Economic Incentives and Residential Waste Management in Taiwan: An Empirical Investigation

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Abstract

This paper presents an empirical study of how three waste management policies have affected residential waste generation and recycling behavior in Taiwan over the past decade. The three policies are unit-pricing of garbage in Taipei, a mandatory recycling program in Kaohsiung, and a nationwide policy of charging for plastic bags. We estimate policy effects on total waste, total recycling, and recycling of four specific materials, all measured by weight per capita. Unlike prior work, we find that unit-pricing and mandatory recycling policies lead to significant increases in recycling of most materials, as well as increased levels of total recycling and garbage reduction. The "plastic bag" policy is generally found to lower material-specific and total recycling rates, as well as total garbage volumes.

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1. Introduction

As incomes and populations have grown over the past three decades, costs of waste disposal have grown in tandem. Suitable landfill sites have become increasingly scarce. Even costs of incineration have grown as environmentally conscious communities seek to avoid the external disamenities that incinerators create. Policy-makers in the developed world have responded to increased disposal costs with measures designed to reduce waste volumes by prompting consumers to demand less waste-intensive products, to recycle more, and to engage in other source-reduction activities (such as composting). Policies include waste charges that rise with volume (called unit pricing), availability of curbside recycling, deposit-refund requirements for recyclables, and government recycling mandates.

The efficacy and effects of such policies have been fertile ground for economic research, on both theoretical and empirical fronts. In the absence of illegal waste disposal opportunities, theory offers a simple prescription for optimal policy: Charge consumers a price for their waste equal to the true marginal social cost of waste disposal (Fullerton and Kinnaman, 1995). However, when illegal disposal is possible, this simple policy is no longer optimal because it can prompt illegal dumping that is very costly to society (Choe and Fraser, 1999; Fullerton and Wu, 1998). A second-best policy can then involve a complex array of policies designed to confront consumers and producers with the true costs of waste disposal, including unit pricing (less than marginal social costs), producer regulations or taxes designed to make them internalize true costs of the waste caused by their packaging decisions, measures to promote consumer recycling (such as deposit-

refund schemes), and enforcement programs designed to deter illegal dumping with appropriate sanctions.

The empirical literature studies consumer and community responses to actual waste management policies, most prominently unit pricing and curbside recycling. In this literature, scholars investigate whether observed behavior conforms to the predictions of economic theory. For example, does unit pricing reduce waste volumes and increase recycling? And does curbside recycling, by lowering consumer costs of recycling, spur increased recycling rates and volumes? Table 1 summarizes the extant empirical research, revealing both the wide variety of communities studied and methods employed. Most studies investigate effects of unit pricing, confirming the effects predicted by economic theory.

In this paper, we add to the empirical literature by studying impacts of three waste management policies introduced in different regions of Taiwan. First, a per-bag garbage charge (unit price) was introduced in Taipei City in July of 2000. Second, a mandatory recycling program was implemented in Kaohsiung City in January of 2001. And third, starting in January of 2003, the National government has required retailers to charge for all plastic bags. In what follows, we study the effects of these policies on waste and recycling volumes using time series data from Taipei, Kaohsiung, and five other jurisdictions in Taiwan, over the 1997-2004 period.

Our study contributes to the literature in four ways. First, we add further evidence on the impact of unit pricing on waste and recycling volumes. Second, in doing so, ours is only the second study (to our knowledge) that focuses on communities outside the U.S.. Hong (1999) studies cross-section South Korean data, finding that unit pricing

actually increases waste volumes there.[1] Third, ours is only the third paper to study policy effects on material-specific recycling. Reschovsky and Stone (1994) study policy impacts on households' probability of recycling different materials, using cross-section data from Tompkins County, New York in 1990. Jenkins, et al. (2003) study policy impacts on households' recycling rates for different materials using cross-section data from twenty U.S. communities in 1992. Unlike these studies, ours focuses on time series data that includes both pre-policy and post-policy outcomes for affected (and unaffected) communities and finds somewhat sharper policy impacts on material-specific recycling activity.[2]

Fourth, and perhaps most important, we are able to study the effects of two policies that have received almost no attention in the literature. To our knowledge, there has been no study of a plastic bag policy of the type implemented in Taiwan, despite the institution of similar policies in many countries around the world and debate of related proposals in many others. The most famous plastic bag tax is the fifteen cent per-bag consumer charge imposed by the Irish government in March, 2002, which reportedly led to a 92 percent reduction in demand for plastic bags within six months (Doe, 2004). Plastic bag taxes have also been introduced in Shanghai, South Africa, Italy, and Denmark, and proposed in California, Australia, New Zealand, and the United Kingdom; outright bans of varying severity (some restricting only thin bags, others prohibiting all plastic bags) have been implemented in parts of India, Bangladesh, and Australia. These policies are motivated as a means to reduce litter, reduce a key source of solid waste (by

