Trends in the Generation and Recovery of Municipal Solid Waste

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I. Introduction

The Environmental Protection Agency ("EPA") defines municipal solid waste ("MSW") as trash or garbage from residential, commercial, institutional, and industrial sources that "does not include industrial, hazardous, or construction waste". In this study, (i) aluminum, (ii) ferrous metals, (iii) other nonferrous metals, (iv) glass, (v) plastics, and (vi) paper and paperboard are analyzed across time from 1960 to 2008 (EPA "Figures for 2008" 2009).[1] Each material exhibits different trends in terms of generation levels, generation shares by material, and recovery rates by material.

This paper traces the causes of each material's level generated, generation share, and recovery rate to the history and policies enacted by the United States within the past 50 years. Statistical and quantitative analysis is performed alongside the qualitative explanations. However due to the limited number of observations in the data set, no time series econometric analyses are conducted. Section II provides a list of definitions for the purposes of this paper. Section III.a. provides the background of MSW by analyzing the total generation in thousands of tons, along with the total recovery rate. Section III.b. decomposes the total generated into the contributions or shares by each material, and then tracks the shares of each material over the specified time interval. Section IV looks at recovery rates material by material, and provides trend explanations through policy analysis and real price movements.[2] Finally, section V reviews the prominent observations and trends, and suggests further topics of concern that are still to be researched.

II. Definitions

All data, unless otherwise noted, pertaining to the generation and recovery of municipal solid waste, in both level and percentage forms were collected from the EPA's report, "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Detailed Tables and Figures for 2008." For the purposes of this paper, generation levels are the thousands of tons of material that the EPA reported that "[refer] to the weight of materials and products as they enter the waste management system from residential, commercial, institutional and industrial sources and before materials recovery or combustion takes place" (EPA "Figures for 2008" 2009). Generation shares by material are the composition of the total generation viewed material by material, and material shares are the total generated by an individual material divided by the total generated in the municipal waste stream.

Recovery levels are the thousands of tons of material that "[include] products and yard trimmings removed from the waste stream for the purpose of recycling…recovery equals reported purchases of postconsumer recovered material plus net exports (if any) of the material" (EPA "Figures for 2008" 2009). Individual recovery rates are defined as the total amount

[1] Data available via the EPA's report is for years: 1960, 1970, 1980, 1990, 2000, 2003, 2005, 2007, and 2008.

[2] Real prices were rebased using annual 2010 Consumer Price Index data from the Federal Reserve of Saint Louis.

recovered by material divided by the total amount generated by that specific material. Total recovery rates are the aggregation of the individual thousands of tons of material recovered divided by the total amount generated.

Lastly, durable goods are defined as products that have a product life of 3 or more years. This includes "major and small appliances, furniture and furnishings, carpets and rugs, tires, lead-acid batteries, consumer electronics, and other miscellaneous durables." "Containers and packaging are assumed to be discarded the same year the products they contain are purchased. Products in this category include bottles, containers, corrugated boxes, milk cartons, folding cartons, bags, sacks and wraps, wood packaging, and other miscellaneous packaging". Total cans include beer, soft drink, and other/food cans (EPA "Figures for 2008" 2009).

III. Background of Municipal Solid Waste

This section provides a general overview of thousands of tons of MSW generated over the time period from 1960 to 2008. It also supplies the total recovery rate to show and explain particular trends in recycling of MSW. Furthermore, the total generated is decomposed to provide individual MSW generation explanations across time.

Figure 1.1: Total Generation of Municipal Solid Waste and Percentage Recovered Over Time

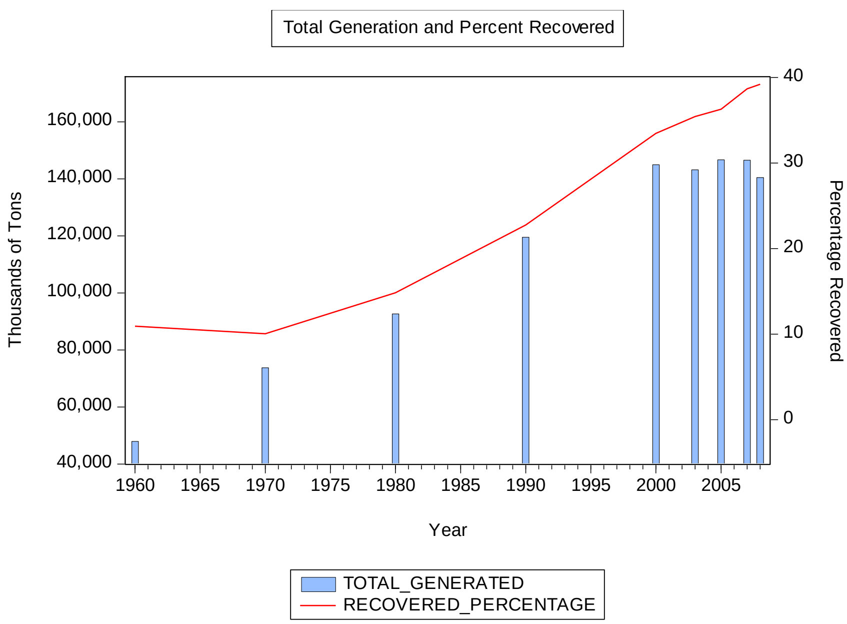


Figure 1.2: Total Generation and Recovery per Capita

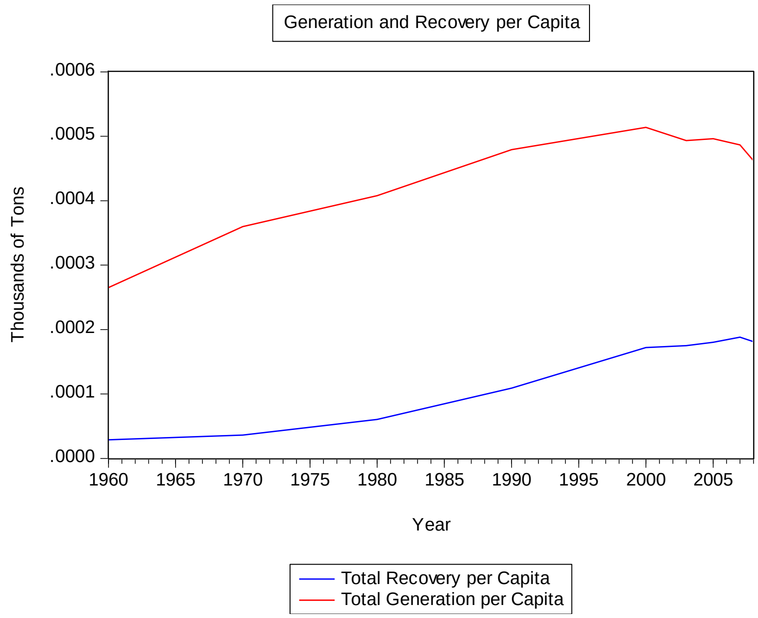
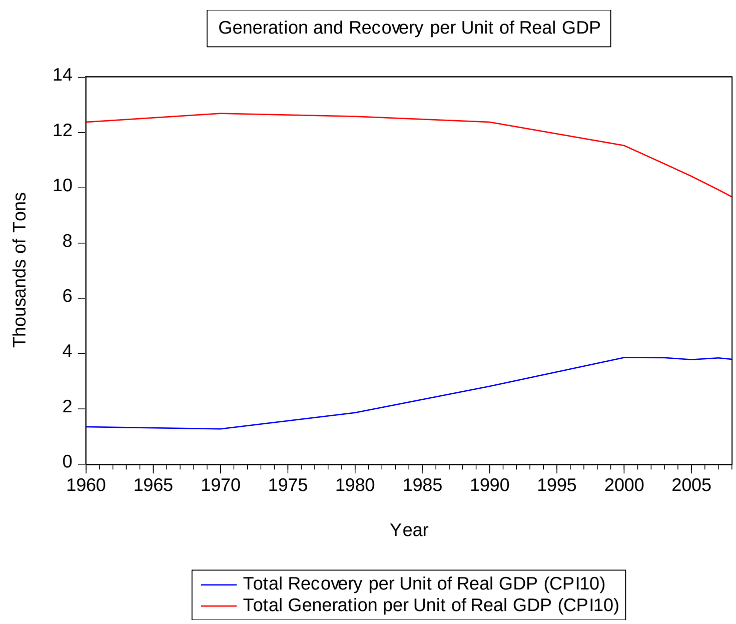


Figure 1.3: Total Generation and Recovery per Unit of Real GDP Deflated Using CPI 2010



a. Generation and Recovery

The left vertical axis in *Figure 1.1* illustrates the total MSW generated from the six materials analyzed in thousands of tons. *Figure 1.2* and *Figure 1.3* respectively show the total generation and recovery in per capita and per unit of real Gross Domestic Product ("GDP") terms. Although *Figures 1.1* and *1.2* reflect a steady increase of total generation from 1960 to approximately 2000, *Figure 1.3* exhibits relatively stable generation levels per unit of real GDP. The subsequent periods (i.e. 2003 to 2008) have a decline in the total amount generated in all three figures. Contrastingly, the right vertical axis in *Figure 1.1* reflects a declining recovery rate from 1960 to 1970, but a relatively linear increase from 1970 to 2008. This essentially shows that the United States is able to recover more MSW from less available in the municipal waste stream.

