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Inducing e-waste sorting investment under imperfect information

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Abstract

In this paper, we apply the theory of incentives to the e-waste market. We want to show how to induce firms in the North to undertake sorting investment to help implement an alternative e-waste market of a joint trade in reusable and non-reusable e-waste. Results show that, if the sorting cost is low, the optimal contract to induce sorting investment and to implement the alternative e-waste market for a joint trade in reusable and non-reusable e-waste is the Baron-Myerson contract. One of the direct implication of the results is that, if the cost is not too high to deter the sorting investment, the firm in the South should give incentives to the firm in the North to invest in sorting so that the alternative e-waste market can easily be implemented.

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1 Introduction

Each year, 20 to 50 million tons of electronic waste (e-waste) is produced around the world, with growth reaching 3-5% per annum. This rate is nearly three times that for conventional waste (Schwarzer et al., 2005). The cost of treating this specific waste is high in developed countries as it is subject to strict waste regulations and requires high intensity labor to process (Sen, 1962 and Kummer, 1999). This context, together with imperfect environmental regulations for exports to developing countries, creates an incentive for e-waste to end up in developing countries where it generates significant environmental damage.

The problem of e-waste has been comprehensively studied in environmental engineering and chemistry, highlighting major types of e-waste with classifications noting hazardous and non-hazardous, their different components, recycling and disposal practices, etc. The literature in economics is less developed. E-waste is a type of used good that has recently received an increased level of attention. The international trade in used goods goes back to Sen (1962). Firms have developed many strategies to avoid the high disposal costs of e-waste. In the case where firms choose to illegally sell e-waste to recycling industries, Higashida (2012) examines the appropriate monitoring of both illegal and legal trade of e-waste. Bernard (2015) focuses on firms that choose to invest in green design in order to increase e-waste reusability and analyses the factors that influence illegal e-waste trade.

Recently, Dato (2017) proposes a simple bilateral North-South trade model that accounts for both the e-waste collector and importer behaviour. The author shows that there exists an alternative e-waste market of joint trade in reusable and non-reusable e-waste that is better than the standard e-waste market for developing countries. This alternative e-waste market results in more reusable e-waste and less non-reusable e-waste, with compensation for disposal services. However, Dato (2017) ignores the implementation problems which are crucial for the alternative e-waste market because of the imperfection of the reusability of e-waste. In this paper, we extend Dato (2017) to analyze the optimal mechanism design for the implementation of the alternative e-waste market. To the best of our knowledge, there is no study that applies the incentive theory to the e-waste market to address imperfect information problems. To implement this alternative e-waste market, one needs to induce collectors to gain more information about collected e-waste and to speak truthfully about the reusability of their exported e-waste.

The model of gathering information used here is provided by Crémer and Khalil (1992, 1994) and Crémer et al. (1998) on productive information.[1] In the e-waste standard market, collectors do not have information about the reusability of e-waste. Collectors can choose to invest in sorting to gain more information about the reusability of e-waste, which then triggers the alternative e-waste market. Our results show that the optimal contract is the Baron-Myerson contract as long as the sorting cost is low. The implication is that e-waste importers in developing countries should give incentives to e-waste collectors in developed countries to invest in sorting, as it is less costly. We recommend that the legal e-waste trade could be coupled with the appropriate technology transfer.

[1] This model is recently extended by Gromb and Martimort (2007) on delegated expertise and Compte and Jehiel (2008) on screening perspective.

2 The model

This model is based on the framework of the economic analysis of the e-waste market developed in Dato (2017). It proposes a simple bilateral North-South trade model in a competitive e-waste market. The model considers one representative firm in the North as a collector in a developed country and one representative firm in the South as an importer in a developing country. The collector collects the amount X of e-waste in the home country (North) at a cost $C_N(q,\text{X})$ (N refers to North), where q is the "degree of purity" and is defined as the part of reusable e-waste in the collected e-waste X. $C_N(q,X)$ is increasing in the quantity of e-waste collected X and in the part of reusable q. The more that is collected, the more money is paid. Likewise, the more the product is considered valuable, the more that is willing to be paid. For technical reasons, standard characteristics for $C_N(q,\text{X})$ are assumed, i.e., $C_N(q,\text{X})$ is convex and twice differentiable and the marginal cost is increasing in the degree of purity q. However, the convex cost assumption can be explained by the existence of capacity constraints on the quantity of e-waste collected X. The marginal cost is then increasing because the collector will need to extend his capacity for collecting e-waste.[2]