[1] Sterner and Bartelings (1999) study household data from Varberg, Sweden, but focus on how household attributes explain waste management decisions, not government policy.
[2] Arguably Taipei's unit pricing policy also produced a more continuous resident cost for marginal garbage than did the Tompkins County trash tags or the discontinuous per-can charges most common in the Jenkins, et al. (2003, p. 312) study communities. See Section 2 below for discussion of Taipei's policy.

promoting the re-use of stronger bags), and inhibit the production of bags that are blamed for such scourges as clogging recycling machines and killing marine life (Herel, 2004). In this paper, we attempt to evaluate the effect of Taiwan's plastic bag policy on solid waste volumes and recycling activity.

Only two prior papers (to our knowledge) evaluate effects of mandatory recycling policies, Reschovsky and Stone (RS, 1994) and Jenkins, et al. (2003). In RS's study area, mandatory recycling was implemented for some households, but generally in conjunction with other policy measures, including curbside recycling and unit pricing (trash tags). Indeed, only 11 households in their sample (out of 1363) were subject only to mandatory recycling. Perhaps as a result, RS did not find any distinct (and significant) effects of mandatory recycling policies on waste-management decisions. Jenkins, et al. (2003) also consider impacts of mandatory recycling (MR) programs. However, in their cross-jurisdiction study, the authors note that the meaning and enforcement of mandatory recycling policies in unclear (p. 311, note 16) and likely to be heterogeneous.[3] These authors also find that MR policies (in conjunction with curbside recycling) have a statistically insignificant effect on recycling behavior. In contrast, Kaohsiung's implementation of mandatory recycling – combined with strict enforcement and not combined with other policy changes – offers us a rather sharp policy experiment; perhaps as a result, we find statistical evidence that mandatory recycling has led to increased recycling in Kaohsiung.

The balance of the paper is organized as follows. Section 2 discusses the waste management setting in Taiwan. Section 3 presents hypotheses on the potential effects of

[3] Mandatory recycling enforcement may, in some cases, be either non-existent or focus on the proper separation of recyclables, rather than assuring that ordinary garbage does not contain recyclable material, as in the case of Kaohsiung's policy.

Taiwan's waste management policies, as suggested by economic theory. Section 4 describes the data. Section 5 presents estimation results for aggregated waste and recycling volumes. Section 6 presents results for material-specific recycling. And Section 7 concludes.

2. Taiwan's Waste Management Experience

Waste management has been a serious issue for Taiwan since the early 1990's. Facing limited landfill space and a large volume of waste (8.38 million-tons/year in 2000), the Environmental Protection Bureau of Taiwan proposed several possible solutions to the Nation's waste problem. Officials turned to incineration instead of traditional tipping systems and, in 1991, started to charge a waste fee proportional to water usage.[4] These policies, however, did not achieve garbage reduction targets, in part because garbage and water usage were not clearly related.

In 1997, officials began to promote recycling as a means to achieve waste reduction. Cities set up recycling sites for residents to dispose recyclable materials, and required small cash rebates for containers such as plastic bottles, iron and aluminum cans in retail outlets (convenience stores, supermarkets, etc.).[5] In January 2003, the central government introduced a plastic bag regulation, requiring all retail outlets to charge for plastic bags and banning the use of polystyrene dishes by restaurants and street vendors. Resulting charges for plastic bags range from one to two Taiwan dollars (approximately three to five U.S. cents).

Local jurisdictions adopted additional regulations on their own in order to address local waste problems. In July 2000, the Taipei City government introduced a user fee

[4] It is believed that the government chose water usage as the basis for waste charges because the water utility is the most highly subscribed.
[5] Deposit/refund schemes were in place in Taiwan through 2002.

policy which required households to purchase official garbage bags (with official stamps) for their general waste setouts. Various sizes of official bags (ranging from 5 litres to 92 litres) are available in all convenience stores and most supermarkets. The pricing schedule for the official bags is linear in volume, with a cost of 5 NT$ (approximately 15 U.S. cents) per ten litres.

In January of 2001, Kaohsiung City implemented a mandatory recycling policy requiring households to separate recyclables from general waste. If a household mixes recyclables in its general waste setouts, it is subject to fines ranging from $35 to $135 (with more severe fines for repeat violators). Notably, our discussions with waste-management officials in Kaohsiung suggests that these fines, combined with vigorous monitoring of waste setouts, ensures near full compliance with recycling mandates. Enforcement is aided by Taiwan's somewhat cumbersome system of waste collection, under which residents bring their garbage (both waste and recyclables) to designated locations at pre-specified times, where they must wait for local environmental management workers to collect the garbage in their presence.

