistic because the large size and limited number of FSFs make them more conspicuous for the regulator. Moreover, the fact that FSFs work in recycling ("circular economy") makes their trademark very sensitive to public opinion, and thus

[17] Actually, the profit function incorporates the cost function. The marginal profit can be defined as $B_s' = p - C_s'$, with $s \in \{i, f\}$. As defined in Ino (2011), p can be the international market price of SRM. In our model, p can also represent the price of the informal local market that uses recycled materials in artisanal manufacture or agriculture. In Cairo, for example, food waste is used in pig feeding and aluminum cans are used in stove manufacturing.
[18] See Ino (2011) for the case where all recycled materials collected are not processed.

becomes too costly to dispose of waste illegally.[19] By contrast, ISFs have no reputation to protect, and are not monitored. Thus, they can illegally dispose of a part of their waste collection instead of inputting it into the reprocessing process. However, we assume that the representative ISF collects only waste that is valuable,[20] that is, r_i.

As a recycling profit function contains the cost of processing MR, it depends on the technology used in the formal and informal sectors. We assume the FSF is more productive than the ISF. However, FSFs bear significant transaction costs and ISFs have opportunities to avoid any regulatory constraints, such as child labor, non-compliance with work safety requirements, insurance against occupational risk, environmental constraints (such as polluting technologies), and taxes. In addition, ISFs may have a number of "endogenous" opportunities, such as remote or inaccessible areas for FSFs: areas with no legal collection.[21] In other words, even if ISFs do not exist, some RMs cannot be processed by FSFs because of their cost structure. To take this into account, we additionally assume that $\lim_{r_i \to 0} B_i(r_i) = 0$ and $\lim_{r_f \to 0} B_f(r_f) = -\infty$. But, the relationship between marginal profits is indefinite. B_f' may be higher (lower) than B_i', depending upon transaction costs in the formal sector and "endogenous" opportunities and social costs that can be avoided in the informal sector.

Furthermore, we assume two necessary conditions in order for ISFs to be operational. They have to either directly access the SRM market or cooperate with FSFs and sell them their production. In the first case, ISFs and FSFs are independent and each representative firm maximizes its profit. Their programs are as follows:

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[19] Formal recycling firms usually recycle, and most of time dispose of waste on behalf of local authorities. Illegal disposal can erode the reputation of the formal firm and lead it to lose its accreditation. This is particularly so in democratic countries where local authorities have to consider the opinion of their constituents and the public opinion in general.

[20] Illegal disposal at least costs time for ISFs.

[21] For example, the average rate of legal collection in low- and middle-income areas is 41%- 85%. Therefore, ISFs have a geographical monopoly on the remaining areas (15%-59%).

$$\max_{r_f}\left[B_f(r_f) - (P_r - s)r_f\right] \quad (9)$$

$$\max_{r_i}[B_i(r_i) - P_r r_i]. \quad (10)$$

In the second case, the FSF maximizes the joint profit as follows:

$$\max_{r_f, r_i} \left[B_f(r_f) + B_i(r_i) - (P_r - s)(r_f + r_i)\right]. \quad (11)$$

2.3. Public sector

The public sector represented by a regulator is responsible for MSW management. MSW can be recycled (reusing, processing RM) or disposed of (by means of landfilling and incineration, for example). It is generally assumed that recycling does not damage the environment while elimination does. MSW disposal is a public good provided by the regulator or by formal firms on behalf of the regulator. Therefore, there is no "formal market" for MSW disposal and its marginal social cost is noted d. It is assumed that both informal recycling and informal disposal damage the environment because ISFs use "dirty" technology. However, the recycling activities of ISFs are preferable to legal disposal. The social marginal cost for informal recycling and disposal are d_{ri} and d_{ei}, with $0 < d_{ri} < d < d_{ei}$. Although ISFs can involve in waste disposal, this does not occur because the ISF has no compensation from the regulator who does not recognize them.

The regulator aspires to internalize the social cost of MSW management by choosing a Deposit and Refund System (DRS) policy or a user fee policy. With the former, the goods are taxed at rate t and recycling is subsidized at rate s. The latter enables the regulator to charge proportional tax τ on the waste that is legally disposed of. We consider that the compliance of households allows the regulator to observe market-based information on the households in the markets of both products and RMs, that is, x_k^d and r_k^s. However, informal activities are unobservable by definition, as is the relationship between FSFs and ISFs which constitutes firms' inside information. FSFs can outsource part of its production to the informal sector to evade costly regulations, for example.[22] We assume that the monitoring activities of ISFs are inefficient.[23] Considering market-cleaning conditions $X \equiv \sum_{k=1}^{m} x_k^d = \sum_{j=1}^{p} x_j^s$, and $R \equiv \sum_k^m r_k^s = \sum_{f=1}^{nf} r_f + \sum_{i=1}^{n^i} r_i$, the regulator program is defined as follows:

$$W \equiv \sum_{k=1}^{m}\left[U_k\left(x_k^d\right) - Cr_k\left(r_k^s\right) - dz_k\right] - \sum_{j=1}^{p}\left[Cx_j\left(x_j^s\right)\right] + \sum_{f=1}^{nf}\left[B_f\left(r_f\right)\right] + \sum_i^{n^i}\left[B_i(r_i) - d_{ri}r_i\right]. \quad (12)$$

The model described above is in the nature of a second-best problem insofar as the regulator cannot internalize the informal recycling social cost.