One possible explanation to this decline in total generation, increasing total recovery in both per capita and per unit of real GDP terms, and an increasing recovery rate is technological advancement. This implies that the Unites States is advancing in terms of resource saving as well as becoming more efficient in MSW recovery. Note the increase in the recovery rate since 1970. During that period there was a rise of interest in the environment which gave way to a series of Federal Acts and the formation of the United States EPA (EPA "History" 2009).

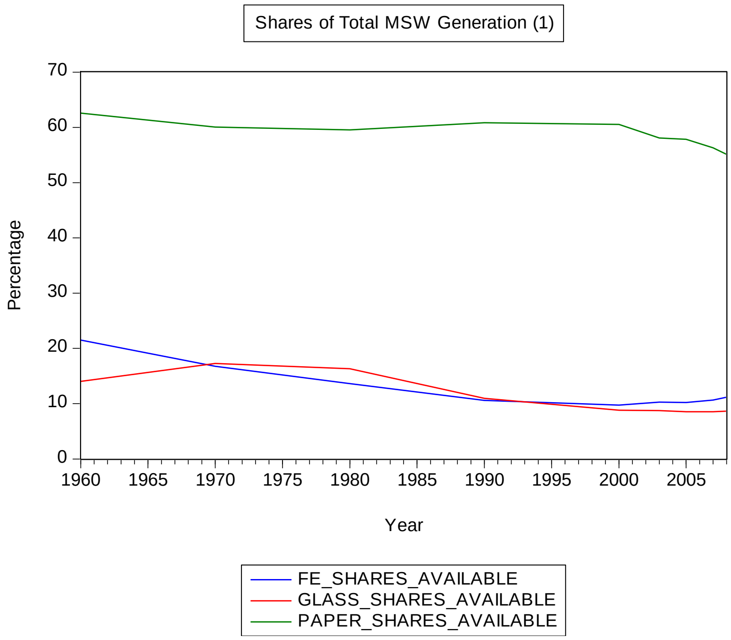
For example, the Solid Waste Disposal Act ("SWDA") was enacted in 1965 to "improve [and regulate] waste disposal technology". Five years later Congress passed the Resource Recovery Act ("RRA") of 1970 to "increase federal involvement with management of solid waste, [and to] encourage waste reduction and resource recovery". Following several amendments to the SWDA, it became the Resource Conservation and Recovery Act ("RCRA") in 1976. RCRA gave the "EPA the authority to control hazardous waste…[which] includes the minimization, generation, transportation, storage, and disposal of hazardous waste" (NM Environmental Department 2009) and "set forth a framework for the management of non-hazardous solid wastes" (EPA "RCRA" 2010). According to federal regulations, "all municipal solid waste landfills must comply [with the landfill design subpart] of RCRA" (EPA "Landfills" 2009).

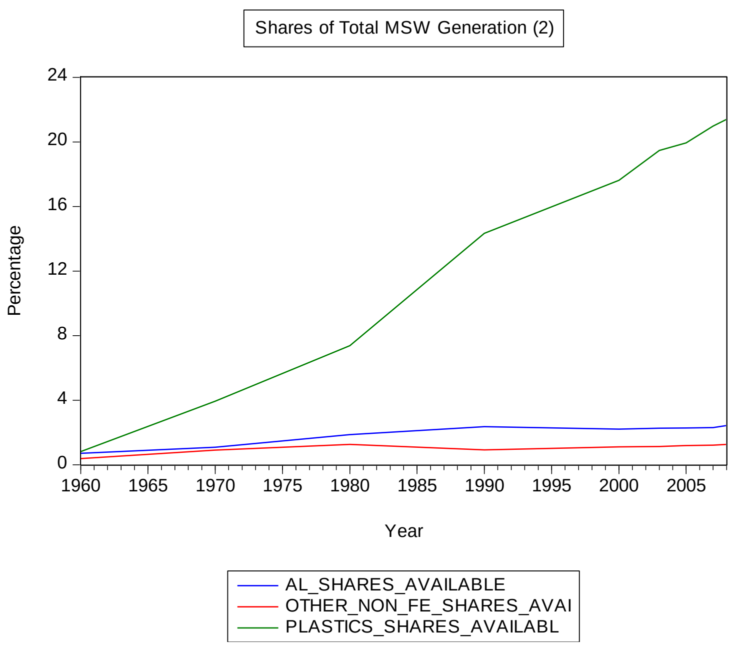
Another explanation could be that if the total generated is dominated by a material with an increasing real price and low substitutability in its respective primary usage, then the recovery rate should in fact increase. This is due to recovered materials becoming economical in comparison to virgin material. However to evaluate this hypothesis, the composition of the total generated in the municipal waste stream must be examined.

b. Composition of Total Generated

Decomposing the total generated into shares generated by material provides the composition movements in MSW. This reflects what materials are becoming increasingly or decreasingly used in everyday items such as durable goods (e.g. appliances and furniture), non-durable goods (e.g. magazines and newspapers), and containers and packaging (e.g. bottles, boxes, and cartons) (EPA "Figures for 2008" 2009).

Figure 1.4: Material Shares of Total Municipal Solid Waste Generated





Graph 1 of *Figure 1.4* depicts the shares of the total MSW generated for ferrous metals, glass, and paper, while graph 2 depicts the shares for aluminum, other nonferrous metals, and plastics. For exact percentages, see *Table 1* in the Appendix. Ferrous metals portray a declining trend. Conversely and as one would expect, aluminum on the other hand are on the rise with the movement from steel beverage cans to aluminum beverage cans (CMI 2010).

Paper shares remain as a large percentage of the total generated, but in the last decade has started to decline. Newspaper is one of the major contributors to this decline, which has steadily decreased from 14,790 thousands of tons to 8,880 thousands of tons generated into the municipal waste stream (EPA "Figures for 2008" 2009). This could be due to office and residential environments becoming "paperless" as well as more people receiving their news via the internet rather than home delivery newspapers. Thus the invention of the internet and e-mail, accompanied with the increasing societal interest in environmental sustainability and availability of recycling bins could have significant explanatory value in this observation.

Glass increased from 1960 to 1970, but then had a declining trend from 1970 onward with reaching a potential steady state from 2000 to 2008. Most glass generation is derived from containers and packaging. Further decomposition of the data shows that beer and soft drink bottles have increasingly become more of a significant share of the portion of glass generated from containers and packaging. This could have similar explanation to that of the ferrous metals and aluminum situation in that plastic bottles became more economic to manufacture compared to glass (EPA "Figures for 2008" 2009).

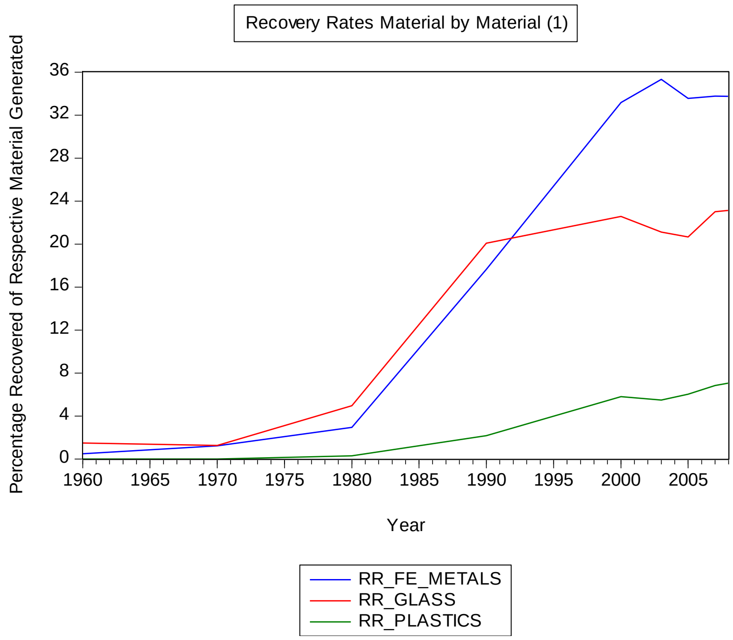
Plastics stand out in that it is the only material analyzed with such a dramatic increase in the share of the total MSW generated. Plastic generation has become more dependent on durables, representing roughly one-third of generation in 2008, with the majority of plastic generation deriving from containers and packaging (EPA "Figures for 2008" 2009). The data from the EPA only decomposes durable goods into types of plastics, not types of durable goods. However, one can speculate that plastics are becoming increasingly apparent in small and major appliances.