3. Hypotheses

Without building utility-theoretic models of household waste management that have been extensively studied elsewhere (Fullerton and Kinnaman, 1995; Fullerton and Wu, 1998; Choe and Fraser, 1999; and others), we can express implications of these models for the positive effects of the policies enacted in Taiwan. In doing so, we are interested in effects on recycling volumes, net waste setouts, and total "garbage" generation (the sum of recycled waste and net waste setouts), all measured per capita.

As is well known, unit pricing provides households with incentives for waste reduction in the form of demand for less waste-intensive packaging, more recycling, and other source reduction.

Hypothesis 1. Unit pricing leads to less total garbage, less net waste, and more recycling.

Effects of mandatory recycling (MR) are less clear. Assuming fines are sufficiently steep as to ensure full compliance with recycling mandates (as appears to be the case in Kaohsiung), these mandates have the direct effect of increasing recycling by those who would not otherwise recycle completely – namely, those whose time costs of recycling are sufficiently high and/or whose direct "altruism" benefits of recycling activity are sufficiently low. However, recycling mandates – by compelling households to bear costs of handling recyclables that they would not otherwise face – may spur some households to reduce their purchases of recyclables and to substitute in favor of non-recyclable products, thus offsetting the direct effect of the MR policy. In theory, such substitution may or may not occur, because by exogenously increasing recycling rates to unity, the MR policy also increases the marginal "altruism" benefit of buying recyclable products. In sum, the net effect of the MR policy on household recycling volumes in analytically ambiguous. We expect nonetheless that the policy's direct effect will dominate. In addition, we expect that the policy may lead to some substitution away from recyclables that is positively related to household incomes and hence, household costs of recycling effort.

Hypothesis 2. The MR policy leads to more recycling (and less net waste setout), but a lesser increase in recycling as household incomes rise.

There is no apriori expectation that the MR policy will change total garbage generation. On one hand, by rasing costs of disposing recyclables, it may spur reductions in recyclable "garbage." On the other hand, as noted above, it may also spur substitution in favor of non-recyclables, increasing this component of total garbage.

The "plastic bag" pricing policy will raise household costs of carrying/handling bulky products, thereby increasing the demand for less waste-intensive product packaging and potentially reducing the demand for bulkier, more waste-intensive products. These effects apply equally to recyclables and non-recyclables; indeed, because recycling may require the use of plastic bags, the "plastic bag" policy may potentially have an even more pronounced effect on recyclables.

Hypothesis 3. The plastic bag policy leads to lower recycling and net waste volumes.

Contrary to Hypothesis 3, proponents of plastic bag charges argue that, by spurring "conservationist" re-use of bags, the policy may lead to other "conservationist" behaviors, such as recycling and source reduction. Hence, there is a clear empirical question about the nature of this policy's effects.

In Taiwan, the onset of the "plastic bag" policy (January 2003) coincided exactly with the termination of small deposit/refunds on recyclable receptacles (cans and bottles). As deposit-refunds promote recycling and thereby reduce net waste setouts, the expected impacts of the "plastic bag" policy will, to some extent, be reinforced (in the case of recycling) and countered (in the case of net waste) by the end of deposit/refunds. However, for some recyclable products (such as paper), deposit/refunds were never in place and, hence, impacts of the "plastic bag" policy are unconfounded. The potential

effects of the deposit/refund terminations are discussed in more depth when we interpret our results in Sections 5 and 6.

4. Data

A. The Data. We have monthly aggregate waste and recycling volume data from Taipei (the largest city in Taiwan with approximately 2.5 million people), Kaohsiung (the second largest city with a population of 1.5 million), and five other local jurisdictions in Taiwan,[6] running from January 1997 through June 2004. The five smaller jurisdictions lacked both the unit pricing (Taipei) and the mandatory recycling (Kaohsiung) policies of interest in this paper. We treat these other jurisdictions as a composite "Region 3" in our analysis, and obtain Region 3 variables by taking population-weighted averages of the five jurisdictions' per-capita data.

