Quantitative Characterization of Domestic and Transboundary Flows of Used Electronic Products

Case Study: Used Computers and Monitors in North America

Commission for Environmental Cooperation

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Acronym or Abbreviation

Acronym or Abbreviation	Description
Basel Convention	Basel Convention on the Control of Transboundary Movements of Hazardous Waste and Their Disposal.
BOL	Bill of Lading
CEC	Commission for Environmental Cooperation
CIF	Cost, insurance, and freight values
CIPREC	Centro Interdisciplinario para la Prevención de la Contaminación, A.C.
CRT	Cathode Ray Tube
EOL	End-of-Life
Export Codes	Harmonized System (HS) export codes
FOB	Free-on-board values
HSOTDM	Hybrid Sales Obsolescence-Trade Data Method
LCD	Liquid Crystal Displays
NVEM	Neighborhood Valley Emphasis Method
OECD	Organisation for Economic Co-operation and Development
Pub.	Published literature method
q	Export Quantity
SICEX	Sicex.com Trade Database
STATCAN	Statistics Canada
u	Export unit value
UAE	United Arab Emirates
UEP	Used Electronic Product
UK	United Kingdom
UN Comtrade	United Nations Commodity Trade Statistics Database
US	United States of America
US EPA	US Environmental Protection Agency
US EPA ORCR	Office of Resource Conservation and Recovery of the United States Environmental Protection Agency
US EPA OSW	Office of Solid Waste of the United States Environmental Protection Agency
USITC	US International Trade Commission
v	Export Value
w	Export Weight

Executive Summary

This report describes the scope, methods, data, and results of a comprehensive quantitative analysis of transboundary flows of used electronics between and from North American countries. It has been prepared for the NAFTA Commission for Environmental Cooperation (CEC) with financial support from Canada, Mexico, and the United States and is part of a multiphase effort to understand the flow of used computers and computer monitors from North America to the rest of the world.

Previous Work: The first phase of this work assessed the feasibility of these modeling efforts, whereas the second phase developed and validated the Mass Balance method. The current phase is an implementation of the Mass Balance method, as well as the Hybrid Sales Obsolescence-Trade Data Method (HSOTDM) that was developed in part for a 2013 Solving the E-Waste Problem Initiative (StEP) study.

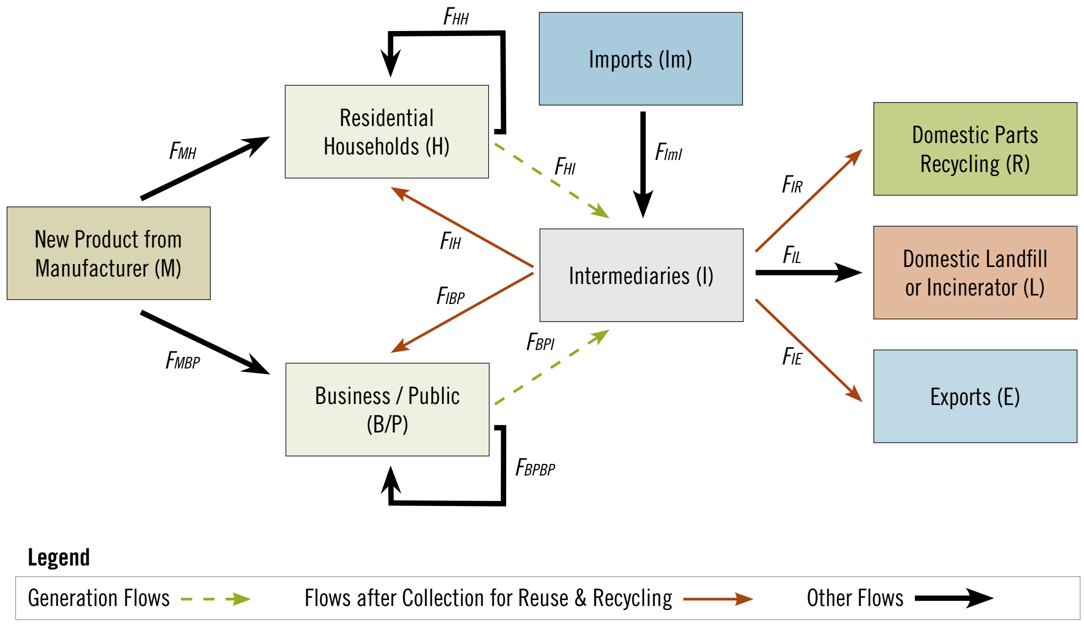
Scope: This study considered used desktops, laptops, CRT monitors, and flat panel monitors in 2010. The CEC is specifically interested in studying export flows of used electronics among the North American countries of Canada, Mexico, and the United States and from these countries to other countries around the world. In addition to export flows, the domestic generation and collection of used electronics are estimated, which add valuable comparison points to export estimates. Due to resource limitations, a variety of used electronic products and e-waste exports are not covered by this study, including separate whole and shredded circuit boards, printers, processed CRT glass, servers, gaming devices, cables, digital imaging devices, and audio and visual equipment.