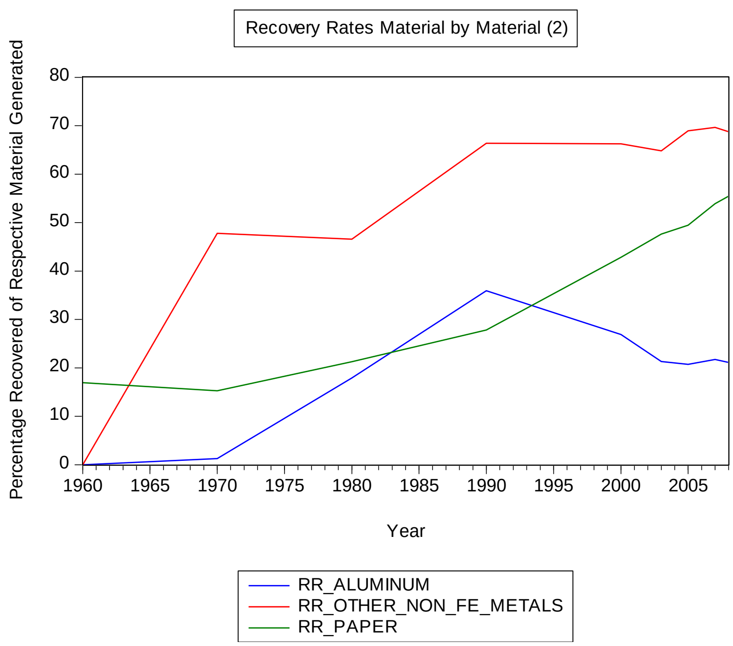
Lastly, the share of nonferrous metals grew consistently from 0.38% in 1960 to 1.25% in 1980. In 1990, the shares of other nonferrous metals dropped to 0.92%, but then grew back to 1.25% in 2008. The majority of the thousands of tons of nonferrous metals generated is lead from lead-acid batteries, which represent approximately 60% in 2000 to 74% in 2005 of the total other nonferrous metal generation from the 2000 to 2008 period (EPA "MSW" 2009). "Note that only lead-acid batteries from passenger cars, trucks, and motorcycles are included. Lead-acid batteries used in large equipment or industrial applications are not included" (EPA "2007 Facts" 2008).

IV. Understanding Recovery Rates for Specific Materials

This section decomposes the total thousands of tons of material recovered into their respective material recovery rates. In addition, significant points in time for each material are identified to provide period by period individual recovery rate analysis and explanation. Note the variation (see *Figure 2.1*) across recovery rates with regards to their magnitudes, percentage recovered, and year(s) that initiated significant changes in the recovery rates. To explain these variations own real prices, prices of inputs, societal changes, and others (e.g. bottle bills for aluminum) are invoked. Having this variation across materials noted, one cannot perform analysis on groups of materials in the municipal waste stream, as each recovery rate is subject to its own explanations.

Figure 2.1: Recovery Rates Material by Material

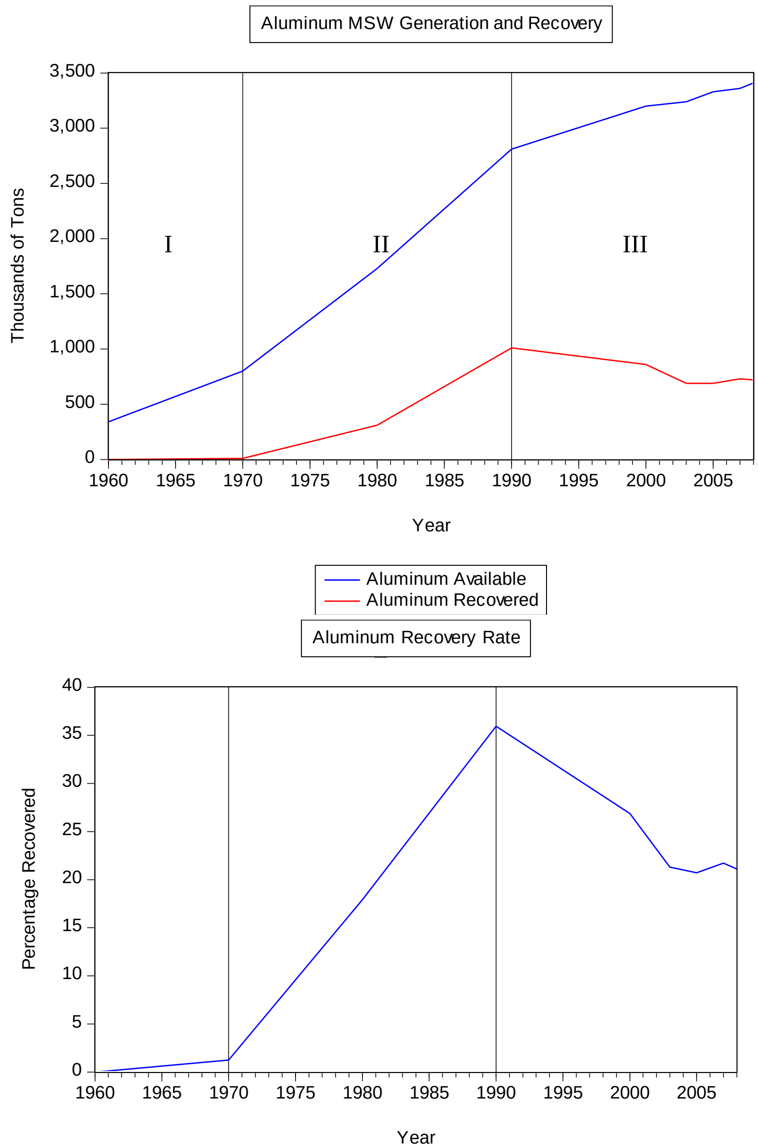




a. Aluminum

From the period studied, 1960 to 2008, one can arbitrarily divide both the aluminum generated and aluminum recovered into three time periods (see *Figure 2.2*). The period from 1960 to 1970, which will be referred to as time period I, exhibits a generous increase (135%) in thousands of tons generated. Contrastingly, a disproportionate increase in the thousands of tons recovered is observed; increasing from a relatively negligible amount to 10 thousand tons during this time period. Also during period I, the quantity of used beverage containers ("UBC") generated as a percentage of the total aluminum generated rose from a negligible amount to 160 thousand tons, representing approximately 20% of the total amount of aluminum generated into the municipal waste stream in 1970 (see *Figure 1* in the Appendix). This increase in the amount of UBC generated is due to the introduction of aluminum in beverage containers in 1965 (CMI 2010).

Figure 2.2: Aluminum Generation, Recovery, and Recovery Rate



Period II looks at the years from 1970 to 1990, and contains a 251% increase in aluminum generation. In addition, thousands of tons of aluminum cans generated rose from 160 in 1970 to 890 in 1980 to 1,570 in 1990; representing 20%, 51%, and 56% of the total aluminum generated in the municipal waste stream, respectively. UBC percentage recovered of aluminum generated by cans (beer, soft drink, and other/food) rose from 6% in 1970 to 36% in 1980 to 63% in 1990.