Tables 2 and 3 describe both our endogenous (waste and recycling volume) data and our explanatory variables. Unfortunately, little economic data is available at a region-level. For example, *GDP* and household consumption expenditure (both per capita) are available at a national level and approximately capture income effects as they vary over time. Similarly, wage rates are at a national level, capturing opportunity costs of time required in waste reduction and recycling effort. However, employment rates are available at a region-level; in an attempt to capture expected wages at a region level, we include the interaction variable *ERW* (employment rate times wage) as an explanatory variable. Other regressors include dummy variables for seasons, the Chinese New Year, and the occurrence of a typhoon. In addition, we control for changes in consumption patterns by using per-capita expenditures on rent and water (*RW*), food, and drink.

[6] Chiayi, Hsinchu, Keelong, Taichung and Tainan.

We have three policy regressors. First, for Taipei, we have the per-bag policy dummy (*bag*) that takes a value of one after the introduction of unit pricing in July, 2000. Second, for Kaohsiung, we have the mandatory recycling dummy (*MR*) that takes a value of one after the introduction of this policy in January, 2001. And third, the plastic policy dummy (*plastic*) takes a value of one after the nationwide policy charging for plastic bags was introduced in January 2003.

In principle, the effect of government waste management policies may depend upon household income. For example, as incomes rise, mandatory recycling may cause households to substitute more in favor of non-recyclables in view of the higher time costs of obligatory recycling. To account for such effects, we considered interactions between all of our policy dummies and GDP per capita; however, we only found statistically (and quantitatively) significant effects for the *GDP_MR* interaction and, hence, present results with only this interaction variable included.[7]

B. Two Issues. In studying the effects of waste management policies (such as unit pricing) on waste management behavior, two issues arise. First, the policies may be endogenous. For example, more environmentally conscious communities – who tend to recycle more and produce less garbage – may be more apt to adopt unit pricing and curbside recycling programs. Alternately, such pro-environment policies may be spurred by waste management "crises," the main symptom of which is a "large" amount of community waste. If the former source of endogeneity prevails, then estimated (negative) effects of unit pricing on waste volumes may be due to correlation, rather than causation. Conversely, if the latter source of endogeneity prevails, then estimated causal

[7] Similar logic suggests that we consider an interaction between our policy variables and our expected wage measure *ERW*. We performed estimations with these alternative interactions and found no significant effects.

effects of unit pricing will be understated when endogeneity is not explicitly accounted for. To our knowledge, Kinnaman and Fullerton (2000) are the only scholars who, using a two stage estimation prodedure, account for joint endogeneity of waste management policies in their cross-jurisdiction study of household garbage; in doing so, they find evidence that the source of endogeity in their sample is of the second type, suggesting that estimates of unit pricing effects on waste volumes tend to understate true causal effects when endogeneity is not taken into account.

With regard to the present study, data limitations prevent us from explicitly accounting for endogeneity of policy decisions. However, we infer the effects of unit pricing and other policies from time series data in three regions of Taiwan from 1997 to 2004. In the case of Taipei, for example, we study effects of a unit pricing (per bag) policy on waste management behavior over this interval. Arguably, during this short time horizon, the "environmental consciousness" of the Taipei community is unlikely to change so appreciably as to explain the timing of the unit pricing policy. However, conceivably, the acuteness of the "garbage problem" in Taipei may have some impact on policy timing. In sum, our inability to account for endogeneity of unit pricing, mandatory recycling and plastic bag policies is likely to imply that our estimates understate causal effects on waste volumes, if there is any bias at all.

The second issue that arises in empirical work on waste management is the potential impact of unit pricing policies on illegal dumping. Theory predicts that pricing of garbage will lead households both to reduce gross waste volumes and to increase illegal dumping. Estimated reductions in legal waste may thus be attributable to either or both of these effects. From a social welfare point of view, this confusion is potentially

important. Whereas reductions in gross waste volumes, legally disposed, is likely a salutary (cost-saving) policy impact, increases in illegal waste volumes are likely to be quite costly to society. Indeed, Fullerton and Kinnaman (1995) show that when illegal dumping is possible, the optimal disposal charge may shrink to zero or even be negative. The only extant empirical study that addresses this issue (to our knowledge) is Fullerton and Kinnaman (1996). These authors attempt to measure the extent of illegal dumping caused by unit pricing in Charlottesville, VA. However, as the authors note, their measure of "dumping" includes garbage taken to worksites or otherwise legally disposed, just not presented for charge by the households themselves. Such "dumping" is found to account for roughly 28 to 43 percent of the garbage reduction attributable to unit pricing.

