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A PROPOSAL FOR ALTERNATIVE GOVERNMENT POLICY TO REDUCE LANDFILL OF HOUSEHOLD WASTE IN ISRAEL[1]

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Abstract

In Israel, the government currently implements various measures intended to reduce the amount of household waste sent to landfill. So far, however, these measures have resulted in only limited success. The commonly heard claim that municipalities prefer to continue sending waste to landfill because it is less costly than recycling is incorrect. A recent study shows that on average, recycling is 11% less costly than landfill, and that over 50% of municipalities would enjoy lower waste management costs by recycling, even ignoring the landfill tax which has since gone into effect. However, despite this basic economic consideration, the vast majority of municipalities are hesitant to make the transition to recycling. The main reason for this is the combination of price uncertainty in recycling on the one hand, and high irreversible investment costs required to make the transition to recycling on the other. This combination of uncertainty and irreversible investment costs is recognized in the literature as a significant deterrent to transition between states, even when the transition is economically profitable. This study present a theoretical model analyzing the decision-making process of the municipality, and then empirically tests the results of the model by using data from 79 municipalities in Israel. On the basis of these results, an alternative government policy is proposed – a policy focused on dealing with the uncertainty factor in recycling, constructed in such a way as to help make the transition to alternative treatment solutions for household waste more efficient.

1. INTRODUCTION

In recent years, Israel has been forced to deal with an increasing shortage of land for landfill of household waste. Each year, about 5 million tons of waste are sent to landfill in Israel. This constitutes about 80% of total household waste, while in many advanced countries landfill now accounts for less than 50% of the waste. The Israeli government, led by the Ministry of Environmental Protection, has been working in the last decade to

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significantly reduce landfill by encouraging municipalities (responsible for the disposal of household waste) to implement alternative treatment solutions. Over the years, the Ministry has implemented various measures, including a deposit/refund law for beverage containers, recycling regulations, government subsidies for placing containers for recyclable waste, subsidies per ton of waste recycled, and, staring July 1st, 2007, a landfill tax imposed on each ton of waste sent to landfill. This tax is set to rise gradually from NIS 10 per ton in 2007 to NIS 50 per ton in 2011 (Lavee, 2007). At the same time, the government provides municipalities with subsidies to help them reduce the amount of waste sent to landfill (for instance: government support in setting up recycling programs, or other types of alternative treatment solutions). Despite these measures, the total amount of waste sent to landfill has only increased (it has decreased in percentage terms, but natural growth in the total amount of waste has outweighed the percentage increase in recycling and other treatment solutions). In light of this, the Ministry is currently considering to raise the landfill tax up to NIS 100 per ton (or even higher), and to introduce new regulations that will widen the scope of the deposit/refund law for beverage containers, mandate recycling of product packages, and prohibit landfilling of wet waste.

There is no doubt that this wide set of measures will eventually lead to a reduction in the amount of waste sent to landfill, but at what cost? The question should be raised whether this set of measures indeed constitutes the most effective policy, and specifically whether the landfill tax will indeed induce municipalities to reduce landfill in the long term. In order to answer this question, we need to investigate why municipalities in Israel have so far avoided taking up recycling measures on a large scale.

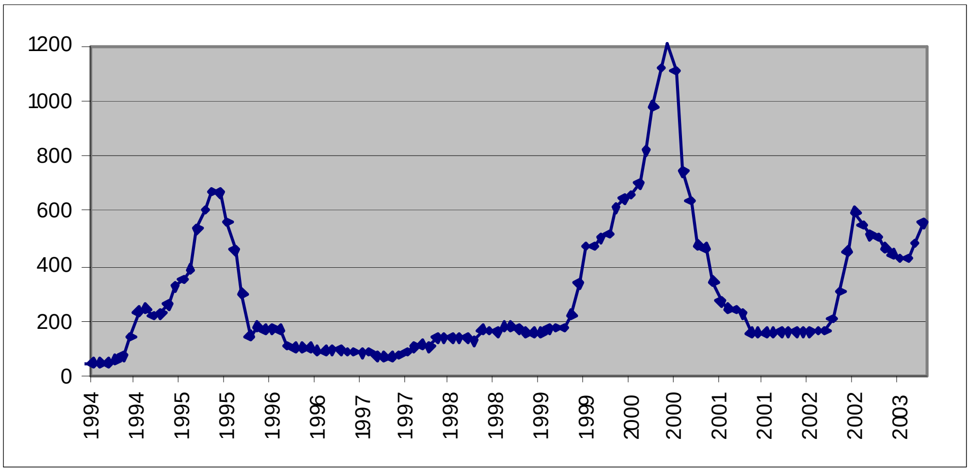
Most economic studies suggest that the direct costs of recycling are higher than those of landfill, and thus that recycling is not economically efficient so long as the external costs of landfill are not taken into account. Such studies therefore justify imposing a landfill tax which will thus induce municipalities to increase recycling. However, a number of studies carried out in the last decade in Israel and abroad (Callan and Thomas, 2001; Folz, 2004; Lavee, 2007; Lavee and Khatib, 2010) show that in many cases, if the municipality organizes its waste management system appropriately and makes the necessary investments, it may actually find a system combining recycling and landfill more efficient than a system in which 100% of the waste is sent to landfill. In Israel, Lavee (2007) analyzed 79 municipalities which jointly generate about 60% of municipal waste in Israel. The study revealed that for 53% of the municipalities, recycling part of the waste would be economically efficient, allowing them to save an average of 11% on total waste management costs. This result was obtained without taking into account the costs associated with the landfill tax (that is, even ignoring the landfill tax, recycling was shown to be economically efficient for most municipalities in Israel).