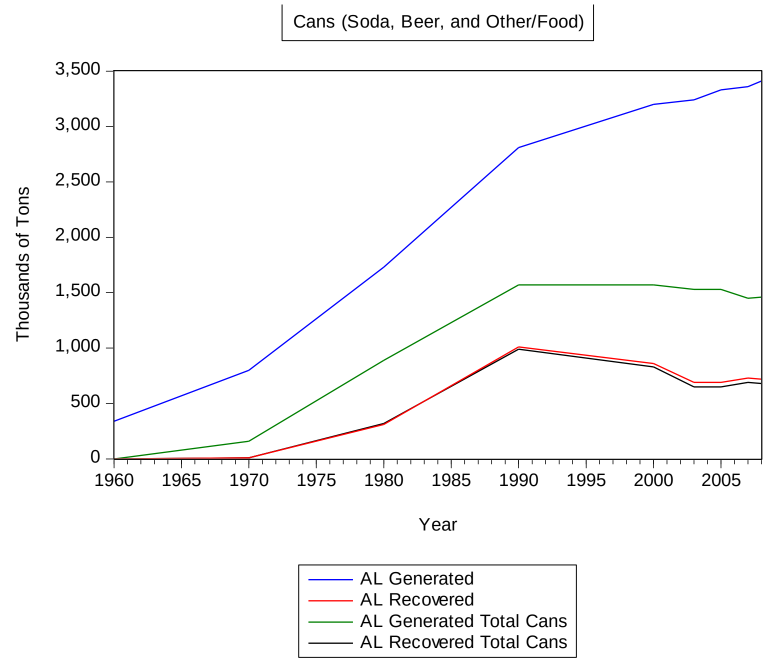
UBC percentage of recovered of total aluminum generated also increased, from 1% in 1970 to 19% in 1980 to 35% in 1990. This dramatic increase in the aluminum UBC recovered is linked to the domination of aluminum in the beverage can market beginning in 1985 (CMI 2010). As more aluminum cans are produced for consumption, more aluminum beverage containers enter the municipal waste stream, which allow for more recovery since aluminum beverage containers are essentially homogenous in material and "can be used directly as a raw material input with no alloy or chemical modifications required" (Fuller 1978).

One other important fact to note is the 1.1% increase in the real price of electricity over period II as displayed in *Figure 2* in the Appendix (EIA 2009). Aluminum being such an energy intensive good to produce, suggests that the recovery rate could be highly sensitive to electricity prices (IAI "Production" 2010). Therefore as electricity prices increase, as in the case for period II, it becomes more costly to produce new aluminum beverage containers. More aluminum beverage containers would be recovered because "recycling aluminum products needs only 5% of the energy needed for primary aluminum production" (IAI "Recycling" 2010). Also, the continuously increasing aluminum recovery rate in period II can be explained through lagged effects from the increase of electricity prices from 1970 to approximately 1983.

In addition to the increase in real electricity prices, are the introduction of bottle bills in 10 states (Bottle Bill "US" 2010). This act of legislation requires a refundable fee to serve as an incentive for people to recycle (Bottle Bill "What is" 2010).

Period III reflects the years from 1990 to 2008. During this period, aluminum generation increased by 21%, while the thousands of tons of aluminum cans generated declined from 1,570 in 1990 to 1,460 in 2008. The decline in aluminum cans generated can be traced to 1991 when aluminum can ends began to use less material and "save natural resources" (CMI 2010). UBC percentages of total aluminum generated and of just aluminum generated by cans also dropped during period III. *Figure 2.3* displays the thousands of tons of aluminum generated, aluminum generated from total cans, aluminum recovered, and the aluminum recovered from total cans. Almost all of the aluminum recovered is comprised of aluminum total cans.

Figure 2.3: Aluminum Cans and Aluminum Generated/Recovered in Thousands of Tons



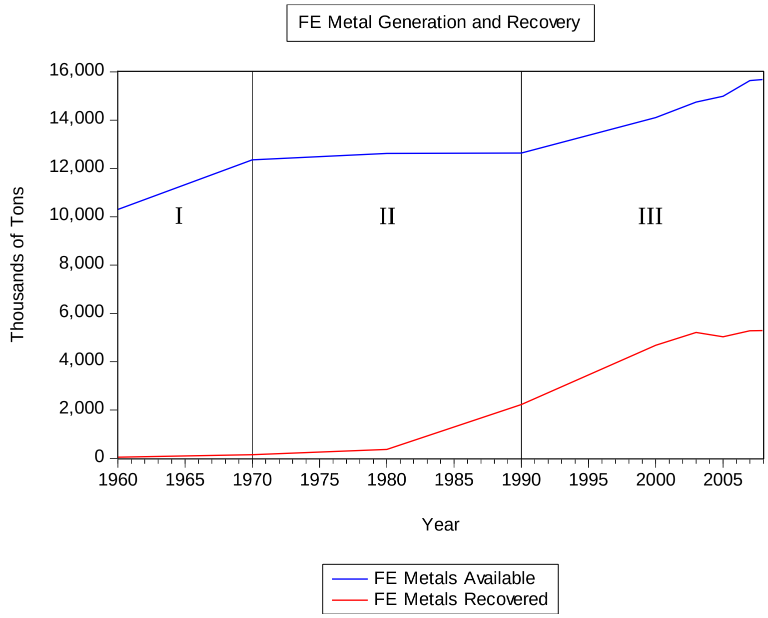
However, as explained earlier with the resource saving of 1991, the total amount of aluminum generated continues to increase. The major categorical contributor to this divergence is durable goods. Durable goods represented 1,310 thousands of tons of the 3,410 thousands of tons of aluminum generated, or 38%, in 2008 (EPA "Figures for 2008" 2009). The increase of aluminum durable goods generation has a direct impact on the recovery rate, as aluminum in appliances are more difficult to separate out in comparison to aluminum cans, which are more homogeneous (Fuller 1978).

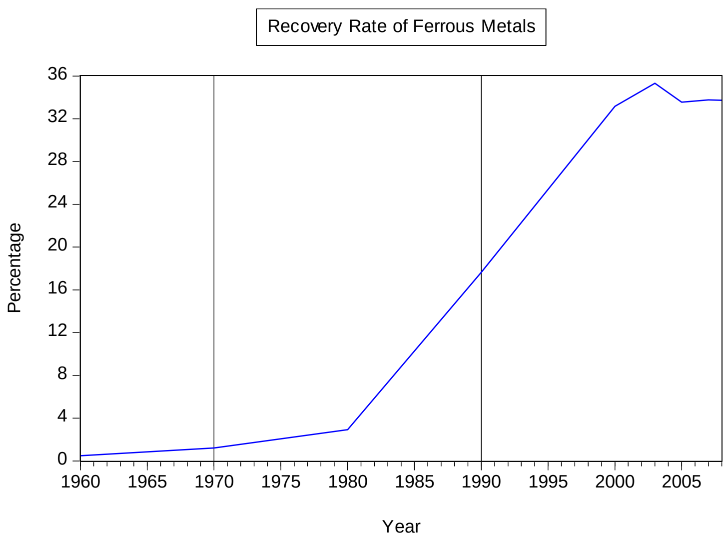
In contrast to what the bottle bills have contributed to recovery in period II, they have a decreasing effect if the monetary incentives are not revised to account for inflation. For example, real prices of have declined (see *Figure 3* in the Appendix) compared to period II (USGS "Aluminum" 2009), but it seems to be that bottle bill values are not updated often (Bottle Bill "All States" 2009).

b. Ferrous Metals

Similar to the devised periods for aluminum, ferrous metals can be portrayed in three time periods. Period I is classified as the years from 1960 to 1970. During this period, ferrous metal generation in the municipal waste stream steadily increased (see *Figure 2.4*) while ferrous metal recovery did not really have any significant changes and remained at a relatively negligible amount. Recall that this is the time period for which aluminum entered into the beverage can market, so steel cans preceded the beverage can market. Steel cans represented roughly 43% of the total ferrous metal generation in 1960, and 41% in 1970 (see *Figure 4 in the Appendix*). The majority of the remaining steel generation comes from durable goods.

Figure 2.4: Ferrous Metal Generation, Recovery, and Recovery Rate





While the total ferrous metals recovered tripled during this time period; it still only represented a small portion of the amount generated; 0.5% in 1960 and 1.2% in 1970. The amount recovered from total cans reflected 60% in 1960 and 53% in 1970. Also note that this time period does not yet include bottle bills. Therefore, there was no monetary incentive to recover steel cans in terms of legislation. Further explanation of no real change in the recovery rate can be sought through the decline of real steel prices (see *Figure 5* of the Appendix). With real prices of steel on the decline, it could be that producing primary steel was less or equally as costly as recovering it from the municipal waste stream.

