

Reducing The Socially Optimal Environmental Impact Of Waste Management: The Economic
Viability Of Various Waste Management Policies

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I.) Introduction

Waste management is a persistent challenge amidst increased economic activity and population. While technological progress enables waste management practices to keep pace with economic growth in some aspects, there is evidence that significant progress needs to be made in order for waste management to reach socially optimal levels. The UN estimates that 1.84 billion tons of municipal waste were produced globally in 2004 (Hamilton et al., 2013 p.1). That number has likely grown significantly - about 5% per year - since then (Ley et al., 2001 p. 3). Governments around the world are increasingly concerned that traditional waste management strategies, including more environmentally-friendly ones such as recycling, are not as efficient as they should be and are now debating how to craft more impactful incentives to encourage greener waste management. Most of the increase in recycling recently is attributable to governments that set recycling standards that are, in fact, not socially optimal, and hurt the environment more than they help it (Kinnaman et al., 2014).

For example, in a study by Pöldnirk (2015), one interesting method of improving the efficiency of waste management was analyzed: the source sorting of bio-waste and paper products. Paper and bio-waste account for the majority of municipal waste and the majority of adverse environmental impacts if landfilled. The study found that source sorting was only economically and environmentally feasible in population-dense areas where the collection facility is relatively close (Pöldnirk, 2015). In rural areas, however, the carbon emissions of transportation negated the environmental savings, and on top of that, the cost was prodigious. (Pöldnirk, 2015). Therefore, in many cases, source-sorting of even the most environmentally damaging waste is neither environmentally nor economically feasible due to transportation and processing costs.

Furthermore, according to Bohm et al. (2010), recycling programs in the United States have continued to grow independently of cost because of legislation. This leads to a socially inefficient rate that, if the factors that influence the cost of recycling are understood, can be remedied. For conventional waste management and recycling, fuel costs, referenced with the term “transportation costs” later, were found to be one of the largest contributors to the overall cost (Bohm et al., 2010). The other finding that lends itself to the purposes of this paper is that cost differences between recycling programs started voluntarily and those started under the mandate of a state or local government are not statistically significant (Bohm et al., 2010). This indicates that a government mandate is not needed to equate the socially and privately optimal recycling rates or increase the socially optimal recycling rate. In fact, synthesizing these findings with those of Pöldnrk (2015), it may even be true that legislation that forces greener forms of waste management often hurts more than it helps. Though many other factors can be taken into consideration, these two should be emphasized to provide a lens for modeling and analysis.

The main focus of this paper would be to reiterate the economic idea that there is a socially optimal rate and privately optimal rate of “green” waste management, show theoretically why those two rates deviate from each other, and propose policies that would equate them. In Kinnaman et al. (2019), the socially optimal recycling rate was calculated from the consumer’s side, but this paper’s model will flip it to the side of the firms providing waste management, similar to Schreck and Wagner (2017). The paper will then explore and build on the ideas of many others to find methods of raising the socially optimal rate of recycling. In section II, a model is introduced to show the differences between the socially optimal and privately optimal recycling rates. Then, in section III, multiple approaches to manipulating the socially and

privately optimal rates of recycling will be presented. Finally, in section IV, directions for further research are explored, and a brief conclusion of the model's findings and analysis is given.

II.) The Model

For this paper, a straightforward, theoretical model will be used in which there are only two forms of waste management: a relatively “brown” option, and a relatively “green” option. In a similar fashion to Schreck and Wagner (2017), this model will first derive the socially optimal rate of both forms of waste management and then derive the firm’s privately optimal rate. The model assumes that a society produces some amount of waste, Q , all of which could be dealt with in a green fashion, represented by g , or a brown fashion, represented by b . Society will choose the optimal rates of g^* and b^* by choosing the quantities that maximize the Total Social Benefit, denoted by TSB . Factors that influence the TSB are the Total Private Benefit(TPB), Total Private Cost (TPC), and Total External Cost (TEC). These factors give the equation:

$$(1) \max[TSB = TPB(b, g) - TPC(b, g) - TEC(b, g)], \text{ where}$$

$$TPC(b, g) = TPC(b) + TPC(g) \text{ and}$$

$$TEC(b, g) = TEC(b) + TEC(g)$$

It is worth noting that, while society does not necessarily benefit from units of waste produced, they do benefit from the proper disposal of waste, making (1) a valid equation for calculating the TSB of waste management for consumers (Schreck and Wagner, 2017). It is also worth noting that $TEC(b, g)$ will be negative if b and g incite positive externalities on society, or positive if b and g incite negative externalities on society. Because b and g are effectively processed units of waste, it can be assumed that $TEC(b) \geq 0$ and $TEC(g) \geq 0$ (i.e. no form of waste management will be perfect and, therefore, all waste management will have some positive,

non-zero external cost). Taking the derivative of (1) confirms that consumers will choose b^* and g^* where:

$$(2) \frac{dT_{SB}}{db} = \frac{dTPC(b)}{db} - \frac{dTEC(b)}{db} = MSB_b$$

$$(3) \frac{dT_{SB}}{dg} = \frac{dTPC(g)}{dg} - \frac{dTEC(g)}{dg} = MSB_g$$

The next step is to derive the privately optimal rates of b^* and g^* that the firm providing waste management services will choose. Any firm will maximize profit, denoted by L , according to:

$$(4) \max[L = (P_b \cdot b) + (P_g \cdot g) - TPC(b, g)], \text{ where}$$

$TPC(b, g)$ is as it was in (1)

Deriving this equation demonstrates that a firm will choose b^* and g^* where:

$$(5) \frac{dL}{db} = P_b - \frac{dTPC(b)}{db}, \text{ where } \frac{dTPC(b)}{db} = MC_b$$

$$(6) \frac{dL}{dg} = P_g - \frac{dTPC(g)}{dg}, \text{ where } \frac{dTPC(g)}{dg} = MC_g$$

Comparing the equations for the socially and privately optimal rates of b , ((2) and (5)), and the privately and socially optimal rates of g , ((3) and (6)), yields a significant difference: the privately optimal rates do not include $TEC(b, g)$. It is worth noting that a firm's profit is also its private benefit. We can assume that g has a positive, upward-sloping Marginal Social Cost (MSC) function. In support of these equations, Figure 1 demonstrates that society will choose b^* and g^* where T_{SB} , represented by the shaded area A , is maximized. This graph will be manipulated in the next section to help analyze the effectiveness of certain policy methods.

This simple model allows for economic policy analysis that works toward two different goals. If the goal is to move the quantity of waste recycled, g , to the socially optimal

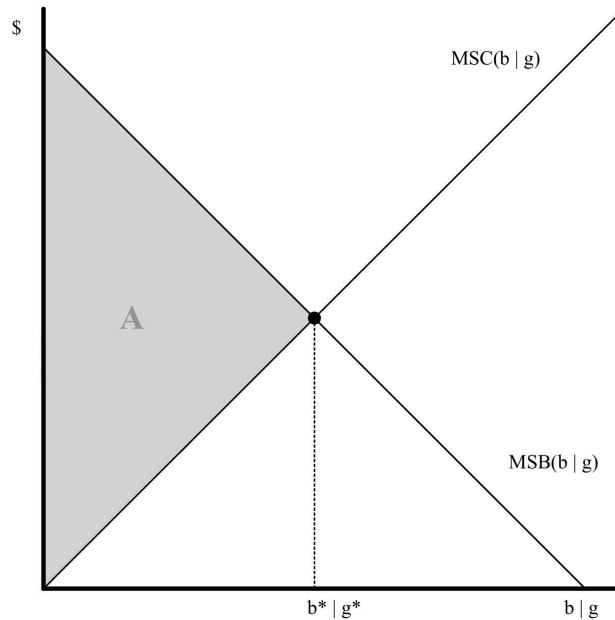


Figure 1: MSC and MSB curves that can be used for either g or b

recycling rate, g^* , economic policy should focus on making sure $TEC(g) = P_g$. If the goal, however, is to increase the socially optimal rate of recycling to g^+ , then economic policy must focus on lowering $TPC(g)$. To analyze the effectiveness of policies at lowering $TPC(g)$, the components of the value should be analyzed. Those components are encapsulated in the equation:

$$(7) TPC(g) = [A(RD) \cdot F(T, D)] + RD$$

A is a function that represents benefits due to technological progress that comes from spending RD dollars on research and development, and F represents a function that contains transportation costs, T , and disposal costs, D per unit of g . Assuming $A(0) = 1$, then any technological progress would be represented by a decrease in A such that $0 < A \leq 1$. Thus, to reduce $TPC(g)$ would involve increasing RD (and subsequently reducing A), decreasing T , or

decreasing D . Notice that, to lower $TPC(g)$, the percent decrease in A will need to be lower than the percent increase in RD , as RD is added into the private cost function. Utilizing this information, multiple economic policies can be analyzed to determine their effectiveness in achieving these goals.

III.) Analysis

Three methods can be used to achieve these changes, each with its own benefits and consequences: strict laws set by governments, making waste management firms liable for the negative external impacts of disposed processed waste, and a tax on or permit market for conventional waste management. The following analysis will consider each of these economic policy methods and determine which may be the most effective in increasing the socially efficient rate of recycling.

Strict government policy would be largely effective at increasing the rate of green waste management, though whether or not those policies achieve a socially optimal rate can be debated. As previously discussed, Pöldnirk (2015) found that the EU policy requiring the source separation of waste was actually more environmentally and economically damaging than conventional forms of waste management. One issue that made compliance with this regulation difficult was the lack of administrative efficiency in rural areas; the lack of cooperation between municipalities and federal funding allowed little room to improve the performance of waste management in rural areas (Pöldnirk, 2015). Another example of this administrative inefficiency can be observed in the interstate transportation of waste in the United States. Only 10% of waste is moved across state borders, but that small amount racks up around \$900 million in transportation costs, due almost solely to the difference in cost of waste disposal across states

(they ranged from \$10/ton in Nevada to \$75/ton in New Jersey in the 1990s) (Ley et al., 2001, p.3). In 1995, The Interstate Transportation of Municipal Solid Waste Act was passed by the Senate, significantly restricting the interstate trade of waste (Ley et al., 2001). These restrictions were all found to yield a large reduction in surplus (Ley et al., 2001). These case studies highlight that strict government intervention in waste management lowers efficiency, achieving the opposite effect from what was intended.

While Ley et al. (2001) and Pöldnirk (2015) did an excellent empirical analysis, it is important to step back and look at the basic theory behind those studies in the context of this paper's model. When a governing body uses legislation to change g , this requires the market to move to that point regardless of if it is socially or privately optimal. Within the confines of the model, the current socially efficient rate of green waste management, g^* , maximizes social benefit and, so long as $TEC(g) = P_g, g^*$, also maximizes the firm's profit. If the government were to force society to a higher quantity of g , all other things equal, a deadweight loss will be created by both firms and society not maximizing benefit. One could supposedly argue that legislation, while it may not produce an efficient outcome socially or privately, will improve environmental quality; however, because adverse environmental effects from waste disposal that cause human harm are already taken into account in (1) in the form of $TEC(b, g)$, increasing g would not increase TSB (i.e. the decrease in $TEC(b, g)$ would be greater than the increase in $TPB(b, g)$ and less than the increase in $TPC(b, g)$). Graphically, Figure 2 demonstrates the deadweight loss (the red-shaded area B) that results in a decrease in TSB ($TSB = A - B$). Therefore, while government policy would increase the recycling rate, it would not increase the socially or privately optimal rate, leaving society at an economic disadvantage compared to previously.

