Quantitative Characterization of Domestic and Transboundary Flows of Used Electronics

Analysis of Generation, Collection, and Export in the United States

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Definitions

Term	Definition
Used Electronics	Refers to electronics at the end of use by their owner. May be reused by a friend, family member, or direct resale to another person before generation (collection or disposal).
Generated Used Electronics	Refers to used electronics coming directly out of use (retired) or post-use storage destined for collection or disposal (landfill or incineration).
Collected Used Electronics	Refers to used electronics collected by a firm or organization. May be destined for refurbishment or repair or may be obsolete, broken, or irreparable electronic devices destined for recycling via dismantling or shredding.
Exported Used Electronics	Collected used electronics that have been exported as whole units.
Whole Units of Used Electronics	Refers to intact used electronics that may or may not be working. This excludes disassembled products that may be exported as several different commodity material or product streams. In the case of CRTs, the term "whole units" is extended to include intact CRT tubes, but not CRT glass cullet. This is done because the CRT tube can function as a whole unit with the simple addition of a new plastic case.
TVs	Televisions, including CRT and Flat Panel TVs, including Rear-projection television (RPTV).
Mobile Phones	Including feature phones and smartphones, for the purposes of business, public and private use. Older mobile phones for motor vehicles are excluded.
Desktop Computers	Desktop computer, server and other process unit. Associated monitors are considered separately.
Laptop Computers	Portable personal computer, excluding tablets.
CRT Monitors	Cathode Ray Tube Monitors, works in conjunction with computers .
Flat Panel Monitors	Non-CRT monitors including Liquid-Crystal Display (LCD)and Light-Emitting Diode (LED) display. These monitors are mainly for computers, video monitors for surveillance are very similar and thus included.
HSOTDM	Hybrid Sales Obsolescence-Trade Data Method, created in this study
Residential	Electronics for personal use in the home
Business/Public	Electronics for use in commercial, institution and education sectors

Term	Definition
NVEM	Neighborhood valley-emphasis method (NVEM), an algorithm employed to determine the used-new threshold value (See section 6.2.1 in appendix).
NA	North America (United Nation regions-based classification)
LAC	Latin America and Caribbean (United Nation regions-based classification)
LI	Low income (Word Bank Income group-based classification)
LMI	Low middle income (Word Bank Income group-based classification)
UMI	Upper middle (Word Bank Income group-based classification)
HI	High income (Word Bank Income group-based classification)
HI-OECD	High income of Organisation for Economic Co-operation and Development (OECD) countries (Word Bank Income group-based classification)

Note: Income group: Economies are divided according to 2012 gross national income (GNI) per capita, calculated using the World Bank Atlas method. The groups are: low income, $1,035 or less; lower middle income, $1,036 - $4,085; upper middle income, $4,086 - $12,615; and high income,$12,616 or more.

Executive Summary

Despite growing interest and concern surrounding transboundary movements of used electronics around the world, there is a dearth of data on their movements. Although a multitude of different data sources exist, coherent sets of information on used electronics and their movement are lacking because of inherent challenges in obtaining such information. These challenges include limited mechanisms for data collection, undifferentiated trade codes, lack of consistent definitions for categorizing and labeling used electronics as well as their components, minimal regulatory oversight, and limited agreement on the definitions of end uses (i.e., reuse vs. recycling). In spite of these challenges, a characterization of the sources, destinations, and quantities of used electronics flows would inform strategic decision-making of numerous stakeholders.

The first step of this research effort involved examining available methodologies to calculate quantities of used electronics generated (coming directly out of use or post-use storage destined for collection or disposal), collected (for recycling versus disposal), and exported (as whole units to developed or developing countries), and assessing the effort required and the quality of information for each approach. A few of the most promising approaches were evaluated in more detail and demonstrated using laptops as a case study. This study builds off of the outcomes of the previous work and details the results from a more comprehensive effort to calculate generation and collection quantities for *whole units* (i.e., not disassembled product or material streams) of used electronics in the United States, along with transboundary flows from the United States for a range of products including: TVs, mobile phones, computers and monitors. The year of analysis is 2010.

A hybrid approach of several methods is used for calculating the quantities of generated, collected, and exported whole units. The sales obsolescence method is used to stochastically (i.e., including uncertainty) estimate the generation of used electronics. Collection rates are modeled and applied to the generation results; the collection results serve as upper bounds on export estimates. Export quantities are calculated using a trade data approach. The advantage of this method is that trade data for all types of electronic products is widely available (including extensive historical data), updated relatively frequently, and provides insight into the destinations of products. The disadvantage is that there are no trade codes for used products and exporters may not be reporting shipments of used products properly. An analytical approach is used here to differentiate used products from new ones in the trade data, but the extent of misclassification by exporters is unknown. Thus, it is not currently possible to say how much error exists in the export estimates as a result of misclassification. Still, it is safe to assume that the estimates of export quantities are lower bounds of actual export quantities due to this likely misclassification error.

Figure ES1 shows that approximately 258.2 million units of used electronics (computers, monitors, TVs and mobile phones) were generated in 2010 and of which 171.4 million were collected, which is 66.4% of the generated estimate on average. Figure ES1 also shows that 14.4 million used electronic products were exported, or 8.5% of the collected estimate on average. Uncertainty parameters were modeled; the error bars for generation and collection represent 90% confidence interval, and the error bars for export represent the minimum and maximum.. When accounting for product weight, approximately 1.6 million tons of used electronics were generated and of which 0.9 million were collected, and 0.027 million tons were exported to the world (including the developed and developing countries), or only 3.1% of the collected estimate.

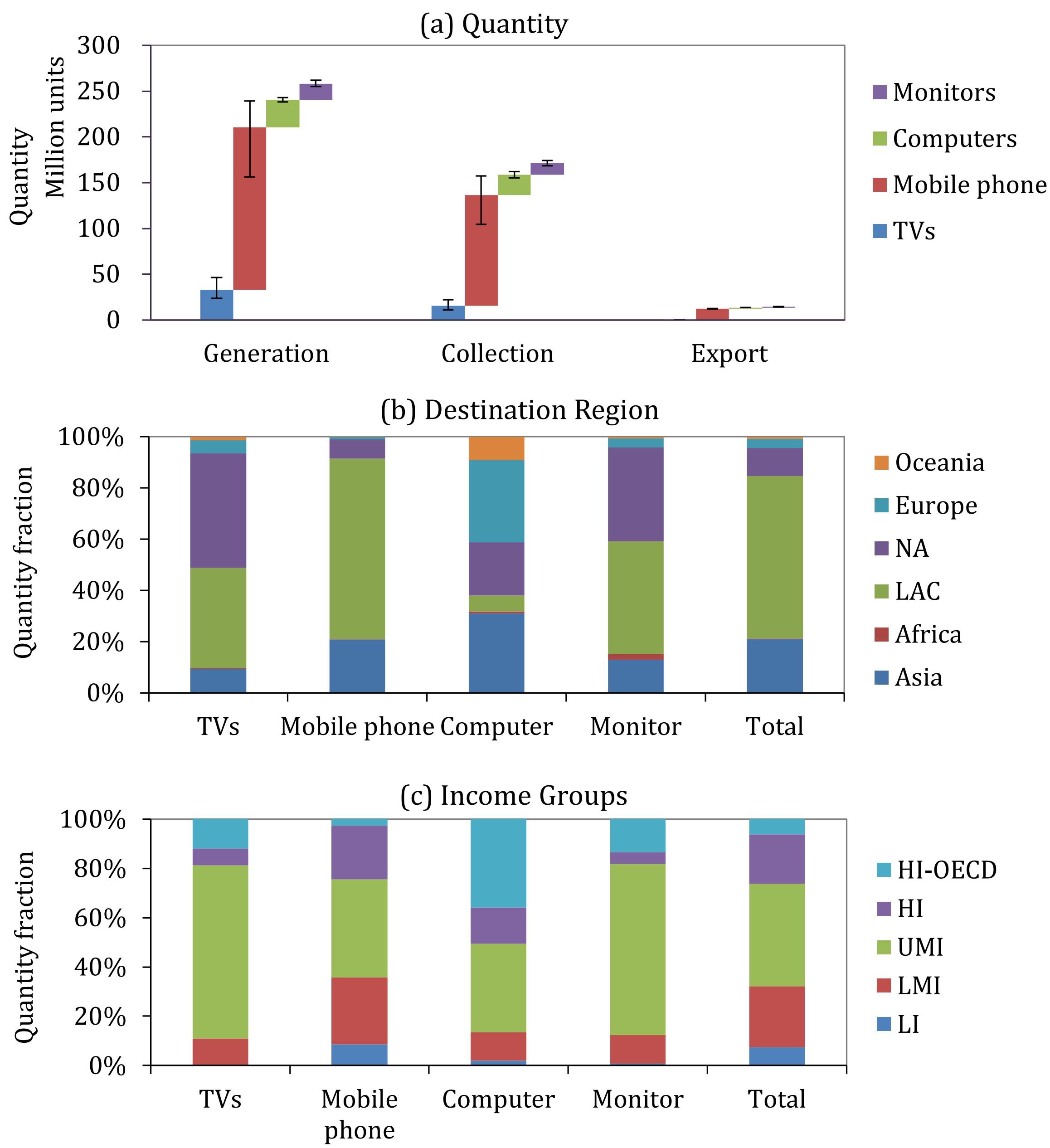


Figure ES1: Flows of Used Electronics in the US in 2010 by Quantity (a) and Normalized Destinations of Used Electronics Exports in 2010 by Destination Region (b) and Income Groups

The results all show that mobile phones account for the largest quantity of used electronics flows, but TVs are the heaviest flow of generated and collected used electronics, while monitors are the most massive exports.

An advantage of the trade data approach is that it tracks the destinations of shipped products. However, the destination in the trade data may be an initial stopping point, and the products may then be reexported to a final destination; reexports and final destinations are not always reported in trade data. Thus, the listing of a destination region in this report is an indication of at least this initial stop, but is not definitively the final destination. However, if it is a stopping point before reexport, the final destination is likely in the same region.

This study depicts the destination regions and the economic classifications of the regions for all products. Basically, bulky electronics, especially TVs and monitors, were more likely to be exported overland or by sea to destinations such as Mexico, Venezuela, Paraguay and China. The major destinations for mobile phones were Asia (Hong Kong, HKSAR) and Latin America and the Caribbean (Paraguay and Guatemala, Panama, Peru and Colombia). By contrast, Asian countries and regions which serve as key transit ports for international distribution in Asia and Africa, including Hong Kong (HKSAR, China), United Arab Emirates (UAE) and Lebanon, were more likely to receive used computers (especially laptops) and therefore may be re-exporting to surrounding countries. It is interesting to note that Africa makes up a very small fraction of the total used electronics exported directly from the US. Around 80% of used electronics, including TVs, monitors and mobile phones have been exported to countries with upper middle, low middle, and low income economies. However, the majority of the upper middle economies, like Honk Kong and UAE, are likely re-export hubs for further distribution to neighboring low income economies.

This analysis provides insights on the quantities of used electronics generated and collected in the United States, and exported from the United States. To summarize, the key findings from this report include:

- The methodology used to make the calculations is comprehensive from generation of used electronics at end-of-life all the way to export to a foreign destination. In addition, the method accounts for uncertainty in generation and collection.
- The scope of products includes information technology (computers and monitors), telecommunication (mobile phones), and consumer electronics products (TVs).
- Approximately 258.2 million units or 1.6 million tons of used electronics were generated in the US in 2010.
- Of the amount generated, 66% was collected for reuse or recycling on a unit basis, or 56% on a weight basis.
- Of the amount collected, 8.5% were exported on a unit basis, or 3.1% on a weight basis.
- Mobile phones dominate generation, collection, and export on a unit basis, but TVs and monitors dominate on a weight basis.

- Latin America and the Caribbean is a common destination for products, along with North America. Asia represents the next largest destination. Africa is the least common destination.

While there is significant rigor behind the calculations, gaps in available data mean that the export quantities represent a lower bound. This is due to a lack of explicit data on used whole unit trade flows, which necessitates several key assumptions in the methodology. Therefore, it is important that other approaches be used to estimate export flows and compared with the quantities calculated in this report. This would provide insight into the magnitude of the error derived from the data gaps.

There are several recommendations that arise from this work.

- The creation of trade codes for used products would enable explicit tracking of those products.
- Investigations should be conducted into the specific trade codes used by exporters for used electronics that are whole units.
- Allowing more open access to shipment level trade data would enable more accurate analyses of export flows.
- Increased reporting of re-export destinations would improve the accuracy of final destinations for trade flows.
- Flows should be analyzed across multiple years in order to discern trends.
- Other approaches should be used to estimate export flows of used electronics in order to understand the impact of the limitations in all approaches on the estimation of quantities.

1 Introduction

1.1 Background

There has been significant interest by a variety of stakeholders in the quantities of used electronic products generated, collected and exported. The federal government in the US has taken a particular interest in understanding these issues. In 2011 an Interagency Task Force on Electronics Stewardship co-chaired by the Council on Environmental Quality (CEQ), the Environmental Protection Agency (EPA), and the General Services Administration (GSA) released The National Strategy for Electronics Stewardship to specify federal actions for ensuring electronic stewardship in the United States (US)[1]. Recommendations focus on incentivizing design of greener electronics, ensuring the federal government leads by example in acquiring, managing, reusing and recycling its electronics, increasing domestic recycling efforts, and reducing harm from US exports of used electronics and improving safe handling of used electronics to developing countries. Furthermore, in January of 2012 the United States Trade Representative (USTR) requested that the United States International Trade Commission (USITC) conduct an investigation and prepare a report that describes US exports of used electronic products [2]. Other studies have estimated the quantity of used electronics generated and collected of at the worldwide, regional, or country level[3-7], including the US [8, 9]. Recent work has sought to quantify flows of used computers and monitors exported from North America[10-12]. These efforts are hampered by a lack of comprehensive data on key topics such as product sales and lifetimes, collection amounts, and no definition of used products in trade records.

Despite the work that has been done in this field, numerous questions remain regarding the quantities of transboundary flows within the US and to other countries and the uncertainty in those estimates. An earlier study [13] by the authors examined available methodologies to calculate quantities of used electronics generated and collected and characterize transboundary flows, and assessed the effort required and the quality of information for each approach. This report details the results from a second phase of this effort in which transboundary flows for the United States are quantified using the most promising approaches from the previous study for a range of products including:

- TVs (CRT and Flat Panel)
- Mobile Phones
- Computers (Laptops and Desktops)
- Monitors (CRT and Flat Panel)

The analyses of desktops and monitors were supported by a separate project initiated and funded by the Commission on Environmental Cooperation (CEC) of North America, but the approach is identical to the one used for other products in this study. The authors gratefully acknowledge CEC's willingness to include results from its study here.

1.2 Scope of the Study

The scope of this study is defined in the table below, including the detailed classification of the focal electronics and the distinction of generation and collection by owner types for the generation and collection analysis[I]; exports were analyzed for all products with owner types combined. The export methods use domestic export trade data, which theoretically captures the exports of goods produced in the US or were used in the US. Since CRT TVs and CRT Monitors are no longer produced in the US, all exports were assumed to be used. For all other products, used-new thresholds based on export unit values were used to distinguish used exports.

Table 1: Scope of Products in Study, Export Approach, and Distinction of Generation and Collection by Owner Types

Product Category	Specific Product (with reference to export definition)	Distinction of Generation and Collection by Owner Types	Export Approach
CRT TV (and Parts)	CRT TV, Color CRT TV, Monochrome	Owner Types Combined	Exports assumed to be used due to non-existent new domestic production
	CRT Tube, Color CRT Tube, Monochrome CRT Tube, Other		
	CRT Glass Envelopes		
Flat Panel TV	Flat Panel TVs	Owner Types Combined	Threshold Approach
Mobile Phone	Mobile Phone	Residential, Business/Public	Threshold Approach
Computer	Laptop	Residential, Business/Public	Threshold Approach (except Desktops with CRTs)
	Desktop		
	Desktop: Server		
	Desktop: Other		
CRT Monitor	With Desktop	Residential, Business/Public	Exports assumed to be used due to non-existent new domestic production
	With Other		
	PC Monitor		
	Video Monitor		
Flat Panel Monitor	PC Monitor	Residential, Business/Public	Threshold Approach
	Video Monitor	Business/Public Only	

1.3 Overview of Methodology

Details of the methodology are in the Appendix. A flowchart of the life cycle of electronics is shown in Figure 1 as a guide for key definitions in this report. The term "generation" refers to electronics coming directly out of use (retired) or post-use storage destined for collection or disposal. Thus, "generation" is consistent with the term "ready

[I] The generation and collection quantities of servers and other kinds of processing units were not estimated separate from desktops due the unavailability of sales data.

for end-of-life [EOL] management" [9, 14]. One generation pathway for items is disposal (F), including landfills and incinerators. Another generation pathway already mentioned is collection for processing in a working (H) or an obsolete (G) state. An assumption is made that after two terms of use, items are obsolete. The used electronics processor, having collected the used electronic whole unit, opts either to prepare it for reuse by a new user in the US (C), recover parts and materials from the item (I) and transfers them to downstream vendors (some of which may be in foreign countries), or export the used electronic product as a whole unit (J). The focus of this study is on used electronic products that are whole units. "Whole Units" refers to intact monitors, computers, mobile phones, etc. that may or may not have been refurbished. Thus, this excludes disassembled products that may be exported as several different commodity material or product streams.

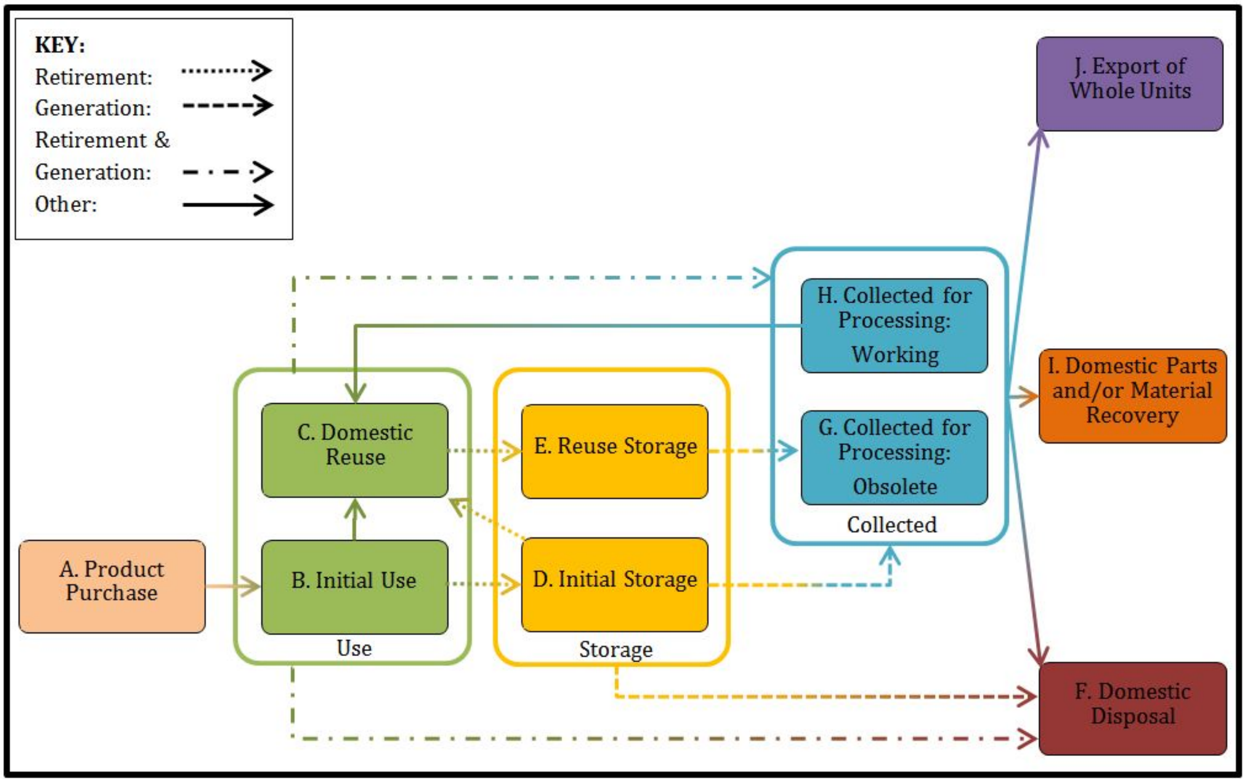


Figure 1: Life Cycle Flow Chart of Electronic Products

1.3.1 Generation and collection

A sales obsolescence approach is used to calculate generation and collection quantities of used electronics. Unlike previous studies, this study includes uncertainty in input quantities and then propagates that uncertainty into outputs using Monte Carlo simulations. Generation and collection quantities are modeled separately and then combined for the following owner types: residential and business/public. This is done because these owner types have different consumption, use, and end of use disposition habits.

The basic approach for quantifying generation and collection includes the following steps:

1. Determine the sales of a product in a region over a time period.
2. Determine the typical distribution of lifespans for the product over a time period using two methods: literature-based and survey-based.
3. Calculate how many products are predicted to be generated in a given year using the sales and lifespan information.
4. Calculate how many of the generated products are predicted to be collected in a given year by applying collection rates.
5. Calculate the weight of generated and collected products by multiplying unit weights by the quantities. Distribution of unit weights of products are found from empirical collection data for a given year. The application of the unit weight distribution to years other than when the empirical data was collected introduces some uncertainty due to changes in product size and weight over time.

1.3.2 Export

The overall approach is to utilize detailed, disaggregated trade data to distinguish the quantity of used electronics exports. The steps are illustrated below and ,the algorithm and numerical example are shown in section 5.21 in Appendix.

1. Collect and prepare disaggregated, detailed export trade data.

Figure 2: Illustration of export quantity and unit value of disaggregated trade data for a given world region

2. Estimate used-new threshold unit value thresholds for different world regions by using Neighborhood Valley-Emphasis method (NVEM, see section 5.2.1 in appendix), see Figure 3. NVEM finds the optimal threshold which simultaneously maximizes the variance between the modes (here, used and new) and minimizes the probability of the unit value bin at and around the optimal threshold. An example of the threshold range found by NVEM in China Export NVEM is shown

in Figure 4, with approximate distributions superimposed on the histogram. Export Pub. Method takes advantage of published reference values for used goods, and applies the same threshold to all world regions.

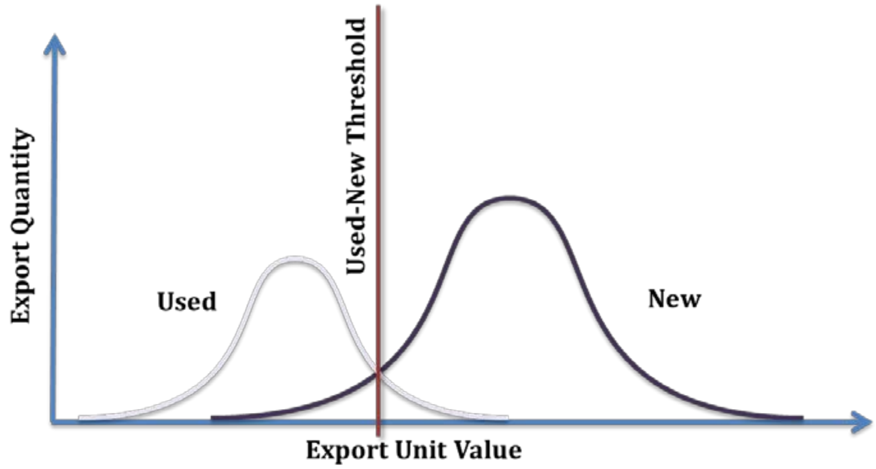


Figure 3: Illustration of export quantity and unit value of disaggregated trade data with Used-New threshold differentiating underlying Used and New distributions for a given world region

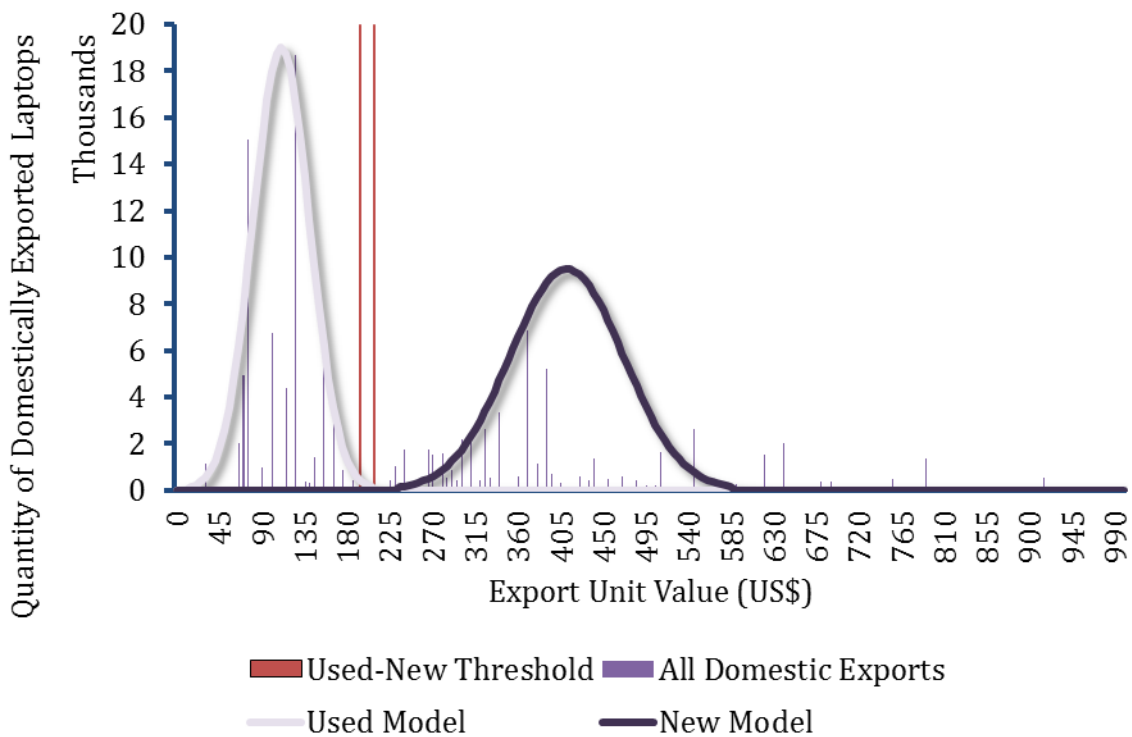


Figure 4: Example of US Export NVEM histogram with threshold range. 2010 export of laptops from US to Upper Middle Income countries in Latin America and the Caribbean. Used and New estimated model superimposed.

3. Sum the quantity of goods domestically exported from the US to partner countries with a unit value below the used-new threshold.

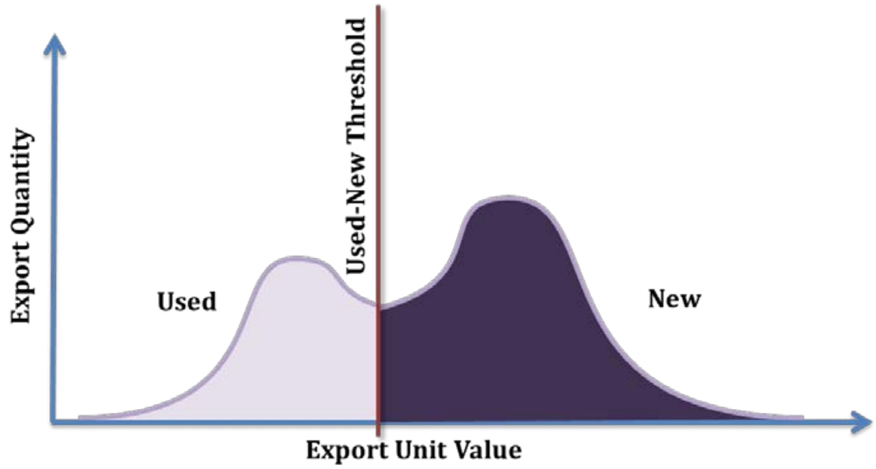


Figure 5: Illustration of sum of Used and New export quantities from disaggregated trade data with Used-New threshold differentiating underlying Used and New distributions for a given world region

4. Optional: Estimate the re-export potential of domestic exports by investigating the top trade partner's re-export activity.

2 Results

2.1 Generation and Collection Results

2.1.1 TVs

2.1.1.1 Generation

Figure 6 shows sales of new products put on the market in comparison with this study's estimation of historical generation, found with a 10,000 trial Monte Carlo simulation in Microsoft Excel using Oracle Crystal Ball. The uncertainty in the generated quantity estimates is caused by the variation in sales quantities (+/-10%) and uncertainty in the lifespan and generation paths. The error bars for the generation estimates in this study represent a 90% confidence interval. While the sales of CRT TVs have declined rapidly since 2002, the generation is still at a high volume during the past few years. That is because the generation is always a lag of the sales data due to the long use lifetime and storage. For example, the generation of used TVs in the year 2010 is mostly from sales in the year around 2000. However, generation started to decrease after 2008. With the widespread substitution of CRT TVs with Flat Panel TVs in the US, the generation of Flat Panel TVs will continue to grow in the near term.

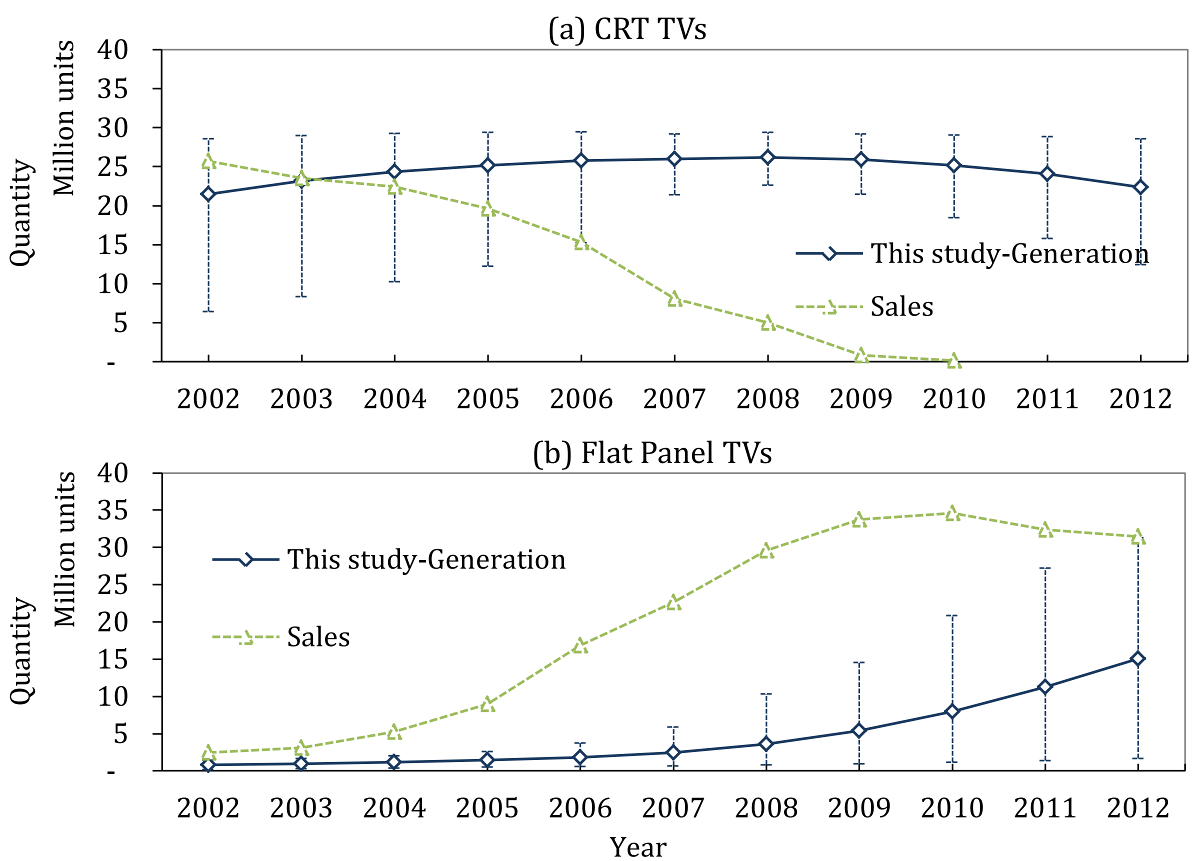
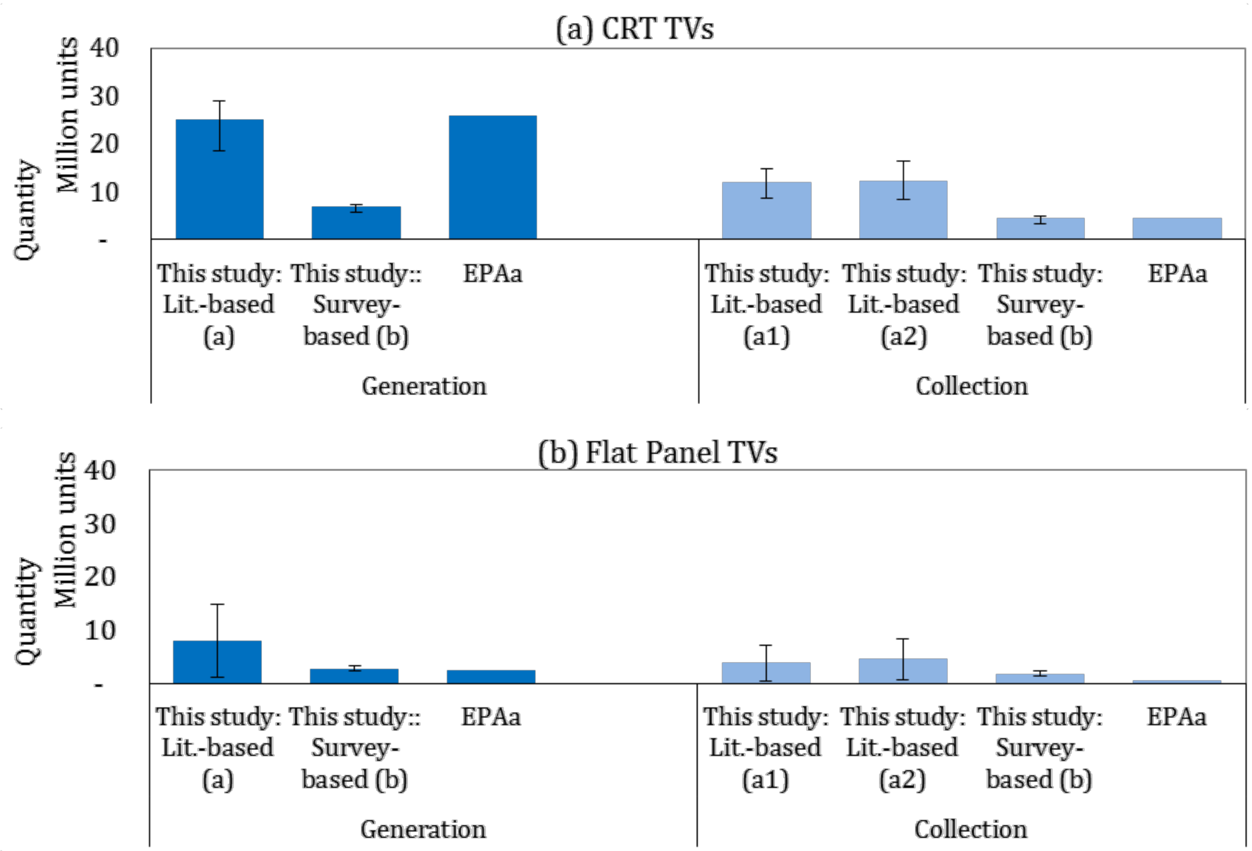


Figure 6 : Sales of New TVs and Comparison of Generation Estimates of Used TVs

2.1.1.2 Collection and Comparison

Figure 7 shows this study's estimate of generation and collection in comparison with EPA estimates (EPAa, 2008 report[8]). Two methods have been used to estimate the collection of TVs in this study, Literature-based A, Literature-based B, and Survey-based (see Appendix 6.1.1 for details). While the residential and business/public sectors were separately surveyed in their survey, the generation and collection amounts from the business/public sector were only 5% and 7% of the residential, respectively. The collection rates calculated in this study using three methods are all around 55% in year 2010, which is much higher than the EPA estimate, which was around 17% [I]. As a reminder, the collection rate used in this study is modeled based on surveys from the year 2010. However, the collection rate from EPA estimate is projected based on data from state and local electronics collection programs that was collected in 2004.



Note: EPAa, 2008 [8] was cited because EPAb 2011 report did not differentiate the type of TVs. The error bars in this study represent 90% confidence interval.

Figure 7: Generation and Collection of Used TVs in 2010 and Comparison with Other Estimates

[I] US EPA, Electronics waste management in the United States (approach 1). US. Environmental Protection Agency (US EPA). Washington, DC, US, 2008: "Collection rate in EPA report is projected based on existing state and local electronics collection program which have been done in 2004."