The thousands of tons of ferrous metals generated in period II, the years from 1970 to 1990, happen to be a period of stagnation while the thousands of tons recovered began to increase in

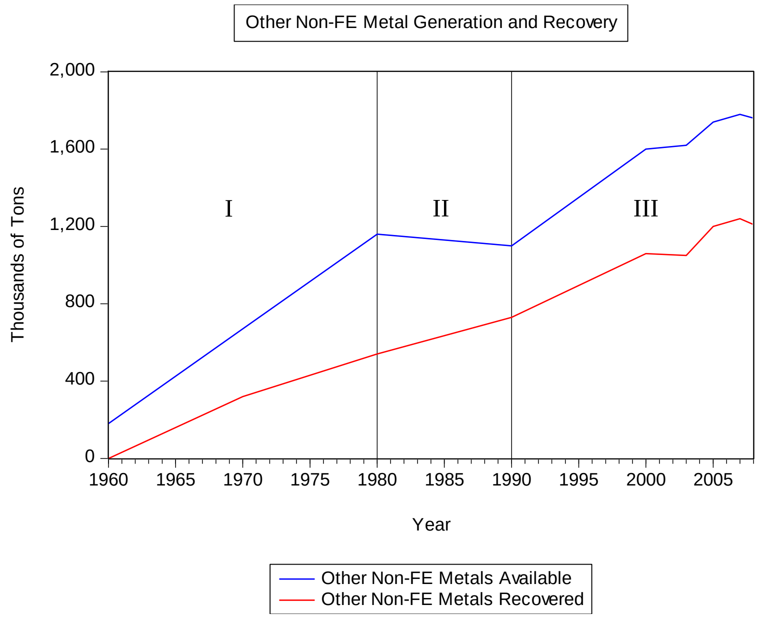
1980. Beverage containers do not have much explanatory value in this increase in recovery, because steel cans actually were being phased out by aluminum cans and therefore the amount of steel cans as a percentage of the total amount began to diverge. The increase in recovery, however, potentially can be traced to the increase in real steel prices from approximately 1974 to 1978, which caused primary steel production to be more costly than recovered steel from the municipal waste stream. Provided that the divergence of recovered steel cans from the total recovered and increase of durable steel goods recovered, it is noted that there is a product lifetime or durability lag between the increase in real prices and the increase in steel recovered.

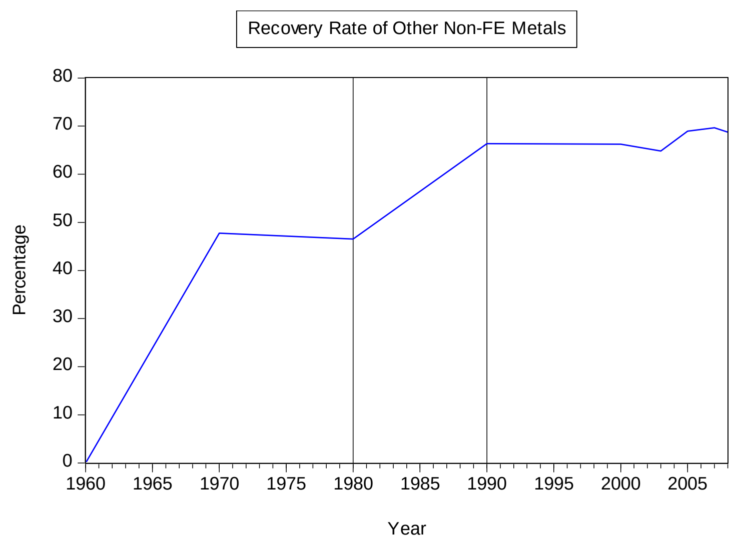
Period III, the years from 1990 to 2008, displays an increase in steel generation, as well as a continued increase in the amount recovered from period II. The real price of steel declined from 1990 to 2003. This could explain why the ferrous metal generation increases. Then why does the United States see an increasing real price from 2003 to 2008 along with the continued amount generated in the municipal waste stream? This could be due to a shortage of material. As more steel is demanded, the price is bid up because of short term capacity constraints. Since the market could not fulfill demand orders, and no substitutes were readily available, the demand remains the same. Therefore, more is recovered from the municipal waste stream as it becomes economical to do so.

c. Other Nonferrous Metals

Other nonferrous metals include lead, zinc, and copper (EPA “2007 Facts” 2008). The periods are broken down into period I, the years from 1960 to 1980; period II, the years from 1980 to 1990; and period III, the years from 1990 to 2008 (see *Figure 2.5*). For periods I and II, the EPA does not provide durable goods data broken down into lead and other (i.e. zinc and copper) nonferrous metals. However, with the increasing real price of lead from 1960 to 1979 as displayed in *Figure 6* of the Appendix (USGS “Lead” 2009) and its relative ease of recovery from the lead-acid battery (University of Denver 2004); it potentially was less costly for battery manufacturers to seek lead, which comprises approximately 60% of the total weight of the battery (Linden 2002), from the municipal waste stream.

Figure 2.5: Nonferrous Metal Generation, Recovery, and Recovery Rate





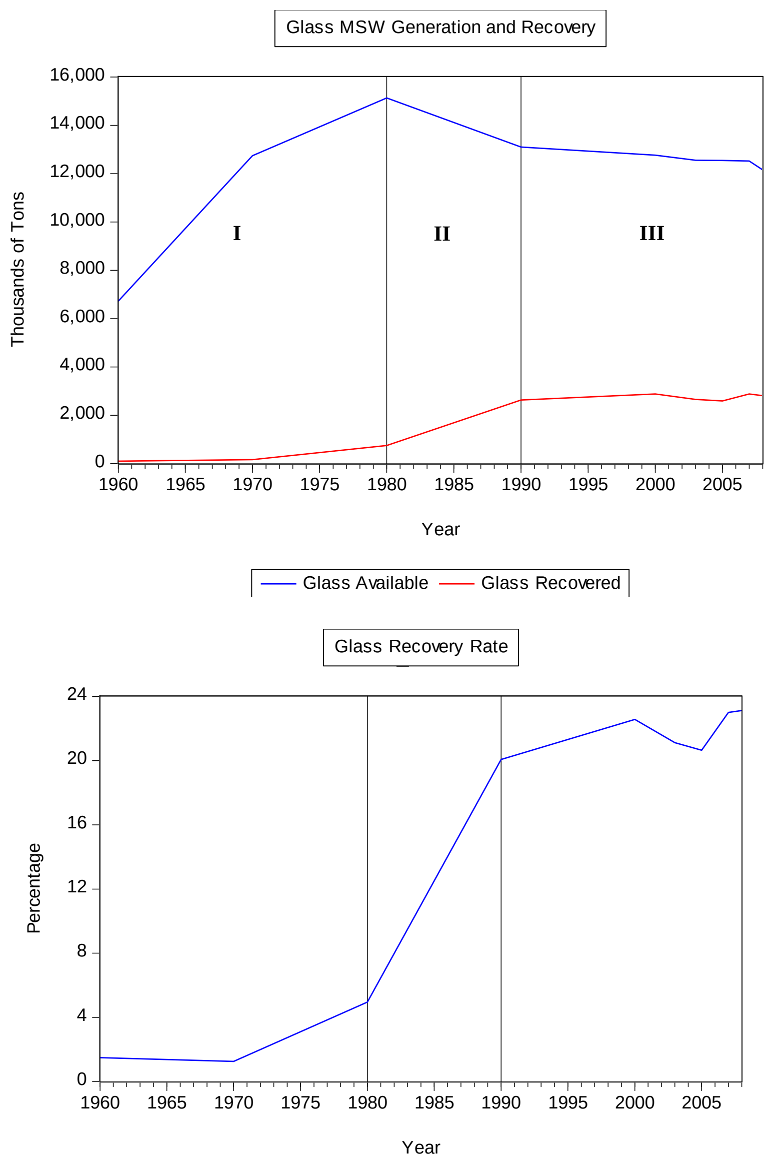
During period II, the real lead price declined and then reached a steady state in the latter part of the 1980s (see *Figure 6* in the Appendix). The variation in the real lead price during period II led to not much of a change in the thousands of tons generated, but continued to reflect an increase in the amount recovered.

In period III, an increase in generation is observed along with the thousands of tons recovered. Most states passed lead-acid battery laws in the late 1980s and early 1990s (BCI 2010). Also in 1996, the Battery Act was put into action in order to "provide for the efficient and cost-effective collection and recycling or proper disposal of…used small lead-acid batteries" (EPA "Battery Act" 2002). The implementations of the deposit laws and the Battery Act actually did not seem to have a significant impact on the thousands of tons recovered or the recovery rate.

d. Glass

The years from 1960 to 1980, denoted as period I in *Figure 2.6*, portray an increase in the thousands of tons generated into the municipal waste stream while thousands of tons recovered do not see much of an increase until the sub-period from 1970 to 1980. Most of which is generated and recovered is classified as containers and packaging (e.g. bottles and jars, see *Figure 7* in the Appendix). The generation of glass materials continues to rise until period II, when plastics took over the market share. The increase in recovery from the sub-period has a direct positive correlation to when the 10 states discussed earlier passed bottle bills as a monetary incentive to recycle.