3. Market structure and social optimum

How will markets react to an incentive MSW policy? We start this section by showing that the second-best optimum cannot be achieved through a decentralized market mechanism. We compare markets' equilibrium to the social optimum, whatever the incentive policy tools are; that is, any $\tau \neq 0$ or $t = s \neq 0$. We consider that the regulator overrides informal recycling when he sets the user fee (τ) or the Deposit and Refund System $(t = s)$ to internalize social costs without encouraging illegal disposal. A representative household's first-order conditions are defined in (6) and (7). A firm's first-order condition on the products' market is:

$$Cx_j'\left(x_j^s\right) = (P_x - t). \quad (13)$$

[22] We consider that the size of the FSFs and the sensibility of their trade mark to public opinion do not prevent them from dealing with ISFs for two reasons. First, it is difficult for the regulator to verify firms' inside information. For example, FSFs can subcontract the collection of RM and declare it as "home collection" in order to have the recycling subsidy. Second, dealing with ISFs helps a part of population to earn their livelihood, and consequently can be seen like a positive action.

[23] As in Biswas, Farzanegan, & Thum (2012), the regulator can theoretically monitor the ISFs and constrain them to pay a maximum fine equal to their benefit. However, their very small size and geographical mobility make the monitoring costs prohibitive. In addition, removed ISFs decrease social welfare because first, the regulator loses the economic benefit of informal recycling; and second, he must provide social assistance for former workers in informal recycling because the livelihood for thousands of people will be lost.

First-order conditions on the RM market depend on interactions between formal and informal sectors, as we have assumed in Section 2.2.

3.1. Formal and informal sectors in "cooperative" competition

We weaken the "perfect" competition assumption on the RM market by limiting access to competitive markets only for formal firms. The necessary condition for the existence of ISFs is cooperation. As we describe in Section 1, formal and informal recycling have a kind of structuralist relationship. Such a vertical relationship enables ISFs to operate even when they cannot directly sell their production on the SRM market. This arrangement is also advantageous for FSFs as it provides an opportunity to cut costs by outsourcing. Thus, the FSF and the ISF have a collusive property to their behavior. Instead of maximizing their respective profit, the FSF maximizes the sum of its profit and the ISF's profit as defined in Equation (11). The first-order condition is:

$$B_f'(r_f) = B_i'(r_i) = (P_r - s). \tag{14}$$

Before any incentive policy, that is, $\tau = s = t = 0$, the markets' equilibrium condition is:

$$\begin{cases} U_k'(x_k^d) = Cx_j'(x_j^s) = P_x \\ B_f'(r_f) = Cr_k'(r_k^s) = P_r \end{cases}, \tag{15}$$

or

$$\begin{cases} U_k'(x_k^d) = Cx_j'(x_j^s) = P_x \\ B_i'(r_i) = Cr_k'(r_k^s) = P_r \end{cases}. \tag{16}$$

These conditions mean that at the market equilibrium, the entire amount of RM in the economy can be processed either by FSFs or ISFs. Since ISFs do not have access to the RM market, only FSFs decide if they process the RM in-house or if they subcontract. If the marginal profit in the formal sector is higher than the marginal profit in the informal one, FSF will process the whole quantity of RM and ISFs do not exist (15). Otherwise, the FSF can increase its marginal profit by outsourcing, and all the RM will be processed by the ISF (16). In this configuration, waste pickers actually provide the recycling. Thus, FSF's strategy depends on the marginal profit in the informal sector $B_i'(r_i)$. In other words, the occurrence of waste picking depends on the trade-off between marginal profits in informal recycling and formal recycling.

Proposition 1 : When there is a "cooperative" competition in the RM market, waste picking exists at the equilibrium, if $\boldsymbol{B_i'(r_i) > B_f'(r_f)}$**.**

In this context and for any MSW policy ($\tau \neq 0$ and $s = t \neq 0$), RM market's equilibrium matches with social optimum only if the formal sector actually recycles, as depicted in Figure 4.b for a representative firm. Both a user fee policy and a DRS policy do not allow the regulator to distinguish ISFs from FSFs if the marginal profit in informal recycling is greater than the marginal profit in formal recycling. With a user fee policy, we have:

$$U_k'(x_k^d) = Cx_j'(x_j^s) = (P_x + \tau) \quad (17)$$

$$B_f'(r_f) = Cr_k'(r_k^s) = (P_r + \tau) \text{ or } B_i'(r_i) = Cr_k'(r_k^s) = (P_r + \tau). \quad (18)$$

With a DRS policy, we have:

$$U_k'(x_k^d) = Cx_j'(x_j^s) = (P_x - t) \quad (19)$$

$$B_f'(r_f) = Cr_k'(r_k^s) = (P_r + s) \text{ or } B_i'(r_i) = Cr_k'(r_k^s) = (P_r + s). \quad (20)$$

Lemma 1: $\frac{\partial P_x^*}{\partial t} > 0;\ \frac{\partial P_x^*}{\partial \tau} < 0; \frac{\partial P_r^*}{\partial s} > 0; \frac{\partial P_r^*}{\partial \tau} < 0; \frac{\partial R^*}{\partial s} = \frac{\partial R^*}{\partial \tau} > 0;\ \frac{\partial X^*}{\partial t} = \frac{\partial X^*}{\partial \tau} < 0.$ (Appendix 1)

With a user fee policy, formal and informal firms benefit from the relative decline of the recycling cost for households while the regulator, having no information about r_i, pays the subsidy to the FSF considering its RM demand. The FSF earns, therefore, a marginal "informal subsidy" by doing nothing. This emphasizes cooperative interactions with ISF. DRS and user fee policy, respectively, encourage firms and households to recycle. Equations (2) and (3) indicate that the user fee impacts households' behavior simultaneously in the goods and RM markets (Fig.3). The same effect can be found in (13) and (14) with the DRS policy which impacts formal firms' behavior. The tax mitigates goods production, while the subsidy increases the demand for RM. As a result, the user fee at the household level shifts to the firm level with DRS.