Under the assumption that municipalities search for ways to become more efficient and reduce their operational costs (without hurting services to their residents), it is thus not clear why they refrain from implementing recycling programs as an integral part of their waste management system. In attempt to shed light on this issue, Lavee (2007) also questioned municipal officials as to why their municipalities do not operate large-scale recycling programs. In response, most officials first pointed to lack of information and bureaucratic difficulties. However, when asked whether now, upon being shown the results of the study, they would move to implement recycling programs, most answered negatively, raising another issue – that of the significant uncertainties associated with recycling.

It turns out to be the case that many municipalities have had bad experiences in the past when attempting to introduce recycling programs. For instance, many municipalities had in the past placed paper recycling containers, only to be forced to return to landfilling paper waste after a short period of time when the contracted recycling firms decided to opt out of the agreements. These developments entailed significant costs associated with making changes to the waste management system, while also damaging the image of the municipalities in the eyes of their residents. In the municipality of Omer, for instance, the municipality continued to maintain paper waste collection containers for recycling, while sending the waste collected in the containers for regular landfill. Municipal officials explained that while the costs associated with this policy were higher than those associated with returning to regular collection for landfill, they wished to avoid the damage to the public image of the municipality. Other municipalities were forced to return to 100% landfilling after recycling firms demanded significant increases in the price paid by the municipality for collection services. In short, efforts to implement recycling programs in the past were clearly associated with significant costs and public image damage, which is why most municipalities now prefer to refrain from adopting such measures, even when recycling is shown to be less costly than continuing with 100% landfilling.

Recycling price volatility is not a problem unique to Israel, especially as Israel itself is affected by world recycling prices. For example, the following figure displays the extreme volatility in world prices for waste newspaper:

Figure 1
Price index for recycled newspaper



Source: USA Bureau of Labor Statistics – Price Producer Index, Series Id: pcuso93#53.

Data concerning world price volatility for several types of recyclable waste are presented in the following table:

Table 1
World price volatility of recyclable waste

Recyclable waste type	Standard deviation of price (as % of mean price)	Share of total municipal waste (%)
White paper	87	4.50
Newspaper and other paper	87	31.33
Cardboard	55	20.77
PET plastic	9	4.83
Other plastic	9	30.21
Glass	17	8.35
Total	**38**	**100**

As can been seen in Table 1, volatility is high for paper waste, while significantly lower for plastic waste. If it is indeed the case that price volatility has a significant effect on the decisions of municipalities whether to engage in recycling, we would expect that municipalities would be more willing to take up plastic recycling than paper recycling.

An analysis of actual recycling levels in Israel indeed supports this hypothesis. Although the costs of collecting and recycling plastic waste are higher than those of paper waste, in 2007 plastic was recycled in about 46% of municipalities, while paper was recycled in less than 20%. The main explanation for this situation is that plastic waste collectors (for recycling) are willing to enter into long-term contracts (normally for 5-year periods), while paper waste collectors are only willing to enter short-term contracts, which may be re-opened on an annual basis.

This observation led to us to examine the possibility of analyzing this practical dilemma faced by the municipality within the framework of a theoretical model. The purpose of this theoretical model is to assess whether the municipality's hesitation in implementing recycling programs may be quantified in light of recycling price volatility (such that a rise in volatility will lead to greater hesitation on the part of the municipality).

The municipality's dilemma is whether to continue with its current waste management system where nearly 100% of the waste is sent to landfill, or to introduce large scale recycling into its system. As long as the municipality continues with 100% landfilling, its waste management costs are constant and known. On the other hand, if the municipality decides to integrate recycling into its system, it may originally enjoy lower costs, but will be forced to face volatile recycling prices, such that in the future its total costs may be higher than under its original system of 100% landfilling. In order to make the transition to recycling, the municipality must take some necessary steps to re-organize its waste management system. These steps include re-planning the collection system, investment in infrastructure, public awareness campaigns, and workforce reorganization (which may include severance payments to workers laid off as a result of the changes, or compensation payments to contractors whose contracts have been broken or modified). All costs associated with these steps are irreversible, such that they may not be recouped if the municipality will choose in the future to return to its previous waste management system. Additionally, returning to 100% landfilling will also be associated with reorganization costs, such that the municipality will probably not hurry to return to its previous system, even when recycling costs rise.

Even if the municipality is risk-neutral, this combination of irreversible investment costs and price uncertainty may very well deter it from embracing recycling, such that it will continue to landfill nearly 100% of its waste even if recycling is shown to be economically efficient. In the survey of municipal officials carried out by Lavee (2007), this assertion was stated outright. For instance, an official from the municipality of Ra'anana said: "We need to invest considerable effort and resources in order to make the transition to recycling and enjoy its benefits; after all this, we will enjoy lower costs today, but in the future, when recycling costs rise, we will have to pay a high price, without being able to return to landfilling. It is better to continue with landfilling, it is much safer and we know the exact costs of disposal".