In our study, we cannot explicitly account for illegal dumping. Hence, our estimated effects of unit pricing incorporate illegal dumping effects. However, government records suggest that illegal dumping is not a serious problem in Taipei and can account for only a tiny portion of our estimated impacts of unit pricing. Specifically, government sources reveal that, on average in Taipei, there were 423 bags found illegally disposed per month in 2002, 376 bags in 2003, and 352 bags in 2004. These quantities represent less than one-fiftieth of one percent of household garbage generated in these years, and less than one-tenth of one percent of the estimated garbage reduction attributable to unit pricing (based on our analysis).[8] Of course, illegal disposal might also take the form of illegal burning. However, our inquiries with city officials indicate that (1) the likelihood of undetected illegal burning in the densely populated city of

[8] These calculations are likely to overstate the illegal dumping volumes, based as they are on the assumption that each "illegal bag" contains 30 kg. of waste. Effects of unit pricing are gauged from our estimates in Table 11.

Taipei is small, and (2) there have been no official reports of illegal burning activity in recent years in either Taipei or Kaohsiung.

C. Waste Volume Trends. Our endogenous variables are recycling volume, waste volume, and total garbage volume (the sum of waste and recycling), all measured in kilograms per capita per month. Figures 1, 2 and 3 indicate general trends for these variables. Note that sharp hikes in general waste and total garbage streams are likely to have been caused by severe tropical hurricanes attacking the island;[9] for Taipei, peaks in waste volumes may also have been exaggerated by the government's provision of free waste collection services immediately following a typhoon.

In Table 4, we report difference of mean statistics for before and after the various policy implementations. For Taipei, for conceptual clarity, we compare recycling and waste volumes before the per-bag (unit pricing) policy to corresponding volumes after the per-bag policy but before the "plastic bag" regulation was introduced (i.e., for July 2000 through December 2002). Similarly, for Kaohsiung, we compare outcomes from before the MR program to those after the MR but before the "plastic bag" policy. To assess the impact of the plastic bag policy in Taipei and Kaohsiung, we compare outcomes after the policy (2003-2004) to those before the policy but after the per-bag and MR programs were introduced in the respective jurisdictions.

The resulting difference of mean statistics indicate that, in Taipei, per-capita waste volumes fell by 23.2 percent, while per-capita recycling volumes rose by 90 percent, after implementation of the per-bag policy; both changes are statistically significant. Similarly, in Kaohsiung, waste volumes fell by 20.9 percent and recycling

[9] Note that cities in the northern part of Taiwan are more prone to damage from extreme weather due to the nature of their geography.

volumes rose by 112.2 percent after implementation of the MR program. In these jurisdictions, the plastic bag policy also had the predicted effects, with waste volumes falling by 29.5 (6.7) percent and recycling volumes falling by 16.1 (26) percent in Taipei (Kaohsiung). In "Region 3," waste volumes fell by 19.6 percent after the plastic bag policy, but recycling volumes *rose* by 38.7 percent. However, from Figure 2, it is evident that the latter increase – measured from the entire 1997-2002 pre-policy period – may be attributable to the general upward time trend in recycling, rather than any real policy effect.

While the mean differences are suggestive of policy impacts and consistent with our predictions from economic theory, they do not account for time trends and other explanatory phenomena (income changes, for example) that may drive changes in waste management behavior. We therefore turn to a more complete econometric analysis.

5. Net Waste, Garbage, and Aggregate Recycling: Models and Results

A. Models

We consider (and present) two linear models for our net waste, total garbage and recycling aggregates (kilograms per capita, by month and jurisdiction). The first is a fixed-effect pooled model that combines our three regions (Taipei, Kaohsiung and "Region 3"). In the pooled model, we allow for region-specific variances (group-wise heteroskedasticity) and serial autocorrelation as revealed by a standard Durbin Watson test (and a stepwise test for higher order autocorrelation). We find evidence for first-order (and not higher order) autocorrelation, and accordingly estimate by feasible generalized

least squares (FGLS) to account for both serial correlation and heteroskedasticity. FGLS estimations are presented in Table 5.[10]

The second model allows for jurisdiction-specific waste, recycling, and total garbage equations, estimated by seemingly unrelated regressions (SUR) to account for cross-jurisdiction covariances.[11] In doing so, we test and correct for serial autocorrelation using Prais-Winston transformations.[12] Testing the SUR jurisdiction-specific equation models against pooled fixed effects counterparts leads to a clear rejection of the pooled model for the recycling equation, weak evidence in favor of pooling for the net waste equation, and rejection of pooling restrictions at a ten percent significance level (but not five percent) for the total garbage equation.[13] The SUR estimations are reported in Table 6. Note that we include a time trend (*month*) in all of our equations and models.