However, the regulator can minimize the deviance of the RM market equilibrium if he uses the DRS policy instead of the user fee policy. As Figures 3.and 4.a show below, both the DRS and the user fee policies allow the regulator to match market equilibrium (E) and the social optimum (O) for the goods' market. However, that is not feasible for the RM market where equilibrium and social optimum diverge when informal recycling exists (Fig.3c and Fig.4.c). Nonetheless, the gap between market equilibrium and the social optimum is lowest with the DRS. A user fee is counterproductive indeed; this still takes into account the assumption that households do not illegally dispose of their waste. Households therefore increase their RM supply, because their relative costs decline. Figure 3c shows that the equilibrium moves to the right (E) while the optimum moves to the left (O_{ei}). In fact, the user fee leads households to provide, in addition to recycling waste, disposal waste to ISFs. Households will compare the user fee to the price that ISF will require from them to remove their waste. They will be willing to pay any $P_r \leq \tau$ to avoid paying a user fee. The no-arbitration condition for households is $P_r = \tau$.[24] We remember that ISFs are not involved in disposal activities because they do not earn any price from doing so. Because households are willing to pay ISFs, they will agree to dispose of the

[24] This is the case when $P_r < 0$ and means that households pay ISF for disposal. We note that illegal dumping differs from informal disposal with social costs higher than the social cost of legal disposal. The former is done by households and the latter by waste pickers. Households are, first and foremost, rational and their compliance does not prevent them from supplying their waste (RM and residuals) to waste pickers.

waste if that price is at least equal to their marginal cost (private). We can consider that this cost is insignificant for ISFs. They simply collect all MSW from households, keep the recyclable waste and dispose of any residual waste. Then, for any $\tau \neq 0$, ISFs will be involved in "informal" disposal. In this case, the whole marginal social cost of the informal sector that the regulator cannot internalize without monitoring is the damage of informal disposal d_{ei}, and the damage of informal recycling d_{ri}. As we assume that the regulator cannot monitor ISFs, any $\tau > 0$ indirectly elicits an informal disposal market.

Proposition 2 : When there is a "cooperative" competition in the RM market and informal waste picking exists, a user fee policy elicits an informal disposal market.