The aim of the theoretical model is to analyze the behavior of the municipality under realistic conditions. Through the model, it will be possible to identify the effect of price uncertainty on the municipality's decision whether to make the transition to recycling. The model is based on the literature on irreversible investment under uncertainty (Dixit and Pindyck, 1994). This literature shows that when this combination of irreversible investment (or sunk costs during transition from one state to the other) and uncertain conditions exists, the transition is often not made, even when it is profitable. For instance, Schatzki (2003) shows that in Canada, even though there is a clear economic incentive to turn agricultural land into forest land (that is, to plant trees on agricultural land – in order to mitigate greenhouse gas emissions), farmers hesitate to do so as a result of the uncertainty associated with the economic compensation, and the irreversible investment required. Louberge et al. (2002) show similar results in the context of nuclear waste treatment (comparing two solutions – one with high but constant costs, the other with lower current costs but uncertain costs in the future).

In the model which we will now present, we identify the price of uncertainty, that is, the premium required by municipalities in order to implement recycling so as to compensate for recycling price uncertainty. Later, we will examine empirically the price of uncertainty and show that in Israel this price is considerable and indeed may very well deter municipalities from making the transition to recycling, even if this transition is currently profitable.

2. THE THEORETICAL MODEL

The theoretical model is described in detail in Lavee et al. (2009). We consider a municipality which must choose between either landfilling all of its waste or recycling part of it. The transition from landfilling to recycling (and back, if necessary) requires a one-time investment. The municipality must treat a constant amount of waste, of which only a certain part may be recycled (q)[2]. If the municipality indeed recycles q, it may save on its

[2] A certain part of the waste must be landfilled in any event, thus the discussion here focuses only on that part of the waste which potentially may be either recycled or landfilled.

total landfilling cost a total amount of H, or unit savings of $C_H = H/q$ [3], thus C_H is the alternative cost of landfilling a unit of waste. The cost of recycling a unit of waste is C_R - this cost includes the costs of collection of recyclable waste and its transport to the recycling plant. For each unit of waste delivered to the recycling plant, the municipality is paid a sum of P_R (by the recycling plant, which uses the waste to produce raw material). Thus, the net cost faced by the municipality of recycling a unit of waste is $C_R - P_R$.

The model's planning horizon is infinite and time is divided into discrete periods (for instance, one year periods). The discount rate r is assumed to be fixed over the time horizon. In each period the municipality must decide whether to implement recycling, or to return to 100% landfilling (if it has made the transition to recycling in the past). Switching from landfilling to recycling requires an investment of W_R, or a per unit cost of $W_R/q = w_R$. Switching from recycling back to landfilling requires an investment of W_H, or a per unit cost of $W_H/q = w_H$. The transition between states is instantaneous and the amount q of waste may be sent either to recycling or to landfilling instantly after the investment is made.

We assume the price paid to the municipality for its recyclable waste in each period - P_R - is an independent stochastic variable distributed according to the density function f and the cumulative distribution F that do not vary over time. Thus, $F(x) = \text{Prob}\{P_R \le x\}$; $f(x) = F'(x)$ and the expected price is

$$\mu_R \equiv E\{P_R\} = \int_{-\infty}^{\infty} x f(x) dx$$

with variance σ^2. The municipality learns the price P_R at the beginning of each period, and then must decide whether to continue with its existing system or make the transition to the alternative system.

We define:

V_H - expected present value of the cost of treating a unit of waste over an infinite time horizon when currently landfilling;

V_R - expected present value of the cost of treating a unit of waste over an infinite time horizon when currently recycling.

A municipality currently landfilling must determine a threshold price (γ_R), so that it will continue landfilling if $P_R \le \gamma_R$. In this case its expected waste management costs will equal

$$C_H + V_H/(1+r)$$

If $P_R > \gamma_R$, the municipality will implement recycling, in which case its expected costs will equal:

$$C_R - P_R + w_R + V_R/(1+r)$$

[3] A unit of waste may be measured either by volume or by weight. Here we take the basic unit to be 1 ton of waste.

We define γ_H as the threshold price for making the transition back from partial recycling to 100% landfilling. That is, the municipality will make this transition if $P_R < \gamma_H$, in which case its expected costs will equal

$C_H + V_H/(1+r) + w_H$

We define (see appendix A)

$$U(\gamma) == \int_{-\infty}^{\gamma} F(x)dx$$

The function $U(\gamma)$ plays a central role in the municipality's decision criteria. The value of $U(\gamma)$ may be interpreted as "the value of bad news" – the expected loss of a municipality which chose to implement recycling, when P_R falls beneath the threshold price of γ_R.

We define $\Delta\gamma$ as the difference between the two threshold prices. In Appendix A it is shown that $\Delta\gamma$ may be expressed as the sum of the investments required to make the transition from landfilling to recycling and back:

$$\Delta\gamma = \gamma_R - \gamma_H = w_H + w_R$$

The difference between the threshold prices, $\Delta\gamma$, reflects the concept of "economic hysteresis" described by Dixit and Pindyck (1994, p.17). Within this range (between threshold levels) the municipality prefers to continue with its existing waste management system, even though making the transition to the alternative system would be profitable. However, given the current system, the municipality prefers to wait until P_R drops/rises further so as to compensate for the lost investment costs as well. As is shown in the equation above, as the transition costs between recycling and landfilling (and back) are higher, so is the difference between the two price thresholds.