Figure 2.6: Glass Metal Generation, Recovery, and Recovery Rate



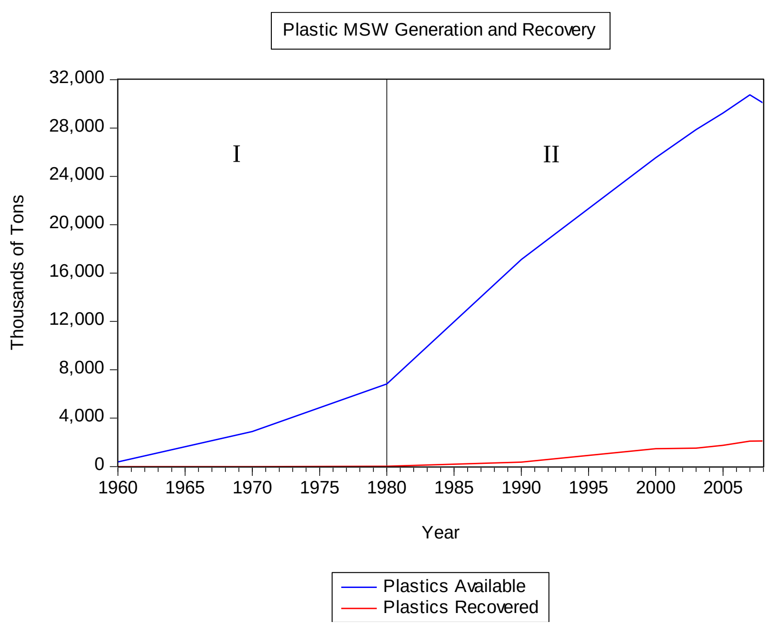
In period II, the years from 1980 to 1990, glass generation began to decline with the rise in plastics. However, glass recovery continued to increase. This increase can still be contributed to the induction of bottle bills.

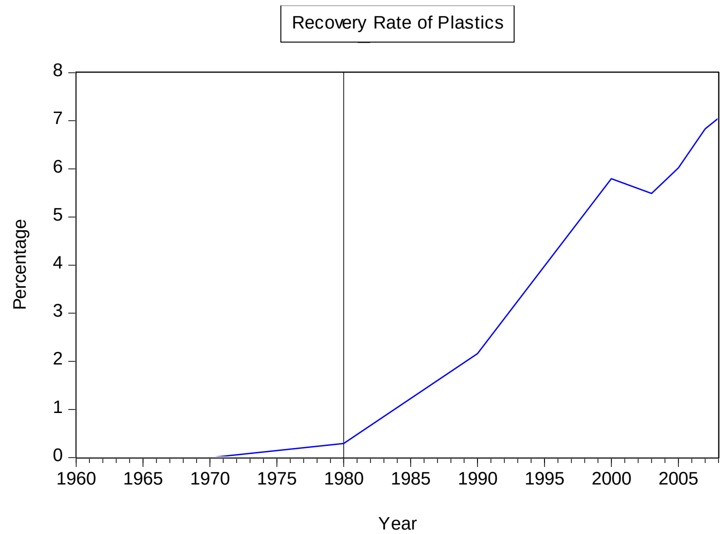
Lastly in period III, the years from 1990 to 2008, both glass generation and glass recovery remain relatively flat. Nevertheless, when decomposing the thousands of tons recovered into types (i.e. glass jars and bottles); it is observed that the portion recovered from glass jars has a dramatic decrease beginning in 2000.

e. Plastics

Plastics are only separated into two periods, period I being from 1960 to 1980, and period II being from 1980 to 2008 (see *Figure 2.7*). Period I reflects a steady increase in the thousands of tons generated with a negligible amount of recovery. As noted in the glass subsection, III.d., plastics and glass generation are inversely related. So during this period, glass was still the dominant force in bottle production.

Figure 2.7: Plastics Metal Generation, Recovery, and Recovery Rate



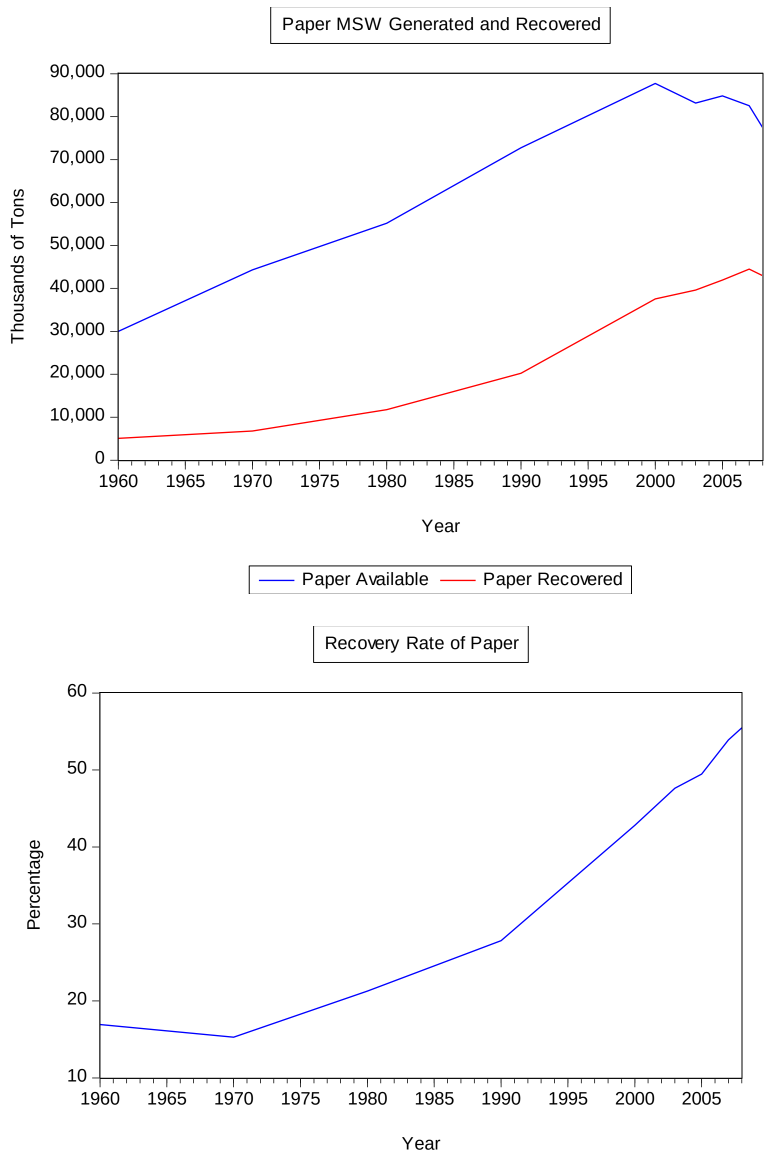


It was not until period II that plastics overcame glass generation. However, plastic recovery increased over this period slightly in comparison to the amount generated. This could be explained through bottle bills, curbside pickup, an increase in recycling bins in offices and other institutional facilities, an increased concern for the environment, and resource saving. Most plastics are actually discarded, but the portion that is recovered comes from containers and packaging (see *Figure 8* in the Appendix). "The cost of recycling a bottle versus making a new one simply varies, depending where the bottle is". However, companies like Coca-Cola are working to "make more lightweight bottles that contain more recycled resin…[because they are] made with 30% less resin and rely on the water or liquid inside to maintain their shape. Using less resin per bottle could translate to a savings on raw materials of about $1.5 billion a year for the bottling industry". Some is recovered from durable goods, which account for a large portion of the plastics generated, but the assumption here is that of separation cost (Intagliata 2008).

f. Paper and Paperboard

Paper and paperboard was not split up into periods, as both generation and recovery have increased reasonably linearly over the time period, with the exception of a decline in paper generated in 2000 (see *Figure 2.8*). Most of which is derived from non-durable goods such as books and magazines. The recovery rate seems to be increasing exponentially, which could be explained through the increase in recycling bins in offices and other institutional facilities, the invention of the internet and e-mail, and the increased concern for the environment.

