Scrap prices, waste and recycling policy.

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Abstract

This study examines the effect of waste and recycling policy on scrap prices and the importance of scrap price feedbacks as a determinate of the costs of waste and recycling policy. The effects of a deposit/refund, advance disposal fee, and recycling subsidies on scrap prices are derived, and the direct and indirect channels of waste reduction are decomposed for the three instruments. Scrap price feedbacks decrease the cost of advance disposal fees, increase the cost of recycling subsidies, and have an ambiguous effect on the cost of deposit/refund. Simulation analysis finds that scrap price feedbacks substantially affect the costs of the policies and alter the ranking of instruments.

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1 Introduction

The world has long engaged in private recycling activities, driven by the tradeoff between the value of scrap materials and the costs associated with recycling. Only recently in the past several decades has recycling become a matter of public policy, due to concerns of declining landfill availability and upstream and downstream externalities in production and disposal processes. Efforts to increase recycling rates above private levels reflect a desire to internalize these costs. Importantly however, these policy interventions will in turn affect equilibrium scrap prices, which may have important consequences for the cost of policy interventions in both waste and recycling markets.

Palmer et al. (1997) examine the costs of waste and recycling policies using a calibrated mass-balance model of recycling and waste levels in the US in 1990. They compare the costs of three price-based policy instruments: deposit/refund, advance disposal fee, and recycling subsidies. Several key results emerge from their analysis. First, deposit/refund is the least-cost instrument for waste reduction ($45 dollars per ton for a 10% reduction in waste), followed by the advance disposal fee ($85 dollars per ton) and recycling subsidies ($98 dollars per ton). Second, they find that flexible deposit/refunds (in the sense that the deposit/refund is applied uniformly to all materials) achieve a 10% reduction in total waste at a substantially lower cost compared to the case where each material must be reduced by 10%.[1] Finally, by comparing the marginal cost of deposit/refund with the marginal social damages of disposal, they suggest that a 7.5% reduction in total waste would have been

[1] This result is driven in part by the fact that, by assumption, each type of material has equal marginal social damage. Acuff and Kaffine (2012) show that a uniform deposit/refund is no longer the least-cost policy when material-specific upstream greenhouse gas externalities are considered.

justified.

Palmer et al. (1997) identify two key channels of waste reduction: *source reduction* and *increased recycling*. By exploiting both channels of waste reduction, deposit/refund policies achieve a given reduction in total waste at a lower cost than either advance disposal fees or recycling subsidies.[2] However, because scrap price is endogenously determined by the level of policy intervention, an *indirect* effect of these policy instruments is also in play. These price effects will generate feedbacks, and as this paper will show, these indirect price feedbacks are substantial, altering both the magnitude of the costs as well as the ranking of the instruments.[3] This result is important for policymakers, particularly in small, open markets where the market price of scrap may be taken as reasonably exogenous. While the original model was calibrated at the national level, in reality, policy is likely to be made at the sub-national level, and it is important to understand which conclusions derived at the national level can be applied at smaller jurisdictional scales.

This paper explores the following three questions. First, what is the impact of waste and recycling policies on scrap prices? Second, how does the change in scrap prices affect waste and recycling levels? Finally, how do these scrap price feedbacks affect the cost of waste and recycling policies? In the analytical derivations below, the effect of each policy instrument on the price of scrap is derived, and the direct and indirect channels of waste

[2] This result is in accordance with earlier theoretical and empirical work on the efficiency of deposit/refund. See, for example, Dinan (1993), Fullerton and Kinnaman (1995), Sigman (1995), Palmer and Walls (1997), and Walls and Palmer (2001). See also Kinnaman (2006) for a summary of empirical studies of waste and recycling policies.

[3] It is important to note that these scrap price effects are present in the simulation model in Palmer et al. (1997), but their role is unremarked upon. For example, the reported recycling rates under an advance disposal fee increase, despite the lack of a direct channel affecting recycling markets.

reduction are decomposed for the three instruments. In the simulation analysis, the costs of deposit/refund, advance disposal fees and recycling subsidies with endogenous prices are compared to the costs of the policy instruments with exogenous prices.

The analytical model finds that advance disposal fees (ADF) increase scrap prices and recycling subsidies decrease scrap prices. However, the effect of the deposit/refund is ambiguous - though the deposit decreases consumption and pushes up scrap prices, the refund increases the recycling rate and decreases scrap prices. The decomposition of the direct and indirect channels of waste reduction shows that the indirect scrap price feedbacks generate indirect *source reduction* and *increased recycling* effects for all three instruments. These indirect effects have opposing signs, implying that, analytically, the effect of price feedbacks has an indeterminate effect on the costs of the policy instruments. The simulation analysis addresses the numerical magnitudes of these effects, and finds that indirect scrap price effects increase the cost of a 10% total waste reduction with a deposit/refund by 30%. The cost of the advance disposal fee falls by 10%, while the recycling subsidy is over 50% more costly due to the indirect effects. As a result, when scrap prices are exogenous, the instrument ranking is altered, with a 10% reduction in total waste costing $36 dollars per ton under deposit/refund, $66 dollars per ton under a recycling subsidy, and $96 dollars per ton under an advance disposal fee. At a marginal social damage of $33 dollars per ton for waste disposal (as used in Palmer et al. (1997)), the optimal reduction in waste is roughly one-third larger when scrap prices are exogenous (10% compared to 7.5%).