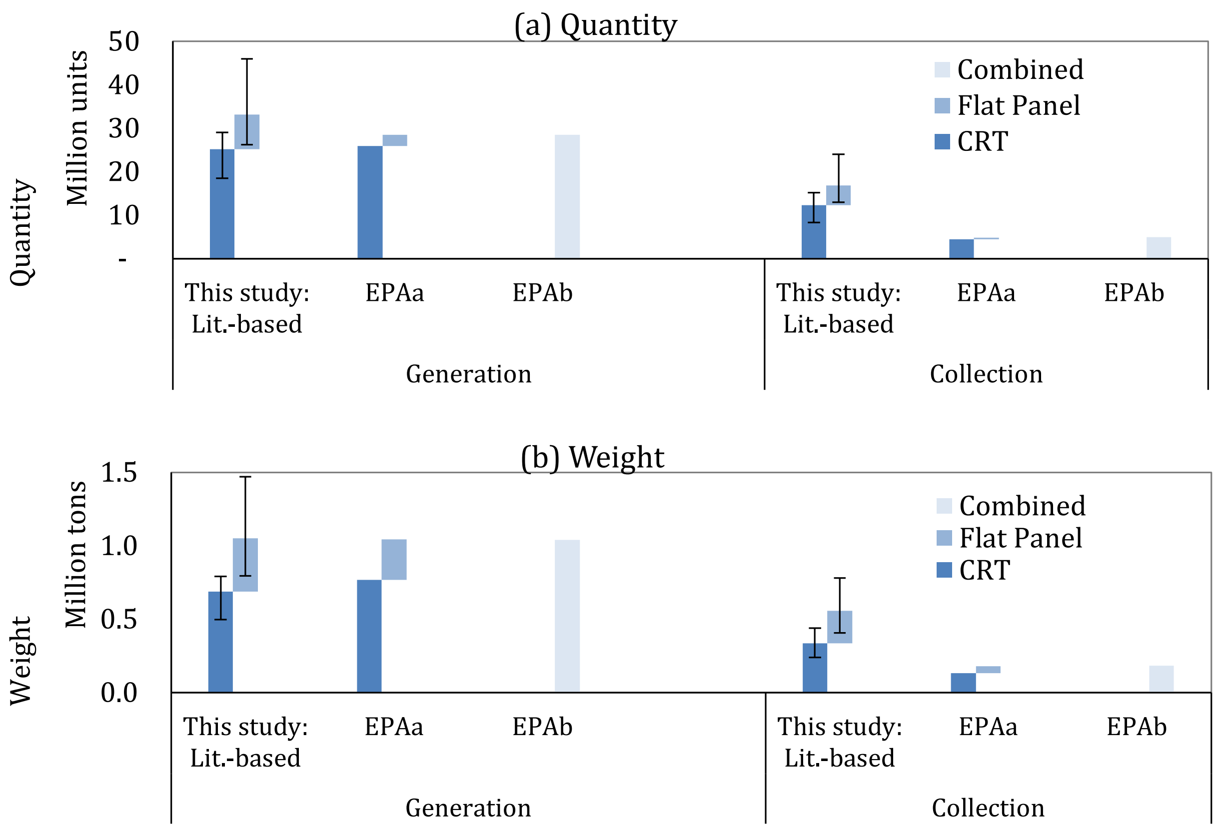
Table 2 presents the estimates of the quantity of TVs generated and collected in the year 2010. The collection rate used to estimate the collection uses survey-based (a) methods.

Table 2: Generation and Collection of Used TVs in 2010 (Thousand units)

Generation/ Collection	Type of TV	Mean		Low	High
		Qty	%		
Generation	CRT TVs	25,141		18,488	29,069
	Flat Panel TVs	7,999		1,146	20,827
	Total	33,141		23,493	46,614
Collection	CRT TVs	12,317	49%	8,772	14,745
	Flat Panel TVs	4,414	55%	528	9,843
	Total	16,879	51%	10,813	22,281

Note: Literature –based method, and the low and high in this study represent 90% confidence interval.

Figure 8 presents comparisons of these results both in quantity and weight with EPA estimations (both 2008 and 2011 reports, the latter is an updated version of 2008). While the estimate of generation of CRT TVs is comparable to EPA results, the estimate of generation of Flat Panel TVs is larger than the EPA results. The difference is because a shorter product lifespan is assumed in this study than in the EPA report. EPA estimates differentiate between CRT and Flat Panel TVs, but use static accounting for shifting trends in lifespans. Furthermore, their "Total life" figures refer to lifespan stages until generation. In this study, lifespan stage assumptions have been disaggregated by TV type, owner type, and distinguish between first use, reuse, and storage based the extensive literature data and survey data by Kahhat and Williams in 2008 (see section 5.1.2 in Appendix). We have done similar assumptions and parameters modeling for other electronics in this study.



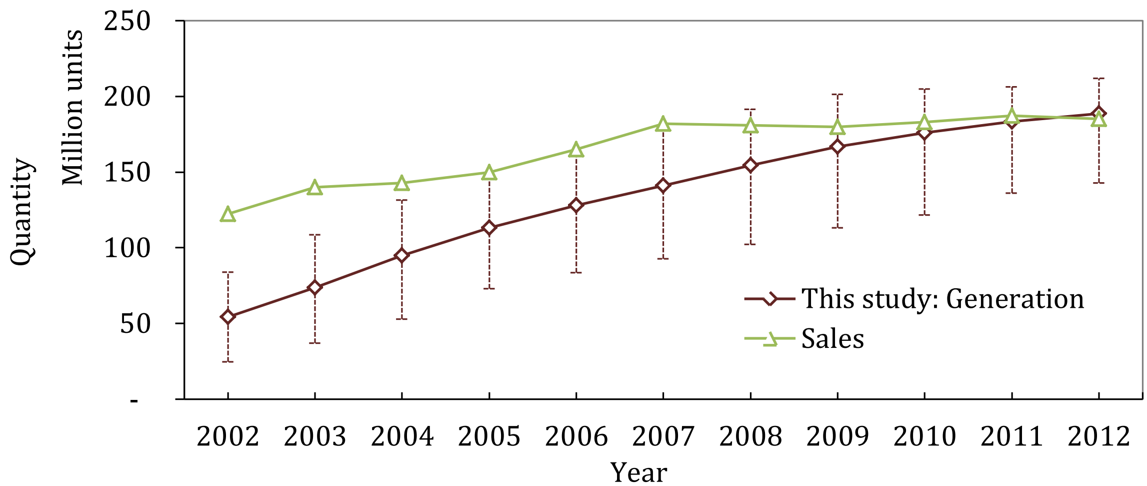
Note: EPAa, 2008 [8]; EPAb, 2011[9]. The error bars in this study represent 90% confidence interval.

Figure 8: Quantity and Weight estimates of Generation and Collection of Used TVs in 2010 a Comparison with EPA Estimates:

2.1.2 Mobile Phones

2.1.2.1 Generation

Figure 9 shows sales of new mobile phone (including feature phones and smartphones) put on the market in comparison with this study's estimate of the historic generation. The result shows that the generation is continually increasing and there were 177 million (coefficient of variation =14%) used mobile phones generated in 2010. Because the life span (3-5 years) of mobile phones is shorter than other electronics, the generation follows the trend of the historical sales data with a shorter time lag. Only the literature-based method is applied to the mobile phone because there is no survey data available.

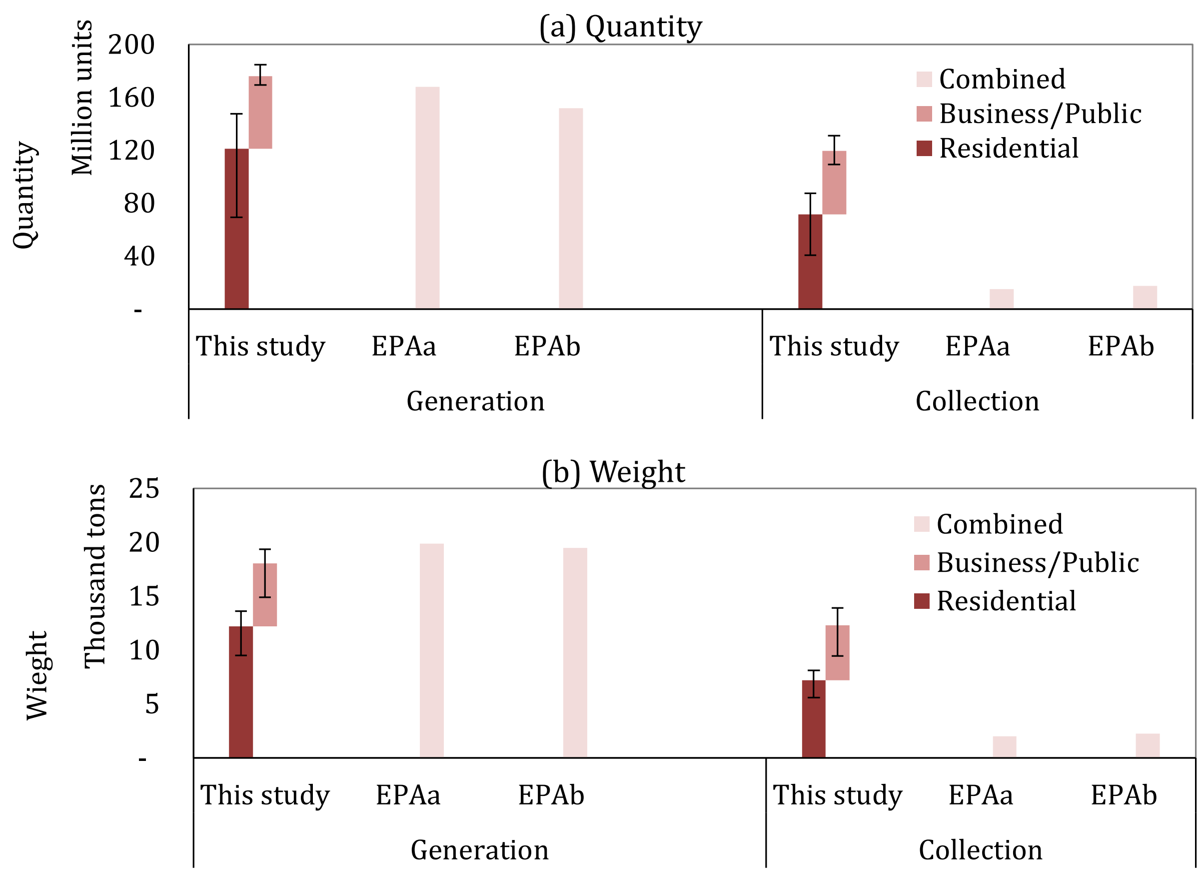


Note: The error bars for the generation estimates in this study represent 90% confidence interval; Uncertainty was assumed for the sales data when modeling (COV=10%).

Figure 9 : Sales of New Mobile Phone and Comparison of Generation Estimates of Used Mobile Phone

2.1.2.2 Collection and Comparison

Figure 10 presents this study's estimate of generation and collection in comparison with EPA estimates (both 2008[8] and 2011[9]); only this study differentiates the owner type of mobile phones. The residential sector dominates the generated and collected mobile phones, which accounts for around 70% of the total. Due to the fact that the collection rate used in this study is 60% (average) in year 2010, the collection volume of used mobile phone is greater than that in the EPA report[8].



Note: The error bars in this study represent 90% confidence interval.

Figure 10 : Generation and Collection of Used Mobile Phone and Comparison with EPA Estimates in 2010

Table 3 presents estimates of the quantity of mobile phones generated and collected in the year 2010. The low and high in this study represent 90% confidence interval.

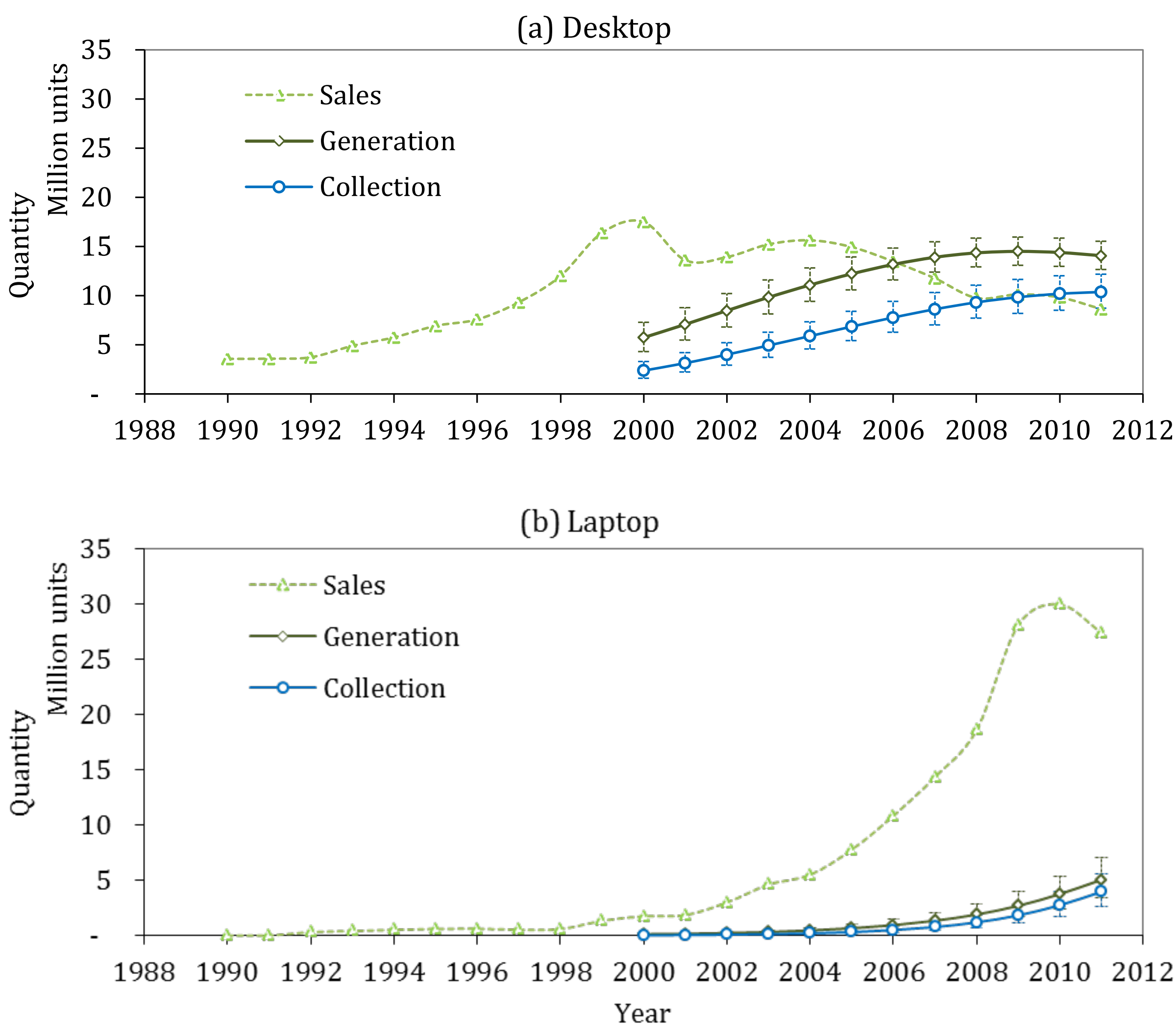
Table 3: Generation and Collection of Used Mobile Phones in 2010 (Thousand units)

Sectors	Generation			Collection			
	Mean	Low	High	Mean		Low	High
				Qty	%		
Business/ Public	54,883	48,069	63,765	48,016	87%	37,797	59,537
Residential	121,174	69,470	147,793	71,468	59%	40,742	87,610
Total	176,057	121,782	204,853	119,484	68%	87,451	140,180

2.1.3 Computers

2.1.3.1 Generation

Figure 11 shows sales of new products put on the market in comparison with this study's estimate of historical generation and collection. Collection estimates were based on survey data. Although the sales of desktops have declined since 2000, generation has been kept at a high volume during the past few years because of the lag caused by long use lifetime (or reuse) and storage. However, there is some evidence that generation has started to decline after 2011. By contrast, generation of laptop has been increasing rapidly due to their popularity. Only the literature-based method is applied to the computers and monitor because the survey data is insufficient.

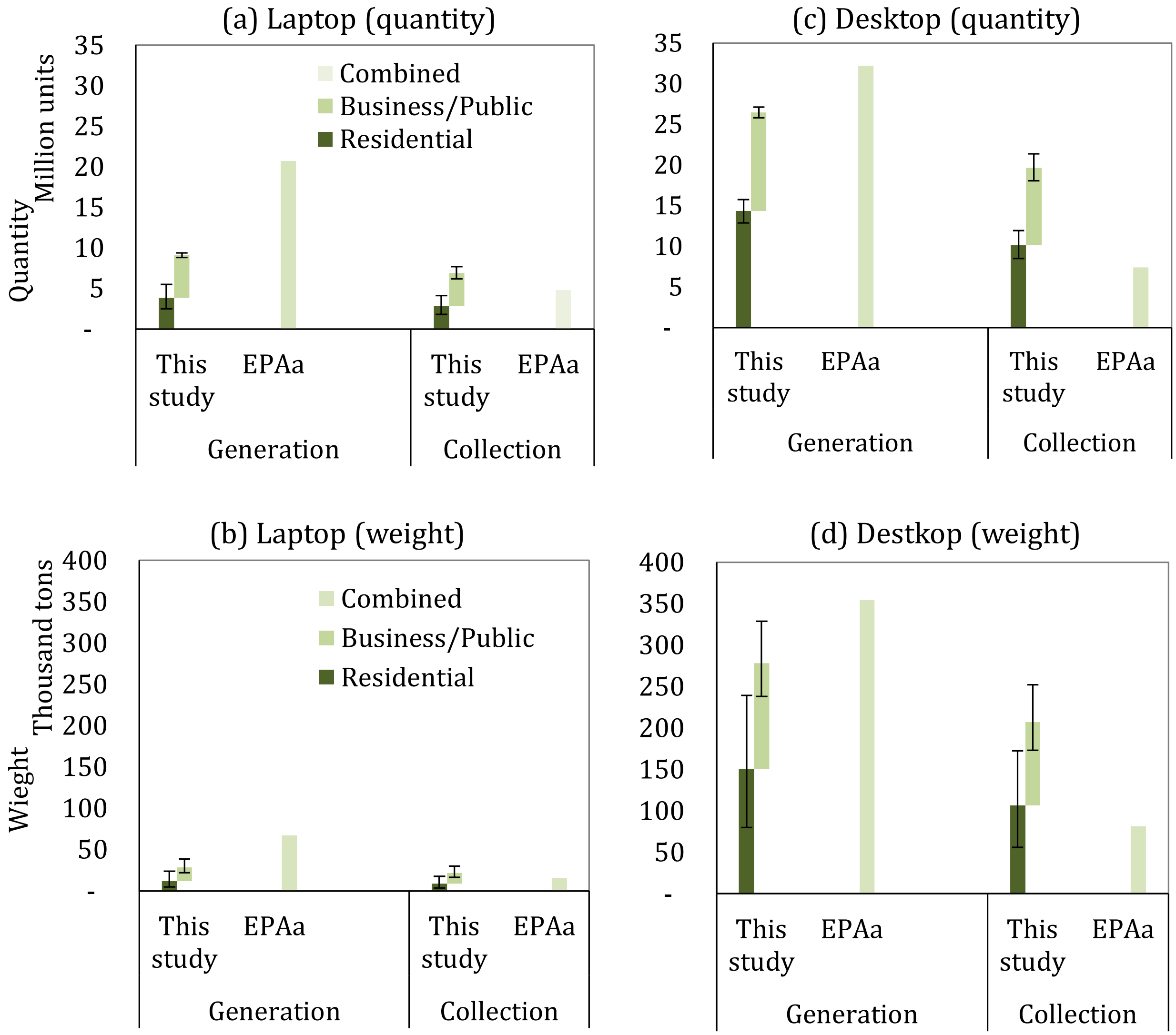


Note: The error bars in this study represent 90% confidence interval.

Figure 11 : Residential Sales, Generation, and Collection Estimates of Used Computers.

2.1.3.2 Collection and Comparison

Figure 12 shows this study's estimate of generation and collection in comparison with EPA estimates (EPAa, 2008[8]). Note that uncertainty in the collected quantity estimates may actually be a lower bound due to uncertainty in the collection rates.



Note: The error bars in this study represent 90% confidence interval.

Figure 12 : Generation and Collection of Used Computers and Comparison with EPA Estimates in 2010

While the generation estimate of desktops in the year 2010 is comparable, the generation of laptops in this study is almost half the EPA estimate. The sales data should be similar due to the use of a similar source. However, the difference is caused by the life span assumptions (see the explanation in section 2.1.1.2). Since the collection rate used in this study is above 70% in year 2010, the collection volume of used computers is greater than that in the EPA report[8], which assumed a 23% collection rate.

Table 4 presents the quantities of computers generated and collected in year 2010 both by type and sector.

Table 4: Generation and Collection of Used Computers in 2010 (Thousand units)

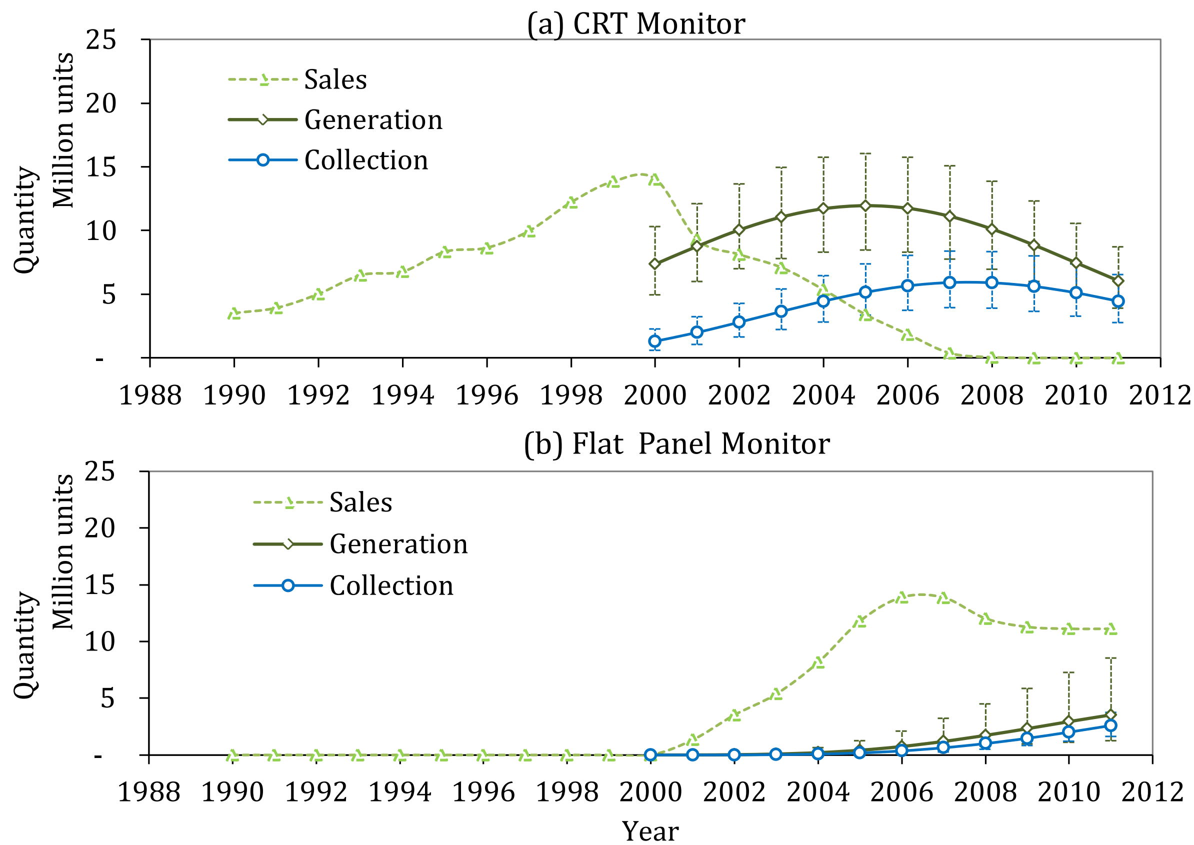
Sectors and Types		Generation			Collection			
		Mean	Low	High	Mean Qty	%	Low	High
Desktop	Business/ Public	8,219	7,501	8,938	6,473	79%	4,698	8,404
	Residential	14,385	12,823	16,049	10,181	71%	8,322	12,249
	Total	22,604	20,773	24,481	16,654	74%	13,821	19,584
Laptop	Business/ Public	3,570	3,258	3,883	2,790	78%	2,005	3,645
	Residential	3,728	2,203	5,627	2,727	73%	1,575	4,243
	Total	7,298	5,731	9,233	5,517	76%	4,013	7,252
Total Computers	Business/ Public	11,789	10,759	12,821	9,263	79%	6,703	12,049
	Residential	18,113	15,673	20,843	12,908	71%	10,346	15,817
	Total	29,902	27,145	32,878	22,171	74%	18,237	26,301

Note: The low and high in this study represent 90 % confidence interval.

2.1.4 Monitors

2.1.4.1 Generation

Figure 13 shows sales of new products put on the market in comparison with this study's estimate of historical generation and collection.



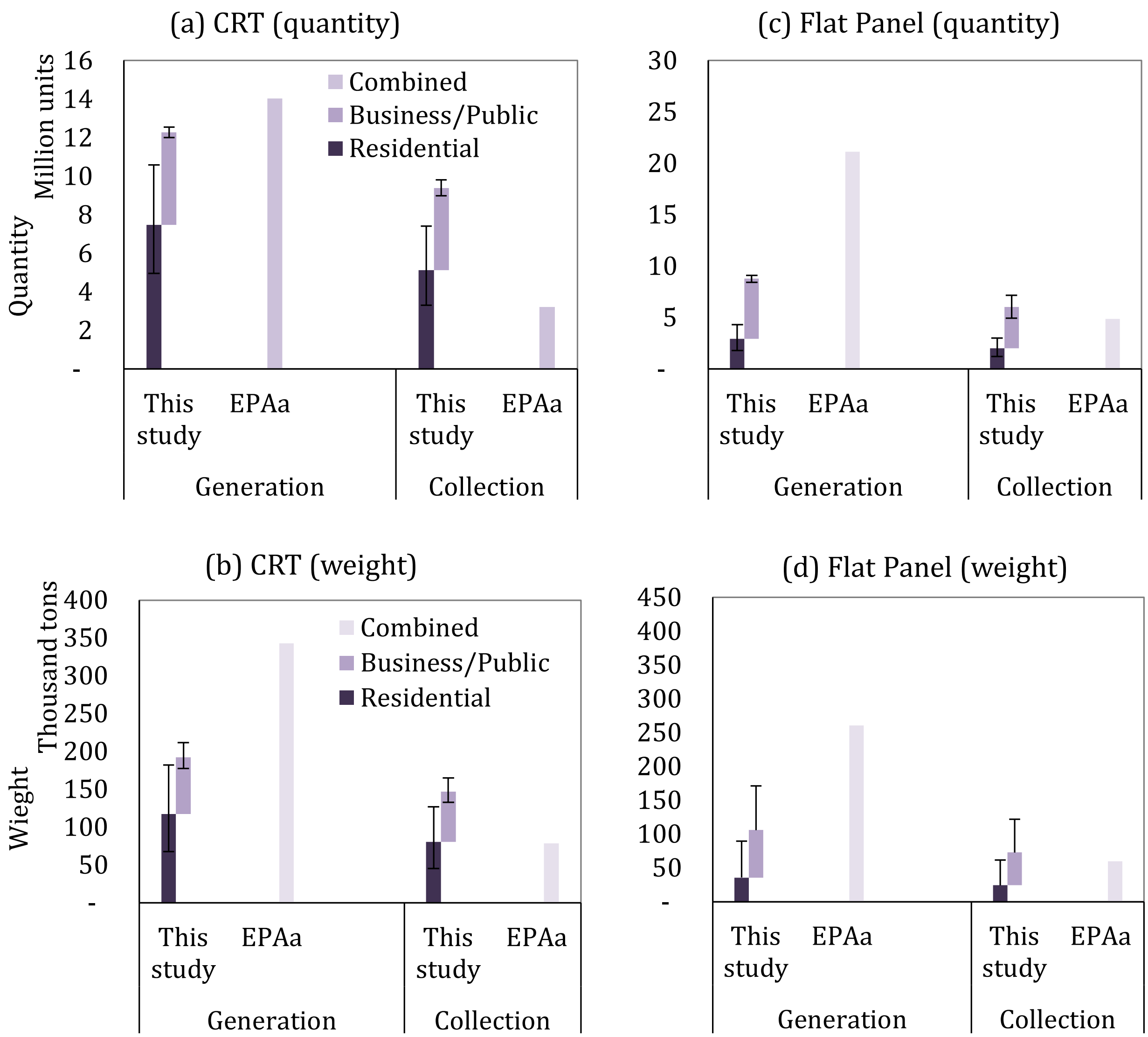
Note: The error bars in this study represent 90% confidence interval.

Figure 13 : Residential Sales, Generation, and Collection of Estimates of the Used Monitors

The inflection point of the sales curve for CRT monitors started around 2000. Accordingly, generation kept increasing before 2010 and then decreasing after that, like the same trend as sales data. Before 2007, there was fast sales growth of Flat Panel monitors because of their increasing popularity. Given the average life span is around 10 years, the generation of Flat Panel monitors has been rapidly increasing in recent years.

2.1.4.2 Collection and Comparison

Figure 14 shows this study's estimate of generation and collection quantities in comparison with EPA estimates (EPAa, 2008[8]) in the year 2010. Note that uncertainty in the collected quantity estimates may actually be a lower bound due to uncertainty in the collection rates.



Note: The error bars in this study represent 90% confidence interval.

Figure 14 : Generation and Collection of Used Monitors and Comparison with EPA Estimates in 2010

While the quantity estimate of generation of CRT monitors in this study is comparable to the EPA estimate, the weight is smaller than the EPA estimate. This is because the assumption of unit weight data is different. The unit weight data for computers and monitors in this study are based on surveys (sampling data in 2010) of used electronics by Oregon and Washington[I], with the survey samples of 3286 and 4191 for crossing brands of monitors by Oregon and Washington, 1774 and 2655 for desktop, 352 and 270 for laptop, respectively. By contrast, the EPA used data from the Florida

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[I] NCER Brand Data Management System, sampling share from computer and monitors (weight)- Oregon and Washington Sampling Data: http://www.electronicsrecycling.org/BDMS/AlphaList.aspx?sort=All

Department of Environmental Protection (DEP) to develop weight estimates for desktop CPUs, hard-copy devices, PC Flat Panels, and CRT TVs prior to 2008.

However, the generation estimate of Flat Panel monitors in this study is almost half of the EPA estimate. Again, the sales data should be similar due to the use of a similar source. The difference is caused by the life span assumptions.

Due to the fact that the collection rate used in this study is above 70% (average) in the year 2010, the collection volume of used computers is greater than that in the EPA report[8], which assumed a 23% collection rate. Table 5 presents the quantity of monitors generated and collected in year 2010 both by type and by sector. More CRT monitors are generated and collected than Flat Panel monitors.

Table 5: Generation and Collection of Used Monitors in 2010 (Thousand unit)

Sectors and Types		Generation			Collection			
		Mean	Low	High	Mean Qty	Mean %	Low	High
CRT	Business/ Public	3,264	2,979	3,550	2,896	89%	2,454	3,369
	Residential	7,485	4,631	11,188	5,122	68%	3,081	7,864
	Total	10,750	7,872	14,446	8,018	75%	5,897	10,782
Flat Panel	Business/ Public	3,968	3,622	4,316	2,730	69%	1,554	4,009
	Residential	2,953	1,690	4,596	2,020	68%	1,115	3,224
	Total	6,921	5,571	8,602	4,750	69%	3,101	6,536
Total	Business/ Public	7,232	6,601	7,865	5,626	78%	4,035	7,359
	Residential	10,439	7,007	14,615	7,142	68%	4,629	10,397
	Total	17,671	14,171	21,910	12,768	72%	9,523	16,421

Note: The low and high in this study represent 90% confidence interval.

2.2 Export Results

2.2.1 TVs

Figure 15 shows the export flow of CRT TVs and Flat Panel TVs in terms of transportation mode, destination region, and income groups classification of the destination region. The export quantity of the CRT TVs via land is greater than via air and vessel, which were shipped to neighboring regions, such as North America (NA) and Latin America and Caribbean (LAC). Exports of CRT TVs are much greater than Flat Panel TVs. For CRT TVs, the fraction of exports to NA is the highest (44%), followed by LAC with a fraction of 39% and Asia by 10%. If grouped by the income, the major destinations are to upper middle income countries (72%).

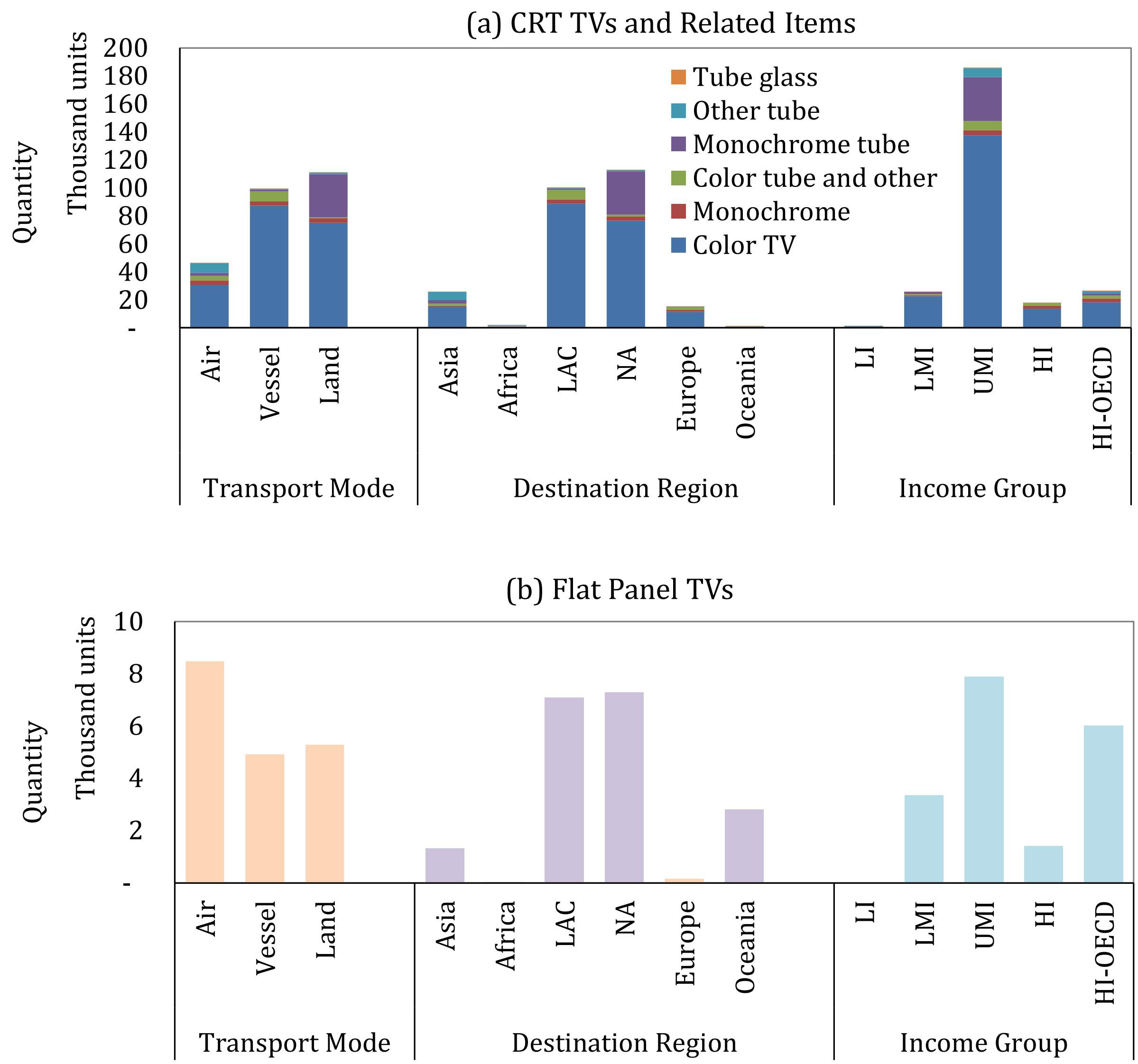
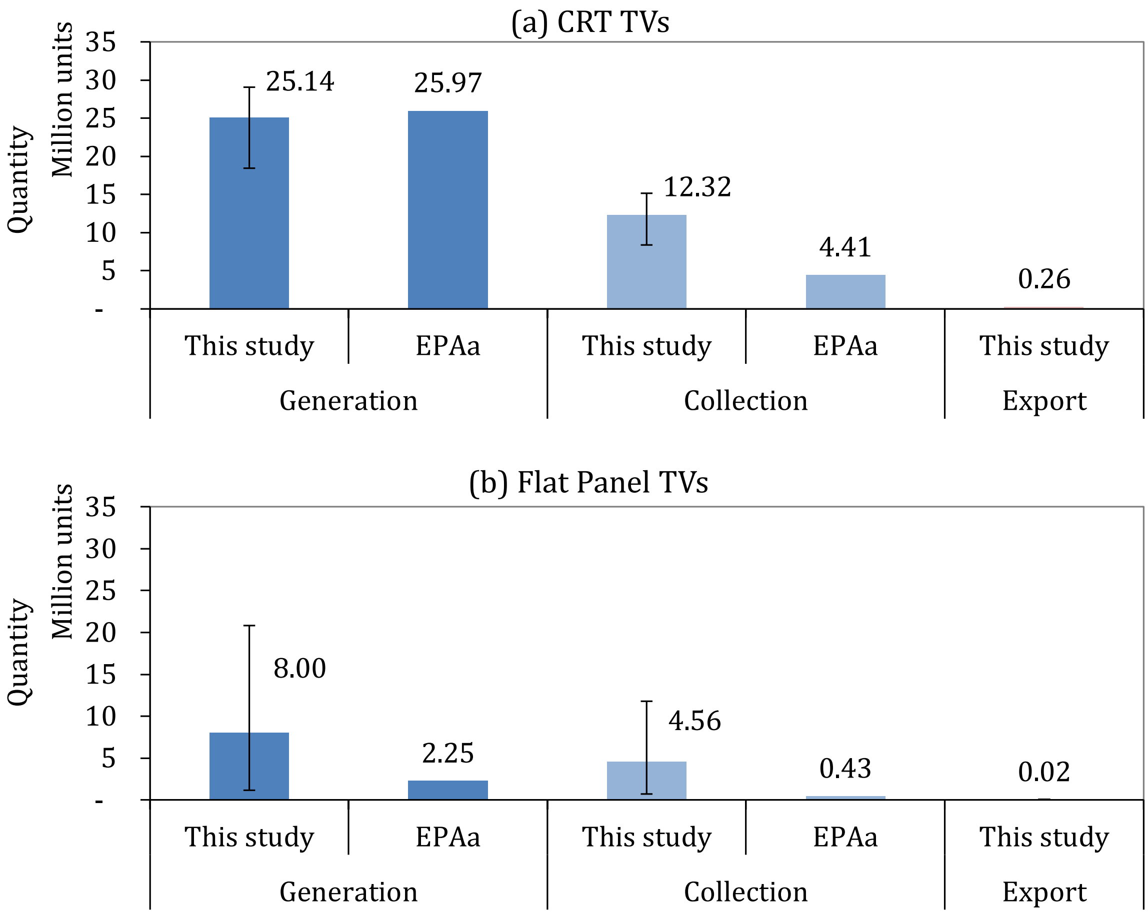


Figure 15: Export Flows of Used TVs in 2010: by Transport Mode, Destination Region, and Income Group Classification of the Destination Region.

Figure 16 compares the estimates and associated uncertainty for generated, collected, and exported used TVs. Considering the uncertainty in these estimates, the fractions of used CRT TVs and Flat Panel TVs collected for processing that are subsequently exported are 2.4% and 0.2% on average respectively. As a reminder, the export quantities presented here only represent the trade of whole units. Of course, disassembled parts and materials may also be exported using different trade codes (e.g., circuit boards or plastics), or used whole units may be misclassified and shipped using other trade codes. These would not be included in the figures reported here.