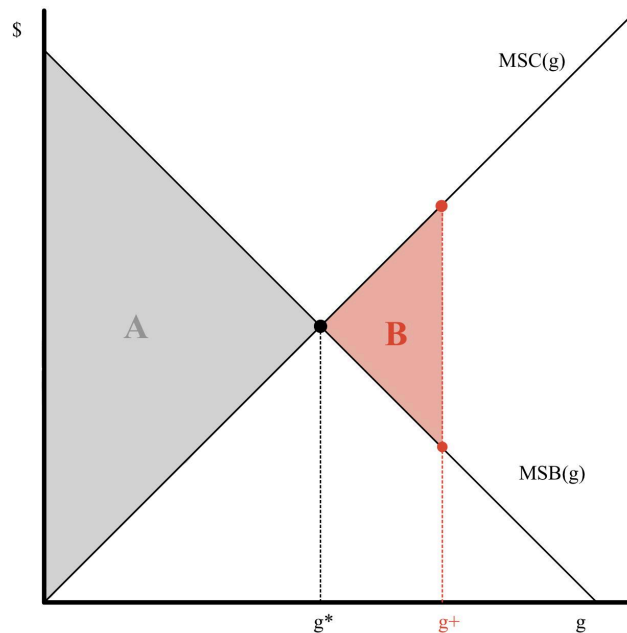


Figure 2: Deadweight loss incurred from strict government policy

Another viable method for increasing the privately optimal rate of recycling that pivots the focus of government policy away from strict regulation and toward allocating rights is liability incentives. In this case, the goal would be to make waste management firms liable for the damages they incur to the environment or surrounding communities with their methods of waste management. Endres and Friehe (2012) studied the relationship between liability and the development of abatement technology, and the same principles apply to this scenario. Their paper found that, under strict liability, firms make first-best choices, where they are optimizing the expected (statistical) damages for which they would be liable (i.e. the firms will spend enough money on abatement to make their abatement costs equal to their probability of being

liable for damages). In the context of this paper's model, assigning liability to firms would redesign (4):

$$(8) \max[L = (P_b \cdot b) + (P_g \cdot g) - TPC(b, g) - \alpha TEC(b, g)]$$

α is a constant multiplier determined by the firm's percentage probability of being liable for external damages their waste management strategies cause (i.e. $0 \leq \alpha \leq 1$, where $\alpha = 0$ means the firm will never be liable for damages, and $\alpha = 1$ means the firm will be liable for all damages).

Redesigning the first-order conditions in (5) and (6) means the firms will now choose b^* and g^* where:

$$(9) \frac{dL}{db} = P_b - \frac{dTPC(b)}{db} - \alpha \frac{dTEC(b)}{db}, \text{ where } \frac{dTPC(b)}{db} + \alpha \frac{dTEC(b)}{db} = MC_b$$

$$(10) \frac{dL}{dg} = P_g - \frac{dTPC(g)}{dg} - \alpha \frac{dTEC(g)}{dg}, \text{ where } \frac{dTPC(g)}{dg} + \alpha \frac{dTEC(g)}{dg} = MC_g$$

Assuming that $TEC(b) > TEC(g)$ because g represents a less environmentally damaging form of waste management, these new first-order conditions will decrease the firm's privately optimal rate of b^* and thus increase their privately optimal rate of g^* .

However, despite the solidity of the theory, for policy involving liability to work, three things need to culminate: first, rights need to be clearly assigned to one party (in this case, waste management firms or citizens), second, the bargaining costs need to be zero, and third, damages need to be known and measurable. The first two constraints are easy to manage in the United States: it is preceded by the Constitution that citizens have a right to a relatively healthy and clean living environment, and firms are always welcome to bargain in the free market. The third constraint is slightly harder to address. In many cases, damages may not be known, and it may be hard to measure exactly how they impact the surrounding areas. This is because, especially in the case of waste management, environmental damages can manifest at multiple points, such as

through transportation emissions, air emissions during decomposition or while sitting in open landfills, or effluent from liquid wastes or soluble solid wastes. The harder environmental damages are to measure and trace back to the firm, the closer α is to zero, despite clearly assigned rights and liability. If the firm bears very little of $TEC(b, g)$, then b^* and g^* will still change, but not nearly as much as lawmakers would probably hope. It is relatively easy to make firms liable for environmental damages caused by waste management, which would cause them to move towards greener alternatives; however, firms are never going to be held to that standard if damages cannot be easily measured or monitored.