In addition to the models reported here, we performed two other estimations. First, in order to ensure that our results are not due to any cross-jurisdiction policy endogeneity, we performed jurisdiction-specific OLS. And second, we jointly estimated waste and recycling jurisdiction-specific equations, allowing for both cross-jurisdiction and cross-material covariances. Both estimations yield results that are qualitatively similar to the SUR outcomes reported here.

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[10] In the pooled model, the GDP interaction terms were found to have statistically insignificant coefficients; hence, these variables are excluded from the reported model.

[11] Breusch-Pagan tests for diagonality yield the LM statistics (p-values), 9.788 (.02) for waste, 28.287 (<.0001) for recycling, and 11.763 (.008) for total garbage models, respectively. All lead us to reject the null that the diagonal elements are zero. In both pooled and SUR estimations, we allowed *GDP* to interact with all policy dummies; however, *GDP_bag* and *GDP_plastic* were dropped because they had no statistically significant effects in any equation.

[12] A Durbin-Watson test was used to detect the presence of autocorrelation and a standard stepwise method was used to determine the degree of autocorrelation. For waste and total garbage generation, AR(1) appeared in Taipei and Kaohsiung data. For recycling, on the other hand, AR(1) occurred in Kaohsiung and region 3, but not in Taipei.

[13] The F-test statistics (p-values), all for models including the *GDP_MR* interaction, are 1.01 (.4514) for the net waste equation, 14.6 (.0001) for recycling, and 1.5 (.0621) for the total garbage model, with 28/222 degrees of freedom.

B. Policy Effects

i. The Per-Bag Policy. Inspecting Tables 5 and 6, we see that our per-bag policy variable has a statistically significant negative impact on Taipei's net waste and total garbage volumes in both our pooled and jurisdiction-specific (SUR) estimations; it also has a significant positive impact on recycling volumes in the SUR estimation. Recalling that we reject the pooled model for recycling, these results broadly support the economic theory of Hypothesis 1. Moreover, these effects are quantitatively significant. The per-bag policy is estimated to reduce net waste and total garbage volumes by 26.9-28.3 percent and 25.9-27.6 percent, respectively. Similarly, recycling volumes are estimated to increase by 64.2 percent due to the per-bag policy (based on the SUR recycling equation).

ii. Mandatory Recycling (MR). The *MR* policy variable has a negative impact on net waste volumes that is statistically significant in our pooled models (which, we recall, are not rejected in favor of the jurisdiction-specific estimations). Moreover, *MR* has a significant positive effect on recycling volumes in both pooled and SUR models. These results lend support to our initial Hypothesis 2 and are again of quantitative significance. Accounting for the GDP interaction (evaluating GDP at its mean value), the *MR* policy is estimated to reduce Kaohsiung's net waste volumes by 9.9 percent (from pooled Model 2) and to increase its recycling volumes by 37.2 percent (from the SUR recycling equation).

iii. The Plastic Bag Policy. Our plastic bag policy variable has a statistically and quantitatively significant negative effect on recycling in all but the Taipei SUR estimation (where the effect is negative but not significant); for example, recycling

volumes are estimated to decline by 29.5 percent in Kaohsiung and 52 percent in "Region 3" after the onset of the "plastic" policy. For Region 3 (where "plastic" is the only waste management policy enacted over our study period), this variable has a significant negative impact on total garbage volumes as well. Although the estimated impacts on net waste volumes are negative in all models, none are statistically significant.

Recall that the onset of the plastic bag policy coincided with the termination of a nationwide deposit / refund program on metal, glass and plastic receptacles. In Taipei and Region 3, ending deposit / refunds is expected to reduce recycling and correspondingly raise net waste setouts. However, in Kaohsiung, where recycling is compulsory, a deposit / refund program should have no direct impact on recycling activity per se; the only indirect impact may be due to the cost in time and convenience of obtaining refunds, which could deter the purchase of recyclables (vs. non-recyclables). Hence, in Kaohsiung, ending deposit / refunds is expected to increase recycling if anything.

The coincidence of the deposit /refund terminations thus has the following implications for our results. First, for Taipei and Region 3, the negative impact of our "plastic" variable on recycling volumes may be due to the combination of the two coincident policy changes and not exclusively to the plastic bag policy. However, this is not true for Kaohsiung, where our results provide support for our Hypothesis 3. Moreover, this is also not true for effects on specific recyclables that never had any deposit /refund program in place; we investigate these specific recyclables in the next section. Second, at least for Taipei and Region 3, the estimated insignificant impacts of our "plastic" variable on waste volumes may be due to the competing impact of the

deposit / refund terminations. However, the latter terminations are unlikely to have had an impact on total garbage; hence, our Region 3 results suggest that the plastic bag policy has the salutary effect of spurring some garbage source reduction.