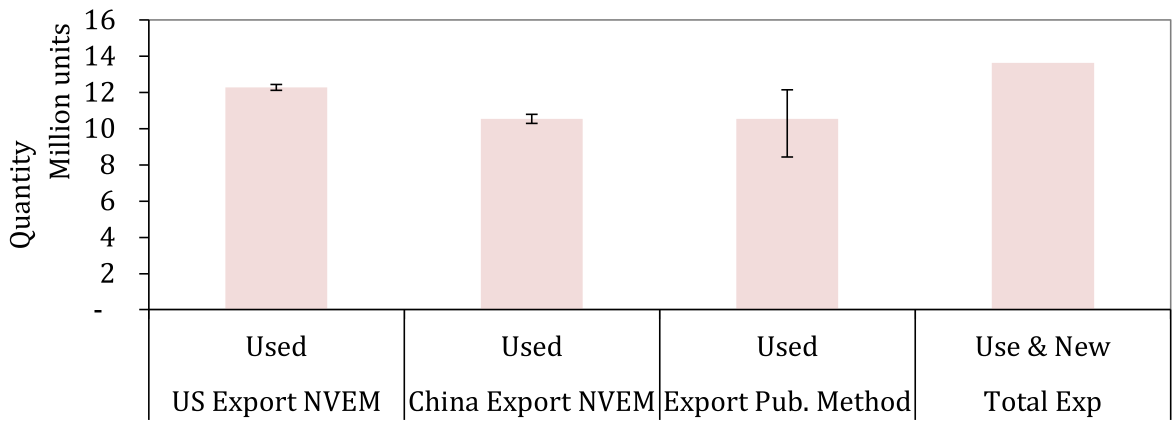


Note: As a reminder, in light of the assumption that there is no CRT TVs manufacturing industry in the US, domestic export of CRT TVs, Tubes and Tubes glass were all assumed as the used. Export result for Flat Panel TVs is based on Threshold China Export NVEM because the US Export NVEM is not applicable due to the insufficient data. The error bars for generation and collection represent 90% confidence interval, and represent the minimum and maximum for export.

Figure 16: Flows of Used TVs in the US in 2010

2.2.2 Mobile Phones

Three used-new thresholds have been applied to mobile phones to distinguish used mobile phones from new based on US domestic trade data. The three thresholds are described in the Appendix 6.2.1. As a reminder, the thresholds are calculated using US domestic export data in US Export NVEM, Chinese export data in China Export NVEM as a comparison [I], and sales value estimates in Export Pub. Method. Figure 17 presents the mobile phone exports calculated using the three threshold methods. There is a high export rate of used mobile phones, which account for around 90% of the total exports (used and new) based on threshold US Export NVEM. The quantity of used mobile phones identified by Export Pub. Method is shown with significant uncertainty, which is due to the broad range of the threshold values.



Note: The error bars represent the minimum and maximum.

Figure 17: Export of Used Mobile Phones from the US in 2010 Using the Three Threshold Methods

Figure 18 depicts the quantities of exported mobile phones broken down by transport mode, destination region, and income group classification of the destination region. With regards to the destination regions, the fraction of exports to LAC are the highest, 71% on average, followed by Asia with a average of 21%. There is a small export fraction to Africa, less than 1%. This finding is comparable to those in the report by the Electronics TakeBack Coalition [II]: "Although there is some market for used cell phones in the US (such as domestic abuse programs), the principal markets for used and refurbished cell phones are in Latin America and South America". In addition, while the mobile

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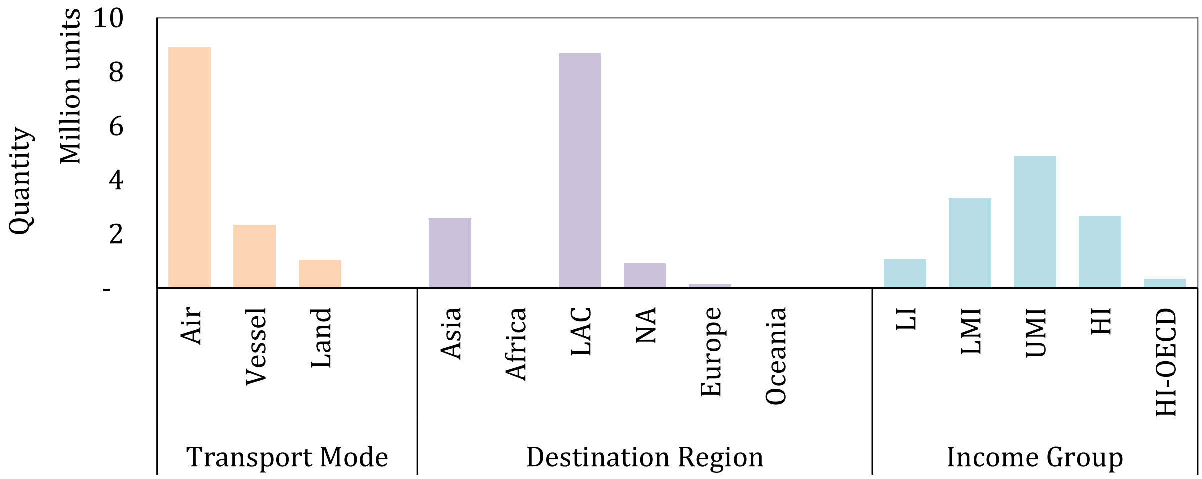
[I] The key assumptions for this method are: the majority of exported electronic goods are new, since China manufactures the majority of the world's electronics, including computers and mobile phones; goods exported directly to destination nations have the same unit value distribution as those exported through transit hubs such as Hong Kong SAR; threshold values for countries in the same world region with the same economic classification are the same; and the threshold value of electronics originating/manufactured in China is similar to that of goods originating from other countries (i.e. U.S.).

[II] Electronics TakeBack Coalition. Electronic Waste (E-waste) Recycling Facts (2008). http://www.electronicstakeback.com/resources/facts-and-figures/

communication standard used by a country is a significant remarketing constraint, Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) prevail in the Americas. Nevertheless, all interviewed industry experts say that demand for secondary handsets outstrips supply for all major standards [I]. As for the income groups classifications, the major destinations are upper middle income (40%), low middle income (27%) and high income (22%). Finally, in the mode of transport, the fractions of air exports are 73%, 19% for vessel exports and 8% for land exports. The large fraction of air transport reaffirms the decision not to use the Bill of Lading data approach to represent all exports because it excludes air export data, and therefore a significant portion of exports.

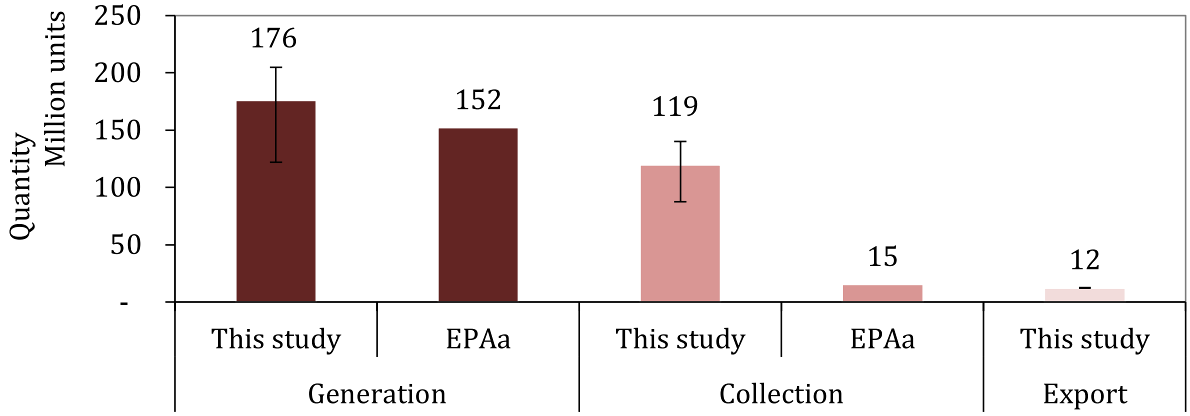


Note: Average results are based on threshold US Export NVEM. NA = North America; LAC = Latin America & Carribean; HI = High Income. UMI = Upper Middle Income; LMI = Low Middle Income; LI = Low Income.

Figure 18: Export of Used Mobile Phone in 2010: by Regions and Income Group and Mode of Transport

Figure 19 compares the estimates and associated uncertainty for generated, collected and exported used mobile phones. Considering the uncertainty in these estimates, the fraction of used mobile phones collected for processing that are subsequently exported is around 10% on average.

[I] Roland Geyer & Vered Doctori Blass (2010). The economics of cell phone reuse and recycling. Int. J. Adv. Manuf. Technol. 47:515–525

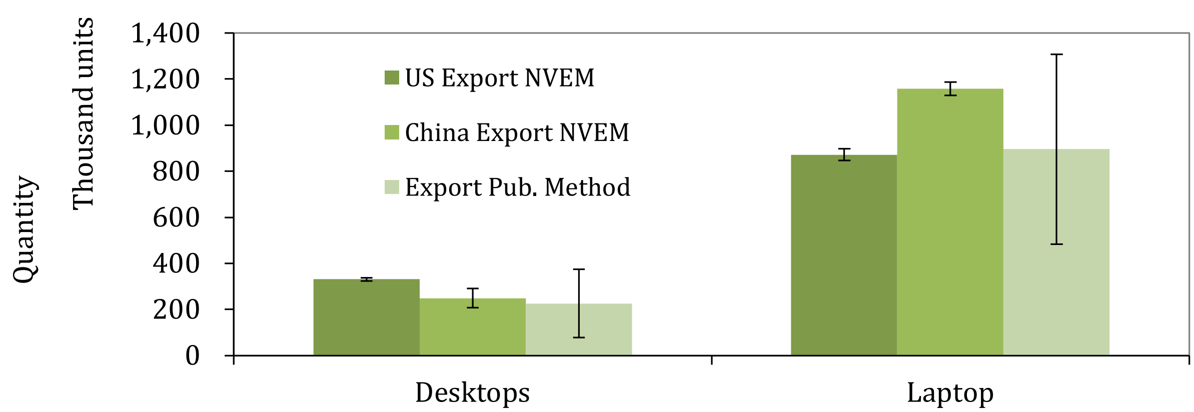


Note: Export results are based on threshold US Export NVEM. The error bars for generation and collection estimates represent 90% confidence interval, and represent the minimum and maximum for export.

Figure 19: Flows of Used Mobile Phones in the US in 2010.

2.2.3 Computers

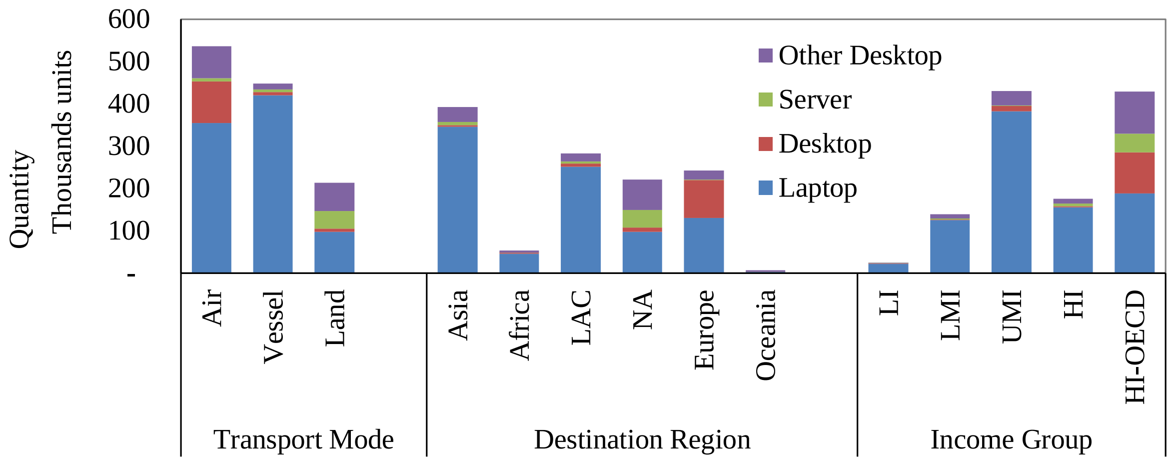
The three used-new thresholds methods have also been applied to computers (which are divided into two types: laptops and desktops (including servers and other process unit)) to determine quantities of used computers exported, and the results for this analysis are presented in Figure 20. Laptops have significantly higher export quantities than the desktops, which is partly because laptops have higher value for further reuse or recycling and can be easily shipped due to the weight and volume advantage as compared to desktops. The uncertainty in the quantity estimates using Export Pub. Method is higher than the other two methods due to the broad range of prices found for used products.



Note: The error bars represent the minimum and maximum.

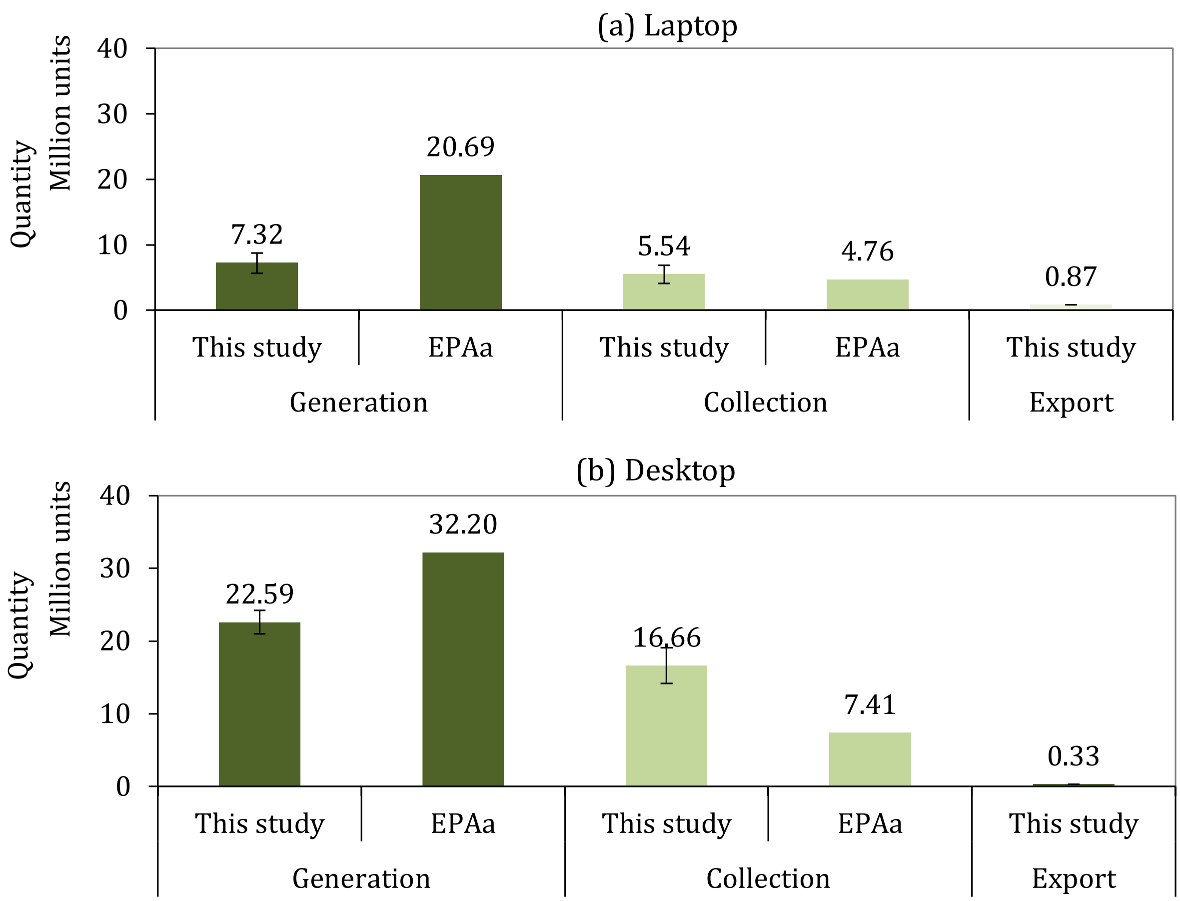
Figure 20: Export of Used Computers from the US in 2010 Using the Three Threshold Methods

Figure 21 shows the export flows of computer products divided by transportation mode, destination regions, and income group classification of the destination regions. Air transport was the most common mode, and the most common destinations were Europe (32% of all used computer exports), Asia (31%), and North America (21%). When dividing by income groups classifications, both the upper middle incomes and high OECD were the major destinations, accounting for 75% of the total.



Note: Average results are based on threshold US Export NVEM. NA = North America; LAC = Latin America & Carribean; HI = High Income. UMI = Upper Middle Income; LMI = Low Middle Income; LI = Low Income.

Figure 21: Export of Used Computers in 2010: by Regions, Income Groups and Mode of Transport

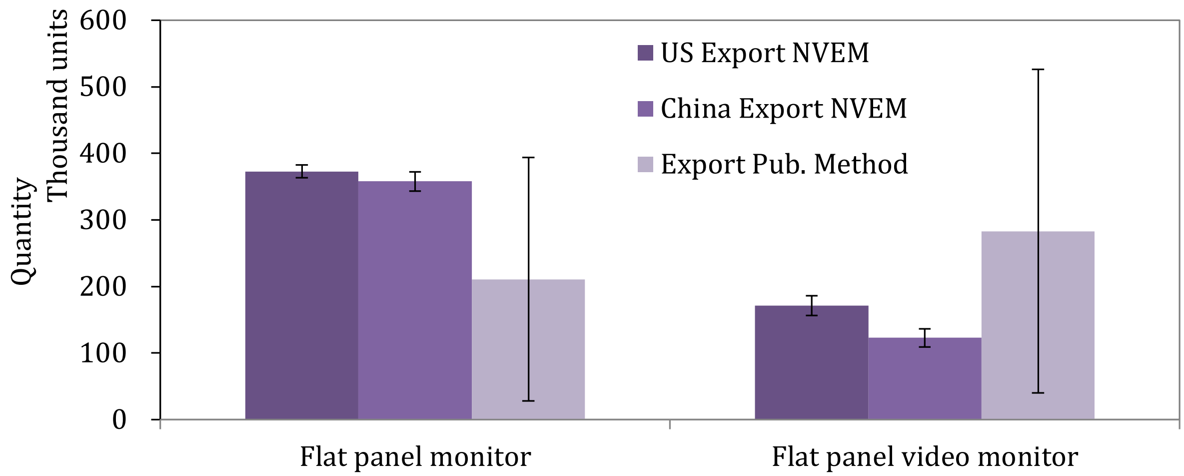


Note: The export number is based on threshold US Export NVEM, and the desktop chart includes the desktop, server, and other desktop categories. The error bars for generation and collection represent 90% confidence interval, and represent the minimum and maximum for export.

Figure 22: Flows of Used Computers in the US in 2010

2.2.4 Monitors

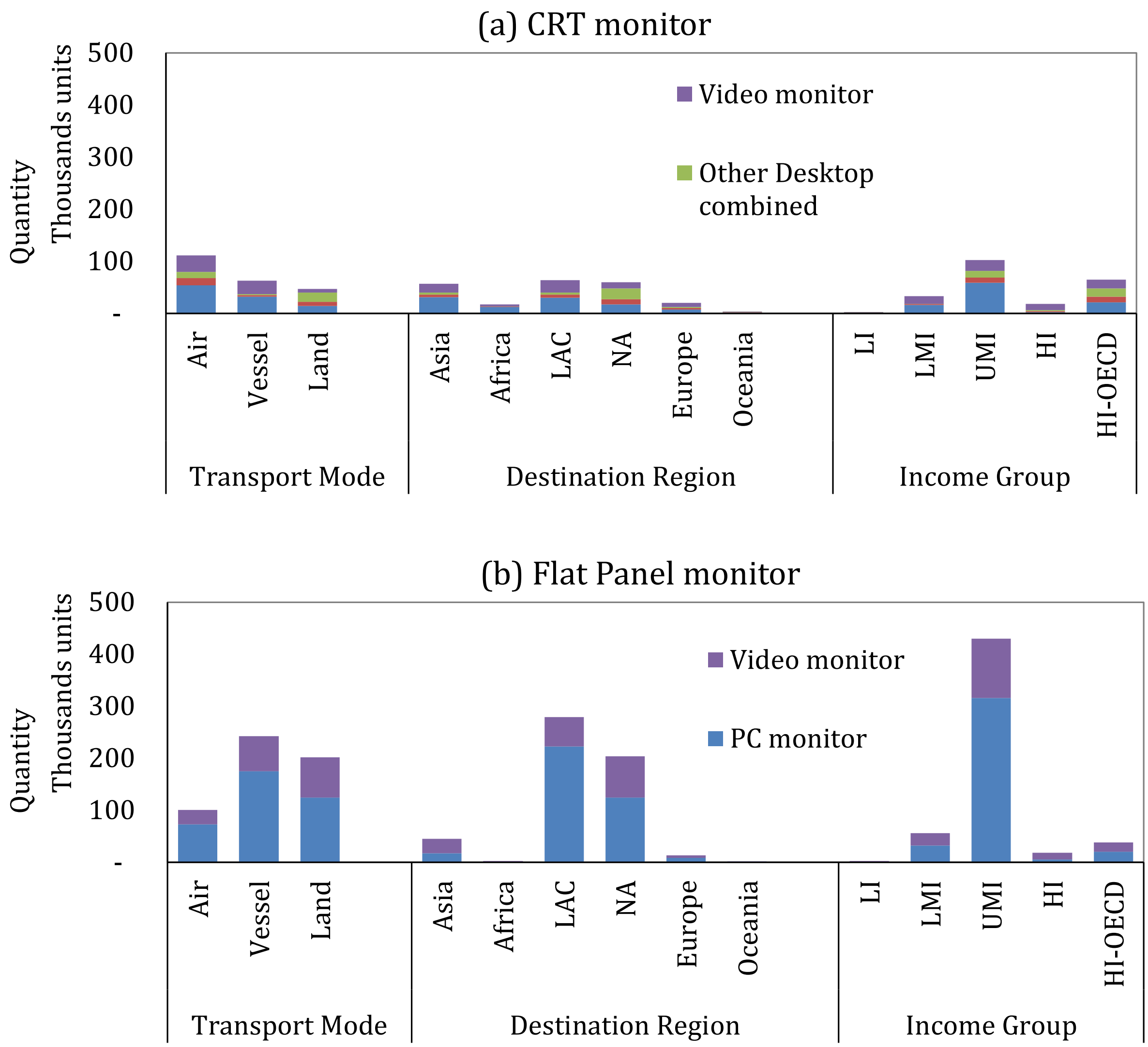
For CRT monitors, all exports listed in the trade data are as assumed to be used because these products are no longer manufactured in the US and the value of the products in the trade data are too low to be new products. Thus, the three used-new thresholds have only been applied to Flat Panel monitors. Figure 23 presents the results of the analysis of exports using the three threshold methods. The quantity of used Flat Panel monitors identified by Export Pub. Method has significant uncertainty because of the broad range of the used Flat Panel prices.



Note: The error bars represent the minimum and maximum.

Figure 23: Export of Used Flat Panel Monitors from the US in 2010 Using the Three Threshold Methods

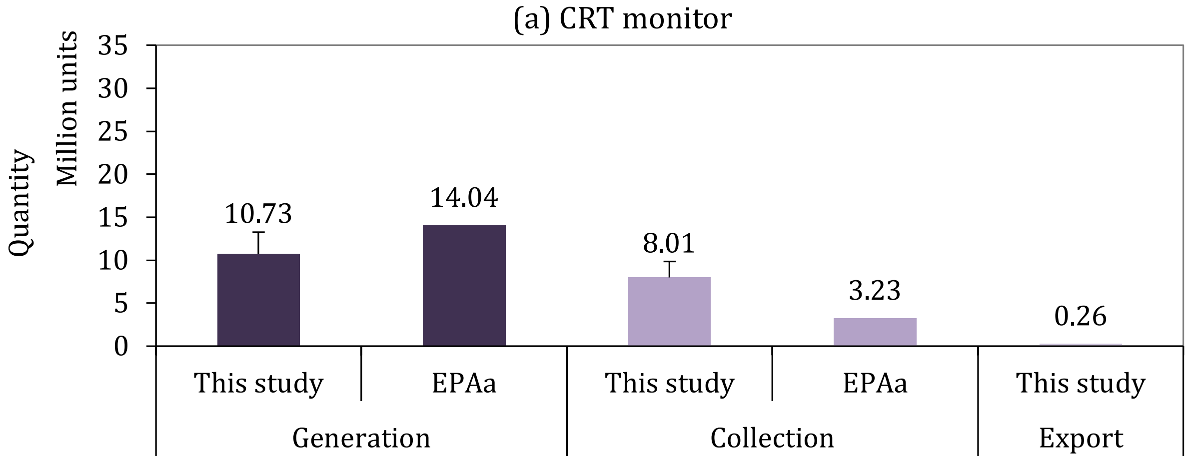
Figure 24 shows the export flow of CRT monitors and Flat Panel monitors in terms of transportation mode, destination regions, and income groups classification of the destination region. There were more exports of Flat Panel monitors than CRT monitor in terms of quantity, and the exports of PC monitors were greater than those of video monitors. While more exports of Flat Panel monitors were shipped via vessel than land or air, exports of CRT monitors were surprisingly highest by air. Neighboring countries were the major destinations for the two types of monitors. For CRT monitors, NA ranks first (34%), followed by LAC (28%), and Asia (23%). When divided by income groups classifications, the upper middle incomes dominate the major destinations for CRTs, accounting for 48% of shipments, followed by HI-OECD with a fraction of 31%. For LCD monitors, LAC ranks first as a destination region (51%), followed by NA (38%), and Asia (8%). When divided by income groups classifications, the upper middle incomes also dominate the major destinations for LCDs, accounting for 79% of shipments, followed by low middle incomes with a fraction of 10%.

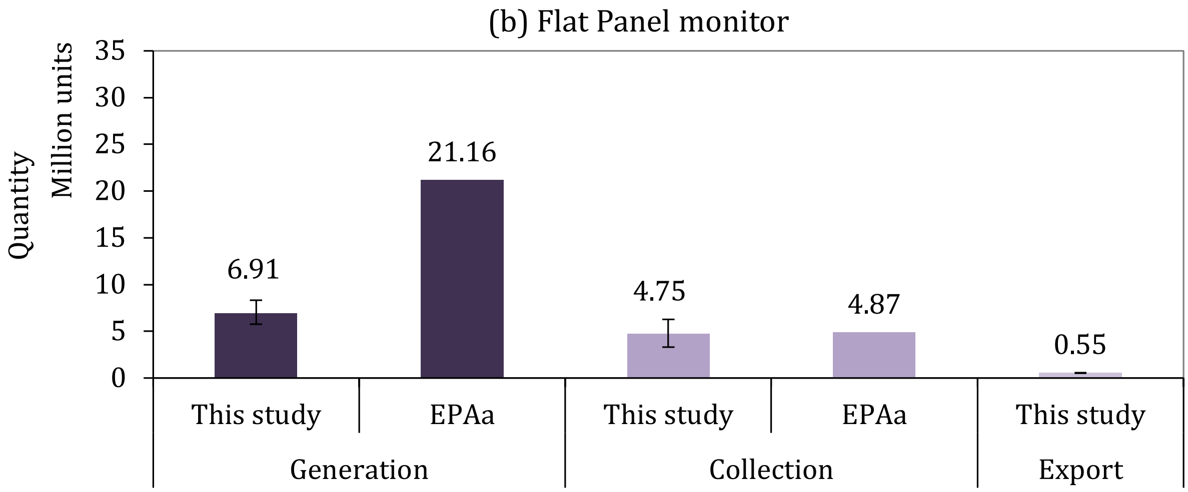


Note: Average results for Flat Panel monitors are based on threshold US Export NVEM. NA = North America; LAC = Latin America & Carribean; HI = High Income. UMI = Upper Middle Income; LMI = Low Middle Income; LI = Low Income.

Figure 24: Export Flow of Used Monitors in 2010: by Regions, Income Groups and Mode of Transport

Figure 25 compares the estimates and associated uncertainty for generated, collected, and exported used monitors. Considering the uncertainty in these estimates, the fractions of used CRT and Flat Panel monitors collected for processing that are subsequently exported are 3.4 % and 12.2% (on average), respectively.





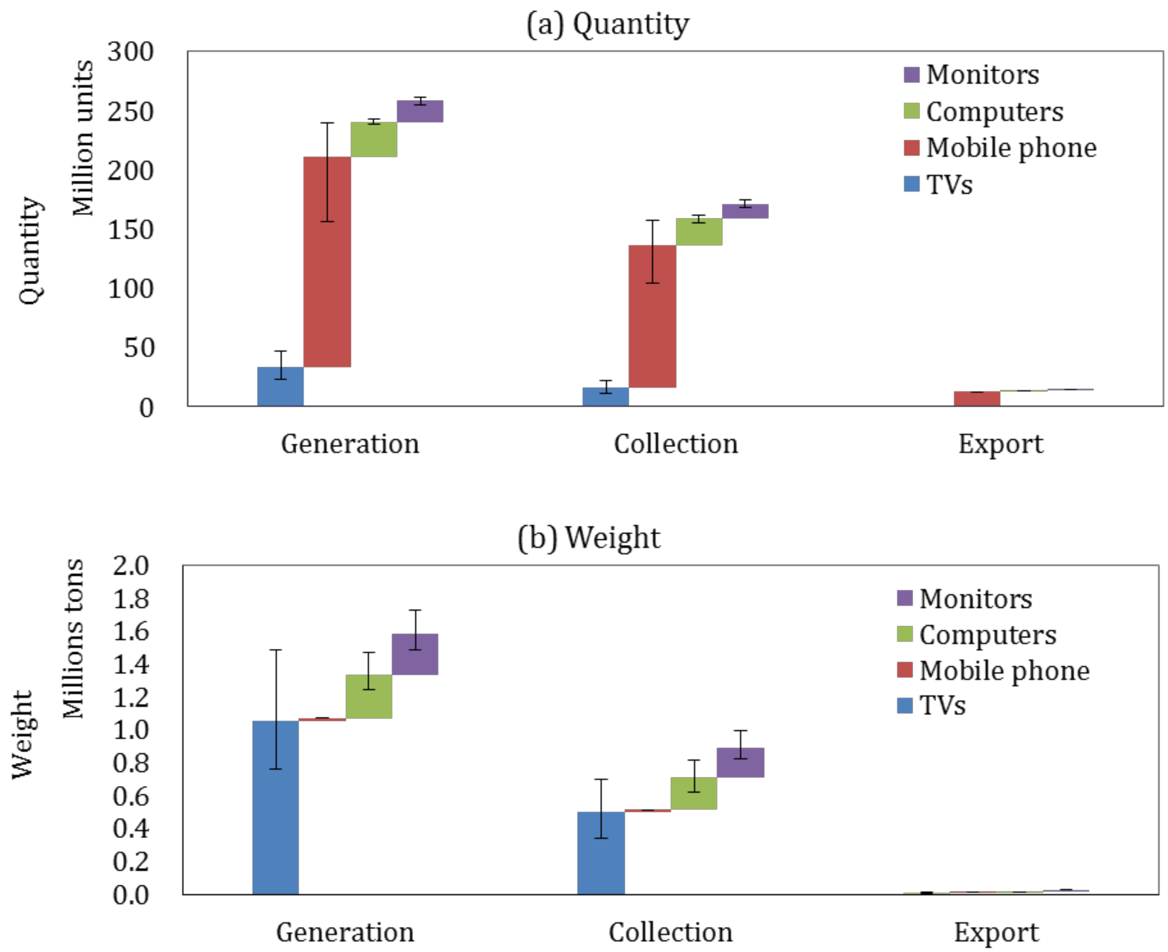
Note: The export of CRTs includes CRT monitors, video monitors, and monitors with desktops; all exports were assumed used. The exports of Flat Panels are based on threshold US Export NVEM. The Flat Panel category includes desktop monitors and video monitors. The error bars for generation and collection represent 90% confidence interval, and represent the minimum and maximum for export.

Figure 25: Flows of Used Monitors in the US in 2010

3 Comparison and Summary of the Flows for All Examined Products

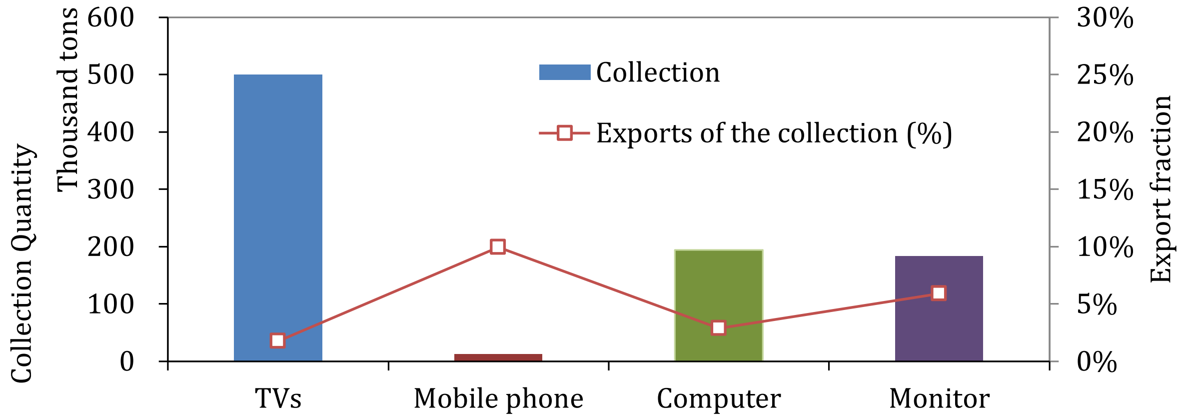
3.1 Generation, Collection and Export Comparison

Figure 26 depicts generation, collection, and export quantities and weight for all used electronic products. The total collection amount of all electronics accounts for more than 60% of the generation, and the export of whole units accounts for 8% of the collection quantity and only 3% weight, respectively. Figure 27 shows the collection weight and the fraction of the weight of the collected products that were exported. Figure 28 shows the weight breakdown by product of generation, collection, and export amounts. These results show that mobile phones dominate the generated, collected and exported used electronics by quantity, and TVs dominate the generated and collected used electronics if measured by weight. However, monitors dominate the types of used electronics for export.



Note: Export results are based on threshold US Export NVEM, if applied. The error bars for generation and collection represent 90% confidence interval, and represent the minimum and maximum from the mean for export.

Figure 26: Flows of Used Electronics in the US in 2010



Note: Export results (average) are based on threshold US Export NVEM if a threshold is applied.

Figure 27: Weight of used products collected in the US in 2010 and the fraction of those collected products that were subsequently exported.

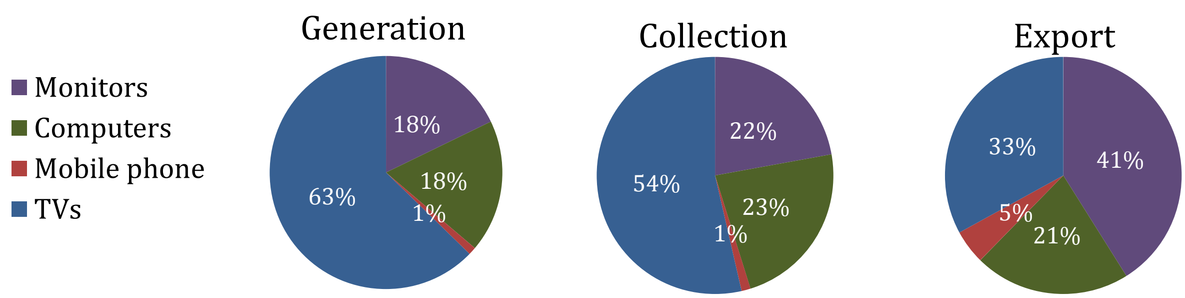
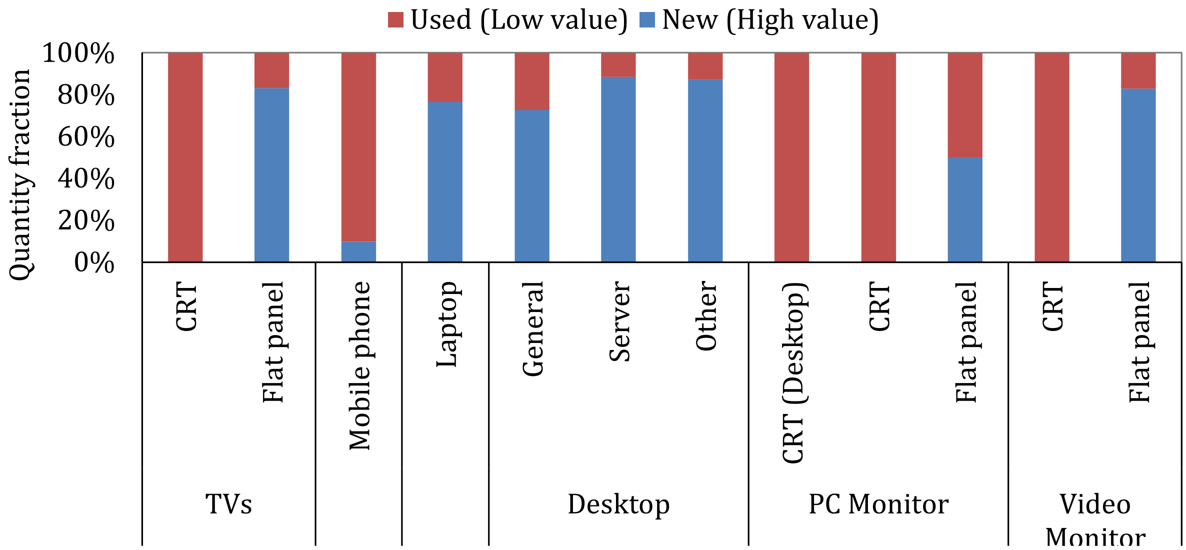


Figure 28: Weight fractions of Used Electronics in the US in 2010

3.2 Export Summary

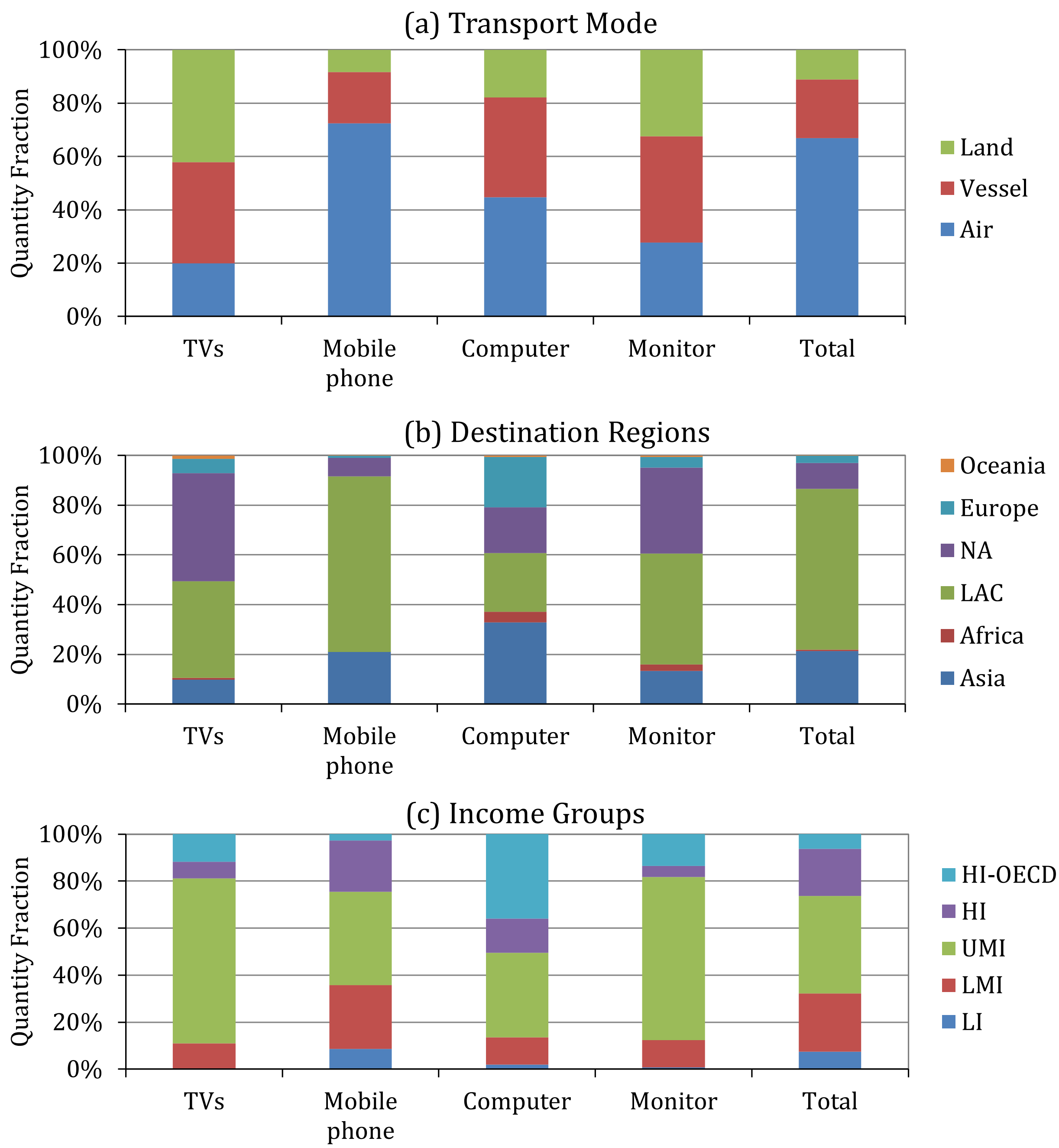
Figure 29 shows the fractions of all US exports for each product type that are used versus new. There is significant variation across the product types, with exports of CRT displays being exclusively used and exports of Flat Panel displays and computing equipment being primarily new. Mobile phones are somewhere in between.