The remainder of the paper proceeds as follows. First, the Palmer et al. (1997) model of waste and recycling is briefly reviewed. Next, the effects of deposit/refund, advance disposal fees, and recycling subsidies on scrap prices are analytically derived, and the direct and indirect channels of waste reduction are decomposed for each instrument. Finally, using a simulation model identical to Palmer et al. (1997), the costs of the policy instruments are compared when scrap prices are endogenous versus exogenous, and the magnitude and direction of the indirect feedback effects are determined.

2 Model of waste and recycling

To begin, the model adopted in Palmer et al. (1997) is reviewed. The basic mass-balance model is described by the following system of equations:

$$W = Q - R, \tag{1}$$

$$Q = D(p_q, p_q - p_r), \tag{2}$$

$$R^d(p_r) = r(p_r)D(p_q, p_q - p_r), \tag{3}$$

where W is disposed waste, Q is total consumption, and R is the amount recycled. The mass balance equation (1) requires that all consumption is either disposed of as waste, or is recycled. Per Palmer et al. (1997), supply of the final product Q is assumed to be perfectly elastic, while demand for the final product Q varies with the price of the final product p_q, and if recycled, with the price net of scrap value $p_q - p_r$.[4] The supply of total scrap goods varies with the scrap price (p_r), and is equal to the recycling rate $r(p_r)$ times total consumption. Finally, demand for scrap goods is assumed to also vary with p_r, such that $R^d = R^d(p_r)$.

[4] There may also be a marginal effort cost or marginal psychic benefit associated with recycling the good, but as in Palmer et al. (1997), these considerations are abstracted from in this study. It should also be noted that the private price of waste disposal is assumed to be zero, and the demand for the final product is assumed to depend only on prices.

Thus, per Equation (3), the market for recycled scrap clears at endogenous scrap price p_r. The following intuitive assumptions hold: $\frac{\partial D}{\partial p_q} < 0$, $\frac{\partial D}{\partial (p_q - p_r)} < 0$, $\frac{dr}{dp_r} > 0$, and $\frac{dR^d}{dp_r} < 0$.

Several assumptions of the original study should be noted. It is assumed that markets for the final material and recycled scrap are perfectly competitive. It is also assumed that there are no lags between when the material is purchased and when it is disposed of or recycled. Another important assumption is that the quantity of the consumption good Q does not affect the demand for recycled scrap $R^d(p_r)$. The final important assumption is that demand for the consumption good only depends on own price, effectively setting the cross-price elasticity across materials equal to zero. Realistically, increases in the price of one material would likely lead towards substitution towards other materials. While relaxing these assumptions would alter the quantitative results in Palmer et al. (1997) and this study, they are unlikely to alter the qualitative comparisons between the two studies.

3 Policy intervention and price feedbacks

Three price-based instruments, deposit/refund, advance disposal fees, and recycling subsidies, are examined. As in Palmer et al. (1997), it is assumed these policies are implemented at the producer level, and that the incentives provided by these policies are passed on to consumers.

The literature has identified two channels that can reduce total waste disposal: *source reduction* and *increased recycling*. Source reduction operates through reductions in consumption, or in terms of the model, by reducing $D(p_q, p_q - p_r)$. The recycling channel operates through increasing the recycling rate, $r(p_r)$. In Palmer et al. (1997), the discussion of these two channels focuses on the direct effects of the various policy instruments. However, through Equation 3, the scrap price p_r is endogenous and will thus be affected by the policy instruments. The derivations below determine the effect of the policy instruments on scrap prices and analytically separate the direct and indirect policy effects on waste reduction. The magnitudes of these various effects are then examined in the simulation analysis.