Figure 2.8: Paper Metal Generation, Recovery, and Recovery Rate



V. Concluding Observations

Even with the United States declining in the thousands of tons generated in the municipal waste stream, recovery rates have continued to increase with the assistance of technological innovation, Federal Acts, monetary incentives (i.e. bottle bills), convenience recycling (e.g. curbside recycling and recycle bins in institutional facilities), and the overall increased concern about the environment and future generations. In addition since 1960, there has been a change in the composition of thousands of tons generated in the municipal waste stream. The U.S. has observed a shift away from glass products to plastic products, as well as a declining share of paper in the past decade. Furthermore, ferrous metal shares are decreasing, while aluminum shares have increased, but not significantly. Other nonferrous metals have not shown much of a change over the past 50 years in terms of generation share.

There are two major findings with regards to recovery rate by material. (1) While the majority of the materials studied have witnessed an increase or point of stagnation in recovery, aluminum is the exception due to declining real prices, resource saving initiatives, and the increase of aluminum usage in durable goods. Further exploration in the cost of recycling aluminum and its end use material substitutability in durable products would provide additional supporting evidence as to why the decline in aluminum MSW recovery. (2) Other nonferrous metals recoveries have increased mainly due to the ease of lead recovery in lead-acid batteries. Its respective recovery rate had significant impact from 1960 to 1980, which possibly is explained by the increasing real price of lead during this period. However, lead battery recycling policies and price incentives do have explanatory value in this finding, so examination in these areas is still to be completed.

VI. Appendix

Table 1: Shares of Each Material Analyzed

Year	AL_Shares	FE_Shares	Glass_Shares	Other NonFE_Shares	Paper_Shares	Plastics_Shares	Total
1960	0.71	21.49	14.02	0.38	62.58	0.81	100.00
1970	1.08	16.75	17.27	0.91	60.06	3.93	100.00
1980	1.87	13.62	16.33	1.25	59.55	7.37	100.00
1990	2.35	10.58	10.96	0.92	60.86	14.33	100.00
2000	2.21	9.73	8.80	1.10	60.53	17.62	100.00
2003	2.26	10.30	8.76	1.13	58.08	19.46	100.00
2005	2.27	10.22	8.55	1.19	57.84	19.93	100.00
2007	2.29	10.67	8.54	1.21	56.31	20.97	100.00
2008	2.43	11.16	8.65	1.25	55.11	21.39	100.00