Note: Normalized results are based on threshold US Export NVEM if a threshold is applied.

Figure 29: The Fraction of All US Exports of Electronics Products from the US in 2010 That Are Used and New.

Figure 30 compares the export of used electronics by transportation mode, destination regions, and income groups classification of the destination regions. The heavy electronics, e.g., TVs and monitors, are more likely to be shipped by land and vessel to neighboring regions (NA and LAC). The major destinations for mobile phone were LAC and Asian countries. European countries and Asian countries were more likely to receive used computers. Africa is the least common destination, which is similar to what is found in the EU country studies, mainly the Dutch Future Flows report [15].

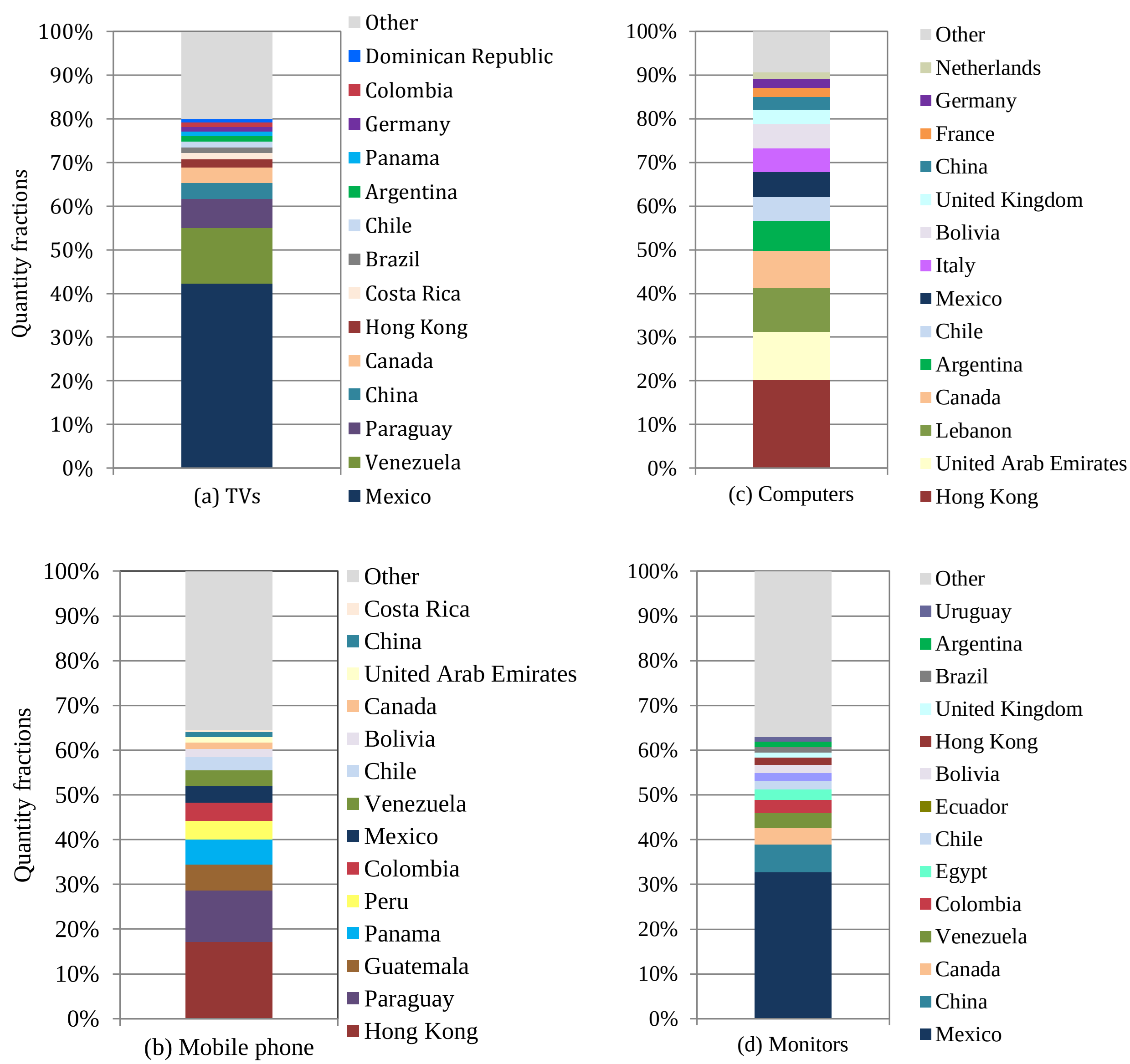


Note: Normalized results are based on threshold US Export NVEM.

Figure 30: Quantity Fractions of US Export Flows in 2010 for the Four Used Electronics Types Broken Down by Transport Mode, Destination Regions, and Income Groups.

Figure 31 compares the top 15 export destinations for the four types of used electronics. Used TVs and monitors have mainly been exported to Mexico, because the world has few CRT processing facilities; most are in Mexico and India. For example, the surveys conducted by USITC [10] revealed that the CRT glass at the Cali Resources/TDM facility in Mexico, where glass is separated and cleaned, has been shipped to Samtel/Videocon in India for the production of new CRT glass. The major destinations for computers were Asian countries, including Hong Kong, United Arab Emirates (UAE) and Lebanon. Both Hong Kong and many LAC countries were most likely to receive used mobile phones. As a reminder, these countries should not be viewed as the final destination countries because they may actually represent a stopping point for products before they are re-exported to another country in the region.

Hong Kong, UAE and Lebanon have been shown to re-export a significant fraction of laptops, though the data cannot distinguish between re-exports of used and new laptops. The trade data does not identify whether products will be re-exported, so it can only be guessed based on the destination (e.g., some countries are more likely to be re-export locations than others).



Note: Normalized results are based on the threshold US Export NVEM if thresholds are applied

Figure 31: Top 15 Export Destinations for Each Product Type in 2010.

3.2.1 Potential of Re-export of Exported Used Laptops

Publically available trade data is reported as transactions between an exporter and an importer. However due to re-exports, sometimes the import country is not the final destination. To get a sense of the final destination of used laptops, the probability of re-export upon import of used and new laptops in the top ten destination countries was estimated, as shown in Table 6. The ratio of re-exports to imports serves as that estimate where the data was available, and is otherwise considered to be less than or equal to the ratio of general exports to imports. Considering that domestic exports from the US are not likely to be re-exported back to the US, all export figures presented exclude the US. Overall, at most 80% of exports from the US to these countries would not be re-exported.

Table 6: Potential of re-export from 2010 top ten destination countries
Quantities of laptops in thousands. Used exports from US based on US Export NVEM.

Country	Used Exports from US	Imports from World	Exports to World, except US	Exports/ Imports	Re-Exports to World, except US	Maximum Re-Exports/ Imports
Lebanon	**114.1**	75.7	31.8	42.0%		**≤42.0%**
Argentina	**71.2**	1,537.3	2.3	0.1%		**≤0.1%**
Hong Kong	**67.3**	5,257.7	2,508.9	47.7%	2,508.7	**47.7%**
Canada	**60.7**	5,436.9	148.2	2.7%	78.7	**1.4%**
United Arab Emirates (2008)	**59.5**	674.6	229.1	34.0%	229.1	**34.0%**
Chile	**57.4**	1,280.0	23.6	1.8%		**≤1.8%**
Bolivia	**56.1**	1,802.7	2.0	0.1%		**≤0.1%**
Mexico	**37.1**	6,418.0	58.1	0.9%		**≤0.9%**
United Kingdom	**33.1**	12,313.5	2,457.3	20.0%		**≤20.0%**
China	**31.9**	1,226.1	134,209.6	10946.0%	376.2	**30.7%**

Considerable trade within the top ten destination countries was observed by as demonstrated in Figure 31. Argentina, Hong Kong, United Arab Emirates, Chile, United Kingdom and China are export destinations from other top ten US destination countries. Canada's top three re-export destinations are top ten destination countries. Also, note that Lebanon reports fewer imports from the world than the US export estimate.

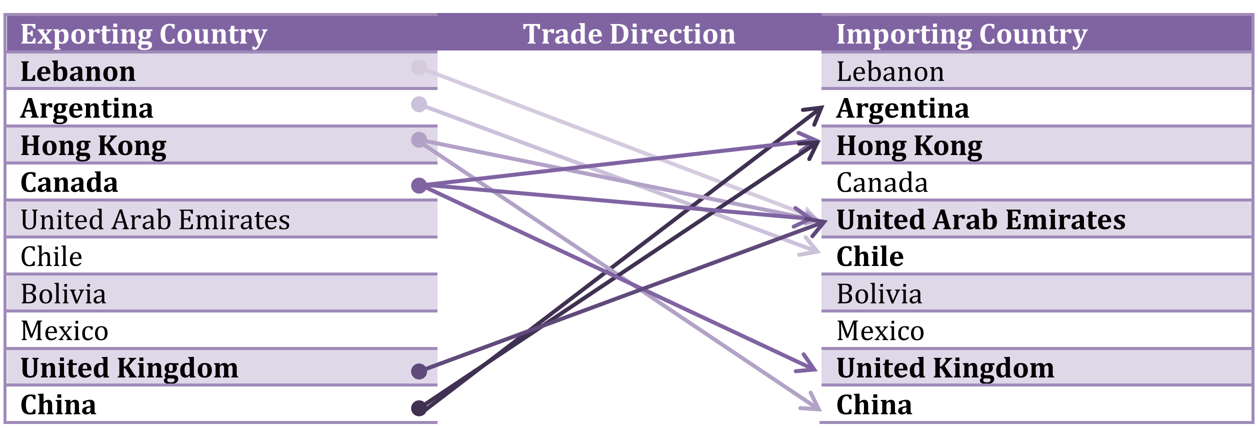


Figure 32: Laptop trade between the top ten destination countries in 2010

3.2.2 Comparison with Other Study

In Figure 33 below, comparisons are made between this study's export estimates, averaged across all methods, and results from the USITC (2013) study [10]. As described in detail in the Appendix 5.2.1.1, the main results of the USITC were inferred from a broad survey of players throughout the used electronics chain. Additionally, analysis of shipment-level trade data from 2011 was completed. Though Used-New thresholds were not identified, statistics were provided at the lowest 10%, 25%, 50% and 100% of trade by average unit value. Comparisons were made between appropriate statistics that were comparable with this study's Used-New thresholds. The comparable results between this study's approach and the USITC shipment-level results, with the exception of laptops, suggest that this study's trade data approach can reasonably approximate shipment-level total quantities.

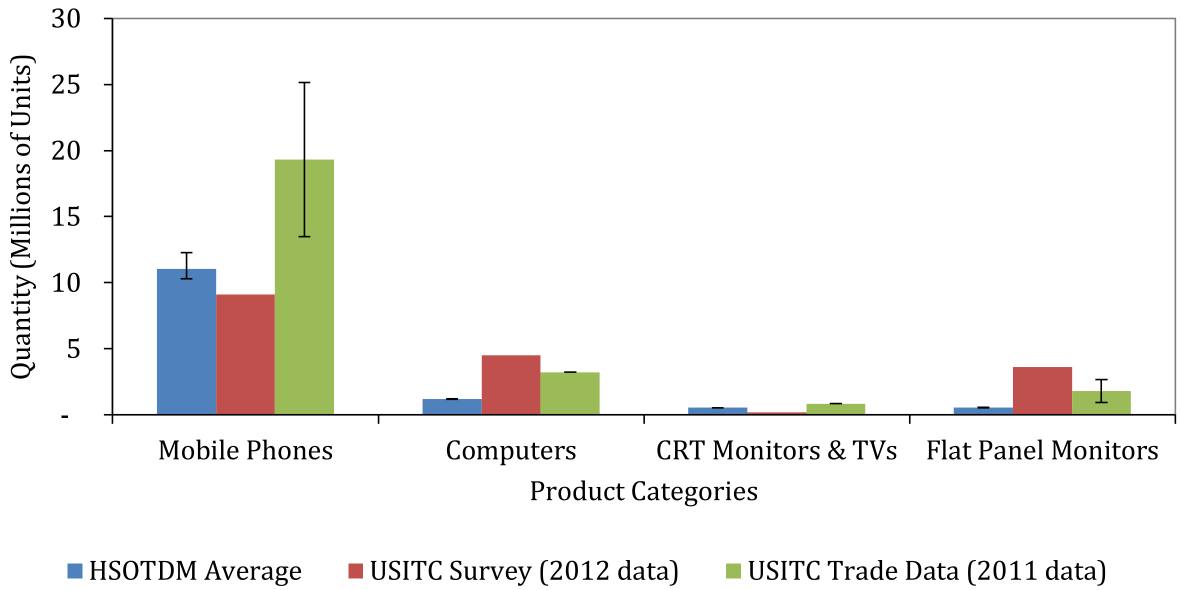


Figure 33: Comparison between this study and USITC report

4 Conclusions and Recommendations

4.1 Conclusions

This report presents the results of an effort to calculate quantities of used electronics (as whole units) generated and collected in the United States, and exported from the United States. The products included TVs, mobile phones, computers and monitors. Generation and collection quantities were calculated using a sales obsolescence method that included uncertainty, and export quantities were calculated using a trade data approach. The advantage of the trade data approach is that trade data for all types of electronic products is widely available (including extensive historical data), updated relatively frequently, and provides insight into the destinations of products. The disadvantage is that there are no trade codes for used products, exporters may not be reporting shipments of used products properly, and the destination listed in the trade data may actually be an initial stopping point and not a final destination. Given these limitations, the export flows should be viewed as a lower bound because they may not be capturing all of the flows of used electronics shipped as whole units.

The results show that approximately 258.2 million units of used electronic were generated and 171.4 million units were collected in the US in 2010. Export flows were estimated to be 14.4 million units, which is 8.5% of the collected estimate on average. On a weight basis, 1.6 million tons of used electronics were generated in the US in 2010 and 0.9 million tons were collected. Of the amount collected, 26.5 thousand tons were exported, which is 3.1% of the weight collected. Mobile phones dominate generation, collection, and export on a unit basis, but TVs and monitors dominate on a weight basis. As a reminder, this methodology can only be used to track whole units and not scrap commodity streams from units disassembled in the US. While the total quantity of used electronics exports reported here is most likely an underestimate due to the likelihood that some shipments of whole units are not reported using the proper trade codes, the proportions of exports to world regions is likely accurate.

Analysis of the destination regions indicates that bulky electronics, especially TVs and monitors, were more likely to be exported over land or by sea to destinations such as Mexico, Venezuela, Paraguay and China. The major destinations for mobile phone were Asia (Hong Kong) and Latin America and the Caribbean (Paraguay and Guatemala, Panama, Peru and Colombia). By contrast, Asian countries (Hong Kong, United Arab Emirates and Lebanon) were more likely to receive the used computers (especially laptops). Around 80% of used electronics, including TVs, monitors, and mobile phones, are exported to countries with upper middle and lower middle income groups. It is interesting to note that Africa receives a very small fraction of the used electronics (selected types of electronics in this study) exported from the US.

Generally, the key drivers of generation of used electronics estimates were the length of the use lifespan stage and the total sales estimates. This suggests that for generation estimates with lower uncertainty, use lifetime estimates with lower uncertainty should be a top priority, followed by more accurate sales data estimates. Unsurprisingly, collection rate is the most important parameter for collection estimates and product unit weight is the most important parameter for weight-based estimates. The range of used-new thresholds drive the uncertainty for the export estimate. Among the three used-new threshold methods, the sales value-based threshold (Export Pub. Method) has a larger uncertainty than the thresholds based on the distributions of the trade data (Export NVEM).

4.2 Recommendations

There are several recommendations that arise from this work.

- The creation of trade codes for used products would enable explicit tracking of those products.
- Investigations should be done into the specific trade codes used by exporters for used electronics that are whole units.
- Allowing more open access to shipment level trade data would enable more accurate analyses of export flows.
- More cooperation and exchange of data between inspection authorities in export and import countries should be encouraged.
- Increased reporting of re-export destinations would improve the accuracy of final destinations for trade flows.
- Flows should be analyzed across multiple years in order to discern trends.
- Other approaches should be used to estimate export flows of used electronics in order to understand the impact of the limitations in all approaches on the estimation of quantities.

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6 Appendices

6.1 Generation and Collection

6.1.1 Methodology Overview

Figure 34 demonstrates that the quantity of generated whole units is greater than that of collected, which is greater than the quantity exported. Different methodological approaches were needed to estimate each quantity, overall this approach is named the Hybrid Sales Obsolescence-Trade Data Method (HSOTDM)[I]. The collected quantity was estimated based on the generated quantity estimated with a Sales Obsolescence model, whereas the exported quantity was determined independently with Trade Data. One test for reasonableness of the export estimate is whether it is less than the collection estimate, since used electronic equipment is assumed to be collected before it is exported. In this section, the methods used to estimate the generation, collection and export quantities for the laptop case study are described, and results are presented.

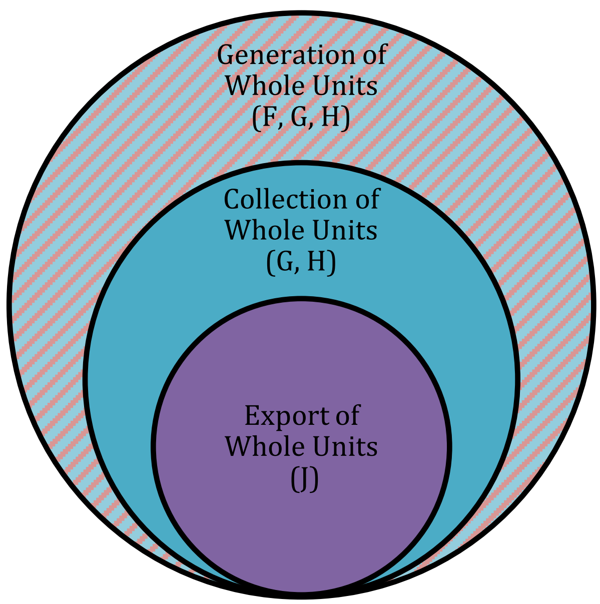

Figure 34: Illustration that exported whole units of used electronics are a subset of collected whole units, which are a subset of generated whole units. [Letters] and colors refer to Figure 1 (repeated below for convenience).

[I] Note that this method was similarly described in Miller et al. 2013. Quantitative Characterization of Domestic and Transboundary Flows of Used Electronics: Case Study: Used Computers and Monitors in North America. Commission for Environmental Cooperation of North America (CEC).

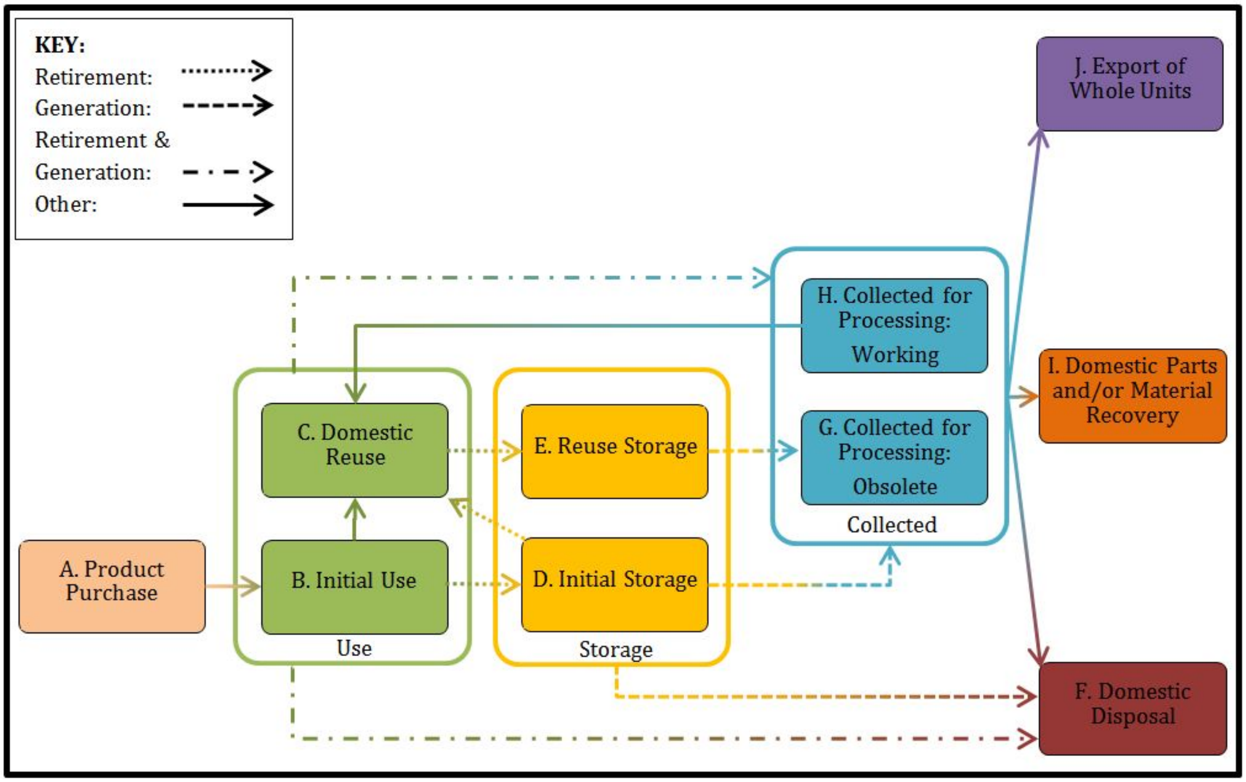

Figure 1: Life Cycle Flow Chart of Electronic Products

The basic approach to determine generation and collection quantities consistent across most studies reviewed involves steps to:

1. Determine the sales of a product in a region over a time period
2. Determine the typical distribution of lifespans for the product over a time period
3. Calculate how many products are predicted to be generated in a given year using the sales and lifespan information
4. Calculate how many of the generated products are predicted to be collected in a given year by applying collection rates
5. *Optional:* Calculate the weight of generated and collected products by multiplying unit weights by the quantities

These generation and collection calculation steps roughly comprise a sales obsolescence model (alternatively known as market supply method [16]). Studies cover different products, time periods, geographical regions, and vary in complexity [17-21].

6.1.1.1 Previous Work

Other studies take advantage of published statistics about the stock of electronics, or extrapolate from in-depth case studies and surveys to estimate generation. For example, UNEP's International Environmental Technology Center (UNEP/DTIE-IETC) described in 2007 several variations of simple stock models [16]. Muller et al. (2009) intentionally utilized "free or cheaply available indicators provided by the International Telecommunication Union (ITU) and the World Bank" for much of their stock and flow model data [22]. Yang and

Willams (2009) and Yu et al. (2010) have created stock and flow models for the US [7, 23]. Babbitt et al. (2009) used employee personal computer property control data from Arizona State University to estimate the higher education generation quantity [24]. Kahhat and Williams (2012) surveyed US computer owners and captured their ownership and disposition behavior[25]; generation and collection estimates in this study in part derives from those same surveys. Wang et al. (2013) developed an "advanced, flexible and multivariate Input–Output Analysis (IOA) method" which "links all three pillars in IOA (product sales, stock and lifespan profiles) to construct mathematical relationships between various data points" and "demonstrates significant disparity between various estimation models, arising from the use of data under different conditions."[26]

Surveys, collection rates from other regions, and government data have been used to estimate US used electronics collection rates. Several surveys, for example Kahhat and Williams (2012), RIS International (2003), Consumer Reports (2006), and Saphores et al. (2009), have been conducted to ascertain the end-of-life (EoL) management options utilized by consumers and business electronics owners; this data can be used to infer collection rates [25, 27-29]. Gregory et al. (2009) adjusted documented European trends in collection for other world regions' CRT collection [20]. US EPA (2011) used data from states with used electronics recycling programs to estimate the share of residential generated electronics that are collected for processing versus disposal. Low collection rates (one pound collected per capita) were assumed for states without programs [19].

In order to estimate the generation and collection of TVs, mobile phones, computers and monitors in the United States in 2010, there remain a few gaps in the existing literature. All but one of the existing generation and collection estimates for 2010 combines desktops and laptops into a single computer category. Lifespan distributions used vary considerably between studies. The existing estimates do not agree with one another; this study will model the generation of laptops factoring in the uncertainty associated with relevant parameters.

6.1.1.2 Methodologies Developed and Utilized

Two separate methodologies were developed to estimate generation and collection within the overall HSOTDM, and both follow the same basic five steps outlined at the beginning of the chapter. Table 7 below outlines the differences in the methodological steps and products covered. The first method described (Literature-based Method) relies on published lifespan estimates and collection estimates, while the second method described (Survey –based Method) relies on directly on lifespan distributions, generation and collection estimates derived from recent consumer and business surveys about electronics purchase, use, and discard habits. These surveys focused on computers and monitors, but touched on other electronics such as TVs as well.

There is additional information available for TVs, and therefore another set of validating methodologies were developed to take advantage of this data. The prevalence of TVs in homes has been studied in depth, and so a simple stock and flow model was used combining TV penetration data with sales data to arrive at generation results. This approach cannot be classified as a Literature-based or Survey-based approach as defined in this study, and so is treated separately. Also, many US states have had collection programs since 2010, and so collection rates were estimated based on reported collection quantities; TVs were the only product category where there were sufficient states to perform this analysis in a robust fashion (Literature-based Method B).

Since different owner types have different consumption, use and end of use disposition habits due to different budgets and priorities, generation and collection were modeled separately for residential and business/public owners. Results are presented with total generation and collection quantities summed.

Table 7: Comparison between Literature-based Method and Survey-based Method for Generation and Collection

Step 1-5 and Products	Literature-based Method	Survey –based Method
1. Sales Data	*Owner Types:* Residential, Business/Public	*Owner Types:* Residential, Business/Public
2. Lifespan Estimation	Published estimates	Modeled survey data
3. Generation Prediction	Probabilistic pathways with lognormal distributions	Computer and Monitors: *Residential:* Reuse model with Weibull distributions *Business/Public:* Survey estimates scaled up TVs: Survey estimates scaled up
4. Collection Prediction	A. Published estimates B. State collection programs	Survey estimated collection rates
5. Weight Estimation	Published estimates	Model of state collection data
Products	TVs, Mobile Phones	Computers and Monitors, TVs

Both methods require sales of a product in a region over a time period for both residential and business/public estimates. Anticipating that some used electronics are generated decades after their purchase, time series sales data is sought from two decades before the year of prediction. Sales data estimates themselves are used in the baseline analysis, and are allowed to vary +/- 10% to capture potential error in the Monte Carlo simulation. Sales data for each product are described in the following Data and Intermediate Results section.

6.1.1.2.1 Literature-based Method

6.1.1.2.1.1 Determine the typical distribution of lifespans for the product over a time period

This method for determining typical distributions of lifespans for the product is a refinement of the model developed by Matthews et al. which accounts for two use stages (initial and reused), and accounts for different fates after each stage[17]. The primary difference is the incorporation of a distribution of lifespan lengths and path probabilities so that both data quality uncertainty and variation are considered. The steps are as follows:

i. Combine literature and industry estimates for the distribution of lengths of each lifespan stage(s) (eg. B. Initial Use, E. Reuse Storage) in Figure 1 (repeated above for convenience) to arrive at a mean estimate with uncertainty for each lifespan stage.

ii. Define pathways to generation (Figure 35) involving combinations of lifespan stages related to Figure 1.

This method is somewhat of an underestimate, because we do not estimate the second round of generation of products that underwent formal domestic reuse. A full model inclusive of the second round of generation is presented in Figure 35; initial sensitivity analyses suggest that the result is not very sensitive to the exclusion of the second round of generation.

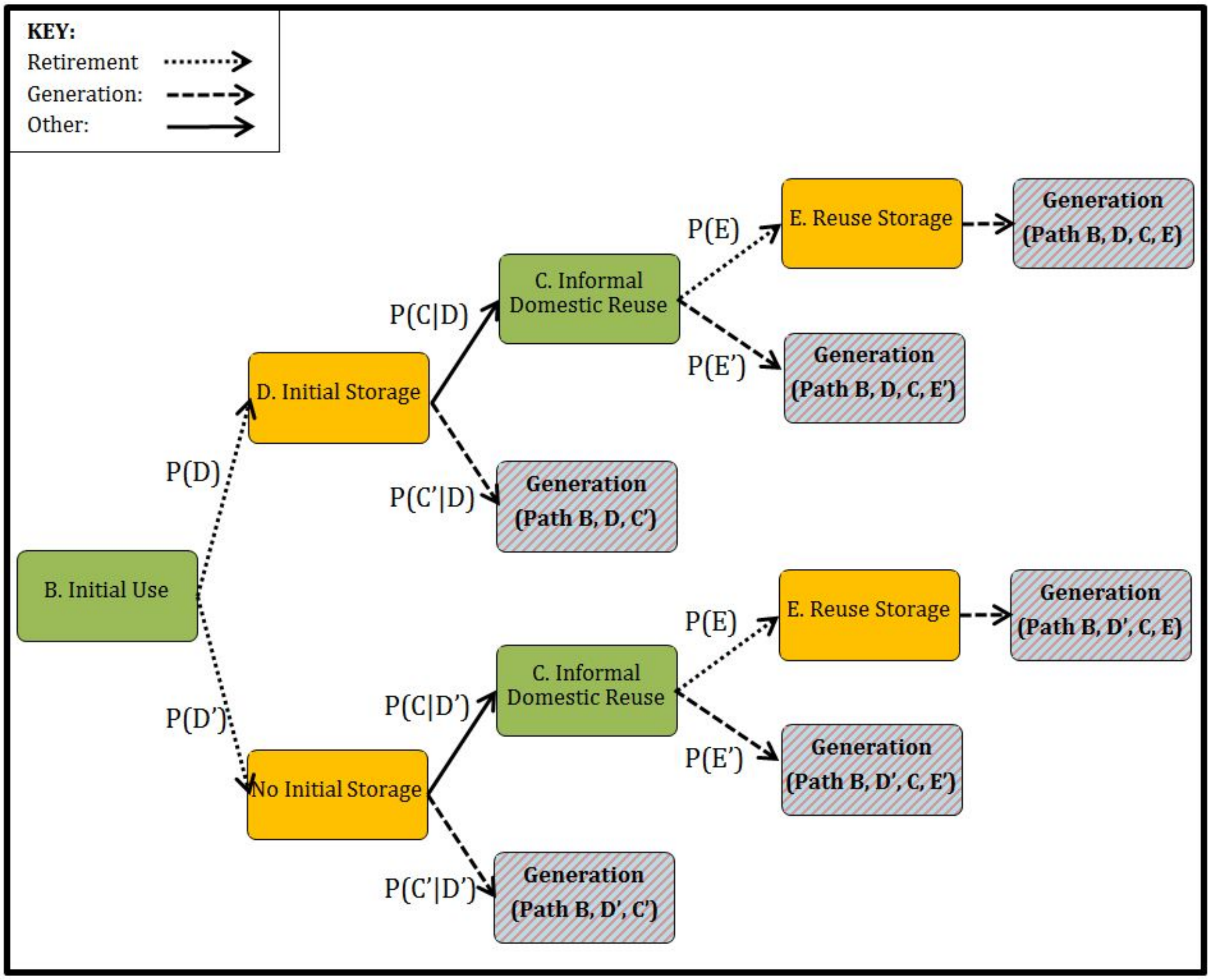

Figure 35: Probability tree diagram of informal paths leading to generation. Letters and colors refer to lifespan stages in Figure 1. The probabilities of a path to a lifespan stage are represented by P(lifespan stage), or its complement P(lifespan stage'). Some probabilities are conditional on previous pathways, P(lifespan stage| previous lifespan stage).

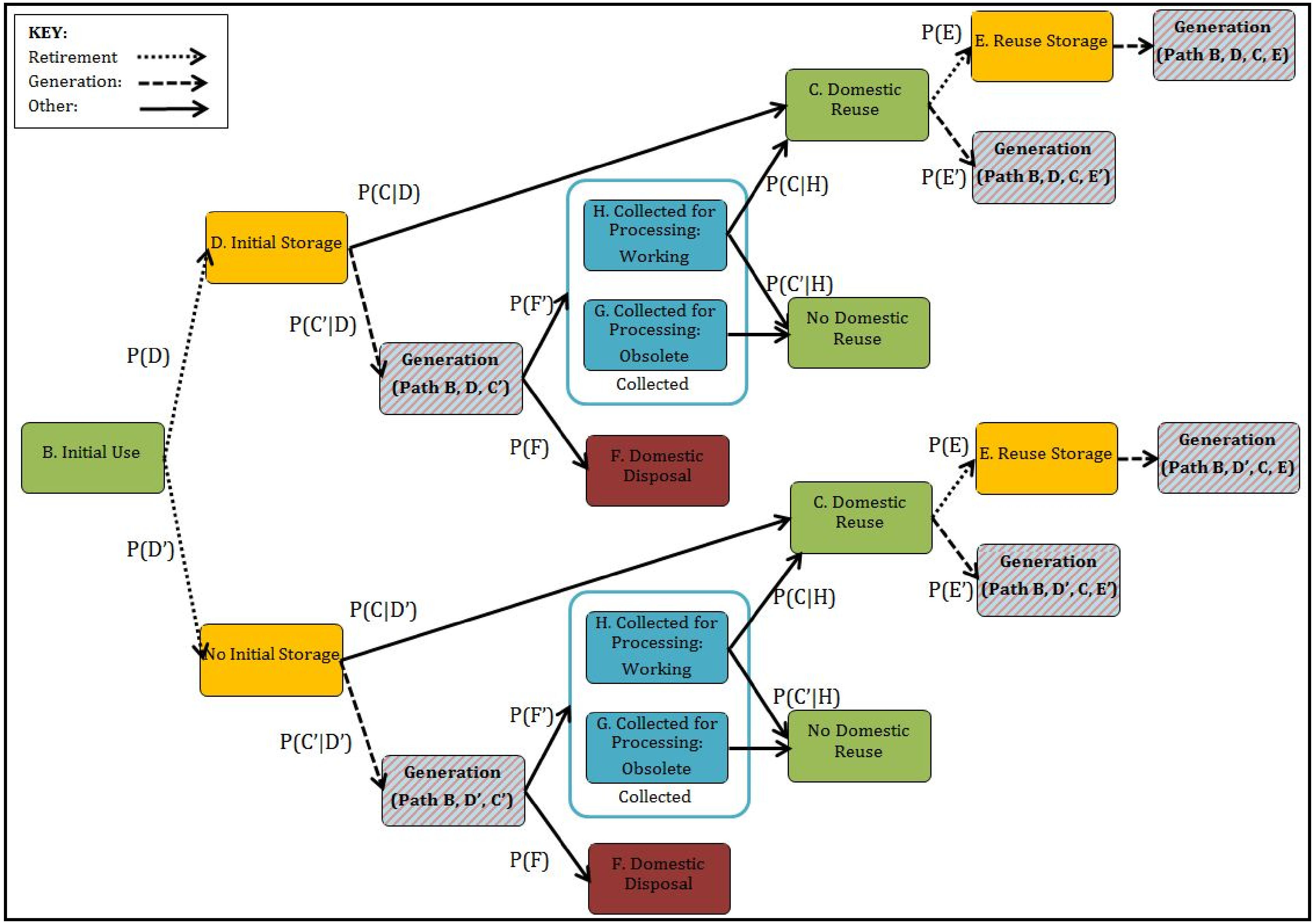

Figure 36: Probability Tree Diagram of Informal and Formal Paths Leading to Generation.

iii. Combine the lengths of the lifespan stages to calculate the lengths of each pathway to generation and estimate the probability of each pathway to generation.