3.1 Advance disposal fee

Consider an advance disposal fee of f per ton. Consumers face this fee regardless if they choose to recycle, such that consumption prices for non-recycling consumers are given by $p_q + f$, and $p_q + f - p_r$ for recycling consumers. Equilibrium in the scrap market under this policy is given by:

$$R^d(p_r) = r(p_r)D(p_q + f, p_q + f - p_r). \tag{4}$$

The effect of the ADF on scrap prices can be derived from the implicit function theorem:

$$\frac{dp_r}{df} = \frac{r(p_r)(\frac{\partial D}{\partial(p_q+f)} + \frac{\partial D}{\partial(p_q+f-p_r)})}{\frac{dR^d}{dp_r} - \frac{dr}{dp_r}D(p_q + f, p_q + f - p_r) + r(p_r)\frac{\partial D}{\partial(p_q+f-p_r)}} > 0. \tag{5}$$

The ADF discourages consumption, which reduces the quantity of scrap available and pushes up prices. The full impact of an ADF on waste can be decomposed into direct and indirect effects as follows:

$$\frac{dW}{df} = \underbrace{(1 - r(p_r(f))(\frac{\partial D}{\partial(p_q + f)} + \frac{\partial D}{\partial(p_q + f - p_r)})}_{Direct\ SR(-)} + \tag{6}$$

$$\underbrace{\frac{-dr}{dp_r}\frac{dp_r}{df}D(p_q + f, p_q + f - p_r)}_{Indirect\ IR(-)} + \underbrace{(1 - r(p_r(f)))\frac{dp_r}{df}\frac{-\partial D}{\partial(p_q + f - p_r)}}_{Indirect\ SR(+)} \tag{7}$$

where the signs indicate whether the effect increases or decreases waste. The ADF exploits one direct channel of waste reduction, through the *source reduction* (SR) effect. Though the policy does not directly target recycling rates, it does reduce consumption and the availability of recycled material, leading to price increases and stimulating the recycling rate through the indirect *increased recycling* (IR) effect. At the same time, the increased scrap price encourages consumption, increasing waste produced through the negative indirect *source reduction* effect.[5] Thus, the magnitude of these countervailing indirect effects will determine whether or not waste reduction increases or decreases relative to the direct *source reduction* effect. In terms of the costs of the policy, if the indirect IR effect dominates the indirect SR effect, a smaller ADF would be needed to achieve a given waste reduction target relative to the case where scrap price is exogenous.

3.2 Recycling subsidy

Next, consider a recycling subsidy of s per ton. Consumers who recycle receive a price of $p_r + s$, and thus the effective price of consumption is $p_q - p_r - s$. Equilibrium in the scrap market under this policy is given by:

[5] The use of the term "negative" to describe the indirect *source reduction* effect under the ADF is potentially confusing, as this effect actually increases waste. However, it is used to denote the fact that the change in waste is opposite the desired goal of decreased waste.

$$R^d(p_r) = r(p_r + s)D(p_q, p_q - p_r - s). \tag{8}$$

The effect of the recycling subsidy on scrap price can be derived from the implicit function theorem:

$$\frac{dp_r}{ds} = \frac{\frac{dr}{d(p_r+s)}D(p_q, p_q - p_r - s) - r(p_r + s)\frac{\partial D}{\partial(p_q - p_r - s)}}{\frac{dR^d}{dp_r} - \frac{dr}{d(p_r+s)}D(p_q, p_q - p_r - s) + r(p_r + s)\frac{\partial D}{\partial(p_q - p_r - s)}} < 0. \tag{9}$$

The recycling subsidy encourages recycling, which increases the quantity of recycled scrap available and pushes down prices. The full impact of a recycling subsidy on waste can be decomposed into direct and indirect effects as follows:

$$\frac{dW}{ds} = \underbrace{\frac{-dr}{d(p_r + s)}D(p_q, p_q - p_r - s)}_{Direct\ IR(-)} + \underbrace{(1 - r(p_r + s))\frac{-\partial D}{\partial(p_q - p_r - s)}}_{Direct\ SR(+)} + \tag{10}$$

$$\underbrace{\frac{-dr}{d(p_r + s)}\frac{dp_r}{ds}D(p_q, p_q - p_r - s)}_{Indirect\ IR(+)} + \underbrace{(1 - r(p_r + s))\frac{dp_r}{ds}\frac{-\partial D}{\partial(p_q - p_r - s)}}_{Indirect\ SR(-)}. \tag{11}$$

Under a recycling subsidy, waste is reduced through the direct *increased recycling* effect. However, by subsidizing recycling, the effective price of the consumption good for consumers who recycle is reduced, increasing consumption and waste through the negative direct *source reduction* effect. Two additional indirect channels of waste reduction are also generated by the recycling subsidy. Due to the decrease in scrap prices, recycling rates fall and waste increases via the indirect negative *increased recycling* effect. On the other hand, lower scrap prices also raise the effective consumption good price for recycling consumers, decreasing consumption and waste through the indirect *source reduction* effect. Again, the relative magnitudes of these two indirect effects will determine how the cost of recycling subsidies with endogenous scrap prices compares to the case when prices are exogenous.