That leads to the third and final environmental policy that would cause firms to return to the socially optimal recycling rate: an emission tax or marketable permit system for waste that is dealt with in a relatively environmentally damaging manner. Through a similar model to the one in this paper and an extension of current literature, Hamilton et al. (2013) determined that not only is a Pigouvian tax or cap-and-trade system necessary to achieve social efficiency, but the farther the source of the waste is from the disposal facility, the more incentives need to be provided. The firm's disposal costs are made higher by increased transportation and disposal costs, which increases their optimal rate of pollution (Hamilton et al., 2013). This logic works with the model presented in this paper. If D is increased, then $TPC(g)$ is increased per (7). All other things being equal, if $TPC(g)$ increases, the privately optimal rate of g will decrease, while the privately optimal rate of b increases. This difference in necessary incentives can simply be combatted by reformatting municipalities so that they are the ideal size (Hamilton et al., 2013). Doing so would restore the previously researched theoretical effectiveness of emission taxes or cap-and-trade systems as a method of improving the socially optimal recycling rate.

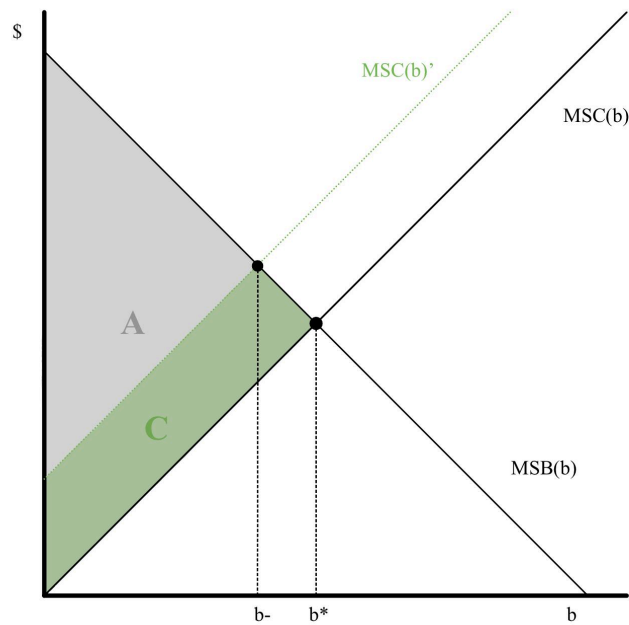


Figure 3: Change in TSB and socially optimal rate in b when $MSC(b)$ rises

If a firm is required to obtain a permit at cost $\beta = TEC(b)$ for each unit of b , or relatively non-environmentally friendly waste management, then the firm's profit maximization presented in (4) would become:

$$(11) \quad \max[L = (P_b \cdot b) + (P_g \cdot g) - TPC((b + \beta), g), \text{ where}$$

$TPC(b + \beta)$ is the new Total Private Cost of b

The new first-order equations would then change to:

$$(12) \quad \frac{dL}{db} = P_b - \frac{dTPC(b+\beta)}{db}, \text{ where } \frac{dTPC(b+\beta)}{db} = MC_b$$

$$(13) \quad \frac{dL}{dg} = P_g - \frac{dTPC(g)}{dg}, \text{ where } \frac{dTPC(g)}{dg} = MC_g$$