Although the term “used electronic products” refers broadly to electronics which have reached the end of their useful life with their original owner, “e-waste” is a buzzword typically referring to a subset of used electronics which are not suitable for reuse, repair, or refurbishment for an extended useful life with a new owner. “E-waste,” therefore, is destined either for disposal or for parts and material recovery by means of disassembly or recycling. Each year worldwide, millions of electronic devices are purchased, and millions reach their end of use. Although some fraction of used electronic devices from households, businesses, and institutions are initially spared from the garbage through collection programs, the growing consumption of new electronics worldwide ensures that the amount of collected used electronics, and its subset of collected “e-waste,” will continue to grow as well.

Context and Limitations: Currently, the Harmonized System (HS) export codes used to capture global trade do not distinguish used electronics from new electronics. A few countries such as Peru and Japan voluntarily capture this level of detail for their imports and exports. In this report, the export flows of used electronics are not distinguished by their final disposition. Exported equipment that is functional and likely destined for reuse markets as well as non-functional equipment destined for dismantling, recycling, or disposal are all included.

Methods: Given the lack of hard data on domestic and export flows of used electronics, two separate approaches were undertaken to compare the results obtained and to provide a range for estimated quantities. This study intentionally sought to capture the uncertainty in the estimates. Sparse data make it difficult to arrive at the exact quantity of used electronics flowing through the system, and hence it is important to arrive at answers using several approaches and to determine a probable range. Monte Carlo simulations were used to model uncertainty in each dataset at each stage. Each of the thousands of Monte Carlo simulations calculates results using a randomly drawn combination of values from within the bounds of reasonable assumptions for each variable.

Figure ES-1: Export material flow analysis for the selected country



Source: Adapted and modified from Kahhat and Williams 2012 [13].
Note: The ordering of indices is from/to, i.e., F_{HI} refers to flows from residential households (H) to intermediaries (I), and F_{IH} refers to flows from intermediaries (I) to residential households (H).

The Hybrid Sales Obsolescence-Trade Data Method (HSOTDM) quantifies generation using a modified sales obsolescence model based on survey and sales data, collection using trends in survey collection rates, and exports using detailed trade data. The Mass Balance method generates and collects extrapolated survey data to quantify electronics flows, and then estimates for three scenarios (intended end-of-use, lower reuse, and higher export) the fractions of the collected electronics that are subsequently exported, and balances all the flows with exports as the remainder. Figure ES-1 depicts the flows of used electronics estimated in this study. In addition, external estimates were compared for validation purposes. Results from this study were mostly well aligned with estimates from other studies, which suggested that the methods are valid.