3.3 Deposit/refund

Finally, consider a deposit/refund of d per ton. Consumers who fail to recycle experience a price of $p_q + d$, while those who recycle the product receive the refund back, offsetting the deposit. Equilibrium in the scrap market under this policy is given by:

$$R^d(p_r) = r(p_r + d)D(p_q + d, p_q - p_r). \tag{12}$$

The effect of the deposit/refund on scrap price can be derived from the implicit function theorem:

$$\frac{dp_r}{dd} = \frac{\frac{dr}{dd}D(p_q + d, p_q - p_r) + r(p_r + d)\frac{\partial D}{\partial(p_q+d)}}{\frac{dR^d}{dp_r} - \frac{dr}{d(p_r+d)}D(p_q + d, p_q - p_r) + r(p_r + d)\frac{\partial D}{\partial(p_q-p_r)}} \lesseqgtr 0. \tag{13}$$

In contrast with the previous instruments, the effect of a deposit/refund on scrap price cannot be signed a priori. While the deposit reduces consumption, pushing up scrap prices, the refund encourages recycling, pushing scrap prices down.

The full impact of a deposit/refund on waste can be decomposed into direct and indirect effects as follows:

$$\frac{dW}{dd} = \underbrace{\frac{-dr}{d(p_r+d)}D(p_q+d, p_q-p_r)}_{\textit{Direct IR}(-)} + \underbrace{(1-r(p_r+d))\frac{\partial D}{\partial(p_q+d)}}_{\textit{Direct SR}(-)} + \tag{14}$$

$$\underbrace{\frac{-dr}{d(p_r+d)}\frac{dp_r}{dd}D(p_q+d, p_q-p_r)}_{\textit{Indirect IR}(-/+)} + \underbrace{(1-r(p_r+d))\frac{dp_r}{dd}\frac{-\partial D}{\partial(p_q-p_r)}}_{\textit{Indirect SR}(+/-)}. \tag{15}$$

The direct effects of the deposit/refund are clear: the refund increases the recycling rate, leading to waste reduction through the direct *increased recycling* effect, and the deposit increases the cost of the consumption good, decreasing consumption and waste through the direct *source reduction* effect. However, due to the ambiguity of the effect of deposit/refund on scrap prices (equation 13), the indirect effects are correspondingly less clear. If scrap price increases ($\frac{dp_r}{dd} > 0$), then the indirect *increased recycling* effect will reduce waste, while the indirect negative *source reduction* effect will increase waste.[6] If the scrap price falls ($\frac{dp_r}{dd} < 0$), then the indirect effects flip signs. Thus, the change in the costs of the deposit/refund policy due to scrap price effects will depend both on the direction of the price change and the absolute magnitudes of the indirect effects.

4 Simulation results

The previous section decomposed the direct and indirect effects of deposit/refund, advance disposal fees, and recycling subsidies on waste. In all cases, the indirect *source reduction* and *increased recycling* effects had opposite signs, and as such, the impact of scrap price feedbacks on the costs of the policies is ambiguous. To resolve these effects empirically, the simulation model in Palmer et al. (1997) is used to compare the costs of the policies when scrap price is

[6] Note that the first sign on the indirect effects correspond to this case.

exogenous versus endogenous. In the simulation analysis to follow, the necessary level of the policy intervention for each instrument is determined in order to achieve a specific reduction in total waste.[7] To ensure the accuracy of the comparison with Palmer et al. (1997), their simulation model with endogenous prices was recreated and checked against their published results.

4.1 Scrap price response to policies

In the preceding section, it was shown that the ADF pushes up scrap prices, recycling subsidies push down scrap prices, and the effect of the deposit/refund is ambiguous. To determine the magnitude of these change in scrap price and examine the change in scrap price under deposit/refund, as an illustrative example, consider the change in the price of a common recycled household good: aluminum beverage cans.

[Figure 1 about here]

Figure 1 plots the change in aluminum beverage can scrap price under each of the three instruments for varying intervention levels. As expected, scrap prices rise under an ADF and fall under a recycling subsidy. At an intervention level of $100 per ton (roughly the cost for each instrument to achieve a 10% reduction in waste), the ADF increases scrap price by 2%, while the recycling subsidy pushes down scrap prices by 6%. While change in price under deposit/refund was ambiguous in the analytical decomposition, here the deposit/refund pushes prices down by 3%, implying that the refund is outweighing the deposit in terms of changing the quantity of scrap material available and thus the price. The other materials

[7] The simulation model uses Palmer et al.'s 1990 data on baseline consumption and recycling by material, as well as own-price elasticities for demand and supply in the consumption and recycling markets.

under consideration show similar trends to those for aluminum cans - advance disposal fees increases scrap prices a modest amount, recycling subsidies decrease scrap prices by a more substantial amount, and for all materials, deposit/refund decreases scrap prices.