In Table 8 below, the equations for determining the mean path length and mean path probability are found for each of the six pathways to generation.

Table 8: Equations used to calculate mean path length and mean path probability

Six Paths (ϖ)	Mean Path Length μ_ϖ	Mean Path Probability $P(\varpi)$
Path B, D, C, E	$\mu_B + \mu_C + \mu_D + \mu_E$	1*P(D)*P(C|D)*P(E)
Path B, D, C, E'	$\mu_B + \mu_C + \mu_D$	1*P(D)*P(C|D)*P(E')
Path B, D, C'	$\mu_B + \mu_D$	1*P(D)*P(C'|D)
Path B, D', C, E	$\mu_B + \mu_C + \mu_E$	1*P(D')*P(C|D')*P(E)
Path B, D', C, E'	$\mu_B + \mu_C$	1*P(D')*P(C|D')*P(E')
Path B, D', C'	μ_B	1*P(D')*P(C'|D')

iv. Determine the overall mean lifespan by aggregating the paths to generation probabilistically. Estimate the variance of the lifespan distribution from literature.

The generation model only incorporates a single mean path length, and so in Equation 1, the overall weighted mean of lifespans for all six paths $\boldsymbol{\varpi}$ is presented.

Equation 1: Overall weighted mean of lifespans for all six paths $\boldsymbol{\varpi}$

$$\mu_{Overall} = \sum_{\varpi=1}^{6} P(\varpi) * \mu_\varpi$$

6.1.1.2.1.2 Calculate how many products are predicted to be generated in a given year using the sales and lifespan information

The quantity of used products generated in year y is based on the sales in year s and the probability $\lambda(y-s)$that a product sold in year s is generated in year y. The probability distribution $\lambda(y-s)$ is created using parameters from the lifespan estimates. Here, a lognormal distribution was assumed, which is comparable to a university computer lifespan study [30]. Equation 2 shows the how the quantity is calculated.

Equation 2: Quantity generated in year y

$$Generated(y) = \sum_{s}^{y} Sales(s) * \lambda(y-s)$$

6.1.1.2.1.3 Literature-based Method a: Calculate how many of the generated products are predicted to be collected in a given year by applying published collection rates

The used electronics collected for processing in year *y* is simply the product of the generated quantity in year *y* and the probability that generated used electronics are collected in that year, $P(F')$, as shown in Equation 3.

Equation 3: Quantity collected for processing in year *y*

$$Collected(y) = Generated(y) * P(F')$$

$P(F')$, shown in Figure 37, can be thought of as the collection rate. The collected quantity was calculated for each owner type because of differing collection rates.

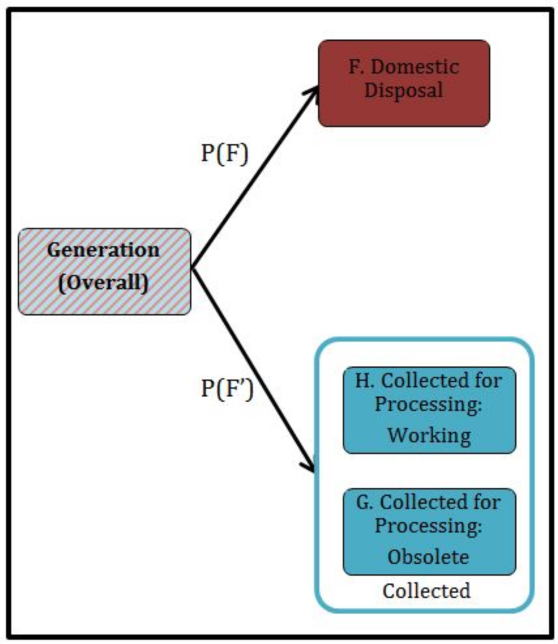

Figure 37: Probability tree diagram of paths directly after generation. Letters and colors refer to lifespan stages in Figure 1. The probabilities of a path to a lifespan stage are represented by P(lifespan stage), or its complement P(lifespan stage').

The overall estimates and associated uncertainty of generated and collected quantities were determined using Monte Carlo simulations. All key calculation parameters were allowed to vary within reasonable distributions. For example, sales were allowed to vary uniformly two standard deviations from the mean. A 10,000 trial Monte Carlo simulation was conducted using Oracle Crystal Ball ® in Microsoft Excel ®.

6.1.1.2.1.4 Literature-based Method B: Calculate how many of the generated products are predicted to be collected in a given year by applying collection rates derived from state collection programs

As this section pertains only to TVs, a description can be found in Section 6.1.2.1.3.

6.1.1.2.2 Survey-based Method

Data used for many steps in the Survey-based Method are from US residential and business/public surveys conducted by Kahhat and Williams in 2011, with a focus on the year 2010 [25]. For computers and monitors, the residential survey asked about each item, while the business/public survey asked about groups of items. Therefore, the residential generation and collection methodology follows the basic approach to determine generation and collection quantities consistent across most studies outlined at the beginning of the chapter, while the business/public is a more simplistic extrapolation, described in this chapter after the residential method. A final question in the surveys ask basic questions about the disposition of a broad set of used electronics. For TVs, generation and collection results are extrapolated from these responses.

The following excerpt describes the survey methodology employed by Kahhat and Williams [25]:

> "In this study two online surveys were launched to collect primary data on adoption and end-of-life management of personal computers in the residential and business/public sector of the United States. The residential sector study included 1000 completed surveys drawn from a larger panel of 350,000 prospective respondents constructed by the consulting firm Research Now. The sample chosen was representative of 2010 Census data for the adult population for the following parameters: Gender, State, Age, Household Income, and Educational Attainment. The survey consisted of 15 questions covering three topic areas: demographics, computer ownership and use at home, and computer disposal. Four hundred complete surveys where obtained from the business/public sector. The sample was representative of the United States business/public sector according to geographic location and number of employees within a company. Although it would be desirable to have a sample matching the national distribution of organizations/employees by industry sector (e.g. North American Industry Classification System (NAICS)), the cost of soliciting such a sample was beyond available economic resources. The respondent pool was about 25,000 eligible participants of a panel of IT experts collected by the consulting firm Opinionology. The panel included IT decision makers and asset managers. The survey questionnaire included 15 questions. Both surveys were launched in April 2011 and the questions addressed the 2010 calendar year. All completed surveys were examined by the survey company and research team before included in the analysis. The residential and business/public sector surveys had a margin of error of 3% and 5%, respectively, considering a confidence level of 95%. Confidence level and margin of error are based on sample size and sample distribution. Survey questionnaire and results are included in supporting information."

6.1.1.2.2.1 Residential Computers and Monitors: Determine the typical distribution of lifespans for the residential product over a time period

Raw survey data provided by Kahhat and Williams [25] was utilized to estimate the lifespan distribution of residential computers and monitors in 2010; these were the focal products of the survey while other electronics were addressed briefly. The business/public method did not model lifespans.

To compute the lifespan distributions for each residential product, survival analysis[I] techniques were employed. Survival analysis is typically employed in studies of patient survival of disease, or of machine failure, and typically involve fitting the Weibull distribution. The Weibull distribution is used in similar studies as well [15, 31, 32]. Adapting that terminology to this study with the intent of understanding the length of time one owner uses and stores an electronic item, a "failure" is defined as the end of one period of ownership, delimited either by generation (collection or trash) or informal reuse. In comparison to the literature method's probability tree diagram in Figure 36, "failure" occurs after "D. Initial Storage" or "No Initial Storage". The distribution of length of one period of ownership is an input into the generation prediction model, which is why it is sought versus time until generation directly as one might expect. The steps to estimate the distribution of length of one period ownership λ are as follows, and elaborated on afterwords:

Overview of steps

i. Prepare the residential survey data.
ii. Determine the age of products either at the point of "failure", or at the time of "censor" (a product is censored if it is still with the owner when surveyed). Where possible, screen the responses by the respondent's precision of estimating the year purchased in comparison estimating time in use and storage (cutoff of 1 year was deemed reasonable).
iii. Determine the year that the product was purchased.
iv. Use Stata® 12.1 to produce Kaplan-Meier (K-M) survivor curves and subsequently Weibull regressions for all of the products together, and use the same K-M curve and associated Weibull regression for all years of purchase [II].
v. Fit additional parameters for the Weibull regression to the K-M curves.
vi. Transform the results of the Weibull regression into a probability density function, which will be used as the distribution of length of one period ownership.
vii. During the Monte Carlo simulation, allow the parameters of the regression to vary between a 95% confidence interval and allow the entire distribution to shift left and right to account for allowable error in the respondents' precision. Figure 41 displays some of the 10,000 laptop distributions modeled during the Monte Carlo simulation described in the next section, and Figure 43 displays the mean distributions for each product.

Detailed explanation of steps using laptops as a case study

[I] Singh R, Mukhopadhyay K. Survival analysis in clinical trials: Basics and must know areas. Perspect Clin Res [serial online] 2011 2:145-8. Available from: http://www.picronline.org/text.asp?2011/2/4/145/86872

[II] Ideally, estimates would be made as a trend for each year, but that was not done due to data limitations. Also, ideally items would be separated into those that were purchased new and those purchased used since new products likely last longer, but that was not possible with this survey dataset.

i. Prepare the residential survey data.

The survey data received from the survey firm needed to be consolidated, because the data originally was arranged by respondent instead of by electronic. There were two sets of relevant questions, requiring separate preparation: questions pertaining to those had been "discarded", and electronics that were still in the home. Some of the "discarded" items were considered to be "failures" and others "censored" in Table 9.

Table 9: Designation of Failure, Generation, and Collection by Discard Type

Discard Type	Fail?	Category	Generated?
Disposal via curbside garbage collection	Fail	Trash	Generated
Recycled via curbside recycling program	Fail	Collected	Generated
Returned to collection depot for recycling	Fail	Collected	Generated
Returned to retailer	Fail	Collected	Generated
Returned to municipality during a special collection event	Fail	Collected	Generated
Returned to manufacturer	Fail	Collected	Generated
Storage off-site	Censor	Not Included	Not Generated
Donated to friend/family within household	Fail	Informal Reuse	Not Generated
Donated to friend/family outside of household	Fail	Informal Reuse	Not Generated
Donated to a charitable organization	Fail	Informal Reuse	Not Generated
Other donation	Fail	Informal Reuse	Not Generated
Returned to seller after lease expired	Fail	Collected	Generated
Sold online (e.g. eBay)	Fail	Informal Reuse	Not Generated
Sold locally	Fail	Informal Reuse	Not Generated
Sold to an acquaintance/friend/family	Fail	Informal Reuse	Not Generated
Other	Censor	Not Included	Not Generated
NA Did not discard	Censor	Not Included	Not Generated

ii. Determine the age of products either at the point of "failure", or at the time of "censor" (a product is censored if it is still with the owner when surveyed). Where possible, screen the responses by the respondent's precision of estimating the year purchased in comparison estimating time in use and storage (cutoff of 1 year was deemed reasonable).

In Table 9, it can be seen that the vast majority of respondents were internally consistent when reporting both the year purchased and the corresponding time in use and time in storage for computers and monitors at home. Figure 38 below illustrates how the precision metric was calculated.

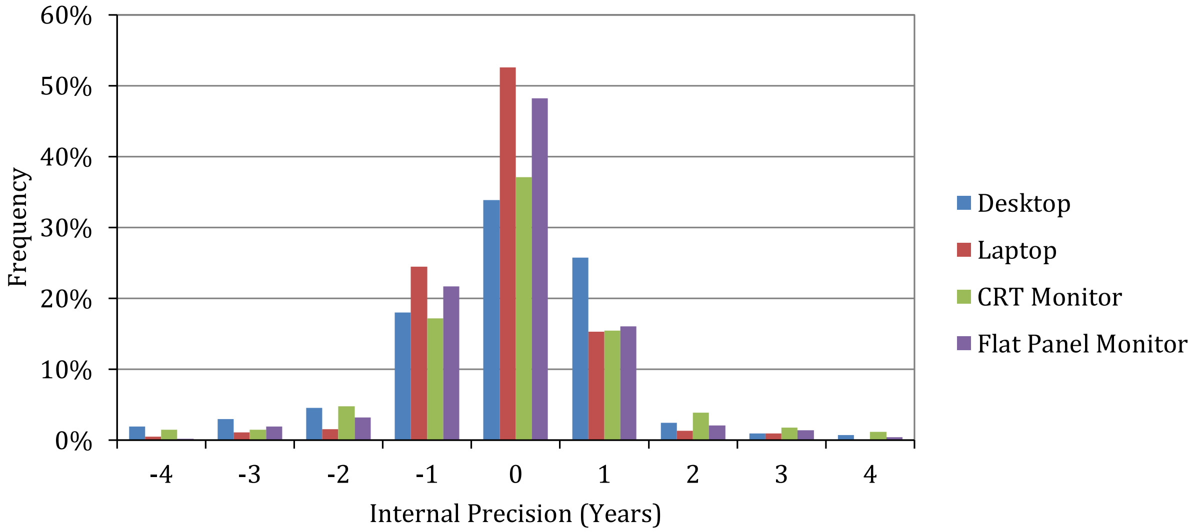

Figure 38: Respondents' internal precision of estimating product age and time at home. Zero represents high precision.

Note that this metric cannot be calculated for those electronics that were "discarded", because the survey asked solely about lifespan in the home, and not about year of purchase of "discarded" products. The only quality control metric available for "discarded" electronics was to ensure that when respondents reported about the lifespan of "discarded" electronics and separately about the "discard method", the type of electronic matched across the two questions (eg. laptop and laptop, not laptop and desktop). Mismatches were excluded.

Equation 4: Determination of Internal Precision of Respondent's "Censored" Electronics

$$Precision = Year\ of\ Survey - Year\ Purchased - Use - Storage$$

iii. Determine the year that the product was purchased.

For "censored" electronics still in the home, the year purchased was given directly by the respondents. For "discarded" electronics, Equation 5 below was used.

Equation 5: Determination of Year of Purchase of "Discarded" Electronics

$$Year\ Purchased = Year\ Discarded - Lifespan$$

iv. **Use Stata® 12.1 to produce Kaplan-Meier (K-M) survivor curves and subsequently Weibull regressions for all of the products together, and use the same K-M curve and associated Weibull regression for all years of purchase.**

The following *code* was input into Stata® 12.1, and relevant output and comments are included.

- Set data for survival analysis:

  stset age, failure(failure)
- Describe data to ensure it was processed correctly:

  stdescribe
- K-M Survival Analysis:

  sts list

  This data, which lists the K-M curve data for the modeled survival curve and the 95% confidence interval is copied into Microsoft Excel® for the next step.

  sts graph

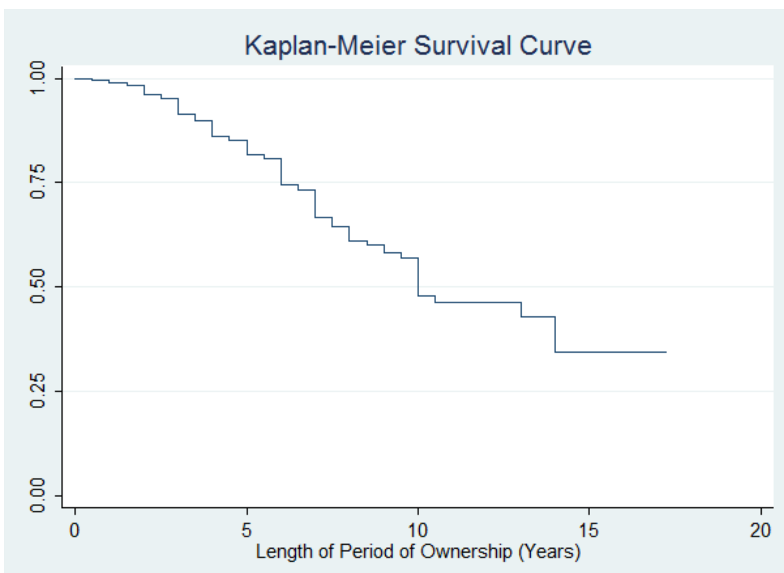

Figure 39: Kaplan-Meier Survival Curve for laptops

- Weibull Regression:

  streg year, dist(weibull)

  This returns the information about the Weibull regression for the laptop dataset. Note that *p* is the scale factor used to model Weibull distributions.

```
Weibull regression -- log relative-hazard form

No. of subjects =         1407                  Number of obs   =       1407
No. of failures =          202
Time at risk    =      5169.75
                                                LR chi2(1)      =      10.84
Log likelihood  =   -533.62163                  Prob > chi2     =     0.0010
```

_t	Haz. Ratio	Std. Err.	z	P>|z|	[95% Conf.	Interval]
year_purchased	.9375928	.0174106	-3.47	0.001	.9040821	.9723456
_cons	1.39e+54	5.18e+55	3.34	0.001	2.56e+22	7.55e+85
/ln_p	.5375423	.059788	8.99	0.000	.4203599	.6547246
p	1.711795	.1023448			1.522509	1.924612
1/p	.5841823	.0349271			.5195851	.6568104

Figure 40: Stata ®Weibull regression analysis for laptops.

stcurve, surviv

This graphs the survival curve based on the Weibull regression; Figure 40 models the K-M survival curve in Figure 38 with the parameters in Figure 39.

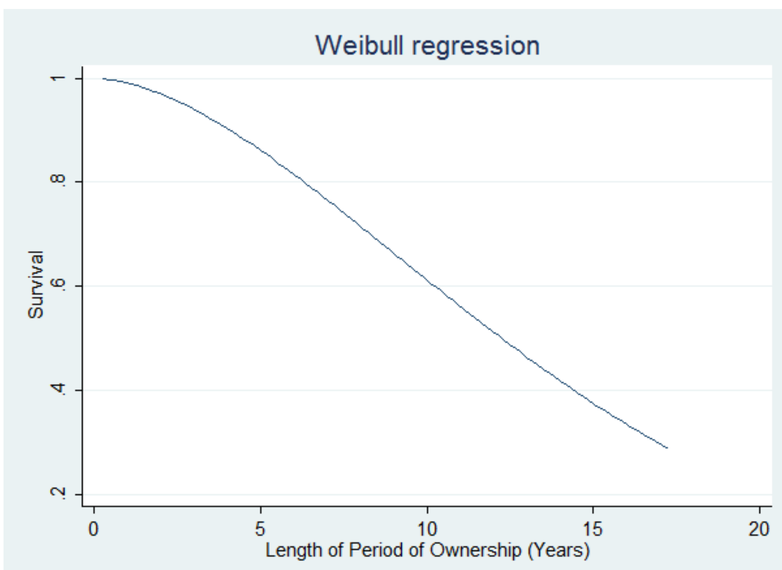

Figure 41: Graph of Weibull regression model for laptops

v. Fit additional parameters for the Weibull regression to the K-M curves.

In order to define a Weibull distribution, both the scale and shape parameter are needed. It is perhaps possible but difficult to extract the shape parameters from the Weibull regression data, and therefore the data from *sts list* is copied into Microsoft Excel ® and the Solver add-in is used to find the shape parameters minimizing the squared error between an inverse cumulative Weibull model and the K-M survivor curves.

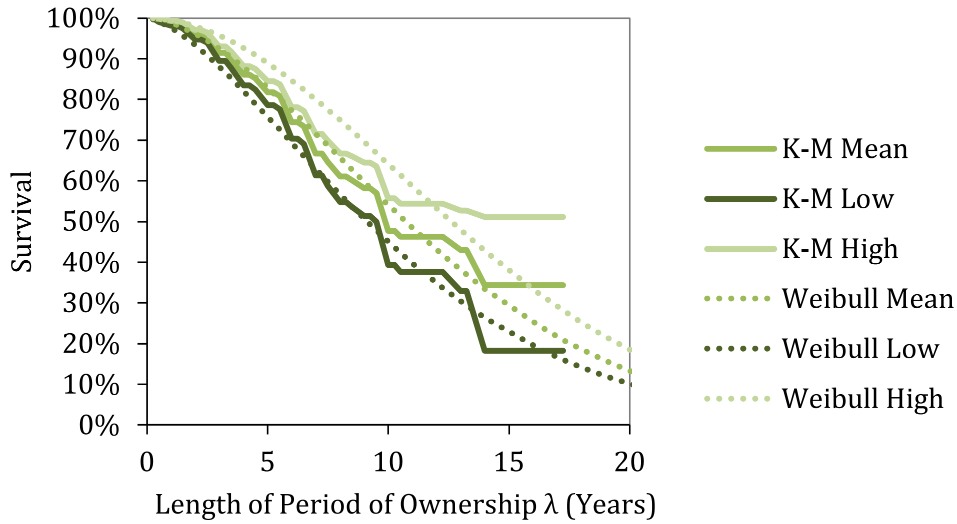

Figure 42: Comparison between K-M curves and OLS fit laptop Weibull regression curves for mean, and low and high bounds of 95% confidence interval.

vi. Transform the results of the Weibull regression into a probability density function, which will be used as the distribution of length of one period ownership.

Using the parameters found through the Weibull regression (scale parameters) and fit with minimum squared error (shape parameters), the lifespan distributions sought for length of one period ownership are modeled with the Microsoft ® Excel Weibull.Dist function.

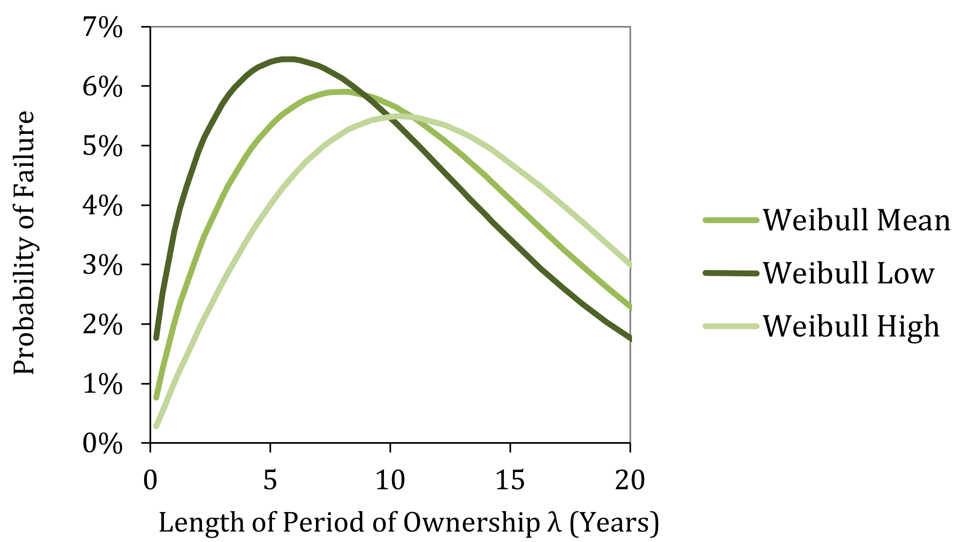

Figure 43: Distribution of laptop length of period of ownership λ

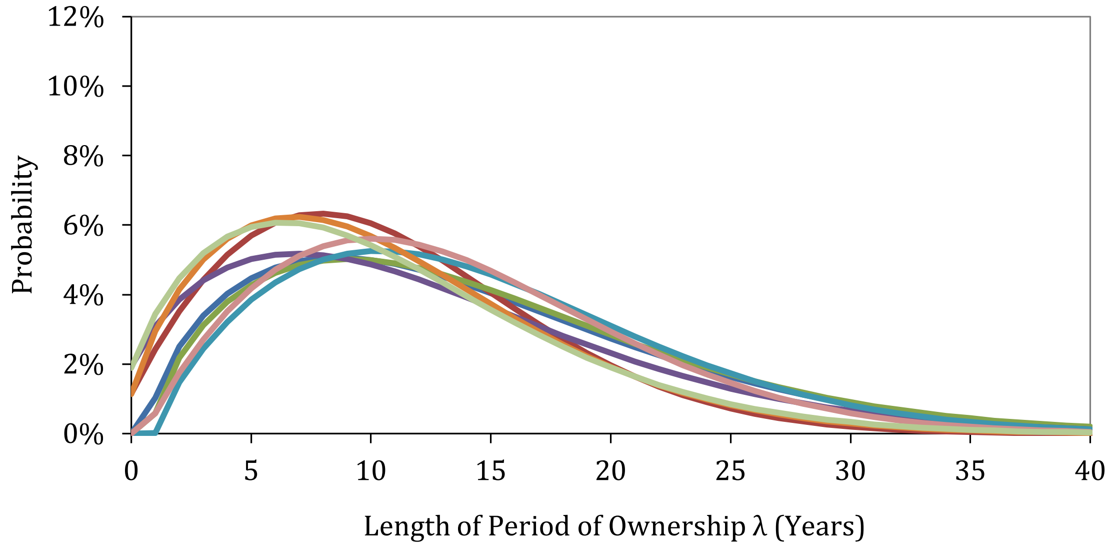

Figure 44: Distributions of laptop length of period of ownership λ allowing variation (random sample)

Another lifespan input to the residential generation prediction model is the distribution of length of time until an electronic is reused. Since not all electronics are reused and those that are tend to be in better condition, the more general period of ownership is likely longer than the time until an electronic is reused. Given the structure of the survey questions, the best approximation is found by modeling the distribution of lifespans of electronics previously "discarded" in the Informal Reuse category (see Figure 44). This does not capture electronics that were sent to recyclers and subsequently reused, nor electronics still in the home which were purchased used. Still, it is a reasonable approximation.

Below in Figure 45 is a histogram of the distribution of length of time until an electronic is reused δ. The mean was allowed to vary +/- 2 years for a margin of error, and the standard deviation was allowed to vary +/- 10% in the Monte Carlo simulation. The survey data are the 100 laptops which were "discarded" for Informal Reuse (see Figure 45). This is input in the generation prediction model.

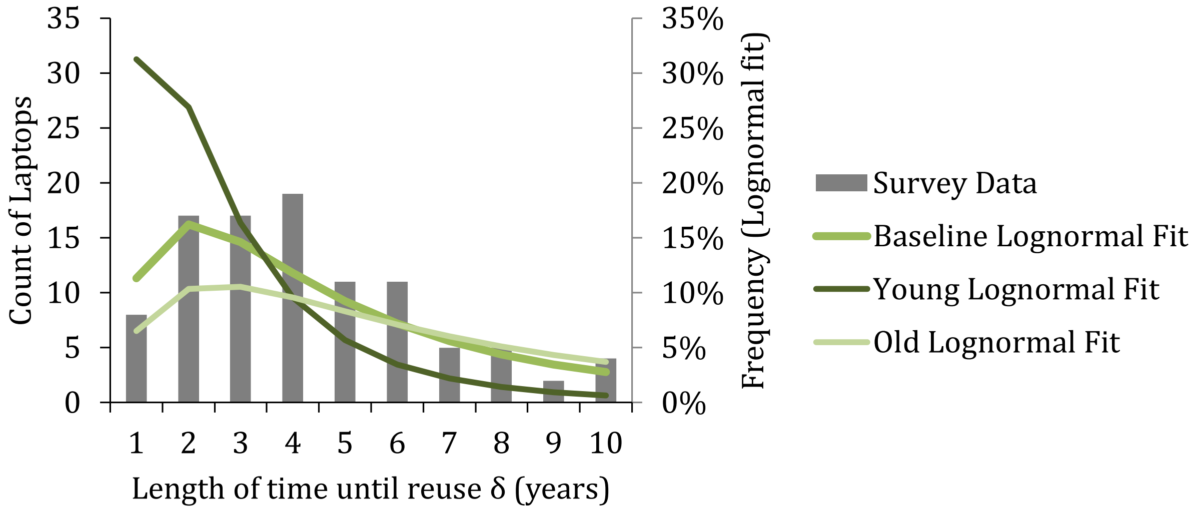

Figure 45: Histogram and fitted lognormal distributions of length of time a laptop is with an owner until informal reuse δ

6.1.1.2.2.2 Residential Computers and Monitors: Calculate how many residential products are predicted to be generated in a given year using the sales and lifespan information

The goal of this step is to estimate how many residential products are generated in a given year and so which "discard" activities lead to generation is defined first; as with the literature method, informal reuse is not considered generation (see Figure 36). Next, the approach is to model the quantity of electronics that are only used once before generation (O), those that are informally reused before generation (I), and that are formally reused after a first round of generation and collection (C). Using Figure 45 from the literature-based method, the quantity generated in each year y was modeled, with the starting year for the period of ownership of reuse purchases (I and C) shifted by the distribution of length of time until an electronic is reused. The same length of period of ownership λ was applied to used and new products given data constraints related to the survey questions; ideally there would be separate distributions since used products likely have a shorter functional use period.

In order to determine in which year y each group (O, I, and C) is likely to be generated, it is assumed that reuse purchases (I and C) in a given year s are strongly correlated with new sales in the same year s. It makes sense that popularity of used products trends with the popularity of new products. The ratios β of used to new purchases in the survey data from 2000 to 2010 were modeled in order to capture this phenomenon. The next step was to approximate the fraction α of used purchases that occurred through informal reuse (I) as compared to formal reuse after generation and subsequent collection (C). Lastly, all of the new purchases in a given year were assumed to undergo one use before generation (O) less those which are predicted to be informally reused in future years (I). The total of these three groups is shown simply in Equation 6.

Equation 6: Total Residential Generation of Used Electronics in Year y

$$Generated(y) = Generated_O(y) + Generated_I(y) + Generated_C(y)$$

6.1.1.2.2.3 Residential Computers and Monitors: Calculate how many of the residential generated products are predicted to be collected in a given year by applying residential collection rates

This step is methodologically similar to that used in the Literature-based method; the calculation follows Equation 3 (repeated below for convenience). The difference is that the source of the residential collection rates calculated solely from survey results, including the Kahhat and Williams [25] study. There were six different representative groups of US Residential computer owners from 2005 to 2012; some surveys covered two years[28, 33-35]. To account for uncertainty in the survey data and regression, the estimated collection rate for a given year were allowed to vary +/- 10% in the Monte Carlo simulation. Figure 46 below provides the results for laptops [28, 33-35].

Equation 3: Quantity collected for processing in year y

$$Collected(y) = Generated(y) * P(F')$$

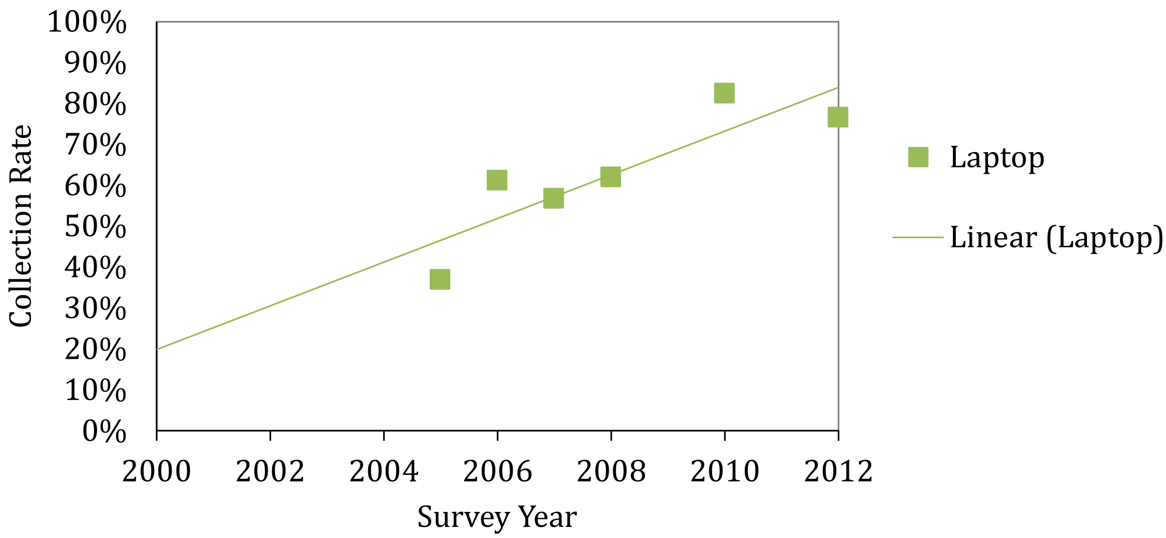

Figure 46: Estimated US residential used laptop collection rates across several surveys.

6.1.1.2.2.4 Business/Public Computers and Monitors and TVs Generation and Collection Survey-based Steps

As a reminder, the residential survey asked about each item, while the business/public survey asked about groups of items. Therefore, the business/public generation and collection steps are a more simplistic extrapolation based on survey and sales data. A final question in the surveys ask basic questions about the disposition of a broad set of used electronics. For TVs, generation and collection results are extrapolated from these responses. In this approach, the responses to survey questions about most recent purchases in year 2010 were tabulated; note that because this question asked about most recent purchases, there is not a full time series of purchases. A Scale Factor for year 2010 was found for each product (laptops, desktops, CRT and Flat Panel monitors) using Equation 7.

Equation 7: Scale Factor for Business/Public Generation and Collection steps

$$Scale\ Factor(2010) = \frac{Sales(2010)}{Survey\ Purchases(2010)}$$

Both inputs to the equation were allowed to vary in a Monte Carlo simulation; the Sales to varied +/- 10% and the Survey data to vary within the bounds of the survey confidence interval (+/- 5%). Since the Scale Factors differed somewhat for each product, due to inaccuracies in either the survey or the sales data, an average mean, minimum and maximum Scale Factor across laptops, desktops, and Flat Panel monitors was found and applied to all products. Sales date reported no sales of CRT monitors in 2010, and therefore the Scale Factors was 0, which brought the overall average down. Table 10 below presents the scale factors by product, and in comparison to a scale factor based on surveyed employees at facilities and total employees; the product scale factor is much lower than the employee scale factor, which may be because surveyed businesses have computers whereas many companies do not.

Table 10: Business/Public 2010 Computer and Monitor Scale Factors

Scale Factor	Mean	Min	Max
Desktop	922	837	1,006
Laptop	1,385	1,258	1,511
Flat Panel Monitor	891	809	973
CRT Monitor	0	0	0
Product Average	**799**	**726**	**873**
Employee	*1,878*	*1,706*	*2,050*

To arrive at 2010 generation and collection estimates, the reported 2010 generated and collected products tabulated from survey were multiplied by the Scale Factors, as shown in Equation 8 and Equation 9. The Scale Factors were allowed to vary between the minimum and maximum values in a Monte Carlo simulation.

Equation 8: Business/Public 2010 Generation

$$Generated(2010) = Scale\ Factor(2010) * Survey\ Generated(2010)$$

Equation 9: Business/Public 2010 Collection

$$Collected(2010) = Scale\ Factor(2010) * Survey\ Collected(2010)$$

6.1.2 Data and Intermediate Results

6.1.2.1 TVs

To quantify generation and collection of used TVs, Literature-based Method B, Survey-based Method, and Stock and Flow models are used.

6.1.2.1.1 Sales

Several sources offer shipment or sales data as shown in Table 11. Shipments here refer to manufacturer shipments into the channel, while sales refer to actual transactions with end users. Sales are therefore expected to be somewhat lower than shipments. Sales data is more representative of the products available for use and subsequent generation.

Table 11: Sales Data Sources for TVs

Source	TVs type	Data Type	Owner Type	Purchase Years Available
Urban, et al., 2011 (CEA data)[36]	Color CRT Monochrome CRT Flat Panel Projections	Sales	Combined	2000-2010
EPAa, 2008 [8] EPAb, 2011[9] (CEA & IDC data)	Color CRT Monochrome CRT Flat Panel Projections	Sales	Combined	1980-2006 (CEA) 2007-2011 (IDC)
Euromonitor, 2012[37]	Analog Digitals (LCD/LED/PDP/Other)	Sales	Combined	2004-2016
US Census Bureau (2012)[I]	Combined	Domestic Manufacturer Shipments	Combined	2009

There are three data sources to get the sales data, and it is necessary to evaluate the uncertainty and make necessary adjustments. The sales data in years 2000-2010 was allowed to vary one standard deviation from the mean of the three data sources in the Monte Carlo simulation. The sales data in surrounding years (before 2000 and after 2010) with a single CEA data source were allowed to vary uniformly one standard deviation from the mean, by given an approximate 10% of Correlation of Variances (COV).

Figure 47 and Figure 48 display the TVs sales estimates considered, as well as the modeled mean. Based on the data availability, the TVs have separated into CRT TVs (Analog TVs, Color and Monochrome TVs) and Flat Panel TVs (LCD, LED, PDP, Projections and other Digital TVs).