Furthermore (see Appendix A):

$$\Delta U = U(\gamma_R) - U(\gamma_H) = \int_{\gamma_H}^{\gamma_R} F(x)dx = \int_{\gamma_R - (w_H + w_R)}^{\gamma_R} F(x)dx$$

and the value of the threshold price for recycling is obtained explicitly by

$$\gamma_R = \Delta C + rw_R/(1+r) + \Delta U/(1+r)$$

The first expression in this equation – ΔC – reflects the difference in direct costs between recycling and landfilling. The second expression - $rw_R/(1+r)$ - reflects the transition cost from landfilling to recycling. The values of these two expressions are known, and their sum value constitutes the municipality's decision criterion in a world characterized by perfect certainty. That is, the threshold price for making the transition from landfilling to recycling under conditions of certainty is $\Delta C + rw_R/(1+r)$. The last expression in the equation - $\Delta U/(1+r)$ - is the "risk premium", that is, the additional compensation required by the municipality in order to make the transition to recycling in light of uncertainty. Thus, the theoretical model isolates the effect of uncertainty on the decision of the municipality. When uncertainty is low, this element - $\Delta U/(1+r)$ - is relatively small, but when it is high – it grows in significance and deters the municipality from recycling.

The effect of ΔU is to deter a municipality from making the transition from landfilling to recycling even though the cost of recycling is lower. The municipality will implement recycling only when the cost of landfilling is sufficiently high so as to cover the risk premium (ΔU) as well. As it is the underlying assumption of the model that at the beginning of the process most municipalities landfill their waste, uncertainty thus leads to less recycling and higher waste management costs.

Let us now examine what determines the "risk premium". We can see from the equation describing ΔU that its value is determined by $w_H + w_R$, that is, the sum of transition costs between landfilling and recycling and back. That is, as transition costs are higher, the municipality will be more likely to avoid making the transition.

It is important to emphasize that the decision to implement recycling is not merely a simple administrative decision. In order to begin recycling, the municipality must make substantial changes in its waste management system. For instance, the number of mixed-waste collection vehicles must be reduced and waste containers must be reorganized. Additionally, the municipality must train workers for different jobs or even lay some of them off, plan and carry out public awareness campaigns, and introduce programs on the subject in the education system. These actions are associated with economic costs, but may also lead to confrontations with labor unions and other interest groups. Thus, a municipality will decide to implement recycling only if its economic benefits are very high, and volatile prices may deter such a move even if it may be expected to lead to significant savings. Another important factor affecting the decision is the price spread, reflected by the range of F. As potential prices are spread over a wider range, uncertainty increases, deterring the municipality from making the transition to recycling (even when the mean price remains constant – that is, a mean preserving spread).

One possible solution to this problem may be government subsidization of transition costs, which would reduce the costs faced by the municipality. However, a significant shortcoming of this option is that when prices for recyclable waste drop, the municipality will find it easier to return to landfilling – an undesirable development from the government's perspective. We will consider government policy options in section 4 of this paper.

In summary, the results of the model show that uncertainty plays an important role in the municipality's decision, effectively preventing the transition to recycling even when it is shown to be profitable. We now move to estimate the extent of this effect using empirical data.

3. EMPIRICAL ANALYSIS

In order to assess the effect of recycling price uncertainty on municipalities in Israel, we conducted a survey of 79 municipalities. For each municipality, we began by carrying out an analysis of the economic efficiency of recycling under conditions of perfect certainty, and then analyzed how the existence of uncertainty affects the results.

The methodology for analyzing the economic efficiency of recycling for each municipality is presented in Lavee (2007) – the paper describes the survey and the data analysis. The following table summarizes the results of the study:

Table 2
Waste management characteristics by municipality type

Type of municipality	(2) Number of recyclable- waste collection rounds per week	(3) Average annual waste (1000 tons)	(4) Average annual waste per capita (tons)	(5) Average recycling costs, per ton of recycled waste C_R-P_R (NIS/ton)
Large	3.1	119.9	0.58	205
Medium-sized	3.3	22.1	0.55	218
Small	3.0	4.7	0.51	277
Regional	2.2	7.2	0.62	337
Total	**2.9**	**31.8**	**0.56**	**264**

Type of municipality	(6) Average landfill costs, per ton of landfilled waste (NIS/ton)	(7) Average cost savings, per ton of recycled waste, gained by reducing landfilling - C_H (NIS/ton)	(8) Average cost savings gained by recycling (% of total waste management costs)	(9) Average transition costs, per ton of recycled waste – w_R (NIS/ton)
Large	280	430	18	546
Medium-sized	216	295	9	1,085
Small	245	391	8	2,877
Regional	227	337	5	1,859
Total	**239**	**360**	**11**	**1,864**

Source: Lavee (2007)

As can be seen in Table 2, when we ignore the element of uncertainty, recycling is quite often worthwhile from an economic perspective. The average costs of recycling (over all municipalities in the sample – column 5) are NIS 264 per ton, while expected savings from reduced landfilling reach NIS 360 per ton. This amounts to operational savings of 36%. Even after we take into account the capital costs involved (transition costs – column 9), recycling is expected to save, on average, about 11% on per ton costs (column 8).