C. Other Results

Some of our variables are estimated to have different effects in Taipei and Kaohsiung. For example, *GDP* has a negative effect on total garbage volume in Taipei, and a positive effect in Kaohsiung; because higher levels of GDP yield competing effects from heightened consumption and conservation, different effects can dominate in different regions. Similarly, per capita consumption expenditures have a positive effect on recycling volumes in Taipei, and a negative effect in Kaohsiung.

However, many variables have qualitatively similar effects across jurisdictions. Coefficients on our "expected wage" variable *ERW* are positive in all equations, significantly so in almost all cases. It is expected that higher wages may spur more consumption, less waste reduction effort (due to its higher time costs), and hence, more garbage, as indicated by our estimates. For recycling, higher wages may have competing effects, raising recycling by increasing consumption (and perhaps also increasing "altruistic" benefits of environmentalism), but lowering recycling by raising its cost in time. Our estimates suggest that the former effect dominates.

Extreme weather significantly affects both waste and total garbage generation, as expected. However, the New Years holiday (NY) has a significantly negative effect on waste and recycling flows in our models, contrary to initial expectations; this seemingly paradoxical result may be due to lags in the New Years' garbage set-outs that are

captured by the seasonal dummy (our intercept), and/or to a high propensity for travel during this holiday.

6. Material-Specific Recycling

Using time series data on jurisdiction-specific recycling of specific materials (again monthly from 1997 to 2004), we estimate recycling equations for four materials: paper (including newspaper), plastic products (including plastic bottles and bags), glass, and metal (including aluminum and iron cans).[14] Table 7 reports descriptive statistics for this data.[15] Table 8 in turn reports SUR estimations of jurisdiction-specific and material-specific recycling equations, accounting for first-order serial correlation as noted.[16] Table 9 presents incremental effects of our key policy variables (policy vs. no policy) as percentages of sample average material recycling volumes.

i. The Per-Bag (Unit-Pricing) Policy. The effects of our per-bag policy variable on material-specific recycling are quite sharp. For three of the four categories (paper, plastic, and metal), the policy variable has a positive impact on recycling volumes that is statistically and quantitatively significant. For example, the bag policy is estimated to increase paper recycling volumes by an average of 78.6 percent. For glass recycling, however, the bag variable has a statistically significant negative effect. One possible

[14]Due to missing observations and data anomalies, we exclude other categories of recyclables (electronics, containers, tires, clothes, and fluorescent tubes).

[15]Due to missing observations for two months of glass recyclables for Taipei, we have two fewer observations in this categories than in the others.

[16]For robustness checks, we also estimated a variety of alternative models. For example, we estimated with a month-squared variable to allow for accelerating (or decelerating) time trends and with material-specific SURs that allow covariances across jurisdictions (but not across materials). (The Table 8 estimation allows for covariances across all twelve equations.) We also estimated alternative functional forms, both log-linear and generalized Box-Cox. Qualitative results are similar across all models with one exception: functional form seems to be of some relevance to estimated MR effects (see note 17 below). Notably, we constructed LM test statistics for the null hypothesis of linearity in the Box-Cox models; for nine of the twelve equations, we do not reject linearity at reasonable levels of significance (with p values of 12.6, 19.2, 25.2, 39.7, 40.8, 83.2, 83.9, 86.3, and 89.8 percent); for Kaohsiung, where we test for MR effects, the LM test arguably provides rather strong support for the linearity hypothesis for three of the four materials (paper, metal and glass), with p-values of the test statistic between 83.2 and 86.3 percent.

explanation for the latter (seemingly paradoxical) result is that the per-bag policy, by spurring more recycling that in turn requires households to carry both waste and recyclables to disposal sites, also spurs substitution from heavier weight and incompressible recyclables (such as glass) to lighter weight and compressible recyclables (such as plastics).

The sharpness of our results contrasts with those of Jenkins, et al. (2003) who find no significant effects of unit-pricing policies on material-specific recycling rates; the difference in our results is likely due to the more continuous unit-pricing of Taipei City, as opposed to the predominant use of the discontinuous "per-can" charges employed in the Jenkins, et al. (2003) study region. Recycling volumes are a relatively small share of total consumer garbage; in Taiwan, for example, less than five percent of garbage is recycled and less than two percent is recycled in the largest material component of recycling (paper). As a result, per-can charges may confront consumers with little or no change in garbage charges when they change their material-specific recycling behavior. Our findings suggest that when consumers indeed face garbage cost savings when they change their recycling behavior, they respond by recycling more of most materials, consonant with the predictions of economic theory.