The advantage of the HSOTDM is that trade data for all types of electronic products are widely available (including extensive historical data), are updated relatively frequently, and provide insight into product destinations. The disadvantages are that there are no specific trade codes for used electronics and that exporters may choose codes other than those used in this study to describe these exports.[†] The Mass Balance method provides the ability to calculate several used electronics flows with few data inputs. The disadvantage is that exports are not calculated using data directly pertaining to exports, with the side effect that the destination countries cannot be identified. Calculating flows using both methods illuminates the level of variation in the methods and can provide insight into the upper and lower bounds of the flows.

Uncertainties: As described in the Methods section, uncertainties were captured at every stage of estimation. Uncertainty in these estimates arises from the sources listed in Table ES-1.

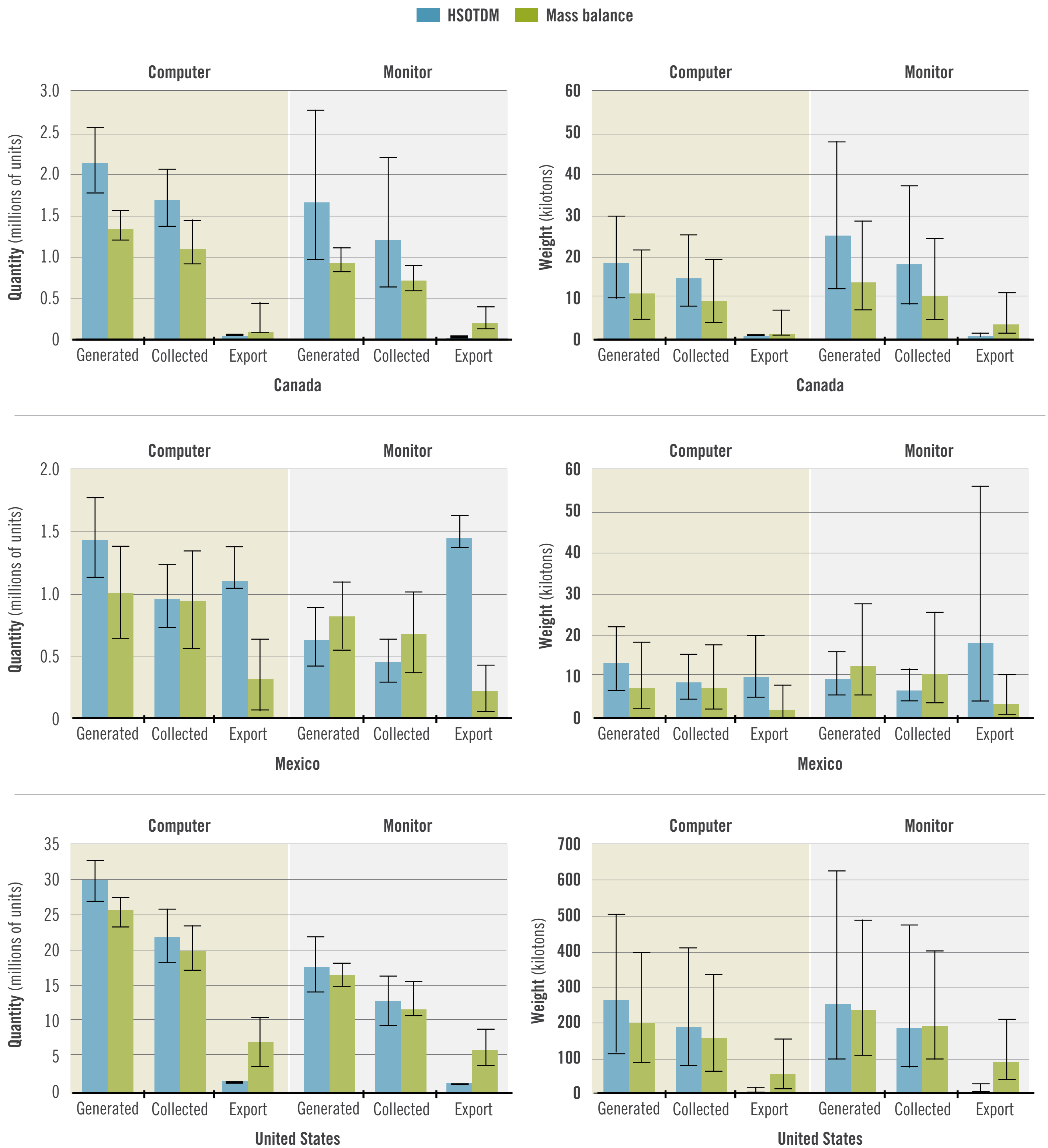
† Note that US Customs and Border Protection maintains a Customs Rulings Online Search System (CROSS) to retrieve rulings related to code classifications of globally traded goods. In addition, the US EPA regulates the export of cathode ray tubes.