As can be seen, however, the savings are not uniform, and there is clear evidence for the existence of economies of scale – recycling is most efficient for large municipalities, and least efficient for small and regional municipalities. Overall, if we ignore the uncertainty effect, we find that for 53% of municipalities, making the transition to recycling is economically worthwhile (see Table 3), such that total economically efficient recycling potential reaches 85% of municipal waste (as most large municipalities – which generate the greater part of the waste – will find it worthwhile to recycle).

However, when the element of uncertainty is taken into account, the results change completely. Table 3 shows the effect of uncertainty on the economic efficiency of recycling. The results presented in the table are based on inserting the empirically obtained parameter values into equation (16) of the theoretical model (see Appendix A).

Table 3
The effect of price uncertainty on the economic efficiency of recycling

Uncertainty Level	$\Delta U/\mu_R$	Recycling municipalities	Recycling/ Potential	Recycling/ total waste (in weight)	Recycling/ total waste (in volume)
Certainty	0	53%	85%	21%	42%
σ/μ_R = 9%	4.6%	51%	83%	20%	40%
σ/μ_R = 17%	10%	48%	82%	19%	38%
σ/μ_R = 38%	34%	34%	69%	17%	35%
σ/μ_R = 55%	48%	29%	64%	16%	32%
σ/μ_R = 87%	66%	23%	59%	15%	30%

Source: Lavee et al. (2009)

As can be seen in the table, in a world characterized by perfect certainty, recycling would be economically efficient for 53% of the municipalities, but under an average uncertainty level of 38% (representing the relation between the standard deviation and mean of the price) this number drops to only 34% of municipalities. Under an uncertainty level of 87% (the uncertainty level of world newspaper waste prices), recycling is efficient for only 23% of municipalities – close to the actual level found in Israel. On the other hand, under an uncertainty level of 9% (that of plastic waste), recycling is efficient for 51% of municipalities, when indeed 46% of municipalities in Israel recycle plastic.

The fact that the results obtained by the theoretical model closely match the empirical findings lends strength to the hypothesis that municipalities in Israel indeed make decisions on the basis of the model's underlying principles.

4. GOVERNMENT POLICY ALTERNATIVES

If it is the case that uncertainty deters municipalities from recycling, the question should be raised whether indeed the current government policy of taxing landfill and subsidizing investment in recycling is indeed the most effective policy available to incentivize municipalities to implement recycling programs. To answer this question, we compare the current policy and an alternative policy suggested by the findings of this study – a policy focused at stabilizing long-term recycling prices. In order to compare the two alternatives, we will use the results of the empirical analysis. We assume that municipalities indeed behave according to the model (as suggested by the consistency of the predictions of the theoretical model with the empirical results), and assess, for each alternative, the total government expenditure required to reach the optimal level of recycling as obtained by the model for the case of perfect certainty (that is, recycling in 53% of municipalities).

We begin by defining the policy alternatives. In the case of the current policy, we make a distinction between its two elements: (1) A landfill tax; (2) Subsidization of investments required to advance recycling (support for investments in infrastructure, containers, etc.). The distinction is important because the current policy is effectively a combination of two independent policies implemented in Israel simultaneously. In principle, however, each of the two policies may be implemented on its own, and its effects analyzed separately. This combination is unique to Israel, and is primarily the result of political considerations[4]. Next to these existing policy tools, we will present the alternative policy, which is focused on stabilizing recycling prices. In what follows we analyze each of the policies:

a. Landfill tax

According to our analysis, in order to raise recycling levels to those that would be achieved under conditions of perfect certainty, waste sent to landfill must be taxed at NIS 50 per ton. The analysis was carried out by identifying the risk premium (ΔU) required to induce municipalities to make the transition to recycling (for those municipalities where recycling would have been optimal in a world characterized by perfect certainty). This premium is equal to 34% of the average price of recyclable waste (34% of 147 = 50). As the cost of landfilling 1 ton of waste is approximately NIS 260, this tax is equivalent to about 20% of landfilling costs. Imposition of the tax is expected to reduce total landfill by 21%. Accordingly, about 3.16 million tons of waste will be sent to landfill each year, and annual tax income will reach about NIS 158 million starting 2011.

This result is interesting as it exactly equals the landfill tax which will be imposed on municipalities starting 2011. Thus, the current landfill tax policy in Israel is expected to bring recycling to its optimal level. However, at the same time, the government is planning to subsidize investments in recycling infrastructure. Thus, another interesting result is that under the current government policy the recycling level in Israel may very well eventually exceed the optimal level (a result which may be justified by the external effects of landfill, which are not incorporated into our model).

b. Subsidizing investments in recycling

In Table 2 we see that the average transition costs reach NIS 1,846 per ton. Our calculations show that in order to reach the optimal level of recycling the government must subsidize

[4] In order to secure the support of the Ministry of Interior and the Knesset, the government promised to return the amount raised by the landfill tax to the municipalities, through subsidization of investments in recycling infrastructure; in other countries, these two policy tools are not generally integrated.

46% of the transition costs[5]. This equals a one-time investment of NIS 1,050 per ton of waste generated. As about 5 million tons of waste is sent today to landfill in Israel annually, of which about 25% may be potentially recycled, the government must fund about NIS 1.25 billion of investments in recycling[6].