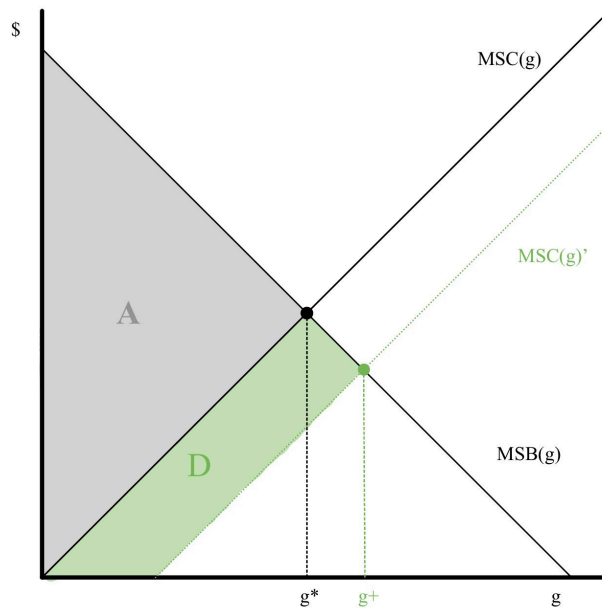


Figure 4: The change in TSB and socially optimal rate of g when $MSC(g)$ falls

Firms will now choose b^* and g^* according to (12) and (13), and because the firm's $TPC(b)$ increases by $TEC(b)$, the privately optimal rate of b^* will decrease, causing the privately optimal rate of g^* to increase. From the social side, however, (1) now becomes:

$$(14) \quad \max[TSB = TPB(b, g) - TPC((b + \beta), g) - TEC(b, g)]$$

This means that, unless the increase in TPC is matched by an equal decrease in TEC , TSB will decrease; however, lawmakers may decide to sacrifice marginal amounts of social benefit for increases in private benefits and decreases in external costs. This system will also likely cause firms to make a decision to invest more heavily in RD so that, in the long run, their technology increases and $TPC(g)$ decreases, as per (7). This would restore firms to their previous levels of benefit, restoring TSB to its previous levels. In the short run, however, government could decide to subsidize greener forms of waste management. Graphically, Figure 3 and Figure

4 demonstrate that, if the increase in $MSC(b)$ is offset by an equal decrease in the $MSC(g)$, then TSB will remain the same while increasing the socially optimal recycling rate. Though efficient implementation of this strategy is somewhat contingent on the redistribution of municipalities as Hamilton et al. (2013) suggest, an emission tax or cap-and-trade system would be extremely effective at equating the socially optimal and privately optimal rate of g in the short run, and possibly even increasing the socially optimal rate of g in the long run. .

IV.) Conclusion

IV.A.) Directions For Further Research

Due to the fact that this paper is a high-level presentation of economic theory, there are innumerable avenues for further research. First, more research could be done regarding the efficiency of waste collection routes, quite possibly using a computer algorithm to take into account an overwhelming amount of data. Das and Bhattacharyya (2015) studied ways to optimize the routes taken by waste management vehicles and were able to reduce the total path length by more than 30%. Nowakowski et al. (2018) focus on electronic waste and find that a computer algorithm would actually make on-demand collection a viable option, though because electronic waste does not need to be collected at nearly every building on a regular basis, on-demand collection may be less feasible for municipal waste management. A computer model would allow for a constantly changing optimal route, and the Nowakowski et al. (2018) model (as suggested in the conclusion of that study) could take into account a broader range of data, such as current traffic conditions. More work could be done on the economic benefits of models such as these. Furthermore, more studies could advance the work started by Hamilton et al. (2013) in terms of redesigning waste management municipalities to be of the optimal size so that

a Pigouvian tax or cap-and-trade market would be just as effective in rural areas as in population-dense areas. More engineering-focused research could also be done on substitutes for recycling that may be either more cost-effective or environmentally friendly.

IV.B.) Summarizing Remarks

Each of the three types of policy discussed in section III has its pros and cons. Legislation that forces an increase in g will create a market situation where g is neither at the privately optimal nor socially optimal rate. Liability legislation would cause firms to take on a percentage of $TEC(b, g)$; however, because $TEC(b, g)$ may be hard to measure, liability may not be as effective here as it is in other areas of environmental policy. A tax or marketable permit system would theoretically equate the privately and socially optimal rates of b and g , but only in a scenario where the increase in $TPC(b, g)$ is equal to the decrease in $TEC(b, g)$. A tax or marketable permit system could also create a situation where, in the long-run, technological developments are incentivized, increasing the socially optimal and privately optimal rates of g further. Of the methods analyzed, a Pigouvian tax or cap-and-trade system, combined with a change in waste management municipalities to more accurately reflect the ideal size, would likely be the most effective in raising the socially optimal rate of recycling or other green forms of waste management. Overall, there is a significant amount of work to be done to reduce the socially optimal environmental impact of waste management; however, with the proper dedication and incentives, it can be done.

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