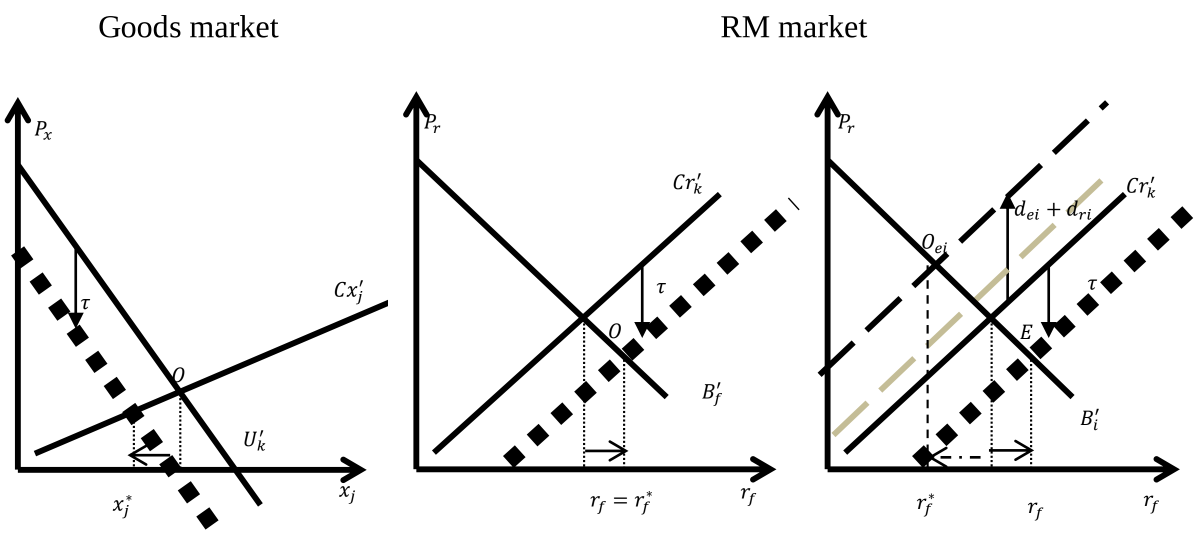

Figure 3a Figure 3b Figure 3c

Figure 3 : Markets' equilibrium with user fee policy

Goods market RM market

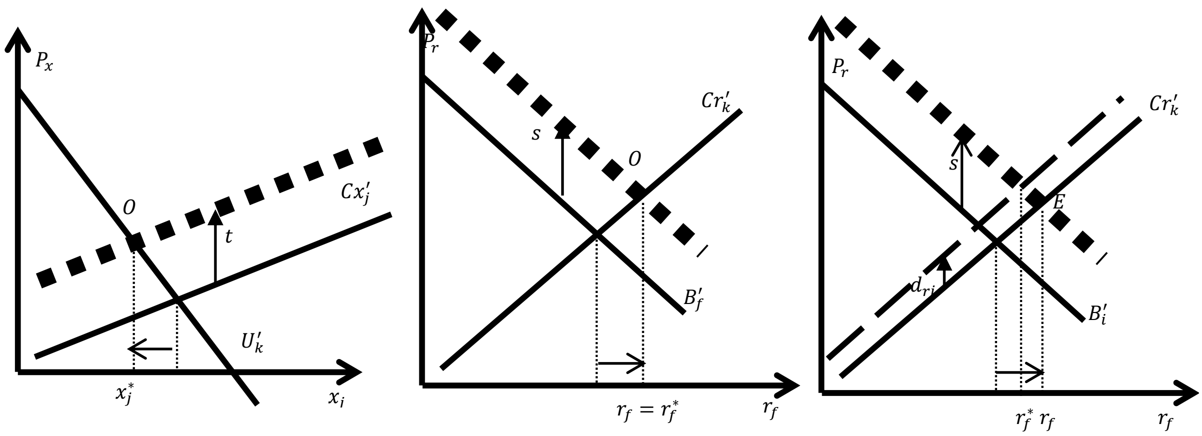

Figure 4 a Figure 4b Figure 4c

Figure 4 : Markets' equilibrium with DRS policy

With a DRS policy, the FSF will still use its arbitration opportunity to maximize its profit. Its rationality wants it to process the RM in-house, only if the marginal profit in the informal sector is lower than the marginal profit in the formal sector. Otherwise, the FSF's RM demand is $P_r = B_i'(r_i) - s$. Contrary to a user fee, a DRS policy has the advantage of not eliciting the informal disposal market, and only the informal recycling damage is not internalized. Besides, we draw the sufficient condition for recycling. The RM market exists only if:

$$B_f' \geq C_r'(r_k^s) \text{ or } B_i' \geq C_r'(r_k^s). \quad (21)$$

This condition is quite intuitive. A representative firm (formal or informal) agrees to recycle if its profit covers the household's marginal cost. In other words, recycled materials are those where the price ((P_r), ($P_r + \tau$) or ($P_r - s$) if an incentive policy) is less than or equal to the marginal profit in a formal or an informal sector. If not, neither the ISF nor the FSF has an interest in recycling. This is similar to Calcott & Walls' (2000-2005) recyclability condition based on cost approach.

Proposition 3: When there is a “cooperative” competition in the RM market and informal waste picking exists, both the user fee and the DRS policies are inefficient.

3.2. Formal and informal sectors in “leadership” competition

In this section, we again weaken the “perfect” competitive assumption by analyzing a kind of imperfect competition, where all firms have access to the SRM market and are price takers. Nevertheless, on the RM Market, ISFs and FSFs behave like two branches. Firms in each sector still have the same size, however, unlike the "cooperative" case, the size of a representative ISF and FSF is asymmetric. This assumption is more likely insofar as ISFs are individual or familial business units and are labor intensive. We recognize oligopsony market features: two buyers (formal and informal), several suppliers (households) and a homogeneous product (RM). Therefore, the RM market price is no longer a competitive price, and is controlled by the "leader": $P_r(r^l)$ with $P_r(r^l) = P_r(r_f + r_i)$. As a result, the RM market will function like a Stackelberg duopoly, and we consider a two-stage game where the "leader" sector’s strategy is to set the quantity. In the first stage, we suppose that the marginal profit in the formal sector is higher than the profit in informal sector: $B_f' > B_i'$. This confers the “leader” position to the formal sector. The informal “follower” sector’s program is:

$$\max_{r_i}\left[B_j(r_i) - P_r(r^l)r_i\right], \tag{22}$$

and its optimal demand of RM is:

$$r_i(r_f) = \frac{B_i'(r_i) - P_r(r^l)}{P_r'(r^l)}. \tag{23}$$

The problem of the "leader" FSF is to maximize its profit whilst knowing the reaction function of the ISF. Its program and its optimal demand are:

$$\max_{r_f} \left[B_f(r_f) - \left(P_r\left(r_f + r_i(r_f)\right) - s\right) r_f\right], \tag{24}$$

$$r_f = \frac{B_f'(r_f) - P_r(r^l) + s}{P_r'(r^l)\left(1 + r_i'(r_f)\right)}, \tag{25}$$

with $r_f \geq 0$ and $r_i \geq 0$. From (24) and (25), the ISF's demand (the FSF's demand) of RM emerges only if the marginal profit in informal (formal) sector is strictly higher than the RM's price. That price represents the household's supply of RM which is increasing with the total demand of RM.[25] Before any MSW policy ($\tau = s = t = 0$), and considering market clearing conditions for a representative household, FSF and ISF, $r_f + r_i(r_f) = r_k^s$, we can rearrange (24) and (25) as:

$$r_i(r_f) = \frac{B_i'(r_i) - Cr'(r_k^s)}{Cr''(r_k^s)} \tag{26}$$

$$r_f = \frac{B_f'(r_f) - Cr'(r_k^s)}{Cr''(r_k^s)\left(1 + r_i'(r_f)\right)}. \tag{27}$$

Lemma 2: For any $r_i(r_f) > 0,\ r_i{}'(r_f) < -1$. (Appendix 2)

As a common outcome of a Stackelberg duopoly analysis, the reaction function of the ISF $r_i(r_f)$, is decreasing: for a constant supply of RM, if the FSF increases its demand, the ISF is forced to reduce its demand. Further, for positive values, the RM demand of the FSF is decreasing with the price. However, for a positive demand of the ISF, $r_i(r_f) > 0$, the optimal demand of the FSF turns zero.[26] In other words, the household's RM supply is not enough to satisfy both the demands of the FSF and the ISF. Knowing this, the optimal strategy for the FSF is to recycle the whole quantity of RM offered by the household and keep the ISF out of

[25] This is because of the hypothesis that the recycling cost for the household is strictly increasing.
[26] The RM demand of the FSF cannot take negative values ($r_f \geq 0$).

the market. The FSF can do this since it is assumes that the marginal profit in the formal sector is higher than the marginal profit in the informal sector. The RM demand of the ISF is equal to zero when the household's marginal recycling cost equals the marginal profit in the informal sector: $B_i'(r_i) = Cr'(r_k^s)$. Once this condition has been satisfied, the perfect competition assumption in the formal sector leads to a market equilibrium as in Equation (15). This condition allows the FSF to both oust the ISF from the market and to maximize its profit.