The issue of subsides for irreversible investment under conditions of uncertainty has been discussed in the economic literature. For instance, Pennings (2000) proposes to subsidize investments and tax future profits expected from the transition. Our model also shows that subsidizing investment will reduce the effect of uncertainty through lowering the risk premium (ΔU). In the extreme case that the transition cost faced by the municipality is brought down to zero, the risk premium will also be reduced to zero and the municipalities will behave as under conditions of perfect certainty. However, the main problem with this solution is that subsidies reduce the incentive for a municipality to stay with recycling once the transition has been made. If the municipality does not face a transition cost when switching from landfilling to recycling and back, it will make the transition repeatedly, as prices rise and fall. Thus, redundant investments will be made, each completely lost when the municipality switches back to the former system. Therefore, transition costs cannot be fully subsidized, and this approach cannot completely solve the uncertainty problem.

A combination of both approaches (landfill tax and investment subsidies) will effectively lead to a recycling level much higher than optimal. In practice, on the basis of our empirical data it may be estimated that imposing a landfill tax while subsidizing investment in recycling will induce almost all municipalities (over 95%) to recycle. Only a small number of regional municipalities will continue landfilling all of their waste. From the perspective of the national economy, this level of recycling is higher than optimal[7].

c. Price stabilization

The problem of uncertainty stems from volatile world prices, and thus cannot be treated directly. However, the government may intervene to create a stabilization program that will allow municipalities to face constant long-term recycling prices. Such a program would induce those municipalities where recycling is economically efficient to indeed recycle. It would be based upon trilateral cooperation between the municipalities, the recycling plants and the government.

[5] Subsidizing investments in recycling affects two elements in equation (16) of Appendix A: the transition costs, $rw_R/(1+r)$, and U (see equation (15)). Taken together, it can be shown that a subsidy of 46% will lead to the optimal level of recycling.

[6] Subsidies cover 30% to 40% of costs for inter-municipal treatment plants, and about 70% of costs for municipal treatment programs. On average, subsides are expected to cover about 35%-40% of the required investment costs.

[7] It should be noted that the landfill tax (set at NIS 50 per ton) equals the negative externalities of landfill. Thus, the current government policy goes against the principle of setting policy to internalize external effects, as in fact the current government intervention equals NIS 100 per ton – a tax of NIS 50 per ton on landfill, and a subsidy of NIS 50 per ton on recycling investments – twice the amount necessary!

The goal of such a program would be to bring the recycling level to its expected level in a world characterized by perfect certainty. In order to do so, the program must set the price of recyclable waste guaranteed within a long-term contract at its long-term expected value. Under this condition, municipalities' decisions concerning their waste management systems should be similar to those they would make under conditions of perfect certainty.

Recycling plants buy the recyclable waste from the municipalities, use it to create raw material, and sell the raw material to industrial companies in a competitive market. The price of the raw material is stochastic, and may, at times, fall. Thus, the government must insure the recycling plants in order to induce them to enter fixed-price long-term contracts with the municipalities. This insurance will cover the losses which the recycling plants may suffer if the price of the raw material falls beneath a certain threshold. In such a case, the insurance will cover the difference between the market price of the raw material and the guaranteed threshold price defined in the contract. This type of insurance will be attractive to recycling plants because it allows them to profit when the price of the raw material rises, while insuring them against excessive losses. Thus, the government would be able to take advantage of the competition between recycling plants to cover the insurance costs.

According to our proposal, the government will publish a tender in which recycling plants will compete over the price paid to the government for the right to participate in the insurance program. Under the assumptions that the recycling market is efficient and that the distribution function of the price of the raw material is known, the price offered by the plants will be exactly equal to the present value of the costs which the government will be expected to bare over the contract period (Appendix B presents a model of a price stabilization program according to this principle).

Thus, a price stabilization program may be carried out such that its only costs are those of administering the proposed mechanism. Such a program provides a net benefit to the national economy – municipalities gain from price stabilization which allows them to choose the most efficient waste management system and recycling plants enjoy compensation for declines in the price of the raw material which they produce. The level of recycling which will be obtained is optimal, as it is the same level that would be obtained under conditions of perfect certainty, such that the inefficiency entailed by uncertainty is avoided. Unlike recycle subsidies, or subsidies for investment in recycling infrastructure, the proposed mechanism does not create incentives for repeated transitions between landfilling and recycling as prices rise and fall. Thus, it prevents redundant investment in the waste management system. The government effectively plays the role of an insurance company, solving a major market failure in the recycling market.

5. CONCLUSION

This paper examined why most municipalities in Israel do not implement large-scale recycling programs. The analysis was based on both a theoretical model and an empirical survey of 79 municipalities which jointly account for about 60% of household waste in Israel. The study examined whether the current government policy to reduce landfill – imposing a landfill tax while subsidizing investments in alternative treatment solutions – is indeed the most effective policy available. In addition, the study also considered an alternative policy, focused at stabilizing recycling prices.

The results of the study show that although recycling is less costly than landfill for most municipalities in Israel, municipalities hesitate to make the transition, preferring to continue with their current waste management system in which nearly 100% of the waste is sent to landfill. Furthermore, the study finds that the main reason for this preference is the excessive volatility in the price of recyclable waste.