Table ES-1: Sources of uncertainty in estimates

Source of Uncertainty	Generation	Collection	Export
Accuracy of survey data and their extrapolation	HSOTDM & Mass Balance	HSOTDM & Mass Balance	Mass Balance
Assumptions about **Intended end-of-use, Lower reuse, and Higher export scenarios**	Mass Balance	Mass Balance	Mass Balance
Estimation of product lifespans from survey responses and literature	HSOTDM		
Estimation of collection rates from survey responses and literature		HSOTDM	
Accuracy of new product sales data	HSOTDM & Mass Balance	HSOTDM & Mass Balance	
Accuracy of product weight estimates	HSOTDM & Mass Balance	HSOTDM & Mass Balance	
Accuracy of trade data, including exporter's choice of trade code and final versus reported destination			HSOTDM

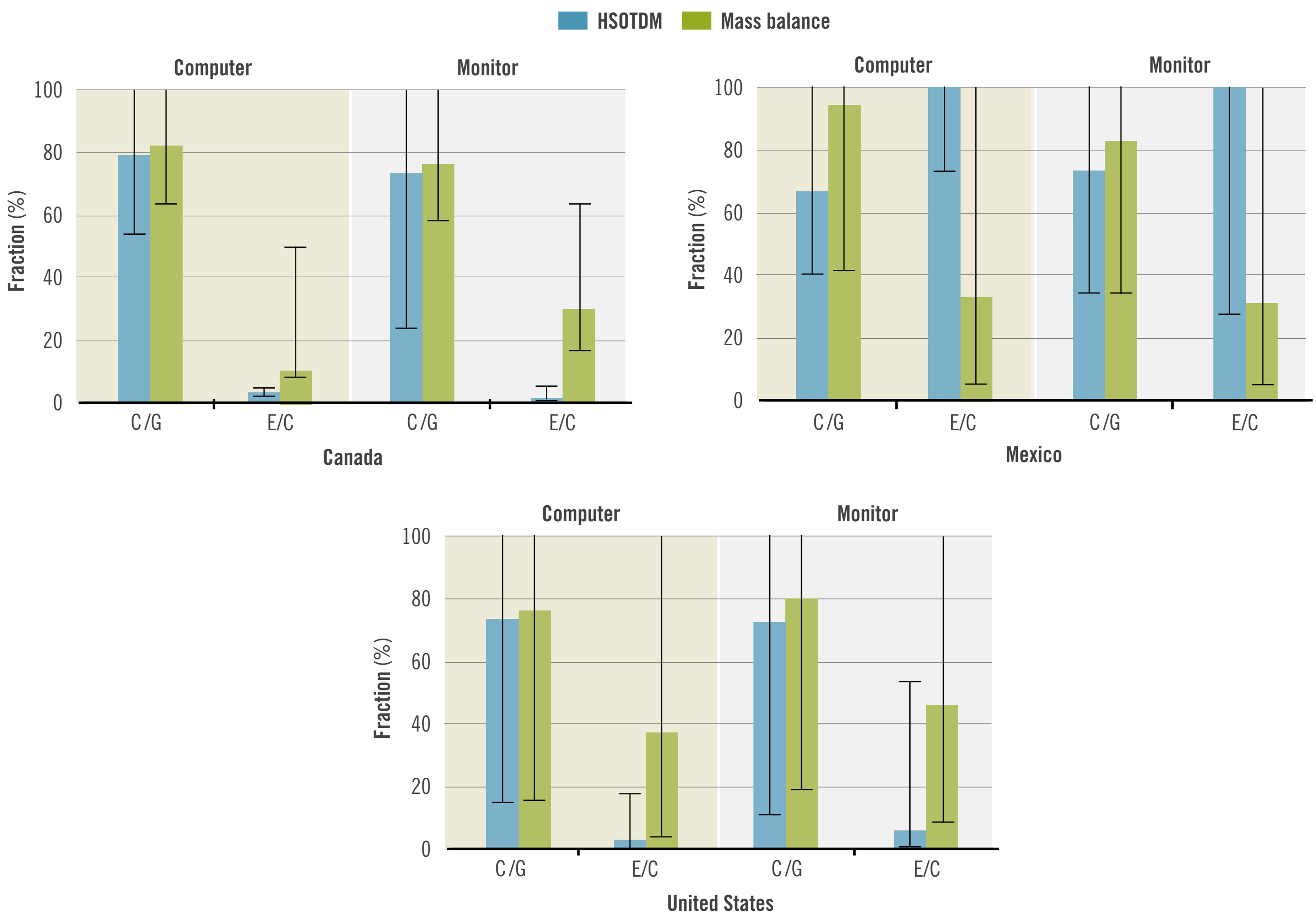
Results: The generation, collection, and export quantities and weight flows estimated by both methods for used computers and monitors for each country are presented in Figure ES-2. Figure ES-3 shows comparisons between the upstream and downstream stages in terms of the collection/generation fraction and export/collection fraction by country, product, and method. Because weight is determined in this report by multiplying quantity by unit weight, the fractions have the same mean values for the quantity and weight estimates; however, fractions based on weight estimates have wider confidence intervals due to the uncertainty of the unit weights. Tables ES-2 and ES-3 present the export quantity and weight respectively for the top five destination countries for used computers and monitor exports from the North American countries studied. Note that there are two HSOTDM export approaches to differentiate used and new exports: the Neighborhood Valley Emphasis Method (Export-NVEM) and reference to the Published Literature (Export-Pub.). Canadian export NVEM estimates are partly based on US trade data due to data limitations, and hence results cannot be estimated for Canadian exports to the United States.