[I] US Census data, Shipments of Consumer Electronics: 2009 and 2008, Available at: http://www.census.gov/compendia/statab/cats/manufactures.html

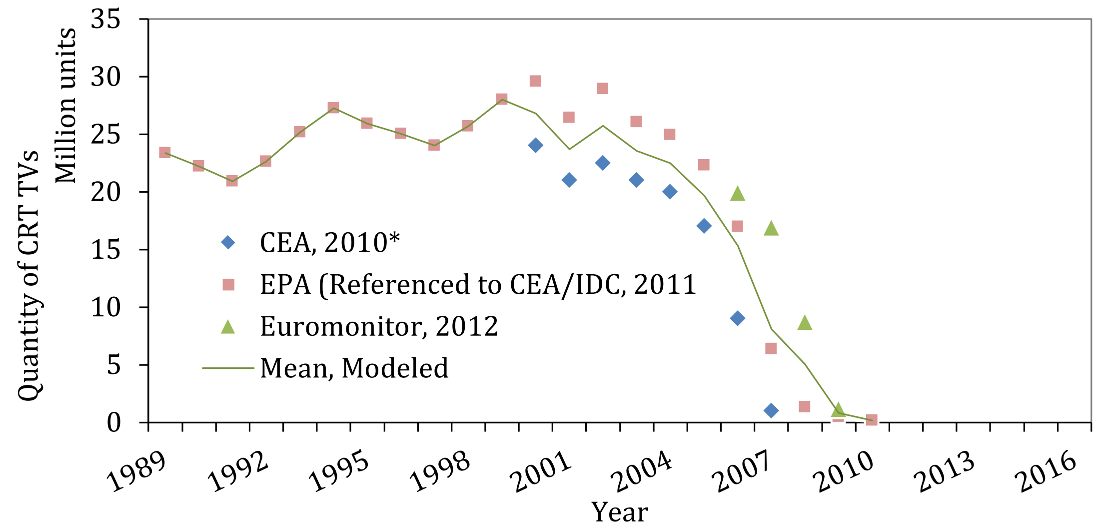

Figure 47: CRT TVs Sales Estimates for Various Data Sources, Model Parameters

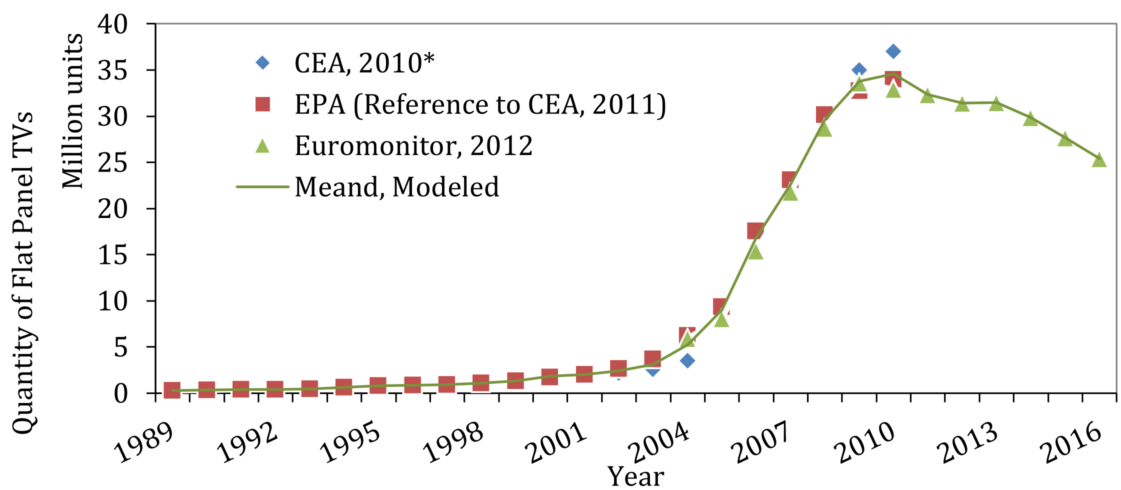

Figure 48: Flat Panel TVs Sales Estimates for Various Data Sources, Model Parameters

If it is required to model each owner type's generation separately, sales need to be modeled by owner type as well. Different to computers, the residential consumers dominate the market for the TVs. Of the available sales data sources consulted, there is no data source distinguished by owner type.

6.1.2.1.2 Lifespan

Ideally, lifespan stage assumptions would be disaggregated by TVs type, owner type, and purchase year and distinguishing first use, reuse, and storage. Table 12 presents the sources used. Many estimates do not differentiate between CRT and Flat Panel TVs. Some model generated TVs using static lifespans, while others account for shifting trends in lifespans. "Total life" refers to lifespan stages until generation.

Table 12: Lifespan Data Sources

Source	TV Type	Owner Type	Years	Lifespan stages
Aoe, 2003[38]	CRT and Flat Panel	Combined	2002	Total life time
Feng & Ma, 2009[39]	Combined	Combined	2009	Total life time
Liu et al., 2006[40]	Combined	Combined	2005	Total life time
Milovantseva and Saphores, 2012[41]	Combined	Combined	2010	Total life time
Consumer Reports, 2006[42]	Combined	Combined	2005	Total life time
US EPA, 2008 & 2011[8, 9]	CRT and Flat Panel	Combined	1980-2010, Static	Total life time
Kahhat and Williams, 2012[11]**	CRT Flat Panel	Residential	2008	Initial lifespan and initial storage life span

*** US National survey in 2008. More detailed data is available just based on internal data sharing.*

Lifespans were modeled separately for the following TVs types: CRT and Flat Panel. Therefore, the relevant estimates for each TV type from Table 13 were included in the development of lifespan stage length estimates.

With a goal of modeling generation in year 2010, the analysis included lifespan stage estimates from twenty one years prior in 1989, which allows for a generous total lifespan of TVs purchased in 1989. Because most of the data sources only reported the total life span and do not differentiate the TVs type, lifespan stage estimates for each TV type were only included the survey data provided by Kahhat and Williams. The mean μ and standard deviation σ for each lifespan stage for each TV type are shown in Table 14.

Kahhat and Williams conducted a national survey (with 1000 questionnaires) to investigate use of electronics (TVs, Mobile phone and Computers) in 2008, including the evaluation of the initial use lifespan (How often is the device replaced?) and initial storage lifespan (How long have you kept unused devices before discarding them). The initial use lifespan is separated into the lifetimes of: less than 1 year, 2 years, 3-4 years, 5-10 years and above 10 years; and, the initial storage lifespan was separated into the lifetimes of: less than 3 months, 1 year, 2-3 years, 4-5 years and above 5 years. Based on the frequencies fell into various scopes of the lifetime, the goodness of distribution fit has been evaluated for the initial use lifespan and initial storage lifespan, respectively. Both the μ and σ are derived from the lognormal distribution fit, which is ranked by one of the best fit. The lognormal distribution has also been widely accepted to represent real situation of the use behaviors. However, there are not surveys data related to the domestic reuse and reuse storage lifetime, which are assumed to be half of the initial use time and initial storage time respectively.

Table 13: Modeled Lifespan Stage Lengths (Years)

TVs		B. Initial Use	D. Initial Storage*	C. Domestic Reuse	E. Reuse Storage
CRT	μ	8.01	1.69	4.01	0.85
	σ	3.09	2.29	1.55	1.15
Flat Panel	μ	6.12	1.69	3.06	0.85
	σ	2.90	2.29	1.45	1.15

** There were only surveys data for initial use lifespan for the Flat Panel TVs, the initial storage for Flat Panel is therefore assumed to be the same to CRT TVs.*

Table 14: Probability of Paths Leading to Generation (CRT TVs)

Source	Scope	Storage rate		Reuse rate		Reuse Storage rate*		Collected for processing rate		Reuse rate after processing	
		P(D)	P(D')	P(C)	P(C')	P(E)	P(E')	P(F)	P(F')	P(H)	P(H')
MTI., 2003[43]	WA King County surveys (2003)	17%	83%			9%	92%				
Florida, 2003[44]	Florida survey (2002, 2003)	16%	84%			8%	92%				
Consumer Reports, 2006[42]* **	National Surveys (2005)			46%	54%			40%	60%		
Kahhat and Williams, 2012[11]	National Surveys (2008)			57%	43%			42%	58%		
Kahhat and Williams, 2012	National Surveys (2010) (CRT)	6%	94%	51%	49%	3%	97%	64%	36%		
Kahhat and Williams, 2012	National Surveys (2010) (FP)	3%	97%	46%	54%	1.5%	98.5%	63%	37%		
EPAb, 2011[9]	National Ind. Surveys (2007)									30%	70%
EPAb, 2011[9]	National Ind. Surveys (2010)									33%	67%
Daoud, 2011 (ISRI)[45]	National Ind. Surveys (2011)									19%	81%
Wisconsin DNR, 2012[46]	Statewide Household surveys (2006)			51%	49%			30%	70%		
Wisconsin DNR, 2012[46]	Statewide Household surveys (2010)			64%	36%			68%	32%		
CCGI., 2008 (WA)[43]	County surveys (2005)			41%	59%			38%	62%		
CCGI., 2008 (WA)[43]	County surveys (2007)			36%	64%			53%	47%		
St. Louis, 2007[I]	City surveys (2007)			51%	49%			51%	49%		
Min		16%		36%		3%		40%		19%	
Max		17%		64%		9%		64%		30%	
Mean		13.0%		49.6%		6.5%		48.3%		27.3%	
Standard Deviation		6.1%		8.8%		3.0%		13.2%		7.4%	

Reuse Storage rate is assumed half of Initial Storage rate; ** Detailed surveys data (2008 and 2010) are provided by the Kahhat and Williams in terms of informal sharing, and the TVs include the CRT and Flat Panel(FP),, all of the other sources do not differentiate the TVs type;* While it is unclear whether the TVs comprise both the CRT and FP, we assumed CRT TVs dominated the generation in 2006.*

[I] St. Louis, 2011, Citywide Residential Recycling Telephone Survey in 2007 Available at: http://stlouis-mo.gov/government/departments/street/refuse/recycle/recycling-survey.cfm

The values of P(D), P(C), P(E), P(F) and P(H) applicable to the TVs types were allowed to uniform distribution in the Monte Carlo simulation of $Generated(y)$. Complements P (D'), P (C'), P (E'), P (F') and P (H') are found by taking the difference with 100%.

The probabilities of each pathway P (ϖ) and mean total lifespan lengths $\mu_{Total,\varpi}$ by TVs type are in Table 15. Similarity across TVs types for P (ϖ) reflects the absence of specific probability estimates for each TVs type.

Table 15: Mean Probabilities and Mean Total Lifespans of 6 Paths to Generation

Scope	CRT TVs		Flat Panel TVs	
	P(ϖ)	$\mu_{Total,\varpi}$	P(ϖ)	$\mu_{Total,\varpi}$
Path 1 (ϖ=1)	6%	9.7	5%	7.8
Path 2 (ϖ=2)	6%	13.7	5%	10.9
Path 3 (ϖ=3)	1%	15.3	0.5%	12.5
Path 4 (ϖ=4)	44%	8.0	45%	6.1
Path 5 (ϖ=5)	46%	12.0	47%	9.2
Path 6 (ϖ=6)	4%	13.7	4%	10.9

6.1.2.1.3 Literature-based Method B: States Collection Program

There are some works going on around the country to promote the used electronics waste recycling, including 25 states passing laws on e-waste recycling, of which most have passed the disposal ban[I].

Most of the states with the electronics waste regulation have a system modeled after the EU approach called Extended Producer Responsibility (EPR), which requires the manufactures to pay for electronics recycling costs. California instead utilizes an Advanced Recovery Fee (ARF), which concentrates on consumers of electronics.

Therefore, the states of the US have been classified into two groups for estimation on the collection rate for the year of 2010:

- States with program: The states with mandate recycling regulation, disposal ban or both in 2010;
- States without program: The states without (or ineffective) regulations and disposal ban in 2010.

The collection rate is based on the statewide electronics waste or municipal solid waste statistic reports or surveys. While most of states with programs have reported the data of total electronic waste collection for one or several of the past years, only a few

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[I] Sustainable Electronic Initiative (2012), Summary of US. State Laws on Electronic Waste and Disposal, Banshttps://ideals.illinois.edu/bitstream/handle/2142/16301/State%20Legislation_May09.pdf?sequence=2 states report breakdowns by product type, shown in Table 16 [47]. Many states do not yet have 2010 data. No states reported mobile phone or laptop collection data.

Table 16: Statewide Used Electronics Collection (lbs) for Those States with Statistics in 2010

State	Population Fraction	Used Electronics	TVs	Desktop	Monitor
California	12.1%	193,720,571			
Hawaii	0.4%	3,237,516			
Illinois	4.2%	30,151,985			
Maine	0.4%	5,366,578	3,960,387		1,208,586
Maryland	1.9%	17,031,978			
Minnesota	1.7%	34,316,395			
Missouri	1.9%	2,215,903			
North Carolina	3.1%	9,154,064			
Oklahoma	1.2%	5,514,486			
Oregon	1.2%	24,174,077	14,972,860	2,897,973	6,520,439
Rhode Island	0.3%	2,820,880			
Texas	8.2%	24,391,194			
Virginia	2.6%	4,480,573			
Washington	2.2%	39,809,277	24,969,639	3,759,919	10,738,240
West Virginia	0.6%	1,646,155			
Wisconsin	1.8%	20,643,759			

To make fair comparisons, it is important to know that these programs are not all accepting the same products, and some collect from more than just households. Thus, the collection rate $P(F)$ shown in Equation 10 for several states report which breakdowns by product type (TVs and computer products) have been selected to represent the collection rate for group (with program) The generation of the specific electronics type in the US refers the estimation for the EPA report (USEPA, 2011).

Equation 10

$$P(F) = \frac{Collection_{State}}{Generation_{US} * \frac{Population_{State}}{Population_{US}}}$$

So far, there is almost no state without program which has reported the collection number. However, some of the states from two groups have reported the disposal quantity of the electronics within their statewide municipal solid waste composition characterization reports during the past several years, shown in Table 17.

Table 17: Statewide Used Electronics Disposal Rate, Percentage of MSW Disposal Weight

States	Report Year	Program in Report Year?	TVs and Monitor	Mobile phone	Computer Related	Used Electronics Total*
California[48]	2008	With program	0.20%		0.10%	0.50%
California[49]	2003		0.60%		0.30%	1.20%
Maine[50]	2011					0.92%
Maryland[51]	2009					1.80%
Massachusetts[52]	2010		1.10%		0.90%	4.10%
New York State[I]	2010					1.40%
Oregon[53]	2009		0.38%		0.08%	1.53%
Washington[54]	2009		0.70%		0.10%	1.50%
Connecticut[55]	2009	Without program	1.00%		0.40%	2.10%
Delaware[56]	2006					1.50%
Florida[57]	2007					2.70%
Georgia[58]	2005		0.10%		0.10%	2.00%
Illinois[59]	2008		0.20%		0.40%	1.30%
Indiana[60]	2009		0.11%	0.02%	0.14%	1.23%
Iowa[61]	2011		0.30%	<0.01%	0.40%	2.30%
Iowa[62]	2005		0.04%	<0.01%	0.15%	1.70%
New York City[63]	2004		0.15%	<0.01%	0.19%	0.85%
Oregon[64]	2005		0.54%		0.30%	1.98%
Oregon[65]	2002		0.67%		0.32%	1.91%
Pennsylvania[66]	2001					1.50%
South Dakota[67]	2007		0.15%	0.01%	0.24%	2.91%
Tennessee[68]	2008					1.66%
Wisconsin[69]	2009		0.60%		0.30%	2.60%
Wisconsin[70]	2001		0.70%		0.10%	2.50%

** Some of the state's report also includes the characterization of other electronics, e.g., large home appliance and miscellaneous small electronic and electric products.*

Based on Table 17, there is some evidence to suggest that the two groups have a similar disposal rate of the TVs per capita. The t-test on the disposal rate also shows that there is no significant difference between the means of the two groups. If we assume the generation of the electronics for the two groups are consistent, the collection rate of the electronic waste should be similar. We therefore assumed the collection rates for two groups are the same, although we recognize that this does not account for the possibility that in states without programs there could be more storage, and owners delay taking action on their used electronics until a program arises.

Aside from the governmental Extended Producers Responsibility (EPR) and Advanced Recycling Fee (ARF) recycling program, some manufacturers, retailers, service providers and some small recyclers are making the effort to take back used electronics beyond what the laws require. That means many firms, non-government agencies and non-profits are actively promoting recycling, and community collection events are common in

[I] MSW Materials Composition in New York State, http://www.dec.ny.gov/chemical/65541.html many areas[I]. Table 18 summarizes the potential approaches for the TV recycling. Due to the unavailability of data for most of the paths, the collection rate based on state recycling which is used is expected to be an underestimate of the total collection rate. Table 19 summarizes the collection rates by two approaches.

Table 18: 2010 TVs Collection Approaches Evaluation

Collection Path	Examples	Data characterization		
		Data availability	Breakdown products	Historical data
Government mandated	States with EPR or ARF programs	Most States	Only a few states	Only a few states
Manufacturer	Dell, Apple, Samsung, Lenovo, etc.	Few	No	Very few
Retailers	Best Buy, Staples, Lowes, Office Depot, etc.	Few	No	Very few
Service providers	Verizon, AT&T, etc.	Few	No	No
Handlers	Recycler, Repairer/Refurbisher, etc.	Few		No
Donation & Reuse options	Charity America, Goodwill Industries, Serious Good, etc.	No		No
Drop-off & Mail-In	Community collection event	No		No

6.1.2.1.4 Survey-based Method

Based on the national surveys conducted by Consumer Report (2006)[42], surveys in 2008 and 2010 by Kahhat and Williams shown in Table 14, it was found that 40% and 60% of the used TVs have been collected for processing in 2006 and 2010 respectively. While the surveys had been conducted by different researches, the results are still comparable. The values of P(F) applicable to the TVs were allowed to vary within reasonable bounds of a uniform distribution in the Monte Carlo simulation of $Collection\ (y)$. Table 19 summarizes the collection rates found by the two approaches.

Table 19: 2010 TVs Collection Rates

	States group	Product	Mean	Min	Max
Literature-based Method B	States with program	All TVs	47%	40%	54%
	States without program	All TVs	47%	40%	54%
Survey-based Method	National	CRT TVs	49%	40%	64%
	National	Flat Panel TVs	62%	57%	65%

[I] Electronics TakeBack Coalition, 2011. E-waste export legislation is the most important action the federal government can take on e-waste problem. Available at: http://www.electronicstakeback.com/2011/06/23/e-waste-export-legislation/

6.1.2.1.5 Stock and Flow Model for Modeling TVs Generation

6.1.2.1.5.1 Methodology

Besides using sales obsolescence model to quantify the generation of used electronics, there is another potential method to estimate the generated quantity in a given year *n*, which is expressed in Equation 11. Muller et al. (2009) presented a similar equation. This method is useful when both the sales data and stock data are available.

Equation 11

$$Generated_n = Sales_n - (Stock_n - Stock_{n-1})$$

6.1.2.1.5.2 Stock data

Two sources of residential TV stock data were found to provide the stock data, though both are based on TV Basics (2012)[I] citing Nielsen 2010. The installed base estimate is from the report directly, while the possession in the home estimate combined US census data in 2009[36] , Florida Electronic Residential Survey in 2003, and the penetration is from Nielsen survey (TV Basics 2012). The stock data does not differentiate the type of TVs between CRT and Flat Panel. Figure 49 presents the trends over time change. Because there is minor difference between the Installed base and possession, thus we used the average value to represent the stock of TVs in the US home. Accordingly, the historic generation for the TVs can be estimated.

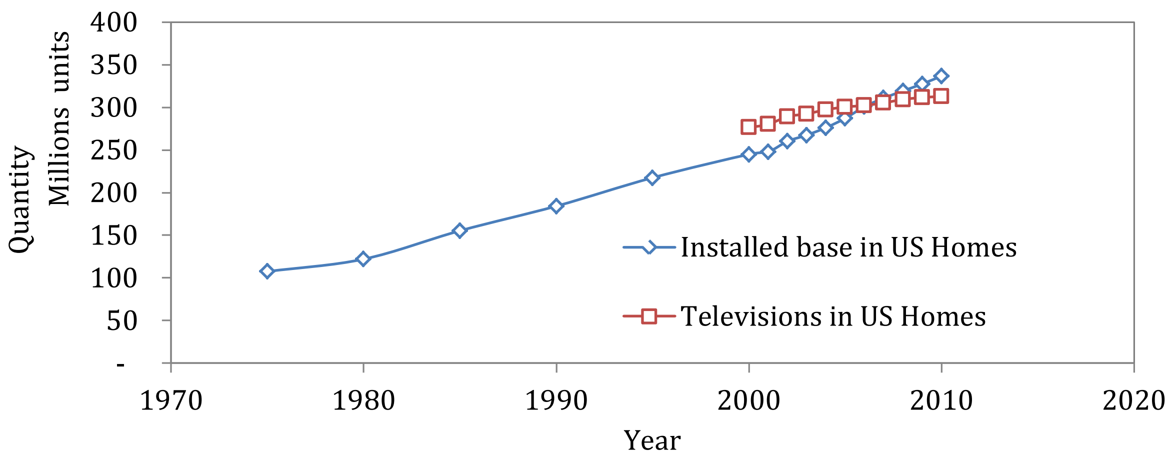

Figure 49: TVs in US Homes

6.1.2.1.5.3 Results and Comparison

Figure 50 presents a comparison of this study's TV generation found with the Sales-Obsolescence model in Literature-based Method and Stock and Flow model and EPA estimates. The results are all comparable. This suggests that though there is not readily available stock data for other products, this study's Literature-based Method is valid for generation estimates.

[I] Television Bureau of Advertising, Inc. (2010, TV Basics), http://www.tvb.org/media/file/TV_Basics.pdf

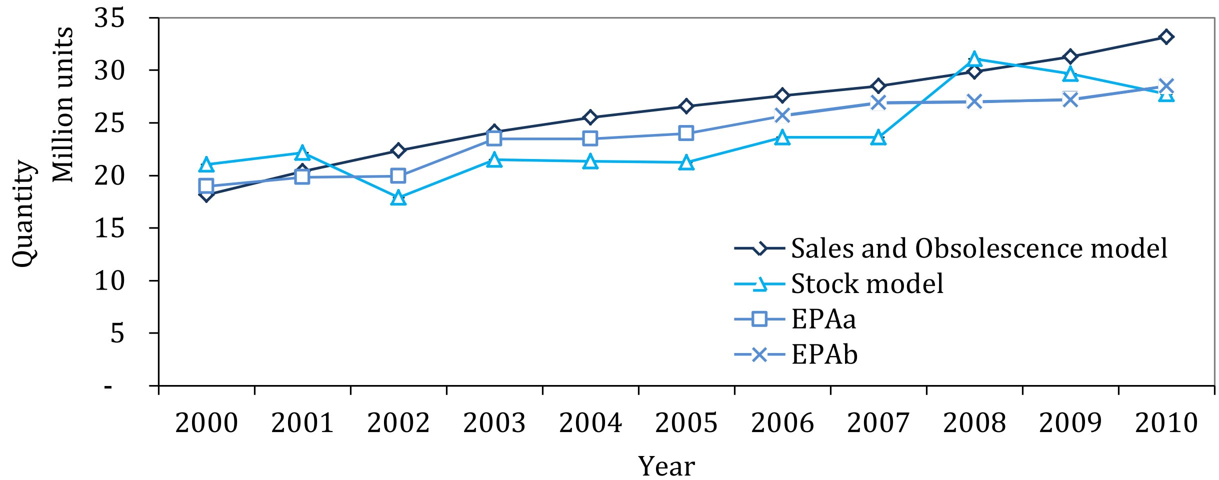

Figure 50: **Comparison of the Generated Used TVs with Various Models**

6.1.2.1.6 Unit Weight

In order to quantify the generated, collected and exported used electronics in weight, the unit weight data is multiplied by the quantity. While recent collection data from Washington and Oregon was used for computers and monitors, the TV data did not differentiate between CRT TVs and Flat Screen TVs. Therefore, the unit weight data for TVs are taken from the US EPA report (EPAb, 2011): Electronics Waste Management in the United States Through 2009. Below is an excerpt of the method.

> "To convert the number of electronic products sold into tonnages sold for each model year, we collected data on the typical weight of individual electronic products by model year. Data from the Florida Department of Environmental Protection (DEP) were used to develop weight estimates for desktop CPUs, hard-copy devices, PC Flat Panels, and CRT TVs prior to 2008. For the remaining categories, estimates were taken from Consumer Reports Annual and Monthly Buying Guides (from 1984 to 1999) and online information. We updated unit weight data for desktop CPUs, portables, multi-function devices, mobile devices, and flat-panel TVs in the 2008, 2009, and 2010 model-years using 2008 and 2009 Consumer Reports Buying Guides and online manufacturer specification sheets.1 For each type of product, we sampled weights across a range of model sizes to calculate a typical weight. We were unable to calculate a sales share-weighted average weight for each product, however, because the data on the sales share of individual models within each type of product were not available."

6.1.2.1.7 Sensitivity Analysis

The assumptions that contributed most to the variance, represented by error bars in Figure 7, are shown in Figure 51. for generation estimates and collection estimates.

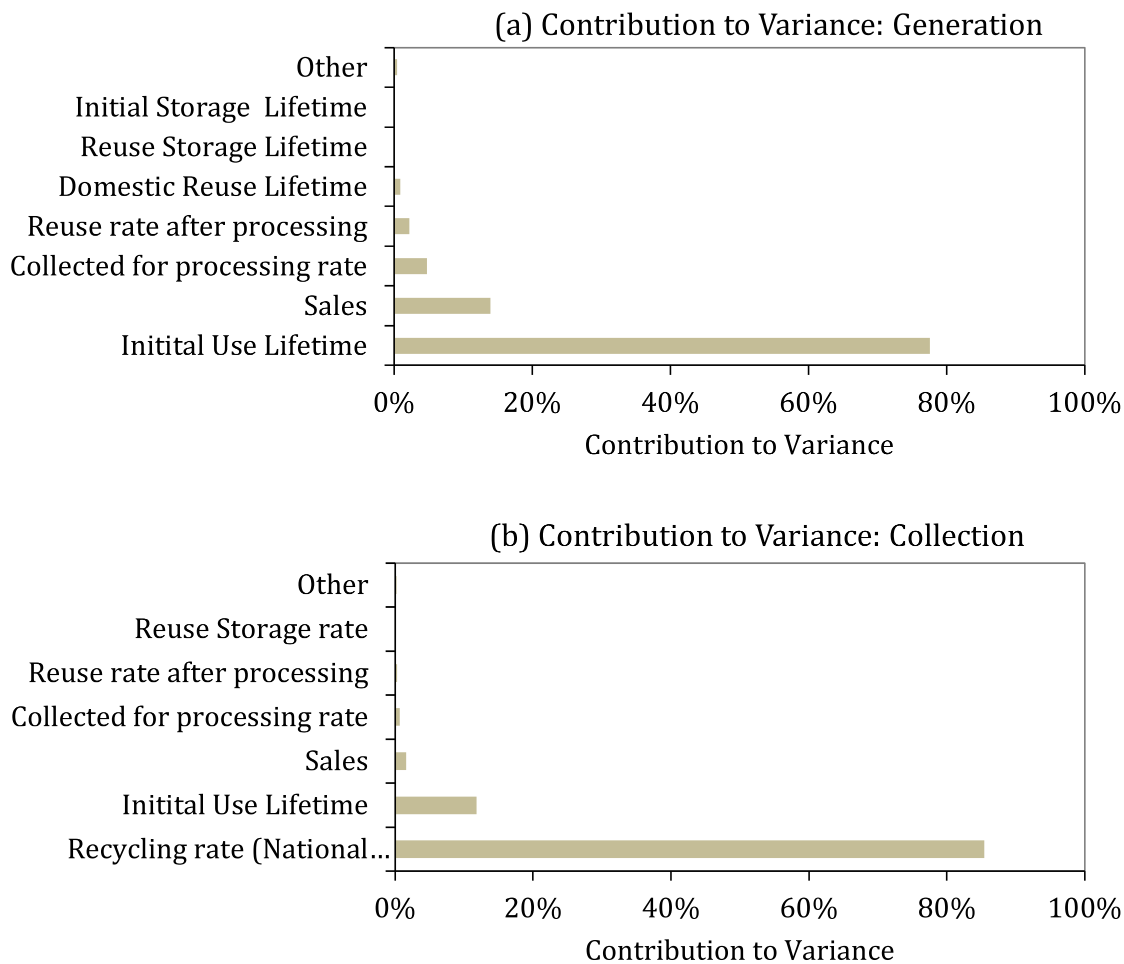

Figure 51: Contribution to Variance of Generation and Collection Estimates of Used CRT TVs in 2010

The major contributors were the length of the initial use lifespan stage and the sales estimate. This suggests that for tighter generation estimates, tighter use lifetime estimates should be a top priority, followed by more accurate sales data estimates. As one would expect, the collection rates were the top driver of variance in the collection estimates, followed by the same drivers for the generation estimates.

6.1.2.2 Mobile Phones

To quantify generation and collection of used mobile phones, Literature-based Method A is used.

6.1.2.2.1 Sales

Several sources offer shipment or sales data as shown in Table 20. Shipments here refer to manufacturer shipments into the channel, while sales refer to actual transactions with end users. Sales are therefore expected to be somewhat lower than shipments. Sales data is more representative of the products available for generation.

Table 20: Sales Data Sources for Mobile phone

Source	Data Type	Owner Type	Purchase Years Available
EPAb, 2011[9] (Inform Inc. data)	Sales	Combined	1995-2014
EPAb, 2011[9] (IDC data)	Sales	Combined	2004-2009
IDC, 2011[71]	Sales	Combined	2010-2015
Urban, et al., 2011 (CEA data)[36]	Sales	Residential	1985-2004
Euromonitor, 2012[72]	Sales	Residential	2004-2016
USITC, 2010 (TIA data)[73]	Sales	Residential	2004-2008
US Census Bureau (2012)[I]	Domestic Manufacturer Shipments	Combined	2007-2011

The mobile phone sales have been separated into Residential and Business/Public owner types in order to model generation by owner type. Business/Public sales were assumed to be the remainder of Combined sales less Residential sales. In years where there were multiple data sources, the mean and standard deviation of the sale quantity were found. In years with a single data source, the mean was allowed to vary 10% in a Monte Carlo simulation. Figure 52 and Figure 53 display the mobile phones sales estimates considered, as well as the modeled mean.

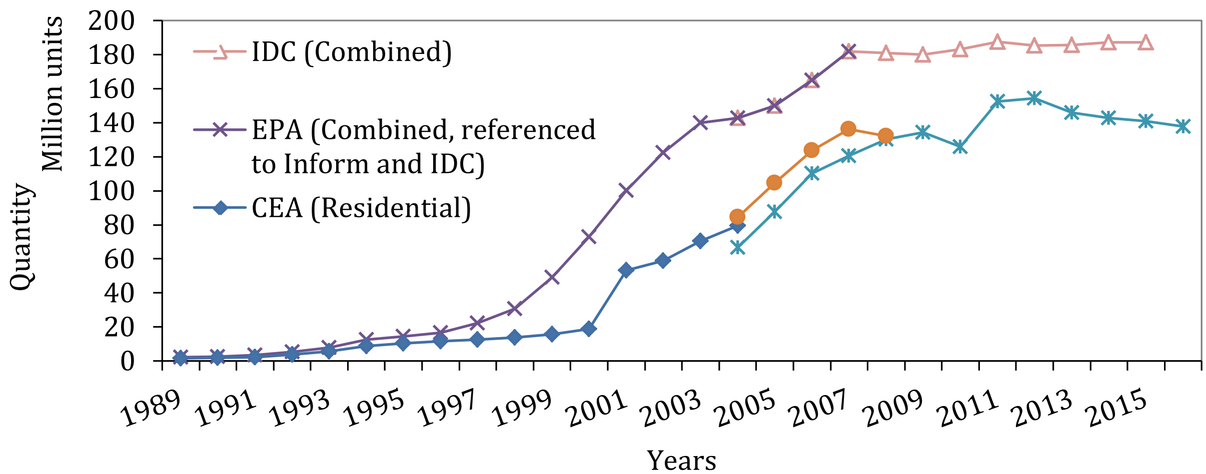

Figure 52: Mobile Phone Sales Estimates for Various Data Sources

[I] US. Census Bureau, Telecommunications – Summary. 2010http://academicarchive.snhu.edu/bitstream/handle/10474/2007/mq334p105.pdf?sequence=1

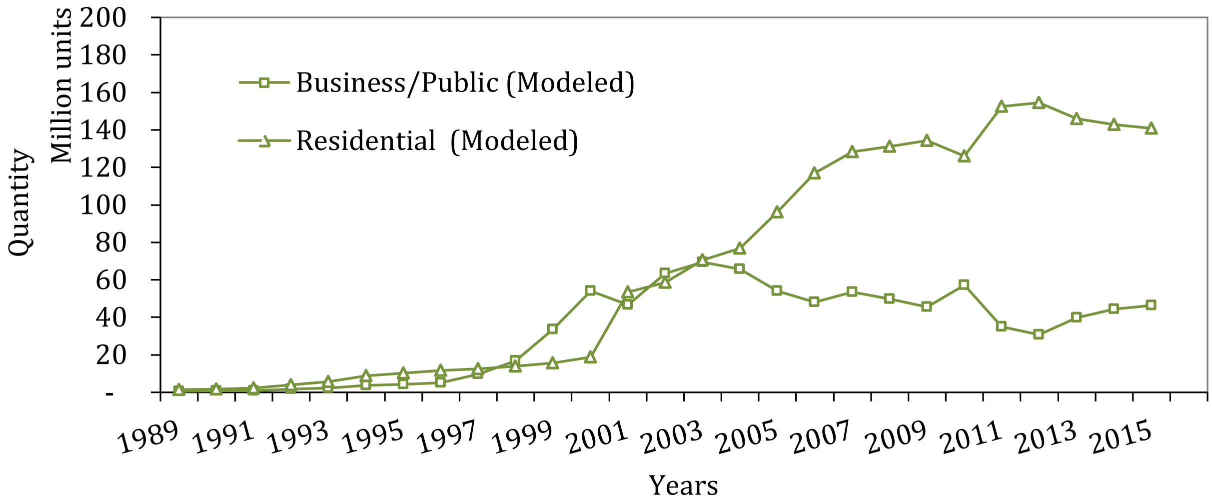

Figure 53: Mobile phone Sales Estimates for Model Parameters

6.1.2.2.2 Lifespan

Ideally, lifespan stage assumptions would be disaggregated by owner type, purchase year, and lifespan stage (first use, reuse, and storage). Table 21 presents the sources used. Many estimates do not differentiate between residential and business/public owner types. Some model generated mobile phone using static lifespans, while others account for shifting trends in lifespans.

Table 21: Lifespan Data Sources

Source	Owner Type	Years	Lifespan stages
Jang and Kim, 2010[74]	Combined	2002	Time until generation
Yu et al., 2010[75]	Combined	2009	Time until generation
Polak and Drapalova, 2012[76]	Combined	2005	Time until generation
Wilhelm et al., 2011[77]	Combined	2010	Initial use
2011, USEPA[9]	Combined	1980-2010	Time until generation (static estimate across all years)
ISG, 2010[78]	Combined	2007	Initial use, initial storage life span
Kahhat and Williams, 2012[11]	Residential	2008	Initial use, initial storage life span

Lifespans were modeled as the same for residential and business/public owner types. Therefore, the relevant estimates from Figure 44 were included in the development of lifespan stage length estimates.

Because most of the data sources only reported the total life span and do not differentiate the owner type, lifespan stage estimate was only included the survey data conducted by Kahhat and Williams in 2008. The mean μ and standard deviation σ are shown in Table 22.

Kahhat and Williams conducted a national survey with 1,000 questionnaires to investigate use of electronics (TVs, Mobile phone and Computers) in 2008, including the evaluation of the initial use lifespan (How often is the device replaced?) and initial storage lifespan (How long have you kept unused devices before discarding them). The initial use lifespan is separated into the lifetimes of: less than 1 year, 2 years, 3-4 years, 5-10 years and above 10 years; and, the initial storage lifespan was separated into the lifetimes of: less than 3 months, 1 year, 2-3 years, 4-5 years and above 5 years.

Both the μ and σ are derived from the lognormal distribution, which is ranked to be one of the best fit. Besides the Weibull distribution, the lognormal distribution has also been widely accepted to represent real situation of the use behaviors. However, there are not surveys data related to the domestic reuse and reuse storage lifetime, which are assumed to be half of the initial use time and initial storage time respectively.

Table 22: Modeled Lifespan Stage Lengths (Years)

Mobile phone	B. Initial Use	D. Initial Storage*	C. Domestic Reuse	E. Reuse Storage
μ	2.54	1.7	1.3	1.7
σ	1.5	2.3	0.7	2.3

6.1.2.2.3 Paths to Generation

Following Figure 35 and Table 8, Table 23 presents the sources of these probability estimates and their applicability. None of the studies differentiate the owner types. Thus, the same paths to generation and same collection rates have been assumed for residential and business/public owner types.

Table 23: Probability of Paths Leading to Generation

Source	Scope	Storage rate		Reuse rate		Reuse Storage rate*		Collection Rate		Reuse rate after processing	
		P(D)	P(D’)	P(C)	P(C’)	P(E)	P(E’)	P(F)	P(F’)	P(H)	P(H’)
Consumer Reports, 2006[42]	National Surveys (2005)			57%	43%			58%	42%		
Kahhat and Williams, 2012	National Surveys (2008)			63%	37%			60%	40%		
Kahhat and Williams, 2012	National Surveys (2010)	16%	84%	64%	36%	8%	92%	59%	41%		
EPAa, 2011[9]	National Ind. Surveys (2007)									38%	62%
EPAb, 2011[9]	National Ind. Surveys (2010)									42%	58%
Daoud, 2011[45] (IDC)	National Ind. Surveys (2011)										
Wisconsin DNR, 2012[46]	Statewide surveys (2006)			52%	48%			30%	70%		
Hanks et al., 2008[79]	Univ. Surveys 2006 (IN)	53%	47%			27%	74%				
Wilhelm, 2011[77]	Univ. Surveys 2010 (IL)	67%	33%			34%	67%				
Overall Mean		45%		59%		23%		52%		40%	
Overall Standard Deviation		26%		6%		13%		15%		3%	

The probabilities of each pathway P (ϖ) and mean total lifespan lengths $\mu_{Total,\varpi}$ are in Table 24.

Table 24: Mean Probabilities and Mean Total Lifespans of 6 Paths to Generation

Scope	Mobile phone	
	P(ϖ)	$\mu_{Total,\varpi}$
Path 1 (ϖ=1)	17%	4.2
Path 2 (ϖ=2)	22%	5.5
Path 3 (ϖ=3)	6%	7.2
Path 4 (ϖ=4)	25%	2.5
Path 5 (ϖ=5)	31%	3.8
Path 6 (ϖ=6)	8%	5.5

6.1.2.2.4 *Collection*

Since most of the states do not include the mobile phone into the recycling program or disposal. There is relatively little data from state reports. Thus, only the second method is suitable for the collection rate. Based on the national surveys conducted by Consumer Report (2006)[42], Kahhat and Williams' surveys (2008 and 2010) shown in Table 25, it was found that 57% and 61% of the used mobile phone have been collected for processing in 2006 and 2010 respectively. While the surveys samples are not consistent, the results are still comparable.

Table 25: 2010 Mobile Phone Collection Rates

States group	Mean	Min	Max
Overall (Literature-based Method B)	59%	57%	61%

**The states reports without breakdown owner types.*

6.1.2.2.5 *Unit Weight*

In order to quantify the generated, collected and exported used electronics in weight, the unit weight data is multiplied by the quantity. While recent collection data from Washington and Oregon was used for computers and monitors, mobile phone data was not included since most collection programs do not include mobile phones. Therefore, the unit weight data for CRT TVs and mobile phones are taken from the US EPA report (EPAb, 2011): Electronics Waste Management in the United States Through 2009. Below is an excerpt of the method.