However, in the MSW management field, the informal sector may not be a marginal phenomenon because it endogenously emerges. In addition, several factors can give it the advantage in this sequential game and allow it to be the "leader." As we argued in Section 2.2, the translation costs in formal recycling and the possibility for the informal sector to avoid any regulatory constraints makes the hypothesis plausible; that is, the marginal profit in the latter is higher than the marginal profit in the former, so the informal recycling sector is the leader. Further, the micro size of the ISFs may give them a relative flexibility. The market interaction described above occurs in this case.

Proposition 4: When there is a **"**leadership" competition in the RM market, the "follower" sector is ousted from the market at the equilibrium.

With a "leadership" competition configuration, the regulator's MSW policy is optimal only if the hypothesis of a formal recycling "leader" is confirmed. In this particular case, a recycling subsidy policy will strengthen the leadership of formal firms. An alternative user fee policy can be used, however and, as we have argued above, this may generate an informal market for disposal and bring the return of an informal sector on the market.[27]

[27] One could suppose that the marginal recycling cost decreases only in informal recycling. The possibility for the household to avoid the user fee by paying the ISF a $Pr < 0$ makes the reaction function of the ISF higher than zero and the FSF loses its leadership position; since the demand of the FSF turns zero.

Otherwise, the user fee has a counterproductive effect similar to that described in Figure 3c, when the informal sector "leader" hypothesis is confirmed. With the DRS Policy, the RM market is not impacted. The regulator can neither subsidize informal recycling nor internalize the recycling social costs of ISF without monitoring. For any $t = s \neq 0$, each representative ISF will recycle the RM quantity which enables it to control the RM market.

Proposition 5: When there is a "leadership" competition in the RM market and the informal sector is in a leading position, both the user fee and the DRS policies are counterproductive.

4. "Informal DRS" policy first-best optimality

Next, we put aside the assumption that the regulator ignores informal recycling. He decides to adopt the ISWM[28] approach which requires him to take into account all stakeholders in MSW management. He can no longer ignore the activities of the ISFs. Between the two tools studied in this paper (the DRS and user fee), only the DRS provides this flexibility to the regulator. In addition, the user fee requires that the regulator monitor informal recycling; where such monitoring costs are prohibitive. Therefore, we assume that the regulator decides to subsidize the activities of the ISFs with $\hat{s}$. The "informal DRS" then comprises the tax on goods (t), the formal subsidy (s) and the informal subsidy ($\hat{s}$). This decision makes waste picking a formal activity because the regulator recognizes it and negatively taxes the waste pickers. The regulator's new program is defined by the following:

$$\max_{x_k^d, x_j^s, r_f, r_i, r_k^s, z_k} W = \sum_{k=1}^{m}\left[U_k\left(x_k^d\right) - Cr_k(r_k^s) - dz_k\right] + \sum_{f=1}^{n^f}\left[B_f\left(r_f\right)\right] + \sum_{i=1}^{n^i}\left[B_i(r_i) - d_{ri}r_i\right] - \sum_{j=1}^{p}\left[Cx_j\left(x_j^s\right)\right] \quad (28)$$

$$s.t \ \sum_{k=1}^{m} x_k^d = \sum_{j=1}^{p} x_j^s, \ \ \sum_{f=1}^{n^f} r_f + \sum_{i=1}^{n^i} r_i = \sum_{i=1}^{m} r_k^s, \ \sum_{k=1}^{m} z_k = \sum_{k=1}^{m} x_k^d - \sum_{k=1}^{m} r_k^s.$$

[28] Integrated Sustainable Waste Management.

First-order conditions for this program are:

$$U_k'(x_k^d) = Cx_j'\left(x_j^s\right) + d \tag{29}$$

$$Cr_k'(r_k^s) = B_f'\left(r_f\right) + d \tag{30}$$

$$Cr_k'(r_k^s) = B_i'\left(r_j^i\right) + d - d^{ri}. \tag{31}$$

We can hereafter define market equilibrium conditions.

4.1. Formal and informal sectors in "cooperative" competition

The decision of the regulator to recognize and subsidize informal recycling discourages ISFs to cooperate with FSFs, and each representative firm then maximizes its profit. The FSF maximizes its profit defined in (9), but the ISF maximizes its new profit:

$$\max_{r_i}[B_i(r_i) - (P_r - \hat{s})r_i]. \tag{32}$$

At the equilibrium, we have:

$$\begin{cases} Cr_k'(r_k^s) = B_i'(r_i) = (P_r - \hat{s}) & if\ B_f'\left(r_f\right) < B_i'(r_i) \\ Cr_k'(r_k^s) = B_f'\left(r_f\right) = (P_r - s) & if\ B_f'\left(r_f\right) \geq B_i'(r_i) \end{cases}. \tag{33}$$

If $B_f'\left(r_f\right) \geq B_i'(r_i)$, optimal conditions meet Ino's (2011) results. The regulator can interchangeably use the user fee or the DRS to reach the first-best optimum. These are:

$\tau = d$ or $t = s = d$.

Otherwise, by comparing market equilibrium conditions to optimal ones, the "informal DRS" is optimal if:

$\tau = 0$; $t = s = d$; $\hat{s} = t - d^{ri}$.

In this recycling market configuration, recycling activities are in fact carried out the sector that has the highest marginal profit. It is optimal to levy a tax on consumption goods equal to the social marginal cost of disposal ($t = d$); this is a deposit. Then the regulator subsidizes the ISF or the FSF for the gap between the disposal marginal social cost and the recycling marginal social cost. As the formal recycling marginal social cost is zero, its subsidy is equal to the tax or deposit. The informal recycling subsidy is less than the formal recycling subsidy insofar as its marginal social cost is non-zero. The regulator can then achieve the first-best optimum by subsidizing the sector that, in reality, completes the job.