4.2 Policy intervention levels under exogenous prices

Figure 2 displays the policy intervention levels required to achieve a given percentage reduction in total waste when scrap price p_r is exogenous. The ranking of the instruments is clear: deposit/refund is the least cost policy at all levels of waste reduction, followed by the recycling subsidy, and finally the advance disposal fee. This stands in contrast to the instrument ranking with endogenous prices, where the advance disposal fee was less costly than the recycling subsidy. A 10% reduction in total waste is achieved with a $36 dollars per ton deposit/refund, a $66 dollars per ton recycling subsidy, and a $96 dollars per ton advance disposal fee.

[Figure 2 about here]

Comparing these results with exogenous scrap prices against the results in Palmer et al. (1997) with endogenous scrap prices, the cost of the deposit/refund and recycling subsidy have decreased, and the cost of the ADF has increased. The differences in costs for the ADF and recycling subsidy are easy to explain. From Equation 6, the fact that the cost of the ADF is higher with exogenous scrap prices implies that the indirect *increased recycling* effect dominates the indirect negative *source reduction* effect, leading to a decrease in waste due to price feedbacks for a given ADF level.[8] As a result, a smaller ADF is required to achieve a given waste reduction when prices are endogenous. Similarly from Equation 9, the

[8] Recall that the indirect negative *source reduction* effect implies an increase in waste.

substantial decrease in the cost of the recycling subsidy under exogenous prices also implies that the indirect recycling effects are larger than the indirect source effects, but in this case, the indirect *increased recycling* effect is negative (as scrap prices fall, recycling rates fall, implying an increase in waste). Thus, the recycling subsidy must be increased when prices are endogenous in order to counteract the waste increases from scrap price feedbacks.

The impact of price feedbacks on the deposit/refund is less clear. As noted in Equation 12, the indirect effects have opposing signs and themselves vary in sign depending on the effect of the deposit/refund on scrap price (Equation 11). The simulation results find that for a 10% reduction in total waste, the change in price due to the deposit/refund is negative $\frac{dp_r}{dd} < 0$ for all materials. Therefore, from Equation 12 and the fact that the cost of the deposit/refund falls under exogenous prices, one can conclude that the indirect price feedbacks are such that the indirect negative *increased recycling* effect dominates the indirect *source reduction* effect. As a result, when scrap prices are endogenous, a larger deposit/refund is needed to offset the scrap price-induced waste increases in order to achieve a given reduction in total waste.

4.3 Magnitudes of the direct and indirect effects

Above, the net direction of the indirect effects was deduced from the changes in the costs of the instruments. In the analysis that follows, the magnitudes of the direct and indirect effects are considered in more detail. Figure 3 displays the ratio of intervention levels for each instrument against the percentage change in total waste reduction, where the numerator is the intervention level under endogenous prices (indirect and direct effects) and denominator is the intervention level under exogenous prices (direct effects only). A value greater than one indicates that the indirect effects increase the required intervention level (price feedbacks increase waste), while a value less than one indicates that the indirect effects decrease the required intervention level (price feedbacks decrease waste).

[Figure 3 about here]

The ratio for the advance disposal fee is invariant across waste reductions, and is roughly 0.9. Thus, price feedbacks lead to a modest 10% reduction in the marginal cost per ton of the advance disposal fee. By contrast, the costs of the deposit/refund and recycling subsidies are increased by price feedbacks, with a more pronounced effect at lower levels of total waste reduction. For the deposit/refund, the indirect effects are initially 50% as large as the direct effects, but decline to roughly 20% as total waste reductions increase. The effect of price feedbacks are even larger for the recycling subsidy - the indirect effects are initially 140% as large as the direct effects, before declining to roughly 30%. Thus, indirect price effects do play a substantial role in the costs of the instruments, particularly for deposit/refund and recycling subsidies.

The magnitudes of the direct and indirect channels of waste reduction are broken down by material in table 1 for a 10% reduction in total waste.[9] While the terminology used in table 1 is similar to that used in table III of Palmer et al. (1997), there is an important distinction to highlight. Palmer et al. (1997) calculate *source reduction* and *increased recycling* as simply the change in total consumption (ΔQ) and total recycling (ΔR). However, because total recycling is a function of total consumption, these calculations are difficult to interpret.

[9] Note that for each policy, the sum of all effects across all materials sums to 9.163 (million tons), corresponding to a 10% reduction in total waste.

For example, while a recycling subsidy increases total recycling by 6 million tons, one cannot determine how much of that increase is due to increases in recycling rates compared to how much of that increase is driven by increases in consumption. Thus, in the table presented here, the terms *source reduction* and *increased recycling* refer to the decompositions derived in section 3 - *source reduction* is the change in waste solely due to changes in consumption, while *increased recycling* is the change in waste solely due to changes in the recycling rate. These definitions have been adopted to more closely match the analytical derivations, and more accurately reflect the channels of behavioral change in response to the policies.