The current government policy to encourage recycling consists of imposing a tax on waste sent to landfill (NIS 50 per ton from 2011) and subsidizing about 40% of costs for investments in alternative treatments of waste. This study reveals that this policy is both excessively expensive and will lead to higher-than-optimal recycling levels. In addition, this policy does not deal with the main deterrent to recycling – the problem of volatile recycling prices. We thus propose an alternative policy – a stabilization mechanism based on an insurance system with the participation of all three relevant players – municipalities, recycling plants, and the government. We believe such a mechanism would be efficient, and prevent the distortions created by the current policy. The only costs associated with this mechanism would be its administrative and supervision costs.

Appendix A: Proof of the Mathematical Model

We define:

$$I(P_R \le \gamma_R) = \begin{cases} 1 & if \quad P_R \le \gamma_R \\ 0 & if \quad P_R > \gamma_R \end{cases}$$

A municipality currently landfilling will choose a threshold price of γ_R so as to minimize the expected present value of its waste management costs:

(1) $$V_H = Min_{\{\gamma_R\}} E\{[C_H + \frac{V_H}{1+r}] I(P_R \le \gamma_R) + [C_R - P_R + w_R + \frac{V_R}{1+r}][1 - I(P_R \le \gamma_R)]\}$$

We define:

$$EC(\gamma) = E\{P_R I(P_R \le \gamma)\} = \int_{-\infty}^{\gamma} xf(x)dx$$

Then:

(2) $$V_H = Min_{\{\gamma_R\}} \{[C_H + \frac{V_H}{1+r}]F(\gamma_R) + [C_R + w_R + \frac{V_R}{1+r}][1 - F(\gamma_R)] - \mu_R + EC(\gamma_R)\}$$

Differentiation of equation (2) with respect to the threshold price γ_R gives:

(3) $$[C_H + \frac{V_H}{1+r}] f(\gamma_R) - [C_R + w_R + \frac{V_R}{1+r}] f(\gamma_R) + \gamma_R f(\gamma_R) = 0$$

We define:

$\Delta C = C_R - C_H$; $\Delta V = V_R - V_H$

Given that $f(\gamma_R) \neq 0$, equation (3) gives:

(4) $$\gamma_R = \Delta C + w_R + \Delta V/(1+r)$$

We define:

$$U(\gamma) = \gamma F(\gamma) - EC(\gamma) = \int_{-\infty}^{\gamma} (\gamma - x) f(x)dx = \int_{-\infty}^{\gamma} F(x)dx$$

From equation (2) and equation (4) we get:

(5) $$V_H = C_H + \frac{V_H}{1+r} + \gamma_R[1-F(\gamma_R)] - \mu_R + EC(\gamma_R) = C_H + \frac{V_H}{1+r} + \gamma_R - \mu_R - U(\gamma_R)$$

And therefore:

(6) $$V_H/(1+r) = [C_H + \gamma_R - \mu_R - U(\gamma_R)]/r$$

We define γ_H as the threshold price for transition from recycling to landfilling. That is, the municipality will return to landfilling if $P_R < \gamma_H$, such that its expected costs will equal:

$C_H + V_H/(1+r) + w_H$

If $P_R \geq \gamma_H$, the municipality will continue to recycle, in which case its expected costs will equal:

$C_R - P_R + V_R/(1+r)$

A municipality currently recycling will choose a threshold price γ_H, so as to minimize the expected present value of the costs of waste management:

(7) $$V_R = Min_{\{\gamma_H\}} E\{[C_H + \frac{V_H}{1+r} + w_H] I(P_R \leq \gamma_H) + [C_R - P_R + \frac{V_R}{1+r}][1 - I(P_R \leq \gamma_H)]\}$$

or:

(8) $$V_R = Min_{\{\gamma_H\}}\{[C_H + \frac{V_H}{1+r} + w_H]F(\gamma_H) + [C_R + \frac{V_R}{1+r}][1-F(\gamma_H)] - \mu_R + EC(\gamma_H)\}$$

Differentiation of equation (8) with respect to the threshold price γ_H gives:

(9) $$[C_H + \frac{V_H}{1+r} + w_H] f(\gamma_H) - [C_R + \frac{V_R}{1+r}] f(\gamma_H) + \gamma_H f(\gamma_H) = 0$$

Given that $f(\gamma_H) \neq 0$, we get:

(10) $$\gamma_H = \Delta C - w_H + \Delta V/(1+r)$$

We define:

$\Delta\gamma = \gamma_R - \gamma_H$

Subtracting equation (10) from equation (4), we get:

(11) $\Delta\gamma = \gamma_R - \gamma_H = w_H + w_R$

From equations (8) and (10) we get:

(12) $$V_R = C_R + \frac{V_R}{1+r} - \gamma_H F(\gamma_H) - \mu_R + EC(\gamma_H) = C_R + \frac{V_R}{1+r} - \mu_R - U(\gamma_H)$$

Therefore:

(13) $$V_R/(1+r) = [C_R - \mu_R - U(\gamma_H)]/r$$

Subtracting equation (6) from equation (13) gives:

(14) $$\Delta V/(1+r) = [\Delta C + U(\gamma_R) - U(\gamma_H) - \gamma_R]/r = [\Delta C + \Delta U - \gamma_R]/r$$

Inserting equation (11) we get:

(15) $$\Delta U = U(\gamma_R) - U(\gamma_H) = \int_{\gamma_H}^{\gamma_R} F(x)dx = \int_{\gamma_R - (w_H + w_R)}^{\gamma_R} F(x)dx$$

By inserting equation (14) in equation (4) we get an explicit expression for the value of the threshold price for recycling:

(16) $$\gamma_R = \Delta C + rw_R/(1+r) + \Delta U/(1+r)$$

Appendix B: A Model for a Government Insurance Mechanism

We assume there are many recycling plants operating in competition. We define:

P_{Wt} – The price paid to the recycling plant for one unit of raw material at time *t*.