The collector can decide to directly export the amount X of e-waste to the South without any additional investment. The mix of both types of e-waste is then supplied in an e-waste market that we denote as the "standard e-waste market". Alternatively, the collector can decide to undertake sorting at a fixed cost ψ in order to separate the reusable part qX from the non-reusable part $(1-q)X$, which are supplied in a joint market of reusable and non-reusable e-wastes that we denote as the "alternative e-waste market". For instance, the sorting can consist of investing in a machine that can be used for all e-waste to verify if it is still working or by using repairers' tools to test the electronic component of the e-waste.[3] The total cost of the collector can be expressed as:

$$C_N(q,X)+\psi 1_\delta,$$

where $1_\delta = 1$ in the case of sorting investment, and 0 otherwise.

Furthermore, it costs $C_S(q,X)$ (S refers to South) for the firm in the South to import and transform—even partially—the second-hand e-materials. The cost function $C_S(q,X)$ is increasing in the quantity of the collected e-waste X and decreasing in the part of reusable q. The more it imports, the more it costs to transform, and the more valuable e-waste is easier to transform. Implicitly, the cost of sorted e-waste is lower as the importer will most likely buy valuable already-sorted e-waste. The cost function $C_S(q,X)$ is also assumed convex and twice differentiable for technical reasons as before. The firm in the South gains P for reselling the reusable part in the South and bears a cost d_s of disposing of the non-reusable part.

In this paper, we extend this framework to address the imperfect information problems and to analyze the optimal mechanism design for the implementation of the alternative e-waste market. In fact, the standard e-waste market is a competitive market which is

[2]Note that this assumption of convexity may not hold in the case where the cost function exhibits internal economies of scale.

[3]Alternatively, we could also assume that the machine has variable operating costs, that is, labor costs for the person who operates it. However, we keep the fixed cost assumption for simplification.

characterised by imperfect information on the degree of purity. The collector in the North has to invest in sorting in order to participate in the alternative e-waste market. The importer in the South does not observe this information which remains private for the collector. Thus, the implementation of the alternative e-waste market of a joint trade in reusable and non-reusable e-waste would require that the firm in the South gives incentive to the collector in the North. To account for this, we use the Principal-Agent framework to design the contract between the two firms. The firm in the South is a buyer (the principal) who offers a contract to the collector in the North who is a supplier (the agent) in order to get the e-waste. The firm in the South needs to know the degree of purity of the e-waste in order to participate in the alternative e-waste market. Then, it can offer an incentive menu of contracts to the collector that encourages him to sort e-waste and to reveal the degree of purity q. Without a sorting investment, neither the firm in the South, nor the collector in the North, knows the exact degree of purity. They only share a common belief on q. The sorting can reveal two possible outcomes: bad news or good news. The bad news, which corresponds to a low degree of purity $\underline{q}$ occurs with a probability $(1-\nu)$, while a high degree of purity $\overline{q}$ (good news) occurs with probability ν.

Following Crémer et al. (1998), we use a simple variant of the standard Baron and Myerson (1982) model. For every possible type, the Baron-Myerson contract consists of a quantity and a transfer from the principal to the agent, which is feasible if it is incentive compatible and satisfies an ex post participation constraint. Note that in the Baron-Myerson contract, the agent is informed and does not invest to learn the information. The firm in the South contracts with the collector in the North for a positive quantity of e-waste X, which is publicly observable. The firm in the South compensates the collector with a monetary transfer t that can be $\underline{t}$, $\bar{t}$ and t^e for the low, for the high degree of purity in the alternative e-waste market and for the standard e-waste market, respectively. Then, the net utility (the profit $\Pi_S(q,X)$) of the firm in the South is:

$$\Pi_S(q,X) = V(q,X) - t, \tag{1}$$

with $V(q,X) = [PqX - d_S(1-q)X - C_S(q,X)]$, a concave and twice differentiable function. The total cost of the collector who provides a quantity X of e-waste is $C_N(q,X) + \psi 1_\delta$, and therefore, his net utility is:

$$\Pi_N = t - C_N(q,X) - \psi 1_\delta. \tag{2}$$

The timing of the game is as follows:

- At date 0: Nature selects the degree of purity q of e-waste.
- At date 1: The principal offers to the agent a menu of contracts. The contract (t^e, X^e) is associated with the standard e-waste market in which the true value of the degree of purity is not perfectly known. The other contract $\left\{(\underline{t},\underline{X});(\bar{t},\bar{X})\right\}$ is related to the alternative e-waste market for the low and for the high degree of purity, respectively.
- At date 2: The agent decides whether or not to invest in sorting. If the agent decides to learn about the degree of purity, he bears a cost ψ.
- At date 3: The agent decides whether he refuses or accepts the contract according to the information he receives from the sorting. If he refuses the contract $\left\{(\underline{t},\underline{X});(\bar{t},\bar{X})\right\}$,

then the alternative e-waste market does not hold and the agent supplies in the standard e-waste market.

- At date 4: The agent chooses the quantity of e-waste X that he is willing to trade and receives the monetary transfer according to the contract.

In the following, we focus on the optimal contract to induce sorting investment by considering two cases: (i) low sorting cost (Section 3.2) and (ii) binding sorting investment conditions (Section 3.3).

3 Inducing sorting investment

3.1 Preliminaries

First Best (FB)

In the first best situation, information on the degree of purity q is perfect. There is no need to induce the sorting investment. The principal maximizes her net utility (Eq.1) subject to the feasibility constraint of the agent (i.e., $Eq.2 \geq 0$) such that he must cover at least his total cost with the monetary transfer t from the principal. Replacing the monetary transfer t from the equality $Eq.2 = 0$ into $Eq.1$ gives the social welfare, which is $V(q, X) - C_N(q, X)$. We can derive the efficient quantity of e-waste $X^*(\underline{q}) = \underline{X}^{FB}$ and $X^*(\overline{q}) = \bar{\mathrm{X}}^{FB}$, where $\bar{q} \succ \underline{q}$ implies that $\bar{\mathrm{X}}^{FB} \succ \underline{X}^{FB}$.

Revelation mechanism

The issue here for the principal is to offer an attractive contract to the agent so that the agent is able to supply in the alternative e-waste market and truthfully reveal the information that he learns after the sorting investment. The revelation mechanism combines the incentives constraints that are related to the true revelation of information on the degree of purity and the participation constraints. The contract should be designed such that the agent with a low (high resp.) degree of purity always finds it profitable to trade. In the same way, the agent with a low (high resp.) degree of purity should not claim after sorting that he has a high (low resp.) degree of purity. The standard revelation mechanism gives:

$$\begin{array}{l} \underline{t} - C_N(\underline{q}, \underline{X}) = C_N(\bar{\mathrm{q}},\overline{\mathrm{X}}) - C_N(\underline{\mathrm{q}},\overline{\mathrm{X}}) \\ \bar{t} - C_N(\bar{q}, \bar{X}) = 0. \end{array} \quad (3)$$

Sorting investment constraints

In addition to the revelation mechanism, the firm in the South has to give incentives to the collector in the North to undertake the sorting investment. The expected profit that the agent will gain by investing in sorting should not be less than that of the standard e-waste market:

$$\nu(\bar{t} - C_N(\bar{q}, \bar{X})) + (1-\nu)(\underline{t} - C_N(\underline{q}, \underline{X})) - \psi \geq \; t^e - C_N(q^e, X^e). \tag{4}$$

3.2 When the sorting investment is not binding

In this first case, the sorting cost is low. The principal induces the agent to undertake the sorting investment and designs the contract such that the agent is always willing to truthfully reveal the degree of purity (Eq. 3) and to participate in the alternative e-waste market (Eq. 4). As the sorting cost is low, Equation 4 can first be ignored. Then, the principal solves the following program:

$$\begin{array}{ll} \max\limits_{\bar{X}, \underline{X}} & \mathbb{E}_q \left[V(q, X) - t \right] \\ st & (3) \end{array} . \tag{5}$$

We claim the following proposition and corollary:

Proposition 1: *There exists a sorting cost threshold below which the Baron-Myerson contract is compatible with sorting investment constraints.*

Corollary 1: *The Baron-Myerson contract is robust to induce the sorting investment when the sorting cost is low.*

Proof of Proposition 1

Proof. By replacing the expressions of $\bar{t}$ and $\underline{t}$ and rearranging, the program (5) becomes:

$$\max_{(\bar{X}, \underline{X})} \; \nu V(\bar{q}, \bar{X}) + (1-\nu) V(\underline{q}, \underline{X}) - C_N(\bar{q}, \bar{X}) + (1-\nu)(C_N(\underline{q}, \bar{X}) - C_N(\underline{q}, \underline{X})). \tag{6}$$

First order conditions with respect to $\underline{X}$ and $\bar{X}$ are respectively given by:

$$\frac{\partial V(\underline{q}, \underline{X})}{\partial X} = \frac{\partial C_N(\underline{q}, \underline{X})}{\partial X} \tag{7}$$

and

$$\nu \left[\frac{\partial V(\bar{q}, \bar{X})}{\partial X} - \frac{\partial C_N(\bar{q}, \bar{X})}{\partial X} \right] = (1-\nu) \left[\frac{\partial C_N(\bar{q}, \bar{X})}{\partial X} - \frac{\partial C_N(\underline{q}, \bar{X})}{\partial X} \right]. \tag{8}$$

Equation (7) states that for a low degree of purity of e-waste, the marginal utility of the principal must be equal to the marginal cost of the agent. This condition is the same as that of the first best with a low degree of purity of e-waste (Section 3.1). This means that at the second best, the principal should not distort the quantity of trade with an agent with a low degree of purity with respect to the first best. Then, the firm in the South trades with the collector in the North the same quantity of e-waste with a low degree of purity at the second best as in the first best: $\underline{X}^{SB} = \underline{X}^{FB}$.

As the principal needs to give a positive rent to the agent with a low degree of purity, Equation 8 states that the expected marginal net utility of the principal if the agent has a high degree of purity (left-hand side, hereafter LHS) should be equal to the expected marginal rent which is given to the agent with a low degree of purity (right-hand side, hereafter RHS). Clearly, the optimal trade of e-waste for the agent with a high degree of purity depends on the rent that the principal is willing to give to the agent with a low degree of purity.

Moreover, $\frac{\partial^2 C_N}{\partial q \partial X} > 0$ implies that $\frac{\partial C_N(\overline{q},\overline{X})}{\partial X} - \frac{\partial C_N(\underline{q},\overline{X})}{\partial X} > 0$. Then, the RHS of Equation (8) is non-negative. We can deduce that: Moreover, as $\frac{\partial^2 V}{\partial X \partial X} < 0$ and $\frac{\partial^2 C_N}{\partial X \partial X} > 0$, $\frac{\partial^2 V}{\partial X \partial X} - \frac{\partial^2 C_N}{\partial X \partial X} < 0$. Hence, $\overline{X}^{SB} < \overline{X}^{FB}$.

The second best level of e-waste trade with an agent with a high degree of purity is lower than that of the first best, which is provided in Section 3.1. The principal must pay to the agent with a low degree of purity a positive rent which positively depends on the quantity of trade with the agent who has a high degree on purity. Thus, there is a distortion of the quantity of e-waste that is traded with the agent who has a high degree of purity. Our second best solution refers to the Baron-Myerson (BM) solutions: $\underline{X}^{SB} = \underline{X}^{BM}$ and $\bar{X}^{SB} = \bar{X}^{BM}$. Replacing these solutions into (4) gives:

$$\psi \leq (1-\nu)\underline{r}^{BM} - r^e \equiv \psi_1, \tag{9}$$

where $r^e = t^e - C_N(q^e, X^e)$ is a rent that should be left to the agent that participates in the standard e-waste market and $\underline{r}^{BM} = C_N(\overline{q}, \overline{X}^{BM}) - C_N(\underline{q}, \overline{X}^{BM})$ is a rent of the agent with a low degree of purity. Equation (9) completes the proof. □