4.2. Formal and informal sectors in "leadership" competition

In a "leadership" competitive market, optimal conditions depend on the sector that controls the RM market. In the formal "leader" sector case, optimal conditions meet Ino's (2011) results, as mentioned above.

Alternatively, in the informal "leader" sector case, the first-best optimum can be achieved by subsidizing informal recycling. Optimal conditions are:

$$\tau = 0\,; \qquad t = d\,; \qquad \hat{s} = t - d^{ri}.$$

In the "leadership" competitive market, the regulator can once again adjust the informal DRS calibration to reach the first-best optimum through a decentralized market mechanism by subsidizing informal recycling. The purpose of the informal recycling subsidy is to encourage the activities of the ISFs. As the informal sector is labor intensive, its marginal productivity is lower than the marginal productivity of capital. It is therefore possible to substitute labor for capital and to increase the production. The regulator can use ŝ as a capital subsidy. For example, if the regulator subsidizes the waste collection vehicle of the ISFs, they will greatly reduce the collection time and also reduce the use of child labor. This subsidy may also be the preferred choice of collection equipment for households in order to reduce the sorting time for the ISFs. Further, the difference between s and ŝ is an additional incentive for ISFs to use clean technology and reduce d_{ri}. Gradually, marginal social cost of the informal recycling declines towards zero, as does the difference between subsidies. Informal recycling is recognized by the regulator who is encouraged to use clean technology, as it becomes progressively cleaner in the long-run equilibrium.

To summarize, the intuition is the same for the two market structures studied in this paper. We use the informal recycling subsidy ($\hat{s}$) to indicate cost information for the informal activities in order to foil coalition strategies and to prevent trade wars between sectors. However, it should be noted that there are transaction costs in the formal sector. So, these costs should be kept low and less than the subsidy for the waste pickers. Indeed, keeping transaction costs low is a condition that allows the recycling subsidy to achieve its goals. In addition, the fact that the informal recycling is labor intensive (relative to formal recycling), in addition to the poor working condition of the workers helps the recycling subsidy to work. Once the informal recycling process is under control, other strategies to upgrade MSW management in developing countries can be developed.

Proposition 6: When there is informal recycling, the informal Deposit and Refund System is optimal regardless of the market structure.

4.3. Discussion

Before concluding, we discuss our results in a general equilibrium framework to test their consistency. The first is the framework of the nature of the formal-informal relationship. Models that have studied this subject show that the formal-informal relationship depends on the relative labor intensity in the informal sector. If the informal sector is labor intensive, the formal-informal relationship is pro-cyclical. In other words, an exogenous shock (positive or negative) that generates an expansion of the formal sector (respectively, the informal sector) leads to the expansion of the informal sector (respectively, the formal sector). If the informal sector alternatively is capital intensive (or at least includes a sub-capital intensive sector), the formal-informal relationship is counter-cyclical (Arvin-Rad, Basu & Willumsen (2010); Chaudhuri & Banerjee (2007); Marjit (2003)).

In our model, we assume that the informal recycling sector is labor intensive, so there is a pro-cyclical relationship between sectors. Some informal recycling characteristics, such as child labor, daily working hours, and working as a family and within the community, support this hypothesis. The subsidy, which is a positive exogenous shock, targets two sectors simultaneously. Recycling in both sectors will then increase. Because there is pro-cyclicality and both sectors are shocked at the same time, there is consequently a "feedback" mechanism. The increase in formal recycling will increase the informal recycling, and vice versa. Insofar as the formal recycling shock is higher than informal one ($s > \hat{s}$), the former will tend to increase more rapidly than the latter. This mechanism is supported by the differential between subsidies ($s - \hat{s}$) and leads to gradual informal absorption by the formal recycling. As well as promoting informal recycling, the informal recycling subsidy ($\hat{s}$) also minimizes its marginal social cost. All these mechanisms work together to encourage waste pickers to become formal and to use clean technologies. In the long run, MSW recycling will be fully formal and without social cost. Furthermore, the pro-cyclicality relationship makes any repressive informal recycling policy undesirable.

The second general equilibrium framework analysis of our findings is direct taxation, and we question whether or not subsidizing the informal recycling is efficient from a Ramsey taxation political point of view. If so, between labor and capital, we question which one would be more efficient. Cerda & Saravia's (2013) model provides an answer to these questions. Their model includes three taxes on capital, labor and profit. They show that the optimal-mix tax includes a negative tax (subsidy) on capital, a negative tax on labor (under certain conditions) and a positive tax on the profit. The intuition is that a capital or labor subsidy encourages economic agents to produce in the formal sector and leads to widening the profit tax base. Analyzing our results in this general framework is consistent. The regulator increases other tax bases in the economy by subsidizing the informal recycling.

5. Conclusion

Over the past three decades, developed countries have justifiably used economic tools to cope with sustainable MSW management. However, to date, the basic theoretical models of these tools have not included a common feature found in developing countries (including transition countries); that is, waste picking. In this paper, we complete the optimal MSW management policy literature by adapting Ino's (2011) model.

Our results first show that, even the second-best optimum cannot be achieved through a decentralized market mechanism without considering waste-picking activities. Second, it is neither economically nor socially optimal to repress waste-picking activities. Third, a Deposit and Refund System policy which includes waste picking is optimal regardless of the strategic interaction between waste pickers and formal recycling firms, all other things being equal. The "informal DRS" is composed of a single tax on final consumption (Deposit) and two subsidies (Refunds). The deposit is equal to the marginal social cost of legal disposal in order to bring the final consumption to its optimal level, and is levied at the national level. Subsidies aim to encourage formal recycling and to minimize the social cost of waste picking. For example, in municipalities or regions where recycling is provided by a single sector, public authorities can alternatively use the formal subsidy or the informal one. If there are municipalities or regions in which waste picking and formal recycling firms coexist, public authorities must simultaneously use both subsidies to encourage the whole range of recycling activities.