[Table 1 about here]

Per the analytical decomposition, the advance disposal fee has no direct effect on recycling rates, and thus the only direct effect of the policy is through source reduction. The indirect *increased recycling* effect dominates the indirect *source reduction* effect, which drives the previously discussed result that the cost of the advance disposal fee falls due to price feedbacks. However, the magnitude of the net indirect effects is relatively small, leading to the modest 10% reduction in the costs of the ADF when prices are endogenous. For the recycling subsidy, the reductions in waste from the direct *increased recycling* effect are substantially offset by increases in waste from the indirect *increased recycling* effect, particularly for steel, increasing the costs of recycling subsidies when price feedbacks are present. A similar story arises for the deposit/refund, where the indirect recycling effects erode the waste reductions from the direct *increased recycling* effect. Furthermore, under deposit/refund the direct recycling channels are typically larger than the direct source reduction channels (except for plastics). Across instruments, the indirect effects are, in general, smaller than the direct effects, but nonetheless are substantial in magnitude.

5 Conclusions

This study examines the effect of waste and recycling policies on scrap prices, and, consequently, the role of these price feedbacks as a determinate of the costs of waste and recycling policies. Though these feedbacks were present in an original study by Palmer et. al (1997), their role was ultimately unremarked upon. In a deeper exploration of their model, the analytical derivations in this study find that advance disposal fees increase scrap prices and recycling subsidies decrease scrap prices, while the effect of the deposit/refund is ambiguous - though the deposit decreases consumption and increases scrap prices, the refund increases the recycling rate and decreases scrap prices. The decomposition of the direct and indirect channels of waste reduction shows that the indirect price feedbacks generate indirect *source reduction* and *increased recycling* effects for all three instruments. These indirect effects have opposing signs, implying that, analytically, the effect of price feedbacks has an indeterminate effect on the costs of the policy instruments.

The simulation analysis addresses the numerical magnitudes of these effects, and finds that indirect price effects increase the cost of a 10% total waste reduction with a deposit/refund by 30%. The cost of the advance disposal fee falls by 10%, while the recycling subsidy is over 50% more costly due to the indirect effects. As a result, when scrap prices are exogenous the instrument ranking is altered, with a 10% reduction in total waste costing \$36 dollars per ton under deposit/refund (versus \$45), \$66 dollars per ton under a recycling subsidy (versus \$98), and \$96 dollars per ton under an advance disposal fee (versus \$85). At a marginal social damage of \$33 dollars per ton for waste disposal, the optimal reduction in waste is roughly one-third larger when scrap prices are exogenous (10% compared to 7.5%).

In addition to providing further insight into the behavioral channels that drive waste reduction and the corresponding costs of policy instruments, this study also may provide guidance for policymakers. While the model is calibrated for the national level where scrap prices are likely endogenous, policy is typically made at sub-national scales where scrap prices are likely exogenous. This paper finds that the absence of price feedbacks will substantially decrease the costs of recycling subsidies and deposit/refund, which may make them more appealing at city and state-levels than the original Palmer et al. (1997) study would suggest. Of course, this also suggests that waste and recycling policy made in one jurisdiction can have spillover effects on the costs of policy in other jurisdictions, which may be an interesting topic for further exploration.