Proposition 1 rules out the possibility of the agent making an arbitrage as expressed in Equation (9). The agent would compare the additional expected rent from undertaking the sorting investment to the sorting cost. Thus, the agent undertakes the sorting investment as long as his expected rent in the alternative e-waste market net of that of the standard e-waste market is higher than the sorting cost. Consequently, the optimal contract for the principal that corresponds to the Baron-Myerson solutions is compatible with the sorting investment constraint. Additionally, Corollary 1 shows that the Baron-Myerson contract is optimal among those contracts that induce the sorting investment when the sorting cost is low (see the Proof of Corollary 1 in Appendix 5.1). We can then conclude that for a low sorting cost, the importer in developing countries trades the same quantity of e-waste with the collector in developed countries with low reusability of e-waste as in the first best, and makes the appropriate monetary transfer (i.e., $\underline{t}$). Similarly, the collector with a high reusability of e-waste gets the appropriate monetary transfer (i.e., $\bar{t}$) and trades a lower quantity of e-waste with respect to the first best. Note that these transfers do not include the sorting investment cost as they are defined with respect to the Baron-Myerson contract.

3.3 When the sorting investment is binding

When the sorting cost is no longer low, the sorting investment constraints cannot be ignored. The principal solves the program (5) plus the sorting investment condition (Eq.4).

The first order conditions with respect to $\overline{X}$, $\underline{X}$ and X^e are respectively given by:

$$\frac{\partial V(\underline{q}, \underline{X})}{\partial X} = \frac{\partial C_N(\underline{q}, \underline{X})}{\partial X}, \tag{10}$$

$$\underbrace{\nu[\frac{\partial V(\bar{q}, \bar{X})}{\partial X} - \frac{\partial C_N(\bar{q}, \bar{X})}{\partial X}] - (1-\nu)[\frac{\partial C_N(\bar{q}, \bar{X})}{\partial X} - \frac{\partial C_N(\underline{q}, \bar{X})}{\partial X}]}_{B(\underline{q},\overline{q},\overline{X})}$$
$$+\lambda(1-\nu)\underbrace{(\frac{\partial C_N(\bar{q}, \bar{X})}{\partial X} - \frac{\partial C_N(\underline{q}, \bar{X})}{\partial X})}_{A(\underline{q},\overline{q},\overline{X})} = 0 \tag{11}$$

and

$$\frac{\partial t^e}{\partial X} = \frac{\partial C_N(q^e, X^e)}{\partial X}, \tag{12}$$

where λ is non-negative and is defined as the marginal decrease of the principal's net utility due to an increase of the sorting cost ψ.

Equations (10) and (11) are arbitrage conditions. Equation (12) states that the marginal transfer that the principal should give to the agent must be balanced with the marginal cost of the agent on the standard e-waste market. Note that the optimal contract corresponds with the first best (resp. the Baron-Myerson) contract when the marginal decrease of the principal's net utility due to an increase of the sorting cost (λ) is equal to 1 (resp. 0). Otherwise, the optimal contract is a second best contract that is different from the Baron-Myerson contract. By replacing $\lambda = 0$ (resp. $\lambda = 1$) in Equation (11), it gives the Baron-Myerson (resp. first best) solutions provided in Equation (8). In fact, the condition $\lambda = 0$ expresses the fact that the principal's net utility is not sensitive to the sorting cost which corresponds to the Baron-Myerson contract in which the sorting investment condition is ignored. If λ lies between 0 and 1 ($0 < \lambda < 1$), then the optimal contract corresponds to a second best solution (NBM, hereafter) that is different from the Baron-Myerson solution.

We claim the following proposition :

Proposition 2: *When the sorting cost is high, the agent with a high degree of purity trades a quantity of e-waste that is higher (resp. lower) than the quantity from the Baron-Myerson (resp. first best) contract.*

The Proof of Proposition 2 is provided in Appendix 5.2.

Note that there is no distortion on the quantity that is traded with the agent with a low degree of purity. Furthermore, as the sorting cost is higher, the agent with a low degree of purity will likely have less incentive to invest in sorting and more incentive to pretend to have a high degree of purity. Then the principal will give a lower rent to the agent with a low degree of purity. This results in a higher quantity of e-waste trade with the agent with a high degree of purity.