Figure 1: Used Beverage Container Generation of Total Aluminum and Recovery Rate

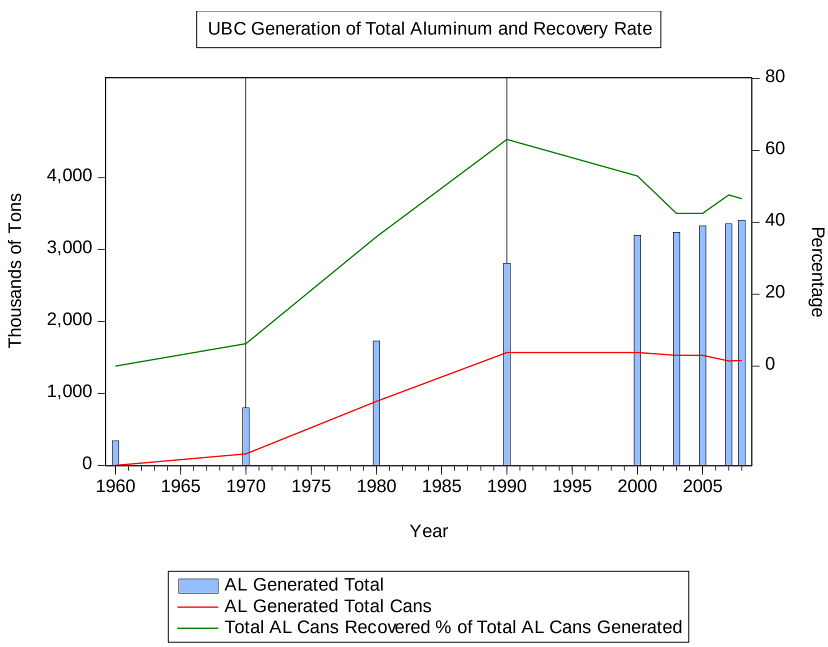


Figure 2: Nominal and Real Electricity Prices – Annual CPI 2010

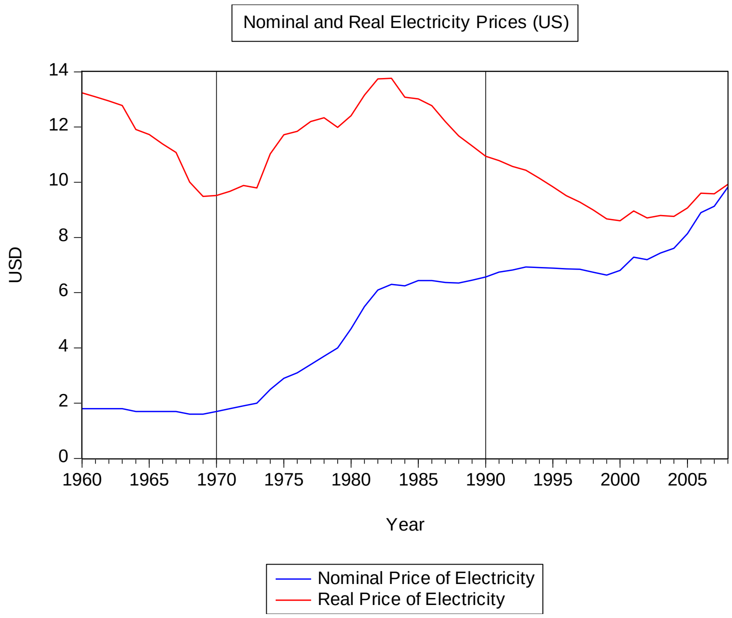


Figure 3: Nominal and Real Aluminum Prices – Annual CPI 2010

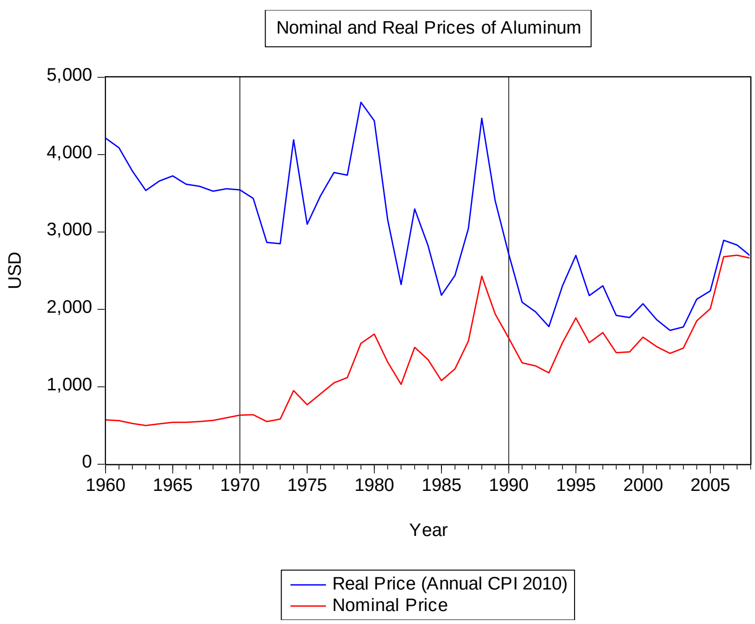


Figure 4: Steel Generation and Recovery with Total Can Weights

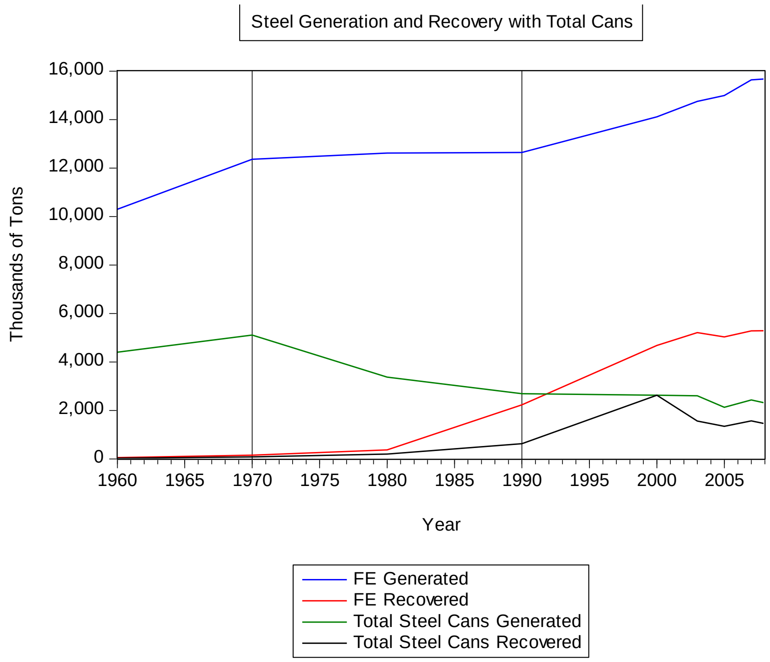


Figure 5: Real Steel Prices – Annual CPI 2010

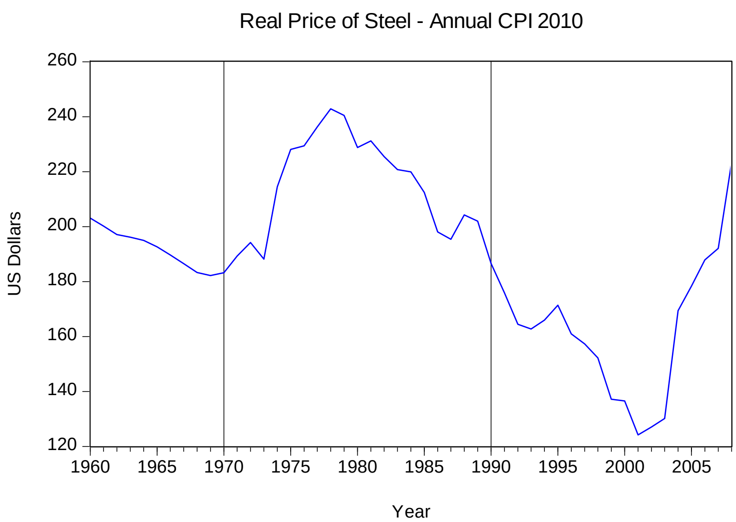


Figure 6: Real Lead Prices – Annual CPI 2010

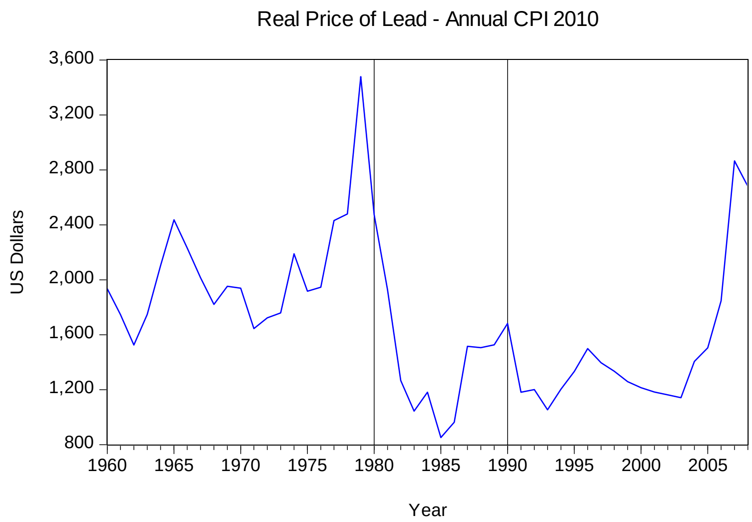


Figure 7: Glass Recovery with Packaging Recovery

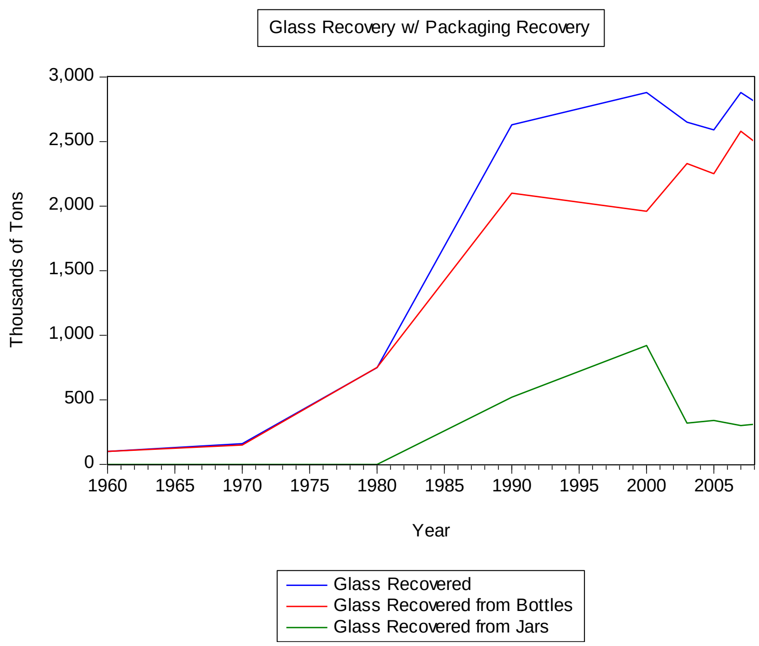


Figure 8: Plastics Recovery with Packaging

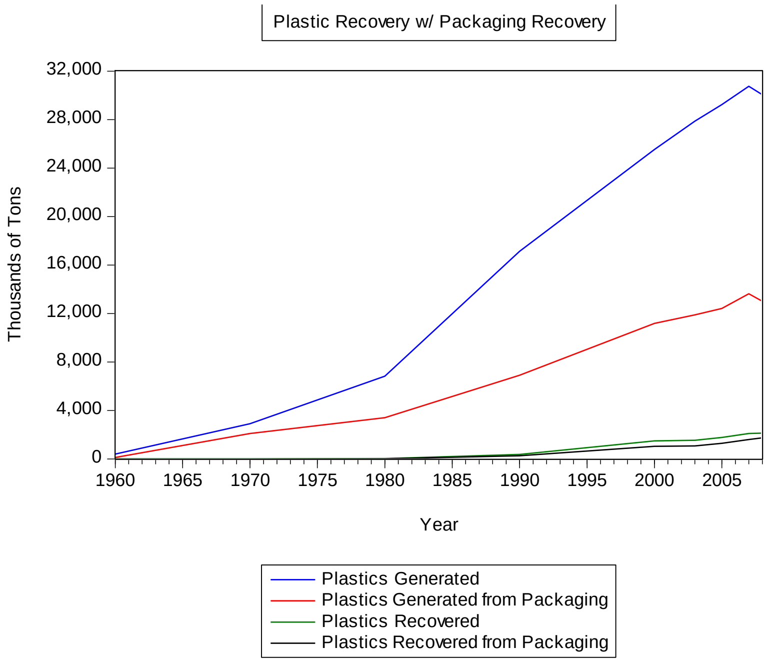
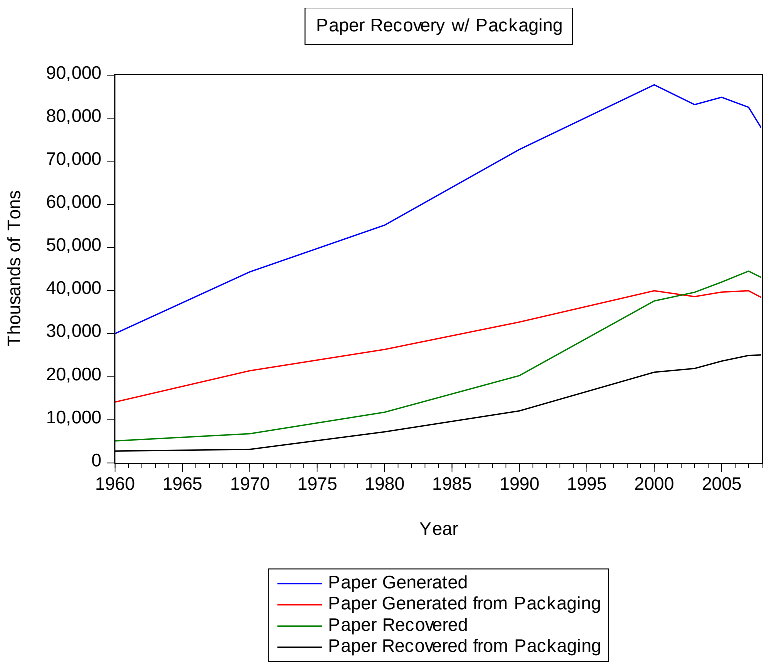


Figure 9: Paper Recovery with Packaging



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