ii. Mandatory Recycling. The impacts of Kaohsiung's mandatory recycling (MR) policy are also quite sharp. In our linear estimation, MR has a statistically significant positive effect on recycling volumes of all four materials, effects which decline with GDP in all cases (with statistically significant negative coefficients on the interaction variable, GDP_MR). The estimated net effects of MR on recycling volumes (accounting for the GDP effect, evaluated at mean GDP) are quantitatively significant as well, with MR

estimated to yield recycling increases of between 5.7 percent (for metals) and 68.7 percent (for plastics), effects which are statistically significant for all materials other than metal (Table 9). In our other "robustness" estimations (see note 16), coefficients on MR are also found to be positive for all materials and all cases, and coefficients on the GDP interaction are negative, effects which are statistically significant in virtually all cases other than the generalized Box-Cox estimation.[17]

Overall, our results suggest that the MR policy tends to increase both overall recycling rates (Section 5) and recycling of many key materials. As noted earlier, these effects need not be salutary in the sense of increasing economic welfare; the MR policy may be compelling recycling that is not cost-benefit optimal.

iii. The Plastic Bag Policy. The impacts of our "plastic bag policy" variable on material-specific recycling volumes are somewhat mixed. In ten of the twelve equations, estimated effects of the plastic policy on material-specific recycling volumes are negative. In six of these equations, the negative effects are statistically significant and, in all of them, quantitatively significant, with the policy estimated to reduce recycling volumes by between 12 percent and 72 percent (Table 9). In two equations (Region 3's plastic and glass recycling), the plastic variable has a significant positive coefficient, providing some evidence against Hypothesis 3 and in favor of the view that a plastic bag "conservation policy" spurs other conservationist behaviors. However, for all materials, the estimated net (population weighted) effect of the plastic policy, summed across all jurisdictions, is negative and statistically significantly (Table 9). Interestingly, moreover,

[17]As noted earlier (note 16), functional form seems to have an impact on some of the estimated MR effects; in the log-linear model, estimated direct MR effects are positive (for all materials) and significant (for three of the four), but marginal effects (accounting for the GDP interaction) are negative for paper and metal; in the Box-Cox estimations, estimated direct MR effects are also positive (for all materials) but statistically insignificant, and marginal effects are positive (but insignificant) for all materials other than paper.

the plastic policy yields a proportional estimated net reduction in average recycling volumes, across the three jurisdictions, that is very similar for all four materials, roughly 22 percent for paper, plastics, and glass, and 29 percent for metals.

Because of the coincidence between the plastic policy and the end of deposit/refunds, we want to pay particular attention to the paper recyclables that were never subject to deposit/refund policies, and also to the Kaohsiung results, as the mandatory recycling policy in place in this city implies a very limited impact of the change in deposit/refunds (see earlier discussion). For Kaohsiung, the plastic policy is estimated to have a negative impact on recycling of all materials; these effects are both statistically and quantitatively significant, implying estimated reductions of between 19 and 44 percent of recycling volumes (Table 9). Similarly for plastic recyclables, estimated effects of the plastic policy are negative for all jurisdictions, significantly so for Kaohsiung and the three jurisdictions taken as a collective. In sum, our findings provide some evidence for our Hypothesis 3 as it applies to specific materials.

7. Conclusion

In closing, we want to stress three findings from our analysis that distinguish our work from the prior literature. First, we find a significant salutary effect of Taipei's continuous unit-weight garbage charges in promoting material-specific recycling; these effects contrast with the negligible impacts of discontinuous per-can garbage charges that predominated in the "unit-pricing" jurisdictions studied by Jenkins, et al. (2003). Hence, one interpretation of our findings is that continuous unit-pricing policies may be likely to promote material-specific recycling, while "discontinuous" policies are unlikely to do so.

Second, mandatory recycling – when combined with the strict enforcement made possible by Taiwan's cumbersome system of garbage collection – has provided a significant spur to recycling, even as a stand-alone policy.

Last but not least, ours is the first analysis (to our knowledge) that studies the impact of plastic bag charges on waste management behavior. "Plastic bag" policies of the type implemented in Taiwan are now common around the world. For example, in Ireland, there is ample anecdotal evidence that plastic bag charges dramatically reduced plastic bag use. We identify effects on other waste management activities. Specifically, by reducing the demand for bulky packaging, thus economizing on the use and wear of plastic carrying bags, plastic bag charges can lower overall garbage generation. We find some evidence that Taiwan's plastic bag policy has had this salutary effect. However, we also find evidence that, by raising the costs of handling recyclables, the plastic policy may have deterred some recycling activity.

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