Figure ES-2: Comparison of computer/monitor generation, collection, and export quantity (left) and weight (right) across countries by product and method



Note: For HSOTDM, Export is determined by one of the two methods described, the NVEM (Neighborhood Valley Emphasis Method). Columns represent mean values, and error bars represent the 95% confidence interval.

Figure ES-3: Fractions at the downstream stage compared to the upstream stage.
Comparison of collection/generation fraction and export/collection fraction by country, product, and method



Note: For HSOTDM, Export is determined by combining both methods. Columns represent mean values, and error bars represent the 95% confidence interval based on quantity. Weight has the same mean fractional values, but larger confidence intervals due to uncertainty in the unit weights.

Table ES-2: Top five export destinations for used computers and monitors in 2010 by quantity (thousands of units) using both HSOTDM export methods, NVEM and Pub

Export Country	#	Destination Country	Export Method: NVEM Mean	Uncertainty	Export Method: Pub. Mean	Uncertainty
Canada	1	USA	N/A	N/A	25	± 5.2
	2	France	8	Negligible	8	± 0.3
	3	Italy	8	Negligible	4	± 3.9
	4	United Arab Emirates	4	± 1.1	5	± 1.4
	5	Sri Lanka	4	Negligible	4	Negligible
Mexico	1	USA	2151	± 102.9	1210	± 436.4
	2	Netherlands	161	Negligible	161	Negligible
	3	Colombia	29	Negligible	65	± 49.7
	4	Canada	40	± 0.1	11	± 11
	5	Venezuela	23	Negligible	24	± 24.1
United States	1	Mexico	274	± 3.4	312	± 239.4
	2	Canada	229	± 2.4	180	± 63.9
	3	Hong Kong	91	± 1	162	± 69.7
	4	United Arab Emirates	80	± 3	119	± 13.3
	5	Lebanon	114	Negligible	83	± 23.4

Note: Note that several destination countries are commonly known to re-export goods regionally, including Hong Kong, United Arab Emirates, and Lebanon, and therefore are not likely final destinations.