We note that the validity of our results depends on the relative labor intensity of waste picking and the degree of substitutability between capital and labor. In the waste-recycling sector, both assumptions are plausible. Despite some restrictive assumptions that are at the limits of our model, our results are consistent with the general equilibrium models of the formal-informal relationship and optimal taxation within the informal sector (see, Cerda & Saravia (2013); Arvin-Rad, Basu & Willumsen (2010); Chaudhuri & Banerjee (2007); Marjit (2003)). Our model has the advantage that it takes into account the possibility of the illegal dumping of waste by waste pickers (informal disposal), the social cost of recycling, the coexistence of formal and informal recycling, and the two types of formal-informal relationships (that is, dualist and structuralist leadership).

The main argument of this paper is that the great opportunity offered by incentive MSW tools cannot be exploited in developing countries without first bringing waste picking under the control of the public authorities. Any incentive MSW policy in regard to waste picking is inefficient because of the illegal dumping of waste by both households and waste pickers. For example, the Public Private Partnership (PPP) policy efficiency also depends on the magnitude of waste picking. The intuition of the PPP policy is that MSW management and its funding privatization (that is, the process used for water and electricity services), will internalize the social costs. Public authorities will thus set standards in order to minimize social disposal costs at the national level. At the local level, they can collect host fees on disposal facilities. In doing so, private industries will be required to meet national standards and to pay host fees by including social disposal costs in their private costs; thereby charging households for the full MSW management cost. However, yet again, the relative importance of waste picking is critical. If the informal “leader” sector assumption is confirmed, waste pickers can effectively compete with private industries and guard their market, in which case, the PPP policy cannot work. The well-known case of "les chiffonniers du Caire"[29] in Egypt is empirical evidence of the market power of waste pickers. The Egyptian national MSW management reform failed because it did not include the waste pickers at the design stage.

Public authorities have two ways by which to deal with waste picking. They can either monitor and/or remove waste-picking activities, or they can cooperate with the waste pickers. The second option (cooperation) is the best because: first, waste picking and formal recycling are pro-cyclical, and thus the removal of waste picking would lead to formal recycling reduction; second, the monitoring cost of waste picking is prohibitive and it has been playing a significant social role in developing countries where social safety nets and social protection do not exist; and third, waste picking has several environmental benefits.[30] We propose in this paper a kind of cooperation with waste pickers based on the polluter-pays principle. This cooperation would aim in the short- and medium-terms to encourage waste pickers to become formal and to adopt clean technology.

Eventually, the implementation of such an incentive MSW policy would involve minimizing transaction costs, the knowledge of the magnitude of waste picking and how it is linked to formal recycling in each municipality or region. It is also essential to assess both disposal and the marginal social cost of waste picking in order to determine the amount of subsidies. Considering the current situation of MSW management in developing countries and the alarmist World Bank's (2012) cost and production forecasts, an incentive policy—even a second-best one—is required.

[29] "Les chiffonniers du Caire" are the most important community of waste pickers in Egypt. This community has challenged the upgrading of the waste management system in Cairo implemented by public authorities in the first decade of the 2000s.

[30] Middle East and North African (MENA) countries are particularly sensitive to the social role of the informal sector. We recall that only recently the Arab Springs was triggered by informal seller control.

Appendix 1 : Equilibrium and comparative statics

At equilibrium aggregate supplies and demands are equal. We have therefore:

$$X^d[P_x{}^*(t;\tau);\ \tau] = X^s[P_x{}^*(t;\tau);\ t] \equiv X^*(t;\tau)$$

$$R^s[P_r{}^*(s;\tau);\ \tau] = R^d[P_r{}^*(s;\tau);\ s] \equiv R^*(s;\tau),$$

with $X^*(t;\tau)$ and $R^*(s;\tau)$ equilibrium goods' and RMs' quantities. We deduce the equilibrium prices using the inverse functions of quantities:

$$P_x{}^*(t;\tau) = P_x[X^*(t;\tau);\tau] \qquad\qquad P_r{}^*(s;\tau) = P_r[R^*(s;\tau);\tau].$$

Recall that aggregate supplies and demands are the sum of individual quantities at the equilibrium:

$$x_j^{s*}(t;\tau) \equiv x_j^s[P_x^*(t;\tau);t]; \quad r_{fi}^{d*}(s;\tau) \equiv r_f^*[P_r^*(s;\tau);s] + r_i^*[P_r^*(s;\tau)]$$

$$x_k^{d*}(t;\tau) \equiv x_k^d[P_x^*(t;\tau);\tau]; \quad r_k^{s*}(s;\tau) \equiv r_k^s[P_r^*(s;\tau);\tau],$$

with $j = 1,2, \dots p$; $f = 1,2, \dots n^f$; $i = 1,2, \dots n^i$ and $k = 1,2, \dots m$. We can therefore deduce changes in aggregate quantities when the incentive tools change:

- Changes in (t) and (s):

$$Cx_j''^{-1}(P_x^* - t)(P_{xt}^{*\prime} - 1) = U_k''^{-1}(P_x^* + \tau)(P_{xt}^{*\prime}); \quad P_{xt}^{*\prime} = \frac{Cx_j''^{-1}(P_x^* - t)}{Cx_j''^{-1}(P_x^* - t) - U_k''^{-1}(P_x^* + \tau)} > 0$$

$$Cr_k''^{-1}(P_r^* + \tau)(P_{rs}^{*\prime}) = B_f''^{-1}(P_r^* - s)(P_{xs}^{*\prime} - 1) + B_i''^{-1}(P_r^*)(P_{rs}^{*\prime})\ ;$$

$$P_{rs}^{*\prime} = -\frac{B_f''^{-1}(P_r^* - s)}{Cr_k''^{-1}(P_r^* + \tau) - B_f''^{-1}(P_r^* - s) - B_i''^{-1}(P_r^*)} > 0;$$