C – The operating cost required to transform one unit of waste into one unit of raw material.

P_{Rt} – The price paid by the recycling plant to the municipalities for one unit of recyclable waste at time *t*.

q_t – The amount of waste treated by the recycling plant at time *t*.

Accordingly, the expected profit of the recycling plant at time *t* is given by:

$\Pi_t = (P_{Wt} - C - P_{Rt})q_t$

In a competitive equilibrium, the recycling plants' profits tend to zero. Thus, the price paid each year to municipalities for their recyclable waste, P_{Rt}, is determined by the price of the raw material, P_{Wt}, and is directly affected by its volatility: $P_{Rt} = P_{Wt} - C$.

In order to induce the recycling plants to sign a long-term contract with the municipalities, in which the municipalities are guaranteed a fixed price for their recyclable waste, set at $\mu_R = E\{P_{Wt}\} - C$, the government must undertake to compensate the recycling plants for the losses which they will suffer if the price of the raw material falls below its expected price.

Each recycling plant that will sign a long-term contract with the municipalities will receive from the government the following insurance policy:

We define: $\Omega_t = \mu_R + C - P_{Wt},$

When $\Omega_t > 0$, the government will pay the recycling plant Ω_t for each unit of waste that it is obligated to purchase under its contract with the municipalities. In this case, the recycling plant will be covered for its potential losses, and thus will have no incentive to break the contract.

On the other hand, in years when $\Omega_t < 0$, that is, $P_{Wt} - C > \mu_R$, the contract generates a positive profit for the recycling plants. Thus, the contract is expected to generate profits for the recycling plants in the long-term.

As the recycling plants stand to profit from the program, the government will be able to charge the plants a participation fee. This fee will be set in a tender. As the market is competitive, and the distribution of the price of the raw material is known, in equilibrium the recycling plants will offer to pay an entry fee equal to the discounted present value of their expected profits from the program. As the fixed price given in the contract is equal to the expected price in the long-term, government losses when prices are low should equal recycling plants' profits when prices are high. Thus, the discounted value of plants' profits is equal to the discounted value of expected government payments, such that the only true cost faced by the government is that of administering the program.

There are three main reasons why such a program must be sponsored by the government, and cannot be implemented privately by the recycling plants:

1. The municipality must make a one-time investment to allow the transition to recycling. This transition is economically worthwhile only under the condition that the price is guaranteed for the long-term. If the municipality enters into a fixed-price long-term contract with a private recycling plant but then raw material prices fall, the recycling plant may go bankrupt, breaking its contract with the municipality in the process. For example: In 1995, while newspaper prices were high, a paper recycling firm in Massachusetts signed contracts for purchasing the newspaper waste of municipalities in the Boston area. In 1996, newspaper prices fell, and the firm went bankrupt (Ackerman, 1997). Only a mechanism which will insure recycling plants against losses in the event of a fall in raw material prices will induce municipalities to enter long-term agreements with these plants, and make the investments required to allow large-scale recycling.
2. Each municipality must enter into long-term contracts for the recycling of every type of recyclable waste. Not all types of waste are suitable for recycling, but the municipality may very well find it efficient to make the transition to recycling only if it is able to recycle all types of recyclable waste (rather than only a single type)[8]. At the same time,

[8] This issue is discussed in section 3 – Empirical Analysis.

each recycling plant deals with only one type of waste, such that the municipality must contract several recycling plants, and each recycling plant must enter contracts with numerous municipalities. According to the Coase theorem[9], the complexity of the mechanism and the expected transaction costs require government intervention to direct the contractual arrangements between municipalities and recycling plants.

3. Small recycling plants in competition cannot take upon themselves the risks associated with world price volatility. If they commit themselves to a long-term fixed price, they expose themselves to risk. Like the municipality, recycling plants also demand a risk premium in such situations. Thus, in effect, the result of such a long-term contract would be to transfer the risk from the municipality to the recycling plant - the risk premium will remain, and the recycling market will not grow. Furthermore, recycling plants do not take into account the positive externalities of recycling, and thus cannot be expected to bring the market to a social optimum.

Unlike private recycling plants, the government does take into account the positive externalities of recycling, and can provide the safety net which municipalities need by guaranteeing long-term fixed prices. In so doing, it would increase the efficiency of the recycling market, help avoid investment losses associated with repeated transitions between recycling and landfilling, and reap the benefits of the positive externalities of recycling.

[9] According to the Coase Theorem, there is no need for government intervention (as the market will lead to a social optimum through negotiations between the relevant parties) as long as a number of conditions are met. With high transaction costs the conditions are violated and the market mechanism will not lead to the social optimum (Coase, 1960).

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