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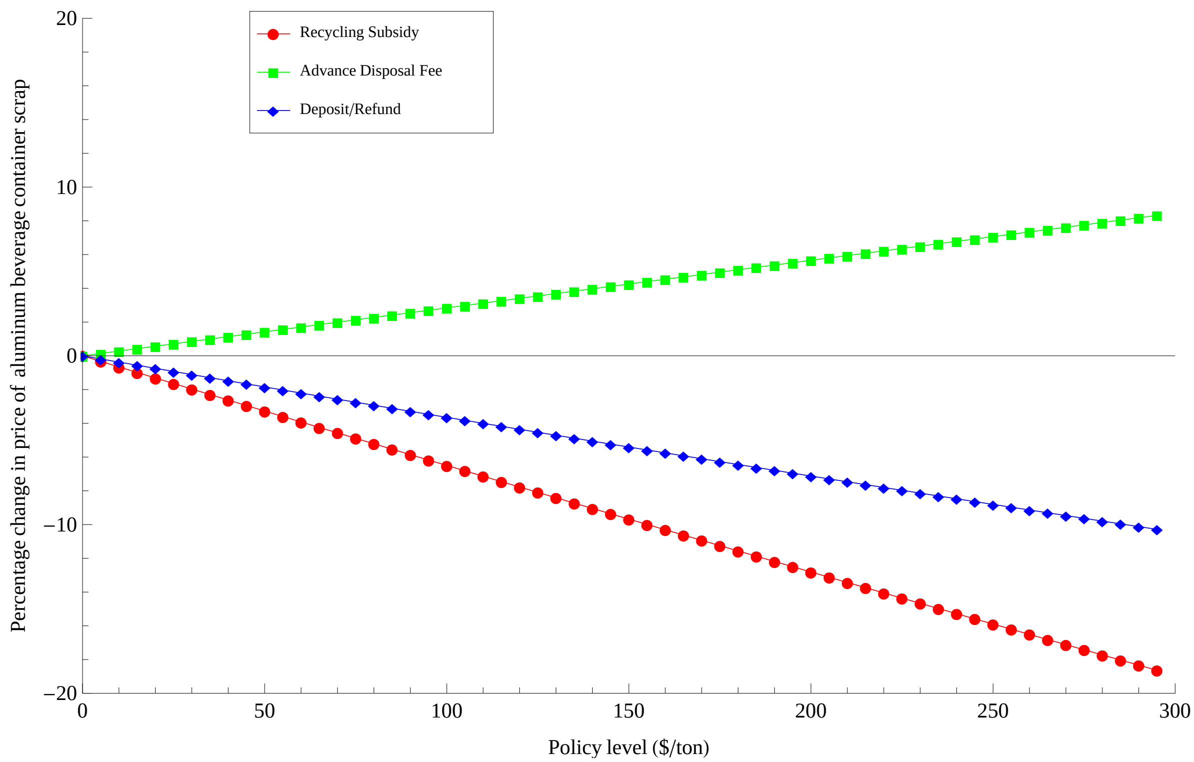

Figure 1: Percentage change in scrap price of aluminum beverage cans versus policy intervention level.

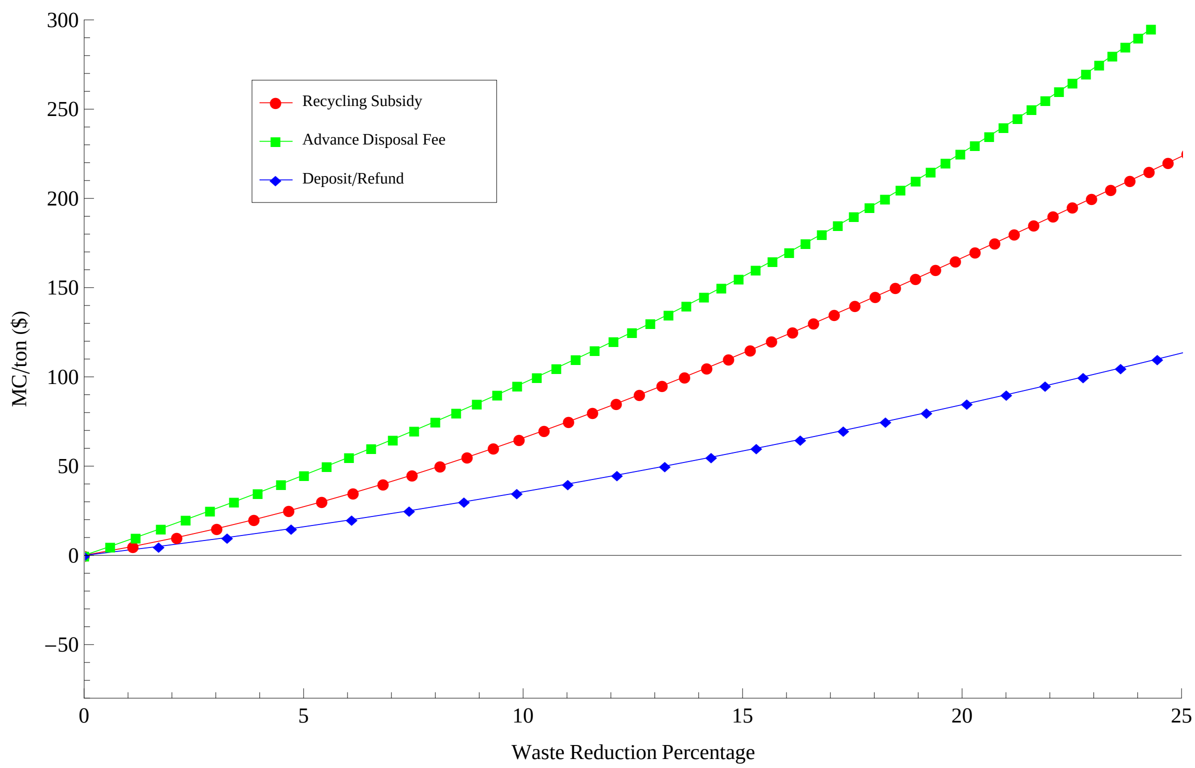

Figure 2: Marginal cost of the deposit/refund, advance disposal fee, and recycling subsidy necessary to achieve various percentage waste reductions when scrap prices are exogenous.