- Changes in (τ):

$$Cx_j''^{-1}(P_x^* - t)(P_{x\tau}^{*\prime}) = U_k''^{-1}(P_x^* + \tau)(P_{x\tau}^{*\prime} + 1)\ ;\ P_{x\tau}^{*\prime} = \frac{U_k''^{-1}(P_x^*+\tau)}{Cx_j''^{-1}(P_x^*-t) - U_k''^{-1}(P_x^*+\tau)} < 0$$

$$Cr_k''^{-1}(P_r^* + \tau)(P_{r\tau}^{*\prime} + 1) = B_f''^{-1}(P_r^* - s)(P_{x\tau}^{*\prime}) + B_i''^{-1}(P_r^*)(P_{r\tau}^{*\prime})\ ;$$

$$P_{r\tau}^{*\prime} = -\frac{Cr_k''^{-1}(P_r^*+\tau)}{Cr_k''^{-1}(P_r^*+\tau) - B_f''^{-1}(P_r^*-s) - B_i''^{-1}(P_r^*)} < 0.$$

Suppose that for all j; f; i and k: $x_j^{s*}(t;\tau) > 0$, $r_{fi}^{d*}(s;\tau) = r_f^*(s;\tau) + r_i^*(s;\tau) > 0$, $x_k^{d*}(t;\tau) > 0$ and $r_k^{s*}(s;\tau) > 0$:

$$\frac{\partial P_x^*}{\partial t} = \frac{\sum_{j=1}^{p}\left(1/Cx_j''\left(x_j^{s*}\right)\right)}{\Delta_1} > 0 \qquad \frac{\partial P_x^*}{\partial \tau} = \frac{\sum_{k=1}^{m}\left(1/U_i''\left(x_k^{d*}\right)\right)}{\Delta_1} < 0$$

$$\frac{\partial P_r^*}{\partial s} = \frac{-\sum_{f=1}^{nf}\left(1/B_f''\left(r_f^*\right)\right)}{\Delta_2} > 0 \qquad \frac{\partial P_r^*}{\partial \tau} = \frac{-\sum_{k=1}^{m}\left(1/Cr_k''\left(r_k^{s*}\right)\right)}{\Delta_2} < 0$$

$$\frac{\partial X^*}{\partial t} = \frac{\partial X^*}{\partial \tau} = \frac{\sum_{j=1}^{p}\left(1/Cx_j''\right)\sum_{k=1}^{m}\left(1/U_i''\right)}{\Delta_1} < 0 \qquad \frac{\partial R^*}{\partial s} = \frac{\partial R^*}{\partial \tau} = \frac{\sum_{k=1}^{m}\left(1/Cr_k''\right)\sum_{f=1}^{nf}\left(1/B_f''\right)}{\Delta_2} > 0,$$

where $\Delta_1 = \sum_{j=1}^{p}\left(1/Cx_j''\left(x_j^{s*}\right)\right) - \sum_{i=1}^{m}\left(1/U_k''\left(x_k^{d*}\right)\right) > 0$ and

$$\Delta_2 = \sum_{k=1}^{m}\left(1/Cr_k''\left(r_k^{s*}\right)\right) - \sum_{f=1}^{nf}\left(1/B_f''\left(r_f^*\right)\right) - \sum_{i=1}^{n^i}\left(1/B_i''\left(r_i^*\right)\right) > 0$$

Appendix 2

The reaction function of the representative "follower" ISF is a function of the demand of the representative "leader" FSF:

$$r_i(r_f) = \begin{cases} \frac{B_i'(r_i) - P_r(r^l)}{P_r'(r^l)} & if\ B_i'(r_i) > P_r(r^l) \\ 0 & otherwise \end{cases} ,$$

with $P_r(r^l) = P_r(r_f + r_i)$

$$r_i'(r_f) = \begin{cases} \frac{-P_r'(r^l)P_r'(r^l) - P_r''(r^l)(B_i'(r_i) - P_r(r^l))}{(P_r'(r^l))^2} & if\ B_i'(r_i) > P_r(r^l) \\ 0 & otherwise \end{cases},$$

$$r_i'(r_f) = \begin{cases} -1 + \frac{-P_r''(r^l)B_i'(r_i) + P_r''(r^l)P_r(r^l)}{(P_r'(r^l))^2} & if\ B_i'(r_i) > P_r(r^l) \\ 0 & otherwise \end{cases}.$$

Considering market clearing: $P_r(r^l) = Cr_k'(r_k^s)$:

$$r_i'(r_f) = \begin{cases} = -1 + \frac{-Cr_k'''(r_k^s)B_i'(r_i) + Cr_k'''(r_k^s)Cr_k'(r_k^s)}{(Cr_k''(r_k^s))^2} & if\ B_i'(r_i) > Cr_k'(r_k^s) \\ 0 & otherwise \end{cases},$$

with $(Cr_k''(r_k^s))^2 > 0$ and $Cr_k'''(r_k^s) > 0$; so $\frac{-Cr_k'''(r_k^s)B_i'(r_i) + Cr_k'''(r_k^s)Cr_k'(r_k^s)}{(Cr_k''(r_k^s))^2} < 0$ and $r_i'(r_f) < -1$ if $B_i'(r_i) > Cr_k'(r_k^s)$ and $r_i'(r_f) = 0$ otherwise.

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