> "To convert the number of electronic products sold into tonnages sold for each model year, we collected data on the typical weight of individual electronic products by model year. Data from the Florida Department of Environmental Protection (DEP) were used to develop weight estimates for desktop CPUs, hard-copy devices, PC Flat Panels, and CRT TVs prior to 2008. For the remaining categories, estimates were taken from Consumer Reports Annual and Monthly Buying Guides (from 1984 to 1999) and online information. We updated unit weight data for desktop CPUs, portables, multi-function devices, mobile devices, and flat-panel TVs in the 2008, 2009, and 2010 model-years using 2008 and 2009 Consumer Reports Buying Guides and online manufacturer specification sheets.1 For each type of product, we sampled weights across a range of model sizes to calculate a typical weight. We were unable to calculate a sales share-weighted average weight for each product, however, because the data on the sales share of individual models within each type of product were not available."

6.1.2.2.6 *Sensitivity Analysis*

The assumptions those contributed most to the variance are shown in Figure 54. Similar to the TVs, the major contributors were the mean length of the initial use lifespan stage, initial storage lifetime and sales estimate. The residential owners accounted for the majority of sales in recent years, explaining the importance of those lifespans as compared to other owner types. This suggests that for tighter generation estimates, tighter life time and sales data estimates should be a top priority, followed by more accurate storage lifetime estimates.

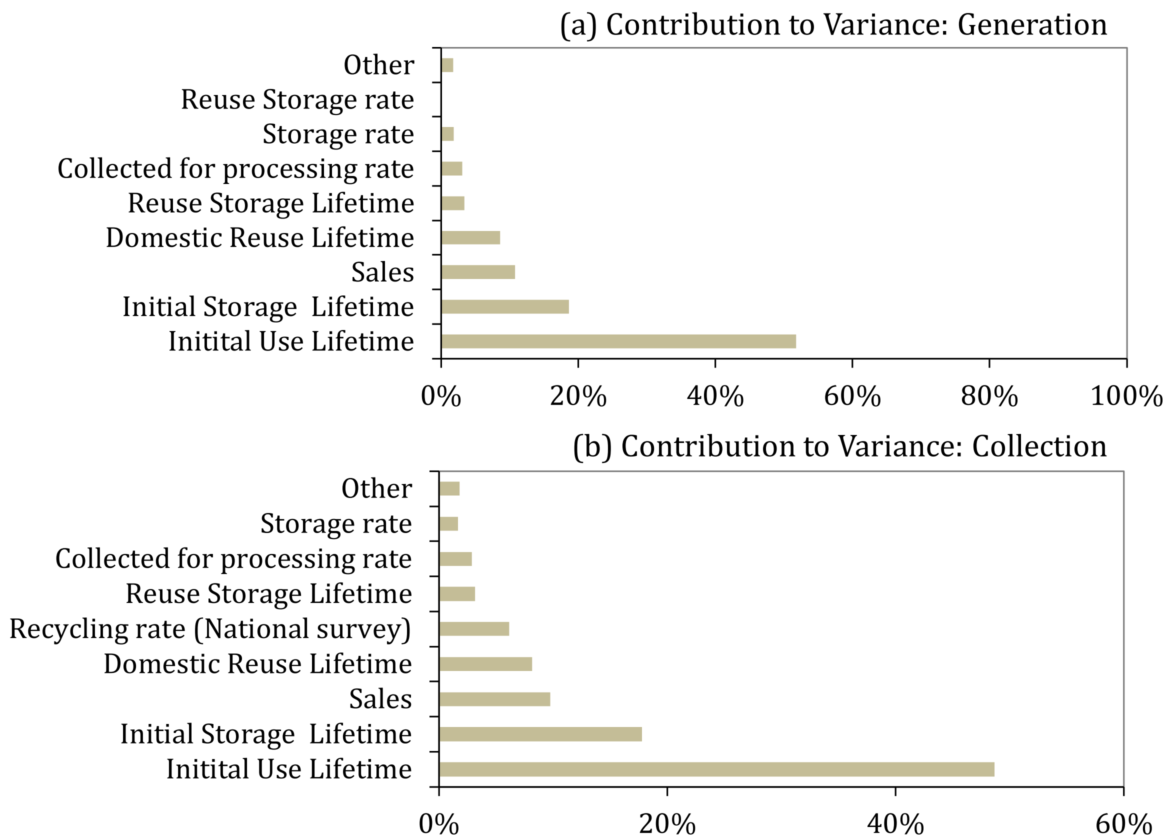

Figure 54: Contribution to Variance of Generation and Collection Estimates of Used Mobile Phones in 2010

6.1.2.3 Computers and Monitors

The Survey-based Method was used to quantify generation and collection estimates of used computers and monitors.

6.1.2.3.1 Sales

Several sources offer sales data as shown in Table 26.

Table 26: Sales Data Sources for Computers and Monitors

Source	Data Type	Owner Type	Year
IDC (EPAa, 2008) **IDC Report***	Desktop	Residential Business/Public	1990-1994 (IDC data from EPA report) 1995-2011 (IDC, data)
IDC (EPAa, 2008) **IDC Report***	Laptop	Residential Business/Public	1990-1994 (IDC data from EPA report) 1995-2011 (IDC, data)
IDC (EPAa, 2008) **GIA Inc.**** **IDC Report&**	CRT and Flat Panel monitor	Residential Business/Public	1990-1999 (IDC data from EPA report) 2000-2007 (GIA) 2008-2011 (IDC)

6.1.2.3.2 Lifespan

Below in Figure 55, the mean residential Lengths of Period of Ownership λ for each product are presented. It is possible that since laptops and Flat Panel monitors have been introduced into the market more recently than desktops and CRT monitors the datasets are impacted in such a way that their λ values are artificially slightly longer. More advanced data modeling may be able to correct for this effect if it is present.

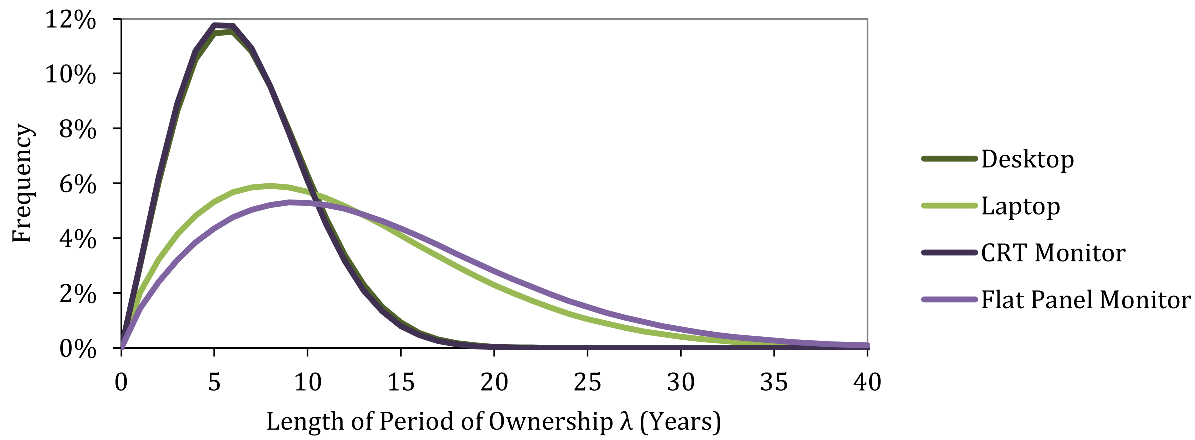

Figure 55: Distribution of residential Lengths of Period of Ownership for each product. Mean parameters presented. During simulation, distribution parameters vary.

Below in Table 27, the Weibull distribution parameters for the mean residential Lengths of Period of Ownership λ for each product are presented.

Table 27: Mean Weibull Distribution Parameters for residential Length of Period of Ownership λ

Product	Weibull Distribution Scale Parameter	Weibull Distribution Shape Parameter
Desktop	2.09	7.61
Laptop	1.71	13.28
CRT Monitor	2.10	7.46
Flat Screen Monitor	1.77	15.05

6.1.2.3.3 Collection

Below in Figure 56, the residential collection rate trends found from several surveys for used computers and monitors are presented [28, 33-35].

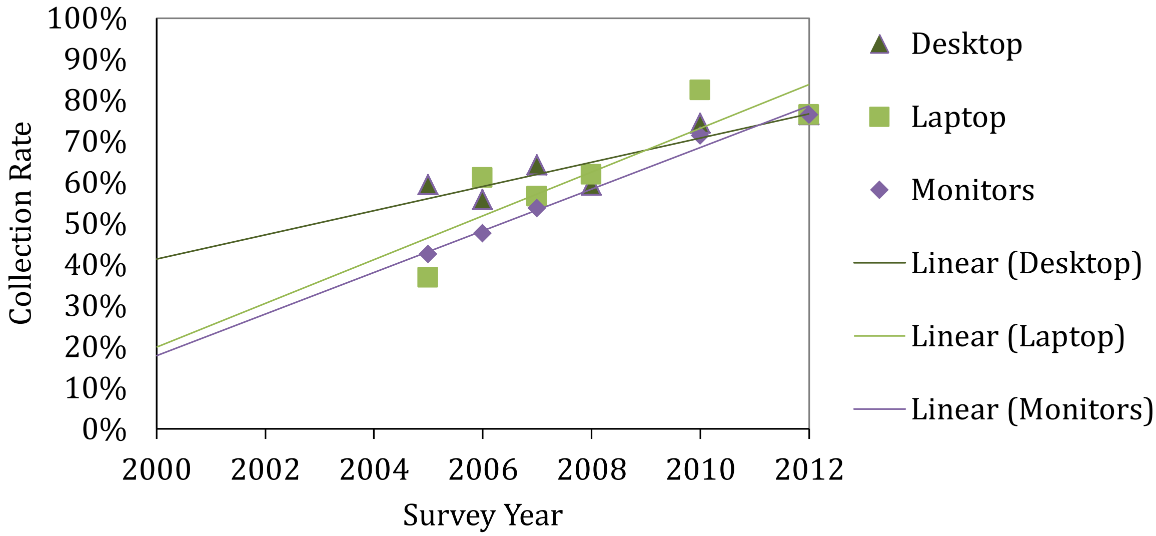

Figure 56: Estimated US residential used electronics collection rates across several surveys

6.1.2.3.4 Unit Weight

Different to the TVs and mobile unit weight data those cited from EPA report, the unit weight data for computers (laptop and desktop) and monitors are estimated based on the sampling data in 2010 of used electronics by the Oregon and Washington States[I], with the sample sizes ranging from 1,000 to 10,000 for brands of each type of electronic.

Figure 56 illustrates the histogram of the unit weight distribution for desktop and laptop computers, respectively. According to the distribution goodness fit by using Crystal Ball, lognormal distribution was confirmed to fit well for both.

Due to the combination of the unit weight data for CRT monitor and Flat Panel monitor data, the Finite Mixture Models[80] (FMM) package embodied in Stata data management software was employed to differentiate the distribution (assumed lognormal distribution for the two components: CRT and Flat Panel) (shown in Figure 58).

[I] NCER Brand Data Management System, sampling share from computer and monitors (weight)- Oregon and Washington Sampling Data: http://www.electronicsrecycling.org/BDMS/AlphaList.aspx?sort=All.

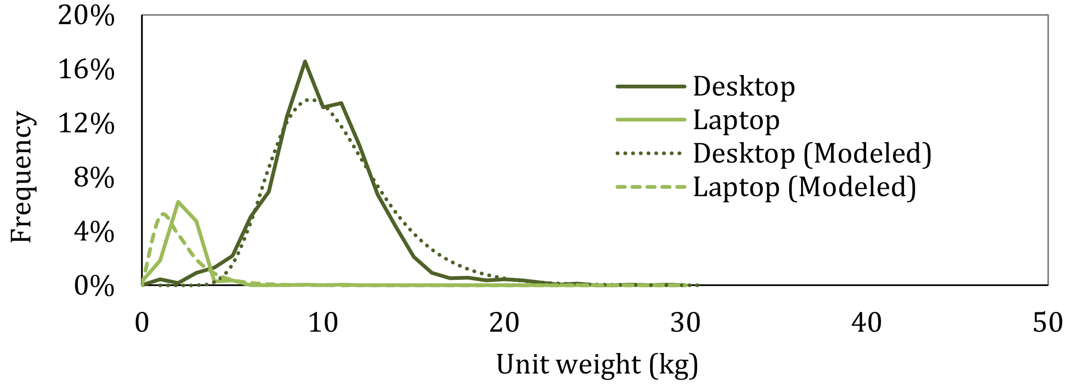

Figure 57: Unit Weight for Computers for Model Parameters

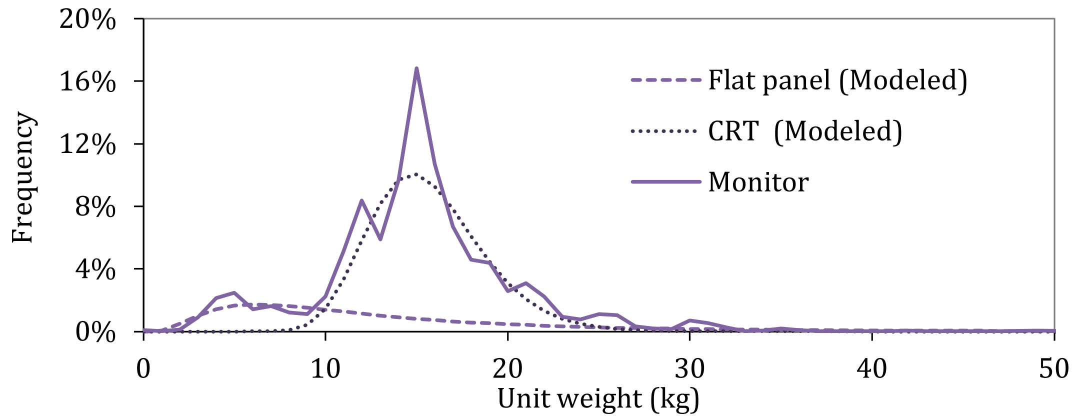

Figure 58: Unit Weight for Monitors for Model Parameters

The unit weight data for computers and monitors from model parameters are shown in Table 28.

Table 28: Unit Weight (kg) Data for Computers and Monitors from Model Parameters

Used Electronics	Distribution	Mean	Standard Deviation
Desktop	Lognormal	10.6	3.3
Laptop	Lognormal	3.1	1.5
CRT monitor	Lognormal	15.4	1.2
Flat Panel monitor	Lognormal	10.4	2.0

6.2 Export

6.2.1 Methodology Overview

A variety of approaches for quantitative characterization of transboundary flows of used electronics were considered for this study. These approaches were gathered through a review of the relevant literature, discussion with stakeholders at a workshop in June 2011, and subsequent discussion amongst the report's authors. A more detailed feasibility assessment of the approaches listed above is provided in *Characterizing Transboundary Flows of Used Electronics: Summary Report* [81].

To estimate the level of effort required for researchers to execute an approach (low to significant), and the quality of information obtained from the results (low to high), four criteria were briefly evaluated: uncertainty, representativeness, availability and cost. *Uncertainty* refers to the reliability in the data being collected, and takes into account any sources of error or estimation. *Representativeness* refers to the ability of sample data gathered to represent the range of used electronics exports. *Availability* refers to the existence of data and accessibility of the data, and *cost* refers to the financial cost to accomplish the research or political cost for diplomatic collaboration. Table 29 provides a summary of results from this brief evaluation. Note that the term "handler" refers to collectors and processors of used electronics. The trade data approach was selected for this research among all of the alternatives as being a reasonable combination of effort and information quality.

Table 29: Matrix of quantitative approaches by effort required and information quality yielded. Approach implemented in this study is in bold.

	Low Effort	Moderate Effort	Significant Effort
Low Information Quality	• Proxy Trade Data • Demographic and Economic Correlation		
Medium Information Quality	• Monitor Internet Trading • State-Level Data • Enforcement Data: Mandatory Reporting	• **Trade Data** • Standard Handler Surveys • Bill of Lading Data • Enforcement Data: Seizures • Mass Balance	
Medium-High Information Quality		• Bayesian Truth Serum Handler Survey • Voluntary Exports Standards Data • Collaboration with OEMs	
High Information Quality			• Material Flow Monitoring

The objective for the export trade data approach is to determine the quantity of used goods exported from the US to various countries and world regions with the associated uncertainty. There are other forms of uncertainty which cannot be quantified by these methods, however. To avoid tariffs, laws and regulations, or other forms of negative attention, sometimes exports are intentionally misclassified or traded in the black market [82]. Various forms of human error could lead to unintentional misclassification or data reporting. These unreported exports would be difficult to quantify without enforcement action. Import partner data rarely perfectly aligns with the export data, suggesting errors on either or both ends. This approach proceeds with recognition that the results are an underestimate of the actual used laptop export quantity.

A version of the trade data approach adopted here has been demonstrated previously for Japanese exports. Yoshida et al. (2009) demonstrated this method using 2004 export price histograms to distinguish used and new desktop and laptop computer exports[83]. Terazono (2008) similarly distinguishes Secondhand and Brand-new TV sets, refrigerators, air conditioners and washing machines exports. For example, Figure 59 presents exports of TV sets from Japan to China in 2001[84].

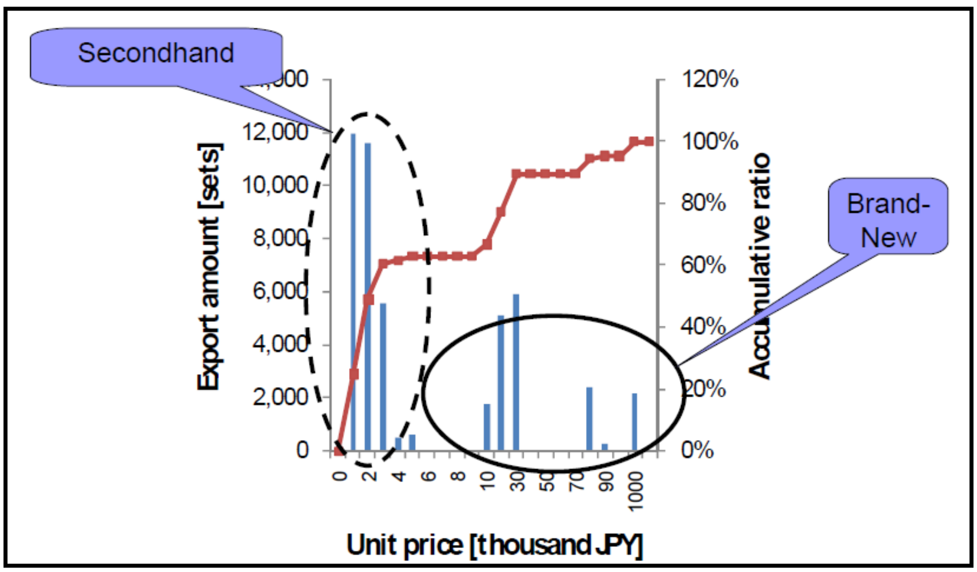

Figure 59: Differentiation of used (secondhand) and new exports using export unit value (unit price). Example of TV sets exported from Japan to China in 2001.

The overall approach is to utilize detailed, disaggregated trade data to distinguish the quantity of used electronics exports. The steps are as follows:

1. Collect and prepare disaggregated, detailed export trade data.
2. Estimate used-new threshold unit value thresholds for different world regions.
3. Sum the quantity of goods domestically exported from the US to partner countries with a unit value below the used-new threshold.
4. Estimate the re-export potential of domestic exports by investigating the top trade partner's re-export activity.

6.2.1.1 *Previous work*

Few comprehensive export comparisons exist for the countries studied. Most pertinent surveys and interviews of industry experts in recent years have produced estimates of the fraction of collected electronics that are exported. The form of the used electronics in the following estimates is either unspecified or may encompass both whole units and disassembled scrap streams. This variation in scope makes it difficult to compare numbers. A survey of used electronics processors in the Northeastern US reported that 45% of the respondents are engaged in export. Allowing for listing of multiple destinations, of the exporting organizations, over two-thirds exported to Asia, a quarter exported to South America, and a quarter exported to Africa [85]. A nationwide industry survey in 2003 reported that "very little of the output from electronics recycling operations is exported outside the US (typically none or less than 10%)" [86]. One can infer from a 2005 industry survey that almost 31% of used electronics collected for processing are exported as whole units [87]. A 2010 survey conducted by IDC said "the US geography remains the biggest market for survey respondents' direct output in both weight and value"; 79% of respondents "reported that their output was traded, sold and/or transferred within the United States" [88]. To translate the export fractions into quantities and capture uncertainty, stochastic methods to estimate collection quantities are also needed.

A recent 2013 report from the US International Trade Commission (USITC) investigated exports of used electronics [10]. According to the News Release:

> "The USITC recently concluded the investigation for the U.S. Trade Representative. The report is based on data collected through a nationwide survey of 5,200 refurbishers, recyclers, brokers, information technology asset managers, and other handlers of used electronic products. It covers the year 2011 and focuses on audio and visual equipment, computers and peripheral equipment, digital imaging devices, telecommunication equipment, and component parts of these products.
>
> The report provides an overview of the U.S. UEP industry, including information on domestic UEP collection, the share of goods that are refurbished compared to the share of goods that are recycled, and the characteristics of exported products. The report also provides information on the types of enterprises that export UEPs and those that import these products from the United States, and it examines the factors that affect trade in these products."[I]

For the purposes of comparison with this study's investigation into exports of used whole units, survey results regarding refurbished, remanufactured, and repaired products were made. This category includes: "used electronic products that are collected from their original users and then cleaned, fixed, or otherwise brought back to working condition and resold. This category includes products that are disassembled and resold as reclaimed electronic parts for use in repairing of other electronic products." While there are whole

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[I] USITC, U.S. Exports of used electronic products valued at $1.5 billion in 2011, says USITC. In *New Release*, 2013. http://www.usitc.gov/press_room/news_release/2013/er0308ll1.htm unit exports for recycling and disposal, the survey results did not distinguish whole units from parts and materials destined for recycling and disposal.

The USITC study also reported 2011 shipment level trade statistics about exports of several products. While this study focused on year 2010, the comparison is made since many survey respondents reported that exports in 2011 and previous years were about the same. Note that for desktops, export code 847150 was not included, differing from our approach (see Table 7). Also, the USITC report includes export codes 851720050, 851720080 but not 851720020 (confirmed typo in report after conversation with staff) whereas this study includes all three. For flat panel monitors, USITC excluded flat panel video monitors, whereas they were included in this study. Lastly, the trade code method was not used for flat panel TVs so no comparison was made.

While the USITC study does not assign a used-new threshold, they provide statistics by the lowest 10%, 25%, 50% and 100% of trade by unit value. Quantities reported sum the quantity below the particular unit value. In order to have an apples-to-apples comparison, the comparison is made between quantities associated with the range of unit values that correspond to the thresholds estimated in this report. Therefore, if this study's threshold range lies above one unit value and below another, the difference of those quantities is found. For CRT TVs monitors, 100% of trade was used since no new CRTs are assumed to be exported. Comparison is shown below in Table 30, with selected USITC comparable unit values in bold.

Table 30: Comparison between HSOTDM Thresholds and USITC Lowest X % Unit Values ($/unit)

Product	HSOTDM Threshold Range			USITC Lowest X % by Unit Value, u			
	US Export NVEM	China Export NVEM	Export Pub. Method	Max. u			Avg. u
				X=10%	X=25%	X=50%	x=100%
Flat Panel TV	120-200	NA	100-200	NA	NA	NA	NA
CRT TV							
CRT TV	NA, 100% Export			263	341	604	431
CRT Tubes	NA, 100% Export			95	149	970	154
Mobile phone	60-195	65-195	75-150	50	**104**	**184**	123
Laptop	100-305	100-300	200-250	**270**	440	400	485
Desktop							
Desktop	305-395	305-400	200-400	**750**	1,250	3,654	2,294
Server	290-400	195-400	300-400	**750**	1,250	3,654	2,294
Other desktop	440-600	500-600	400-600	NA	NA	NA	NA
Flat panel monitor							
Flat panel monitor	140-200	115-200	100-200	100	**118**	**161**	175
Video monitor	115-200	110-200	100-200	NA	NA	NA	NA
CRT monitors							
Alone	NA, 100% Export			227	353	780	359
With Desktop	NA, 100% Export			324	570	1,712	740

6.2.1.2 Methodologies Developed and Utilized

6.2.1.2.1 Collect and prepare disaggregated, detailed export trade data

Figure 2: Illustration of export quantity and unit value of disaggregated trade data for a given world region

Above in Figure 2 (repeated for convenience), the export quantity and export unit value of disaggregated trade data is illustrated. For this approach, the unit value of each product shipped is modeled; even when each record of shipment is known, only the overall value for the shipment and quantity is reported and not the unit value of each individual piece of equipment.

6.2.1.2.1.1 Export Trade Datasets

In order to most accurately model the value of the exported equipment, disaggregated, detailed export trade data is sought. When shipment-level data is not available, port-level or district-level data are used as substitutes as described at the end of this section. Ideally, substitute trade datasets would:

- Report trade monthly
- Contain value *v* in FOB, quantity of goods *q*, and weight *w.*
- Disaggregate domestic exports (originating in export country) from re-exports (originating in partner country)
- Disaggregate modes of transport
- Provide trade codes at the 10 digit level

After comparing all of the publically available US export trade datasets that we were able to locate in Table 31, three were selected, see Table 32. Table 33 below presents the symbols and terms used to describe the datasets as well as in the equations in the following section.

Since the ideal US export trade dataset of detailed shipment level reporting is not available in full[I], nor is the ideal set of port-level data, a method was developed to

[I] After completing the calculations presented in this report we discovered that these type of data are available from the Census Research Data Centers as Restricted–Use Transactions Microdata:

approximate port-level domestic export unit values and quantities. All datasets compared reported trade monthly and contain value, *v.* Some datasets considered contain quantity of goods *q,* and/or weight *w.* Some aggregated shipments at the port, district or country level, and some aggregated domestic exports (originating in US) with re-exports (originating in partner country); some aggregated modes of transport as well.

Table 31: Attributes of US Export Trade Datasets

Attribute	UN Comtrade[I]	USITC DataWeb	USA Trade Online	SICEX (US Exports)	SICEX (MX Imports)	Statistics Canada (CAN Imports)
Value, *v*, Measure	FOB, CIF	FOB	FOB	FOB	FOB, CIF	CIF
Quantity, *q*, Measure	Quantity, Weight	Quantity	Weight	Quantity, Weight	Quantity	Quantity
Trade Flows, *f*	All Available	Domestic Exports	*General Exports*	Domestic Exports	Imports by Origin	Imports by Origin
Period	*Annual*[II]	Monthly	Monthly	Monthly	Monthly	Monthly
Transport modes, *t*	*Combined*	*Combined*	Air, Vessel	Air, Vessel, Multi, Other	Air, Vessel, Land, Other	Air, Vessel, Land
Region, *r*	*Country*	*District*	Port	*District*	*District*	Port

Table 32: Datasets Utilized for US Exports Calculations. Some datasets do not report quantity or weight.

Database	1. USA Trade Online	2. SICEX (US Exports)	Statistics Canada (CAN Imports)
Value, *v*	$v_1(f_g, m, n, r_p, t)$	$v_2(f_e, m, n, r_d, t)$	$v_3(f_i, m, n, r_p, t)$
Quantity, *q*	--	$q_2(f_e, m, n, r_d)$	$q_3(f_i, m, n, r_p, t)$
Weight, *w*	$w_1(f_g, m, n, r_p, t)$	$w_2(f_e, m, n, r_d, t)$	--

http://www.census.gov/ces/rdcresearch/. However, one must go through an extensive application process in order to access the data.

[I] BACI data was considered as well, but not utilized for any purpose due to its inability to reconcile re-exports, and its use of 1996 export codes which are not as detailed as 2007 export codes used in other datasets. Gaulier, G. and S. Zignago BACI: International Trade Database at the Product-level: The 1994-2007 Version. CEPII.

[II] UN Comtrade launched a free beta version of "UN Monthly Comtrade" in mid-2012 but it only reports value. http://comtrade.un.org/monthly/Public/Metadata.aspx.

Table 33: Export Trade Data Symbols and Terms

Symbol	Term	Symbol	Term
u	Export unit value	**FOB**	Free-on-board values
v	Export value	**CIF**	Cost, Insurance and Freight values
q	Export quantity	m	Month (of specific year)
w	Export weight	n	Trade partner nation
x	Export unit weight	t	Transport mode (air and vessel)
f_g	General export trade flows	r_s	Shipment-level regional aggregation
f_e	Domestic export trade flows	r_p	Port-level regional aggregation
f_{g-e}	Re-export trade flows	r_d	District-level regional aggregation
f_i	Total import trade flows	r_c	Country-level regional aggregation

Port-level weight (or quantity) data are needed to calculate the approximate port-level unit value, which is generally available through USA Trade Online. Unfortunately, the datasets utilized do not contain this information for land shipments, so district-level data was used for most exports to Canada and Mexico from the US.[I]

[I] "Canada and the United States participate in a 'data exchange', in which the export statistics of each country are derived from the counterpart import data; therefore, there are no unexplained differences in their trade statistics. However, differences between the official trade statistics of the United States and Mexico, and Canada and Mexico are sizeable" (Economics and Statistics Administration of US Census Bureau 2000). Therefore, port-level Canadian import data from STATCAN is used for US domestic export data to Canada for the case of laptops only. District-level

6.2.1.2.1.2 Export Trade Codes

The following tables present the trade codes for the focus products of this study. Table 34 presents the codes for TVs.

Table 34: TV Export Trade Codes Used in this Study

Product Type	Schedule B Export Code	Official Description
CRT Color TVs	852872 3000	TV reception apparatus, color, incorporating video recording or reproducing apparatus
	852872 6005	TV reception apparatus, color, with picture tube, combined with radiobroadcast receivers or sound recording apparatus
	852872 6010	TV reception apparatus, color, having a picture tube, not exceeding 52 cm (<20 inches)
	852872 6040	TV reception apparatus, color, having a picture tube, exceeding 52 cm (>20 inches)
Monochrome TVs	852873 0000	Other, black and white or other monochrome
Flat Panel TVs	852872 6057	TV reception apparatus, color, not having a picture tube
CRT Tubes	854011	Tubes, parts thereof Cathode-ray television picture tubes, color
	854012	Tubes, parts thereof Cathode-ray television picture tubes, monochrome
CRT Glass Envelopes	701120	Glass envelopes (bulbs and tubes) for cathode-ray tubes, and glass parts thereof cathode-ray tubes or the like

Note that for mobile phones, a subset of the HS code under 851712, 8517120020 (Radio telephones designed for installation in motor vehicles for the Public Cellular), has been excluded due to its dissimilarity with typical mobile phones.

Table 35: Mobile Phone Export Trade Code used in this study

Product Type	Schedule B Export Code	Official Description
Mobile phone	851712	Telephones for cellular networks or for other wireless networks*

Below in Table 36 are the export codes pertaining to computers and monitors. US export data at the 10 digit level was used to identify the quantities of Desktops with CRTs (Schedule B Export Codes 8471410110 and 8471500110). Given that all CRTs exported are assumed to be used, desktops exported with CRTs are also assumed to be used.

Table 36: Computer Export Trade Codes Used in this Study

Product Type	Schedule B Export Code	Specific Product
Desktop	847141 0110	Desktop with CRT Monitor
	847141 0150	Desktop without CRT Monitor
	847149	Server
	847150 0110	Other Desktop with CRT Monitor
	847150 0150	Other Desktop without CRT Monitor
Laptop	847130	Laptop
CRT Monitor	847141 0110	With Desktop
	847150 0110	With Other Desktop
	852841	PC Monitor
	852849	Video Monitor
Flat Panel Monitor	852851	PC Monitor
	852859	Video Monitor

6.2.1.2.1.3 Preparation of Export Trade Data

First, all data utilized was aggregated to the annual, all transport mode, partner country level to check for consistency across *v, q,* and *w* and in comparison with UN Comtrade data. Minor issues were encountered with regards to inconsistencies in country classification (e.g. Sudan, Curacao) across datasets; trade with these countries was very small.

The disaggregated US domestic export unit value was calculated at two levels of aggregation: district- level, and approximate port-level. The term "approximate port-level" is used to represent that unit values cannot be calculated from port-level data directly due to lack of quantity data, and therefore approximations are made to arrive at port-level unit values and quantities. District-level unit values can be calculated directly from district-level quantities, so district-level results are found in order to check that the approximate port-level results are within reason. At the approximate port-level, Canadian import data was substituted for US domestic export data, and district-level export data was used for exports to Mexico.

The district-level US domestic export unit value $u_2(f_e, m, n, r_d, t)$ was calculated with SICEX data as shown in Equation 12. Since SICEX does not provide quantity disaggregated by transport mode, the export unit value is disaggregated just to for each month, partner nation, and district.

Equation 12

$$u_2(f_e, m, n, r_d) = \frac{v_2(f_e, m, n, r_d, t)}{q_2(f_e, m, n, r_d, t)}$$

To arrive at the approximate port-level data for non-North American countries, the general export port-level value per weight is multiplied by the corresponding domestic export district-level unit weight $x_2(f_e, m, n, r_d)$ for each month, partner nation, and district as shown in Equation 13 and Equation 14.

Equation 13

$$x_2(f_e, m, n, r_d, t) = \frac{w_2(f_e, m, n, r_d, t)}{q_2(f_e, m, n, r_d, t)}$$

Equation 14

$$u_{1-2}(f_e, m, n, r_p, t) \cong \frac{v_1(f_g, m, n, r_p, t)}{w_1(f_g, m, n, r_p, t)} \times x_2(f_e, m, n, r_d, t)$$

To approximate the port-level quantity, $q_{1-2}(f_e, m, n, r_p, t)$, the weight fraction of district-level domestic exports out of general exports is multiplied by port-level general export weight in order to determine the approximate port-level domestic export weight, and then weight is converted to quantity by dividing by the corresponding district average unit weight, as shown in Equation 15. Substituting $x_2(f_e, m, n, r_d, t)$from Equation 13, Equation 15 is equivalent to the fraction of port-level general export weight out of district-level general export weight multiplied by the district-level domestic export quantity as shown in Equation 16. Therefore, the approximate port-level quantity essentially allocates a district's domestic export quantity to a port based on the port's share of the district's general export weight for a given month and trade partner nation.

Equation 15

$$q_{1-2}(f_e, m, n, r_p, t) \cong \frac{\frac{w_2(f_e, m, n, r_d, t)}{w_2(f_g, m, n, r_d, t)} \times w_1(f_g, m, n, r_p, t)}{x_2(f_e, m, n, r_d, t)}$$

Equation 16

$$q_{1-2}(f_e, m, n, r_p, t) \cong \frac{w_2(f_e, m, n, r_d, t)}{w_2(f_g, m, n, r_d, t)} \times q_2(f_g, m, n, r_p, t)$$

To calculate both of the North American import unit values for trade with US as country of origin n, the value is simply divided by quantity for each month, port or district, and transport mode. Canadian import unit value is shown in Equation 17.

Equation 17

$$u_3(f_i, m, n, r_p, t) = \frac{v_3(f_i, m, n, r_p, t)}{q_3(f_i, m, n, r_p, t)}$$

An example to arrive the Approximate Port-Level Calculations for Laptop export is shown in Table 37.

Table 37: Example Approximate Port-Level Calculations for Laptop export (From the US to Argentina) (Results Shaded)

Trade partner nation *n* & Month *m*	n=Argentina, m=September 2010 (Note: some records excluded for this demonstration)					
District, *d*	Houston-Galveston, TX		Miami, FL			New York City, NY
Port, *p*	Houston Intercont-inental Airport, TX	Houston, TX	Miami Internatio nal Airport, FL	Miami, FL	Port Everglades, FL	JFK Interna-tional Airport, NY
$v_2(f_{g-e}, m, n, r_d)$	$634,444	$634,444	$3,389,603	$3,389,603	$3,389,603	$-
$q_2(f_{g-e}, m, n, r_d)$	912	912	5,742	5,742	5,742	-
$w_2(f_{g-e}, m, n, r_d, t_{air})$	$5,877	$5,877	$27,842	$27,842	$27,842	$-
$w_2(f_{g-e}, m, n, r_d, t_{ves.})$	-	-	350	350	350	-
$v_2(f_e, m, n, r_d)$	$113,541	$113,541	$4,099,759	$4,099,759	$4,099,759	$56,440
$q_2(f_e, m, n, r_d)$	300	300	10,941	10,941	10,941	208
$u_2(f_e, m, n, r_d)$	$378	$378	$375	$375	$375	$271
$w_2(f_e, m, n, r_d, t_{air})$	-	-	26,625	26,625	26,625	212
$w_2(f_e, m, n, r_d, t_{ves.})$	815	815	589	589	589	-
$w_2(f_e, m, n, r_d)$	815	815	27,214	27,214	27,214	212
$x_2(f_e, m, n, r_d)$	3	3	2	2	2	1
$v_1(f_g, m, n, r_p, t_{air})$	$634,444	$-	$7,412,903	$-	$-	$56,440
$w_1(f_g, m, n, r_p, t_{air})$	5,877	-	54,467	-	-	212
$u_{1-2}(f_e, m, n, r_p, t_{air})$	$293	$-	$339	$-	$-	$271
$v_1(f_g, m, n, r_p, t_{ves.})$	$-	$113,541	$-	$48,674	$27,785	$-
$w_1(f_g, m, n, r_p, t_{ves.})$	-	815	-	589	350	-
$u_{1-2}(f_e, m, n, r_p, t_{ves.})$	$-	$378	$-	$206	$197	$-
$\frac{w_2(f_e, m, n, r_d, t_{air})}{w_2(f_g, m, n, r_d, t_{air})}$	0%	0%	49%	49%	49%	100%
$\frac{w_2(f_e, m, n, r_d, t_{ves.})}{w_2(f_g, m, n, r_d, t_{ves.})}$	100%	100%	63%	63%	63%	0%
$q_{1-2}(f_{g-e}, m, n, r_p, t_{air})$	912	-	5,671	-	-	-
$q_{1-2}(f_{g-e}, m, n, r_p, t_{ves.})$	-	-	-	45	27	-
$q_{1-2}(f_e, m, n, r_p, t_{air})$	-	-	10,704	-	-	208
$q_{1-2}(f_e, m, n, r_p, t_{ves.})$	-	300	-	149	88	-

6.2.1.2.2 Estimate used-new unit value threshold values for different world regions

Following Terazono (2008), the approach in this study assumes that exports below a unit value threshold are used and those above it are new. The threshold approach assumes that the used-new threshold is consistent across a region for a type of good. World regions were defined by World Bank country income groups [89] and UN macro geographical region[I] [90] for vessel, air, and land transport. Due to price adaptation to different markets, methods developed in this study do not assume the same export unit value to all countries. Co (2007) found that "US exporters do price discriminate across markets", based on income level, English language, and to some extent changes in currency exchange rate[91]. Baldwin and Harrigan (2007) analyze all 2005 US export data and find that "distance has a very large positive effect on unit values"; exports to destinations farther than 4000 km away had unit values a factor of two larger than exports to other countries in North America. They also found a negative relationship with export unit value and destination market size[92].