4 Conclusion

In this paper, we apply the theory of incentives to the e-waste market and show how to induce firms in the North to undertake sorting investment to help implement an alternative e-waste market. The alternative e-waste market we propose would consist of a joint trade in reusable and non-reusable e-waste. Results show that, if the sorting cost is low, the optimal contract to induce sorting investment and to implement the alternative e-waste market is the Baron-Myerson contract. One of the direct implications of this result is that the firm in the South should give incentives to the firm in the North to invest in sorting as it is less costly. One policy decision could be to allow legal e-waste trade and enforce the appropriate technology transfer, such as the pyrometallurgical methods and de-gassing CFC/HCFC.

This paper could be extended in many ways. The optimal contract when the sorting cost is high needs to be studied together with the optimal decisions of the firm in the South over the set of sorting costs. One possible extension could also be the empirical implementation of the contract by means of an experiment or a survey.

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5 Appendix

5.1 Proof of corollary 1

Proof. From Proposition 1, the optimal contract that corresponds to the Baron-Myerson solution is compatible with the ex-ante sorting investment constraints. Therefore, for all sorting cost that is below the sorting investment threshold ψ_1, Baron-Myerson (1982) contract satisfies the sorting investment constraints and is optimal among contracts that induce the sorting investment. We can then deduce that for a low sorting cost, Baron-Myerson contract is robust to induce the sorting investment. The principal trades the same quantity of e-waste with the agent with low degree of purity as in the first best ($\underline{X}^{BM} = \underline{X}^{FB}$) and makes a monetary transfer of $\underline{t} = C_N(\underline{q}, \underline{X}^{BM}) + C_N(\overline{q}, \overline{X}^{BM}) - C_N(\underline{q}, \overline{X}^{BM})$. By the same way, the agent with high degree of purity gets a monetary transfer of $\overline{t} = C_N(\overline{q}, \overline{X}^{BM})$ and trades a lower quantity of e-waste $\overline{X}^{BM}$ with respect to the first best. □

5.2 Proof of proposition 2

Proof. $\frac{\partial^2 C_N}{\partial q \partial X} > 0$ implies that $A(\underline{q}, \overline{q}, \overline{X}^{NBM}) > 0$. Then, $B(\underline{q}, \overline{q}, \overline{X}^{NBM}) < 0$, as $\lambda(1-\nu) > 0$. We can then deduce that:

$$\nu\left[\frac{\partial V(\bar{q},\bar{X}^{NBM})}{\partial X} - \frac{\partial C_N(\bar{q},\bar{X}^{NBM})}{\partial X}\right] - (1-\nu)\left[\frac{\partial C_N(\bar{q},\bar{X}^{NBM})}{\partial X} - \frac{\partial C_N(\underline{q},\bar{X}^{NBM})}{\partial X}\right] <$$

$$\nu\left[\frac{\partial V(\bar{q},\bar{X}^{BM})}{\partial X} - \frac{\partial C_N(\bar{q},\bar{X}^{BM})}{\partial X}\right] - (1-\nu)\left[\frac{\partial C_N(\bar{q},\bar{X}^{BM})}{\partial X} - \frac{\partial C_N(\underline{q},\bar{X}^{BM})}{\partial X}\right].$$

Taking the derivative with respect to X gives:

$$\underbrace{\nu[\underbrace{\frac{\partial^2 V}{\partial X \partial X}}_{<0} - \underbrace{\frac{\partial^2 C_N(\overline{q}, \bar{X})}{\partial X \partial X}}_{>0}]}_{<0} - (1-\nu)\underbrace{[\underbrace{\frac{\partial^2 C_N(\bar{q}, \bar{X})}{\partial X \partial X}}_{>0} - \underbrace{\frac{\partial^2 C_N(\underline{q}, \bar{X})}{\partial X \partial X}}_{>0}]}_{>0} < 0 \Rightarrow \overline{X}^{NBM} > \overline{X}^{BM}.$$

We can then conclude that the quantity of e-waste that is traded with the agent with a high degree of purity ($\overline{X}^{NBM}$) is greater than that of the Baron-Myerson solution (X^{BM}). Hence, the trade for the agent with a high degree of purity lies between that of the Baron-Myerson contract and that of the first best contract, whenever λ lies between 0 and 1. □