Table ES-3: Top five export destinations for used computers and monitors in 2010 by weight (metric tons) for both HSOTDM export methods, NVEM and Pub

Export Country	#	Destination Country	Export Method: NVEM Mean	Uncertainty	Export Method: Pub. Mean	Uncertainty
Canada	1	United States	N/A	N/A	156	+363/ -115
	2	Italy	84	+102 / -43	42	+100 / -42
	3	Sri Lanka	59	+47 / -21	59	+27 / -21
	4	United Arab Emirates	40	+138 / -33	43	+113 / -35
	5	Chile	41	+77 / -25	30	+64 / -18
Mexico	1	United States	23,555	+42243 / -16917	12,390	+38069 / -9299
	2	Netherlands	1,707	+1194 / -883	1,707	+1194 / -883
	3	Colombia	270	+897 / -208	710	+2191 / -645
	4	Canada	496	+895 / -393	137	+1192 / -136
	5	Venezuela	275	+495 / -217	293	+1226 / -293
United States	1	Mexico	3,088	+7042 / -2192	3,655	+13454 / -3158
	2	Canada	2,250	+2743 / -1087	2,003	+2377 / -1141
	3	Colombia	967	+1936 / -612	706	+1641 / -458
	4	Venezuela	940	+1955 / -623	622	+1657 / -436
	5	Italy	952	+1154 / -489	493	+1130 / -475

Note: Note that several destination countries are commonly known to re-export goods regionally, including Hong Kong, United Arab Emirates, and Lebanon, and therefore are not likely final destinations.

Conclusions: Both HSOTDM and the Mass Balance method can produce reasonable ranges of estimates for the generation and collection of used electronics, as demonstrated by comparison to estimates from other studies. With few exceptions, the methods used in this study seem to provide a reasonable representation of the likely range of used computer and monitor exports from Canada, Mexico, and the United States. The juxtaposition of the HSOTDM and Mass Balance methods has proved useful for estimating the lower and upper bounds of the export quantity, and comparison with the collection estimates enables validation of the export figures. The HSOTDM, because it uses trade data, has the advantage of giving insight into export destinations. However, characterizing potential illegal shipments of these materials is beyond the scope of this work.

Comparing the generation and collection of products for all three North American countries investigated, slightly more computers were generated and collected than monitors. The weight of generated and collected monitors, however, was greater than that of computers due to their higher unit weights. Comparing countries, the generation and collection of used computers and monitors are roughly proportional to the population and per capita income of each country; the United States has the largest population and by far the largest estimated generation and collection volume. Although Mexico has a larger population than Canada, Canada has a much higher per capita income and hence higher purchasing power, which probably accounts for their similar amounts of used equipment.

The quantities and weights of used computers and monitors exports from Canada, Mexico, and the United States in 2010 have been estimated using two methods, HSOTDM and Mass Balance. Considering the two methods, on average Canada exported 55 to 114 thousand used computers and 22 to 218 thousand used monitors. Citing only the Mass Balance results because of outlier HSOTDM results for Mexico, on average Mexico exported 315 thousand used computers and 215 thousand used monitors. Lastly, comparing the two methods, on average the United States exported 1,122 to 6,992 thousand used computers and 779 to 5,669 thousand used monitors

Considering again the two methods, the overall fraction of used computer and monitor export quantity (or weight) compared to collection quantity (or weight) is estimated to be on average 1% to 30% for Canada and 3% to 47% for the United States. For Mexico, using the HSOTDM gives a result greater than 100%, but the Mass Balance method yields an estimate of 31% to 33%. Known issues with overestimation in Mexican trade data across all trade categories [1] as well as capture of low-value newly manufactured goods may account for the overestimation of the Mexican export fraction using HSOTDM. The other estimates are reasonable considering other domestic processing options for used electronics such as reuse and recycling.