The threshold value z is the valley between the used and new distributions embedded in a bimodal distribution, as demonstrated in Figure 3, repeated below for convenience.

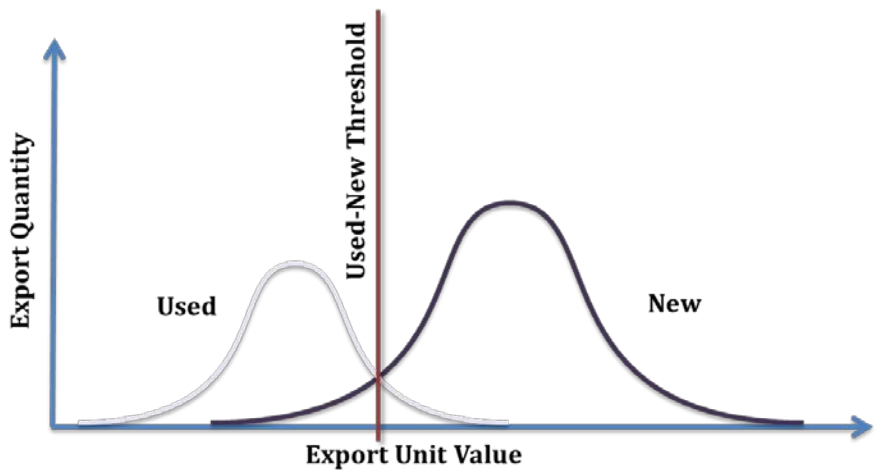

Figure 3: Illustration of export quantity and unit value of disaggregated trade data with Used-New threshold differentiating underlying Used and New distributions for a given world region

In this study, it is assumed that the magnitude of the error due to including new goods in the sum below the threshold is roughly equivalent to the magnitude of the error due to including used goods in the sum above the threshold. This error will actually vary depending on the magnitude and form of the distributions.

The threshold values were determined using three separate methods for comparison purposes. US Export NVEM and China Export NVEM utilize the neighborhood valley-emphasis method (NVEM) for each destination world region with US export and

[I] These are followed with the exception of Mexico being assigned to North America in this study; it is ambiguous in UN classifications, and elsewhere Mexico is assigned to North America.

Chinese export data, respectively[I] [94]. Chinese data is considered anticipating that the majority of exported goods are new, since China is a major manufacturer [95]. NVEM finds the optimal threshold which simultaneously maximizes the variance between the modes (here, used and new) and minimizes the probability of the unit value bin u at and around the optimal threshold. An example of the threshold range found by NVEM in China Export NVEM is shown in Figure 60, with approximate distributions superimposed on the histogram. Export Pub. Method takes advantage of published reference values for used goods, and applies the same threshold to all world regions.

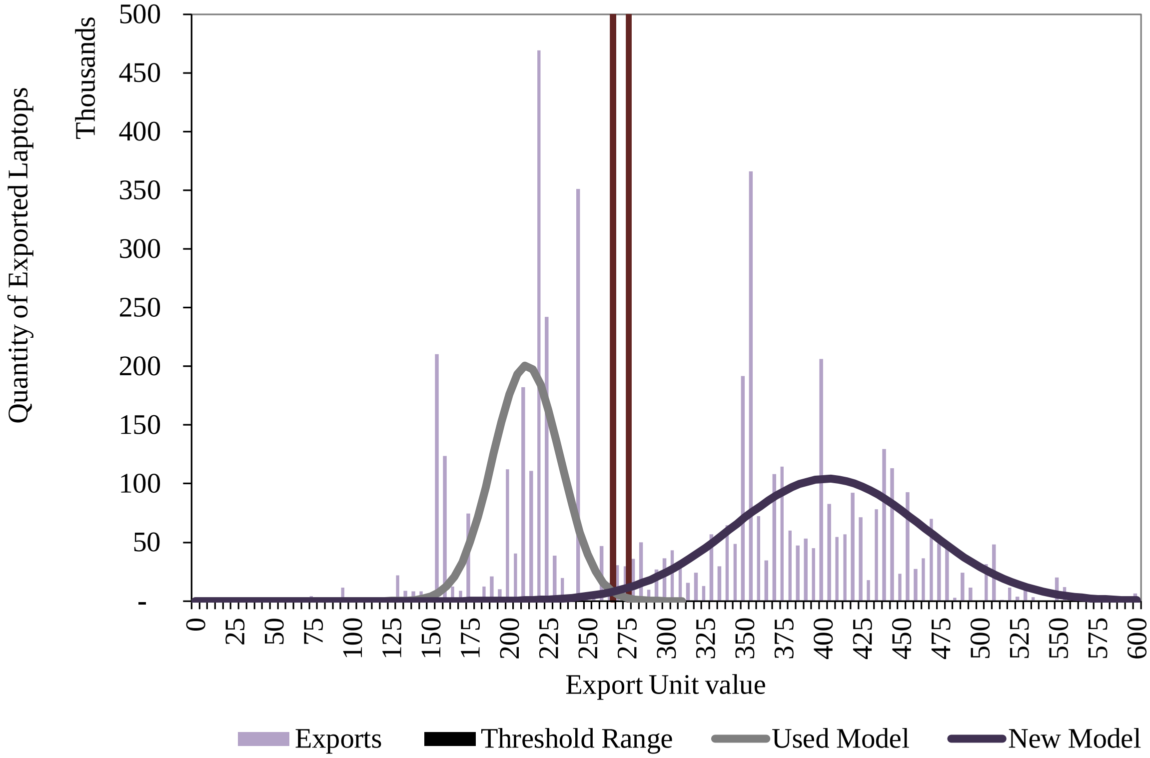

Figure 60: Example of China Export NVEM histogram with $5 export unit value for 2010 export of laptops from China to Latin America and the Caribbean (LAC) by vessel.

6.2.1.2.2.1 Neighborhood Valley-Emphasis Method (NVEM) for Used-New Thresholds

Thresholds were calculated at the approximate port-level (or district level to Canada and Mexico), for each world region and for both vessel and air transport (and land transport for North America). Since the datasets utilized largely report export values that do not include freight costs, it may seem superfluous to find different thresholds for transport modes. Still, considerable differences in unit values distributions have been observed for this dataset based on mode of transport, so it may be useful.

[I] Note: a different method for numbering was used in reference [93] Miller, T. R. *Quantitative characterization of transboundary flows of used electronics: A case study of the united states*. MIT: **2012**.

The neighborhood valley-emphasis method (NVEM) was employed to determine the used-new threshold value z for the US Export NVEM and China Export NVEM. Fan and Lei (2012) describe their approach for determining the threshold for differentiation between modes in a distribution, developed for application in finding the threshold of a bimodal histogram of a grayscale image. They demonstrate the wider applicability of their NVEM versus the Otsu and valley-emphasis methods, which they modify. This method was chosen because the threshold z[I] values are not easily distinguished by the eye, and Fan and Lei (2012) convincingly demonstrated the superiority of this method. Since this requires a histogram with a developed distribution, the method was only applied to suitable datasets with considerable trade quantity (here above 10,000 units); these calculated thresholds substituted for missing thresholds in world regions with low trade quantities. For world regions with a smaller trade quantity, the Export Pub. Method was substituted.

The method finds the optimal threshold, z^*, which simultaneously maximizes the variance between the modes (or classes) and minimizes the probability of the unit value bin u at and around the optimal threshold. By considering not only the probability at the threshold value bin considered (the term "value bin" is used because a histogram is analyzed) but its neighbor unit value bins as well, sporadic dips not corresponding to true valleys are not selected. The method proceeds as follows.

Each unit value bin u is evaluated as a possible threshold z, and thus its neighborhood probability $\bar{h}(u)$ is calculated. Equation 18 is the sum of neighborhood unit value probability in interval $L = 2 + B1$ for unit value u, where L is the neighborhood length, normally an odd number, and B is the count of bins evaluated on either side of z(Fan and Lei 2012). The analysis proceeds for several values of L to find a reasonable length, based on the size of the value bin and reasonableness of the results in terms of avoidance of extraneous values. The results are presented for L = 7, 9, and 11 representing export unit value neighborhood lengths of \$35, \$45, and \$55, respectively.

Equation 18

$$\bar{h}(u) = [h(u-m) + \cdots + h(u-1) + h(u) + h(u+1) + \cdots + h(u+m)]$$

Modes (or classes) are defined as $c_0 = [0, \dots, z]$ and $c_1 = [z+1, \dots, B-1]$ where $B-1$ is the maximum unit value bin. The total probabilities of each class are found with simple summations, shown in Equation 19 and Equation 20. The means of each class are shown in Equation 21 and Equation 22.

Equation 19

$$p_0(z) = \sum_{u=0}^{z} h(u)$$

[I] Notation used here differs from that presented in Fan and Lei (2012)

Equation 20

$$p_1(z) = \sum_{u=z+1}^{B-1} h(u)$$

Equation 21

$$\mu_0(z) = \sum_{u=0}^{z} u \cdot h(u)/p_0(z)$$

Equation 22

$$\mu_1(z) = \sum_{u=z+1}^{B-1} u \cdot h(u)/p_1(z)$$

The optimal threshold, z, corresponds to the maximum across all value bins of the objective function of the neighborhood valley-emphasis method, $\xi(z)$, in Equation 23.

Equation 23

$$\xi(z) = \left(1 - \bar{h}(z)\right)\left(p_0(z)\mu_0^2(z) + p_1(z)\mu_1^2(z)\right)$$

6.2.1.2.2.2 Export Pub. Method for Used-New Thresholds

In order to get the sales values for the used electronics in the US market, a number of sales trade platforms have been investigated, including business to business (e.g., Alibaba), business to individual consumer (e.g., Amazon and PriceGrabber) and individual to individual (e.g., ebay). The advantage is that these potential transactions show us a direct sale values for the used electronics, as well as the normal price for the new products as a comparison. However, there are several constraints as follows:

(a) The prices cannot represent the sales value of the whole year, only the most recent specific date;

(b) There is change between the auction prices and the finalized trade prices;

(c) It only represents the major internal-based trades.

6.2.1.2.3 Sum the quantity of goods domestically exported from the US to partner countries with a unit value below

For this step, the quantity of exports that fall below the used-new threshold for each world region are summed. Results are reported for each threshold method and each world region. The top used export recipients are determined. Significant differences in the results from US Export NVEM, China Export NVEM and Export Pub. Method are investigated. Figure 5 below (repeated for convenience) illustrates the summed quantities.

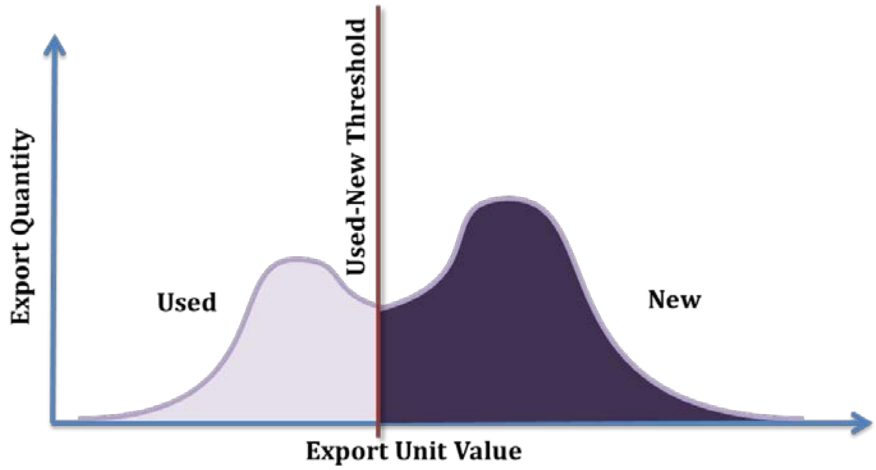

Figure 5: Illustration of sum of Used and New export quantities from disaggregated trade data with Used-New threshold differentiating underlying Used and New distributions for a given world region

6.2.1.2.4 Estimate the re-export potential of domestic exports by investigating the top trade partner's re-export activity

The US domestic export data utilized details the export trade partner, but not necessarily the final destination as some trade partners will then re-export the imports. Therefore, to approximate the potential of re-export after import from the US, ratios based on aggregate UN Comtrade data [96] were found as a demonstration for the laptop case. Note that this method assumes equal likelihood of re-export across all unit values instead of distinguishing used from new. Few countries distinguish re-exports, therefore ratios are developed comparing exports to imports for most countries. Some countries do not report trade data to the UN; for major US export destinations, trade flows are inferred from reporting countries' import and export flows with these countries. China was treated differently since it is a known major manufacturer and exporter. Utilizing shipment level Chinese export data (HS International Inc. 2012), re-export destinations of used laptops (under US$250) were found.

6.2.1.2.5 In Depth Exploration of TV Production, Collection, and Export

Based on our previous work[I, 20], it was found that there are almost no new CRT TVs being manufactured in North America, which implies there is probably no new CRT TVs which can be exported out of this region (except the re-export). There is a hypothesis that the exports of CRT TVs from the US are all used. In another word, it is unnecessary to distinguish the used from the trade under the HS code of CRT related products. This section aims to review the CRT industry in the US and help confirm the hypothesis.

6.2.1.2.5.1 Global TV Production

[I] Jennifer Atlee, Jeremy Gregory, and Randolph Kirchain, 2005, An overview of cathode ray tube recycling internal report. previous work done by Materials Systems Laboratory at MIT.

US firms led the world in TV technology and production until the early 1970s. Then, foreign-owned firms gradually took control of the US market [I]. A report from IHS iSuppli [II] indicated that global TV shipments reached an all-time high of 255 million units in 2011 but will decline to 241 million in 2013. The major reasons for the decline in unit shipments are the continued fall of CRT TVs and the rise of internet television. This is not a surprise given the long-term decline of the market, but it is having an impact on the overall shipment of televisions and causing a period of adjustment. Currently, there are no CRT TVs being shipped in Western Europe, North America and Japan. Eastern Europe now represents only a sliver of what once was a major shipment destination for the technology. Even the former stronghold of Latin America is experiencing a decrease in the number of shipments of CRT TVs in the region, with digitization and economic growth spurring the uptake of flat-panels. By 2016, CRT TV technology will become nonexistent as all regions switch to LCD and organic light-emitting diode (OLED) technology, IHS iSuppli believes. The majority of CRT TVs that are shipped now go into the Asia-Pacific region, of which 60% are shipped into India and Indonesia, with the next most significant region being the Middle East and Africa, primarily sub-Saharan Africa, at 15 percent. However, even these regions will be phasing out of the CRT-TV business during the next three years.

6.2.1.2.5.2 US CRT Glass Manufacturers

In 1993 (USITC, Industry & Trade Summary)[97]:

- Television Picture Tubes and Other: there were 7 producers of color television picture tubes in the United States, about 30 other producers of other types of CRTs, and 21 producers of electron tube parts except glass blanks; there was no monochrome (black and white) tube production in the United States.
- Regarding the CRT tube glass, Techneglas was the major supplier of glass for picture tubes in the United States, supplying an estimated 60 to 70 percent of US demand.

In 1997 (USEPA, Computer Display Industry & Market Profile [III]):

- The majority of CRT display fabrication took place outside of the United States. In 1997, Asia (excluding Japan) produced 54 percent of all color TVs and 79 percent of all CRT monitors.
- CRT glass: Five CRT glass manufacturing plants, Techneglas was the major supplier
- Picture tubes: 7 in total, Sony for Color monitor; Hitachi, Matsushita, Philips, Thomson, Toshiba, and Zenith for TVs tubes.
- CRT display assembly, 8 in the US.

[I] US Congress, Office of Technology Assessment, the Decline of the US. TV Industry: Manufacturing. Appendix A from "The Big Picture: HDTV & High-resolution Systems", 1990. Available at: http://www.princeton.edu/~ota/disk2/1990/9007/900709.PDF

[II] Tom Morrod, Global Television Shipments to shrink in 2012, IHS-iSuppli, 2012, Available at: http://www.isuppli.com/Display-Materials-and-Systems/MarketWatch/Pages/Global-Television-Shipments-to-Shrink-in-2012.aspx

[III] USEPA, 1998, Computer Display Industry & Market Profile: Chapter 2. Available at: http://www.epa.gov/dfe/pubs/comp-dic/tech_reports/SEC2-0.pdf

Mizuki et al. (1997)[98] state, "The only color-display production in the US is of large entertainment systems (19" or larger) because of the high cost of importing these heavier items. Only 5% of the monochrome monitor and TV CRTs consumed in the US are manufactured in the US, and no color monitors or small color entertainment systems (less than 19") are produced domestically."

Since 2000 [I], there were three CRT manufacturers (Thomson Consumer Electronics Inc., Techneglas Inc., and Corning Asahi Video Products Company Inc.) that purchased furnace ready CRT cullet (Toto 2003b[II]). However, the situation has changed in the past few years.

- American Video Glass Company (a Corning Asahi & Sony Partnership) is still involved in glass business, but not CRT manufacturing[III]
- Thomson Consumer Electronics has apparently moved offshore (to Europe? – unverified)
- Techneglas recently went out of business[IV] (Basel Action Network 2004[V])

6.2.1.2.5.3 US Glass-to-Glass and Glass-to-Lead Cullet Providers

Around a decade before, there were only two recyclers providing furnace-ready cullet in the US (De-manufacturing of Electronic Equipment for Reuse and Recycling 2002[VI]). Descriptions of these recyclers are provided in (Materials for the Future Foundation 2001[VII]):

- Envirocycle, Inc. (PA)[VIII]:
  "All materials received by Envirocycle are inspected for the possibility of resale. Units with no value are sent to be dismantled and sorted into the proper material streams for recycling. The average time for processing CRT glass is 2 weeks. Within one month the cullet is back into the commerce stream as a new CRT. Envirocycle employs approximately 50 people in their tear-down process and is currently investing in research and development to improve the dismantling technology."

[I] This section is partly from to the previous work done by Materials Systems Laboratory at MIT: An overview of cathode ray tube recycling (Jennifer Atlee, Jeremy Gregory, and Randolph Kirchain, 2005, internal report).
[II] Toto, D. (2003), Monitoring the future, Recycling Today 41(12): 24-8.
[III] EPA announcement about partnership: http://www.epa.gov/epaoswer/hazwaste/minimize/avglass.htm
[IV] Auction announcement from the bankruptcy court:
http://www.zonetrader.com/Auctions/AuctionDetail.asp?auctionID=9926
News item on Techneglas filing for bankruptcy:
http://www.dailyitem.com/archive/2004/0903/biz/stories/05biz.htm
[V] Basel Action Network (2004), CRT Glass Recycling Survey Results, Available at:
http://ban.org/library/crt_survey_2004.pdf
[VI] De-manufacturing of Electronic Equipment for Reuse and Recycling (Task N.302) , Available at:
http://www.ndcee.ctc.com/task_descriptions/N_302.pdf
[VII] Materials for the Future Foundation (2001), CRT Glass to CRT Glass Recycling, Available at:
http://www.calrecycle.ca.gov/electronics/resources/Publications/GlassMFF.pdf
VIII Envirocycle, Inc. (PA): http://www.enviroinc.com

- Dlubak Glass Company, Inc. (OH & PA)[I]:
  "Dlubak Glass is the largest glass recycler in the country; Dlubak handles automotive glass, lighting industry glass, and CRT glass. The company currently handles 300 tons of glass per year and employees approximately 50 workers in the US Five employees handle CRT recycling at the Dlubak site in Sandusky, Ohio. The site handles 20 to 30 truckloads per day. CRTs are de-manufactured by US Federal Prison Industries, also known as UNICOR. Dlubak's partnership with UNICOR provides dismantling for funnel and panel glass, ferrous and non-ferrous metal removal for all non-glass materials and panel glass sorting by materials."

Even a decade ago, there were many CRT recyclers that sent glass to lead smelters. A few of the larger processors are mentioned here (Novelli, 2003[II]).[III]

- United Recyclers Industries (IL): http://www.unitedrecycling.com
- Gold Circuit (AZ): http://www.goldcircuit.com. Tipping fees of $0.18-$0.25/lb, are principal revenue for plant.

6.2.1.2.5.4 ***Lead Smelters Using CRT Cullet***

Mizuki et al. (1997[98]) stated that thirteen smelters existed in the US (in 1997) who had primary and secondary SIC codes for lead smelting or refining, with Noranda, Asarco Incorporated, and Doe Run Company appearing to be the most widely used primary smelters.

Doe Run and Noranda are consistently listed as the primary lead smelters in North America accepting CRT cullet. However, Weitzman (2003)[99] also lists Gopher Resource Corporation in Minnesota, Metalico/Golf Coast Lead in Florida, and Teck Cominco Metals LTD in western Canada as alternatives. The latter two do not currently use CRT cullet, but are experimenting with the practice and have plans to bring the practice on-line.

6.2.1.2.5.5 Current CRT Tube and Glass Reuse Market

Like reuse of any electronics, CRT markets are primarily foreign, and small remaining markets for reuse of whole monitors & TVs: Mexico, Central and South America, Africa and Asia. A recent report released by CalRecycle CEW Recycling Program (2013[IV]) indicated that the sole manufacturer of new CRTs accepting processed glass is located in India and is charging between $100 and $200 per ton to do so.

[I] Dlubak Glass Company, Inc. (OH & PA): http://www.dlubak.com
[II] Novelli, L. R. (2003), Making CRT recycling work. Scrap 60(2): 107-115.
[III] United Recyclers Industries (IL): http://www.unitedrecycling.com
Gold Circuit (AZ): http://www.goldcircuit.com.
[IV] CalRecycle CEW Recycling Program (2013), Residual CRT Glass Management and the CEW Recycling Payment System, Electronic Waste Recycling Stakeholder Workshop, March 13, 2013. Available at: http://www.calrecycle.ca.gov/Actions/Documents/77/20132013/835/Overview%20of%20CRT%20Issues%20and%20the%20CEW%20Program.pdf

Reportedly only three large metal smelters in North America, where only one facility in the US (Doe Run, Missouri) and two in Canada (Teck Cominco and Xstrata) known to accept CRT glass in quantity and at a price, though new lead extraction technologies for high-lead content funnel glass are allegedly being developed on smaller scales. The example below shows the reuse and recycling (flows) of CRT tube and glass in California based on the CalRecycle CEW Recycling Program (2013[I]):

> "By mid-2009, approximately 75% of residual CRTs and/or CRT glass were being shipped to Mexican processors. However, in the 4th quarter of 2009, access to Mexican CRT glass processors was interrupted for nearly a year. Because CEW recyclers were required to ship CRT glass to a destination "authorized to receive and further treat" the glass prior to filing CEW recycling claims, this interruption caused the volume of claimed CEW to decrease dramatically while recyclers searched for alternative outlets for CRT glass. A couple of recyclers pursued establishing their own in-state CRT processing capabilities, while other enterprises started or offered capacities out-of-state".
>
> "As of January 2013, over 300 million pounds of residual CRTs and CRT glass had been shipped by CEW recyclers since January 2010. At the same time, though, substantial reduction in destination options occurred over these last three years, particularly to out-of state and foreign locations. With the exception of Doe Run (smelter) and Samtel Glass / Videocon Industries (the CRT manufacturer in India), all out-of-state destinations that received shipments in 2012 are not ultimate endpoints; instead, they are intermediate facilities that possibly perform some degree of CRT processing before presumably shipping the glass onto a subsequent destination or ultimate disposition".

The following Figure 61 is a summary of initial residual CRT/CRT glass shipment destinations, derived from documentation contained in CEW recycling payment claims [I]. The figure presents shipments in all three years since January 2010 as well as just those shipments since January 2012. It implies the exports of residual CRT and CRT glass account for 25% of the total collection, which excludes the exports with or without processing by the first-hand receivers. All listed in-state destinations are ostensibly authorized to treat CRTs under 22 CCR 66273.73 and may accumulate CRTs and/or CRT glass for up to one year under universal waste rules before presumably being shipped onto another appropriate destination. Out-of-state destinations that received shipments in 2012 are not ultimate endpoints. Foreign destinations include primarily Mexico, India, Malaysia and Korea. In addition, note that data for 2012 may be incomplete due to a time-lag in receiving CEW recycling payment claims. Also note that a small number of incidental shipments amounting to less than 0.1% of total volumes shipped are not accounted for here.

Figure 61: Initial Residual CRT and CRT Glass Shipping Destinations (fractions of weight)

The review on leaded class conducted by Thomas who went through the notifications to the US.US EPA for the shipment of broken CRTs in the year of 2010 and 2011 (enforcement data) found that 56% and 24% of exported CRTs scrap were been shipped to Canada and Mexico[I].

6.2.1.2.5.6 Global and US CRT Supply Based on International Trade Platform

In order to confirm that there is almost no manufacturing industry of the CRT-related products in the US, this study also investigates the suppliers' worldwide and the US based distribution on the international business to business (B2B) and exports-oriented trade platform-Alibaba.

Based on the searching on the suppliers' information of CRT TVs products (both new and used) in October 2012[II], it was found that most of the suppliers were from China, see the Table below.

Table 38: Statistics on Worldwide CRT TVs Suppliers Based on Alibaba B2B Platform

Region	Number of suppliers	Fractions of suppliers
East Asia	22,223	98.3%
South Asia	66	0.3%
Southeast Asia	154	0.7%
Middle East	27	0.1%
Europe	77	0.3%
South America	2	0.0%
North America	38	0.2%
Africa	31	0.1%

[I] Jake Thomas. A look through the leaded glass. E-scrap News, June, 2013. http://resource-recycling.com/node/3958

[II] http://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&SearchText=CRT+TVs

While there are 38 suppliers for CRT TV in North America (mainly from the US), the products classified into CRT TVs only include the secondhand items with extremely low sale prices (less than $50/unit), such as the Broken Screen TVs, CRT/TVs scrap, used CRT monitor, used TVs or CRT TVs, untested Color TVs (used), tested TV for reused and clean funnel and panel CRT glass, CRT glass and TVs plastic scrap. In addition, there is a few suppliers that trade the products classified into CRT tubes or processed glass from the US. This information helps provide indirect evidence that there is almost no manufacturing industry of the CRT-related products in the US.

6.2.1.2.5.7 CRT Glass Recycling Summary

- No glass-to-glass recycling market for US generated CRT glass, markets for reuse of CRTs in manufacturing new TVs is in Asia.
- Only end-use at the moment for leaded CRT funnel glass is a lead smelter. Not enough smelting capacity to manage the supply of leaded CRT funnel glass.
- There are end-market options for CRT panel glass with options in the building products and insulation markets[I].

6.2.1.2.6 Substituted Methodology for CRT Exports

While the US market still has high demand for Flat Panel TVs and related products[II], it was found that there were almost no manufacturers for CRT TVs in the US at least after the year of 2010. In addition, only a small quantity of Flat Panel TVs have been domestically[III] manufactured. The report released by USITC [10] - in terms of their survey – also stated that the "US has limited capacity to process used electronics in two segments of the industry—CRT glass and final smelting—creating incentives to export CRT monitors, CRT glass, and circuit boards destined for smelting to retrieve precious metals. Some CRTs are exported to large plants in Mexico, where they are reportedly washed and readied for further processing, and Canada, where the lead is removed. According to one industry source, it is likely that future U.S. exports of CRTs for recycling will end up in India, as the only other glass-to-glass furnaces in the world (in China and Malaysia) are scheduled to close by 2013." An latest report of "U.S. CRT Glass Management: A Bellwether for Sustainability of Electronics Recycling in the United States" published by TransparentPlanet LLC [IV] discussed about the current status of CRT recycling from the perspectives of: "Factors contributing to stockpiling,

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[I] Waste Management World, 2011, Market for Recycled CRT Glass Drying Up as Volumes Rise, Available at: http://www.waste-management-world.com/articles/2011/09/market-for-recycled-crt-glass-drying-up-as-volumes-rise.html

[II] Statista, the statistic (from US Census Bureau) illustrates the television, VCR and other video equipment imports from 2002 to 2011. The US. imports amounted to 33,486 million US. dollars in 2011. Available at: http://www.statista.com/statistics/221693/us-imports-of-tvs-vcrs-and-video-equipment-from-world/.

[III] United States Census Bureau, Current Industrial Reports: MA334M – Consumer Electronics (2010 Annual). Available at: http://www.census.gov/manufacturing/cir/historical_data/ma334m/index.html

[IV] TransparentPlanet LLC, 2012. U.S. CRT Glass Management: A Bellwether for Sustainability of Electronics Recycling in the United States. http://transparentplanetllc.com/us-crt-glass-management/

estimated volumes and cleanup costs; Current volumes generated in the US and capacity for CRT recycling in North America; The case against landfilling-the race to the bottom". This study concluded that "CRT industry experts estimate that 660 million pounds of CRT glass are currently being stored at locations throughout the US. It will cost between $85 million and $360 million to responsibly recycle all of this stockpiled glass, depending upon the condition of the glass; There are currently 16 companies with 24 US facilities processing CRT tubes in preparation for final recovery. None of these are operating at capacity in spite of what would seem to be a huge market demand. They simply cannot compete with stockpiling."

To summarize, there is limited capacity for the US market to reuse and recycle (glass to glass, or lead recovery) the CRT glass. These qualitative analysis suggest that the overseas market dominates the reuse and recycling. During the last 5-10 years, There is relative little quantitative study on worldwide CRT glass manufacturing were found in the literature or on the Internet, such as the historical production data of CRT TVs and glass [20] .

Thus, the HSOTDM which uses the used-new threshold to differentiate the used electronics is not appropriate for CRT TVs and related items (CRT tube and CRT glass) because all of these exported items can be classified as used. As a consequence, we assumed that the exports of CRT TVs are all the used goods, including the color and monochrome CRT TVs (852872 and 852873), CRT tubes (854011 and 854012) and tube glass (701120). It is unnecessary to identify and estimate the used and new products.

However, we can still use the HSOTDM to quantify used Flat Panel TVs which have an independent trade code (8528726057) and there are indeed manufacturers for this item. Since the total domestic export of Flat Panel TVs (new and potential used) is quite small, there was insufficient data for the Export NVEM thresholds, so we only used the Export Pub. Method secondary market sale prices-based threshold method to track the used TVs, which ranged from $100 to 200 per unit.

The same substituted methodology has been applied to CRT monitor, including desktop combined CRT monitor (trade codes 8471410110 and 8471500110 under the desktops), CRT monitor (852841) and CRT video monitor (852849).

6.2.2 Data and Intermediate Results

6.2.2.1 Used-New Threshold Unit Values

Used-New thresholds for each geographical region, country-income groups and transport method based on export unit values were found using three methods, of which two involved in the neighborhood valley-emphasis method, and the third method using sales values (shown in Table 39). As a reminder, US domestic export data is applied to US Export NVEM, Chinese export data was utilized in China Export NVEM, and sales value estimates in Export Pub. Method.

Table 39: Summary and Comparison of the Thresholds for All Electronics (unit value: $/unit)

Used Electronics	US Export NVEM (US Export data-based)*	China Export NVEM (China Export data-based)*	Export Pub. Method (Sale values - based)
Flat Panel TVs	120-200	N/A	100-200
CRT TVs	N/A, All Used	N/A, All Used	N/A, All Used
Mobile phone	60-195	65-195	75-150
Desktop	305-395	305-400	200-400**
Server	290-400	195-400	300-400**
Other Desktop	440-600	500-600	400-600**
Laptop	100-305	100-300	200-250
CRT Monitors	N/A, All Used	N/A, All Used	N/A, All Used
Flat Panel monitor	140-200	115-200	100-200**
Flat Panel video monitor	115-200	110-200	100-200**

**The min. and max. values for US Export NVEM or China Export NVEM for a specific product represent the minimum and maximum of all thresholds across all world regions and income groups.;*

*** Estimated with significant uncertainty due the limitation of data. In addition, the thresholds of China Export NVEM for Flat Panel TVs are difficult to obtain due to the mixture of trade codes.*

6.2.2.1.1.1 Export Pub. Method (all electronics)

The sale valued-based thresholds (Export Pub. Method) for mobile phone, Flat Panel TVs, desktop computer and monitors are shown in Table 40. Both due to the time constraints mentioned earlier and data availability from the platforms, the sales prices are based threshold are based on investigation in 2013, which may not accurately reflect 2010 prices.

Figure 62 below shows an example for the prices gap between the used and new laptops found from Amazon in August, 2012. There is significant gab between the used and new, which indicated the threshold for used can be set from $200-250 per units.

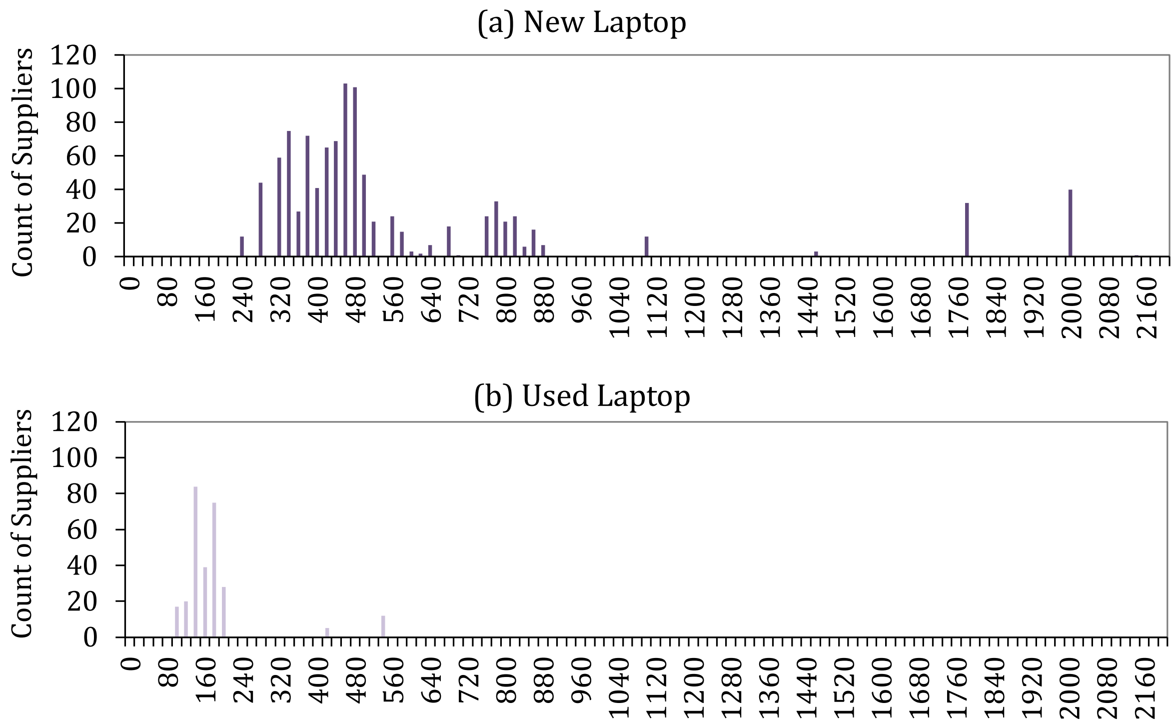

Figure 62: Price Gap between the Used and New Laptops Found from Amazon (Aug. 2012)

In additional, a report from Kwak (2012) did a survey in 2011 to look at the buy-back sales value for used laptop and mobile phone [100]. Figure 63[100] shows the prices ranges associated with the age of the used laptop, which implies that the older of the laptop, the lower prices for the used laptop to buy back. The 2-years old laptop can resell with an average unit price of $250.

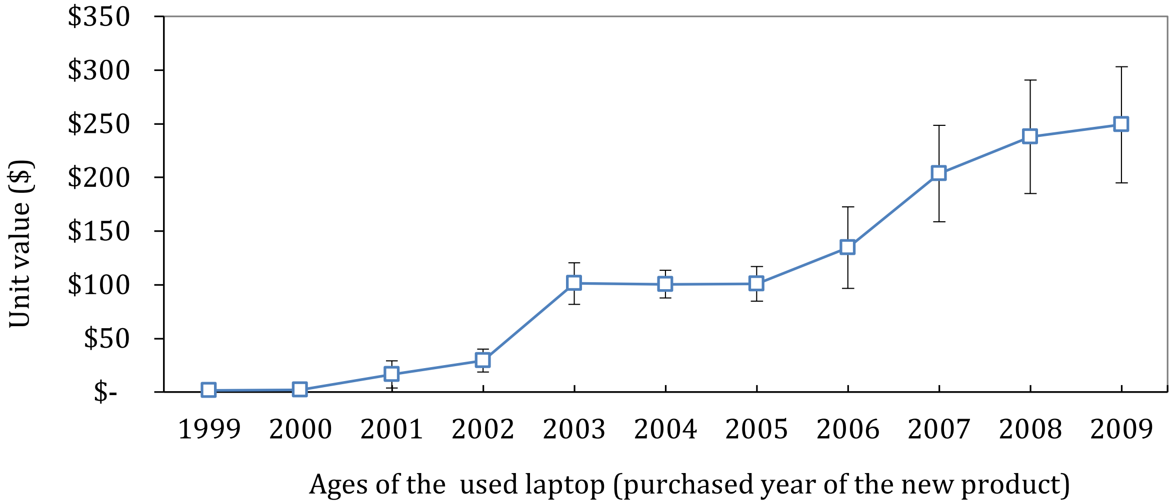

Figure 63: Buy-back Prices with Excellent Cosmetic Condition and no Hardware Failure (survey in 2011, responses 367). The error bars represent one standard deviation from the mean.

Table 40: Auction Sale Prices for Used Electronics from Various Sources (unit value: $/unit)

Source	Flat Panel TV	Mobile phone	Computer	Server	Laptop	Monitor	Sale Type	Status
***Babbitt, et al.* 2011** [31]			1.30-275	1.40-475	1.30-385	0.40-125	Resale	Both**
Kwak, 2012[100]		2-115			2-250		Trade-Back	Both
Recycle.net		10-100	10-50		10-150	10-50	Recycle	Non-working
Alibaba.com	50-200	100-150	50-100		125-250	25-50	Resale	Both
Ebay.com	100-300	50-125	200-600		150-400	50-150	Resale	Used
Amazon.com			250-600		200-250		Resale	Used-Like new
Price Grabber.com	200-600	100-500	250-1000	300-1000	200-1000	100-400	Resale	Like new
Threshold used in this study	**100-200**	**75-150**	**200-400**	**300-400**	**200-250**	**100-200**	**Used**	

** A survey has been done in 2008 at Arizona State University by Babbitt et al. (2013).*
*** Including working and non-working.*