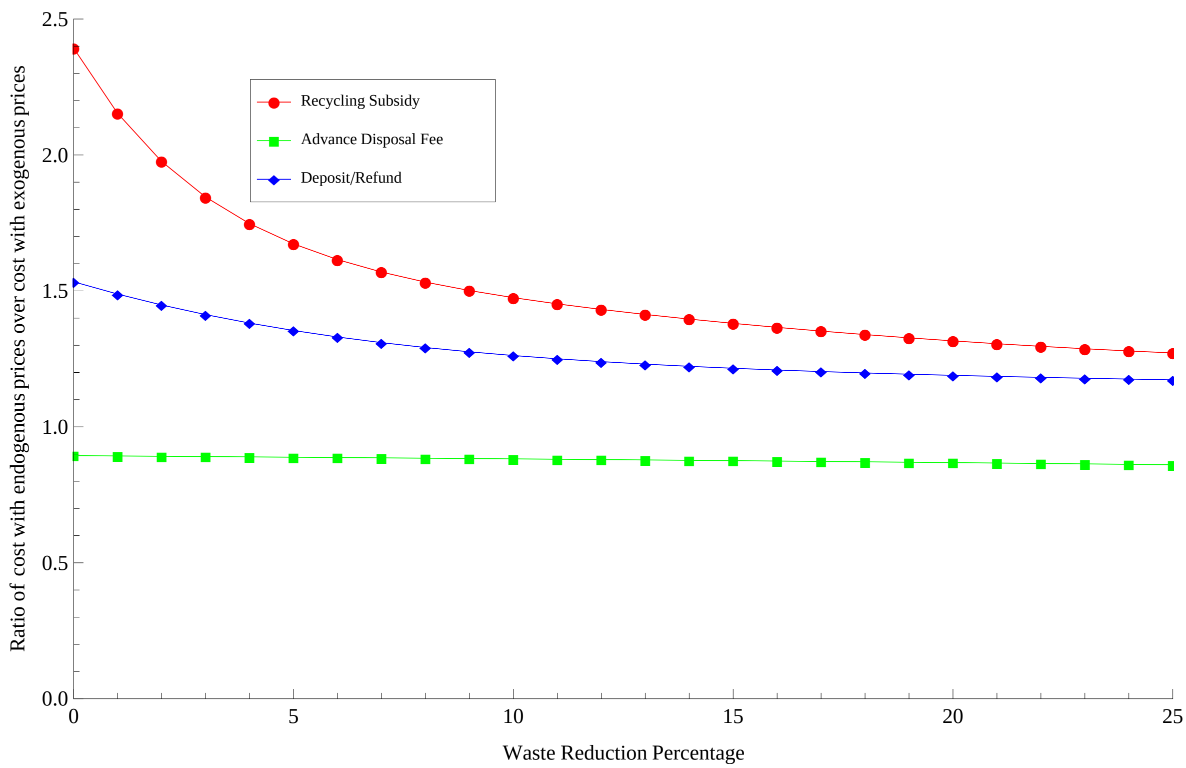

Figure 3: Cost ratio of the deposit/refund, advance disposal fee, and recycling subsidy for a given reduction in waste. The cost ratio is defined as the cost of the policy with endogenous prices over the cost of the the policy with exogenous prices.

Table 1: Direct and indirect channels of waste reduction: 10% total reduction in waste

	Material				
Policy	Paper	Glass	Aluminum	Steel	Plastic
Advance disposal fee					
Direct increased recycling effect	N/A	N/A	N/A	N/A	N/A
Direct source reduction effect	3.871	1.730	0.070	1.077	1.462
Indirect increased recycling effect	0.768	0.202	0.028	0.131	0.015
Indirect source reduction effect	-0.152	-0.014	-0.010	-0.009	-0.005
Total waste reduction	4.487	1.917	0.089	1.199	1.471
Recycling subsidy					
Direct increased recycling effect	6.754	4.276	0.133	3.755	0.056
Direct source reduction effect	-1.693	-0.609	-0.053	-0.331	-0.027
Indirect increased recycling effect	-1.141	-0.913	-0.090	-2.104	-0.044
Indirect source reduction effect	0.503	0.503	0.036	0.130	0.022
Total waste reduction	4.442	3.256	0.027	1.450	0.007
Deposit/refund					
Direct increased recycling effect	3.812	2.117	0.053	1.460	0.023
Direct source reduction effect	1.527	0.797	0.021	0.507	0.797
Indirect increased recycling effect	-0.922	-0.405	-0.025	-0.868	-0.013
Indirect source reduction effect	0.172	0.0370	0.011	0.056	0.006
Total waste reduction	4.589	2.255	0.060	1.156	0.813

Change in waste disposal (million tons)