The top destination for Canadian and Mexican used computers and monitors was found to be the United States (according to HSOTDM). Following high-income OECD North American countries (namely the United States), for both Canada and Mexico, upper middle-income countries and European countries were the second–most-popular destination groups. It is noteworthy that commonly discussed used electronics destination countries in Asia, Latin America, and Africa do not appear in the top destination lists. However, it is likely that some of the destinations listed here are preliminary destinations before the products are re-exported to a final destination country. For example, several of the top five US destination countries by quantity, Hong Kong, UAE, and Lebanon, are all known trade hubs, which suggests re-export to regional destinations upon import. These destinations are not present in the top five list by weight because relatively lower-weight items are exported to these destinations. It is not possible to determine the degree to which re-export occurs using the available data.

Recommendations: Several recommendations arise from this work to improve the generation, collection, and export estimates and to reduce the associated uncertainty:

- Flows could be analyzed across multiple years to discern trends. The methods proposed in this study can be used to model generation, collection, and export across several years.
- More accurate sales data, especially for Mexico, would enable more accurate generation estimates.
- Additional, annual, detailed surveys of business/public firms could enhance the accuracy of business/public generation and collection estimates.

- Creation of trade codes for used products would enable explicit tracking of these products (to the extent that these codes are properly used).
- Allowing more open access to Canadian and US shipment-level trade data would enable more accurate analyses of export flows.
- The Canada Border Services Agency could record the quantity of all exported electronics to enable more accurate analyses of export flows.
- Other approaches could be used to estimate export flows of used electronics to understand the impact of the limitations in all approaches on quantitative estimates.
- Although cumbersome to record, increased reporting of re-export destinations would greatly improve the accuracy of final destinations for trade flows because it would provide a more realistic depiction of the transactions taking place. The current trade code system can denote only two trade partners.

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1. Introduction

This study seeks to provide a quantitative characterization of transboundary flows (exports) and related domestic flows of used electronics in North America. Robust methods to quantify and capture the uncertainty associated with transboundary flows of used electronics from the North American countries of Canada, Mexico, and the United States are developed, and results for 2010 are presented. These estimated export quantities are compared to estimates of generation and collection of the same products.

There is significant interest by a variety of stakeholders in the quantities of used electronic products generated, collected, and exported. Despite this interest, there is a dearth of data, particularly on transboundary export flows. For example, the US Government's Interagency Task Force on Electronics Stewardship [2] has written that:

> There is very little verifiable information about the trade flows of used electronics, including amounts exported or imported. Better data are needed to create a more comprehensive picture of the overall trade flows; countries could use such data to assist in managing their used electronics in accordance with their relevant domestic policies. Accurate information about the amounts, types of materials and destinations of used electronics exported will provide valuable information for the Federal Government, private industry, and other stakeholders. [2]

Although the term "used electronic products" refers broadly to electronics that have reached the end of their useful life with their original owner, "e-waste" is a buzzword typically referring to a subset of used electronics which are not suitable for reuse, repair, or refurbishment for an extended useful life with a new owner. "E-waste," therefore, is destined either for disposal or for parts and material recovery through disassembly or recycling. Each year worldwide, millions of electronic devices are purchased, and millions reach their end of use. Although some fraction of used electronics from households, businesses, and institutions is initially spared from the garbage through collection programs, the growing consumption of new electronics worldwide ensures that the amount of collected used electronics, and its subset of collected "e-waste," will continue to grow as well. In this study, the terminology precedent set by the US Government's Interagency Task Force on Electronics Stewardship [2] is followed:

> The use of the term "e-waste" is intentionally minimized in this document simply to emphasize the importance of reuse and responsible recycling. Reuse of used electronics will reduce the amount of waste generated, and proper recycling of used electronics can yield raw materials (e.g., gold, copper, glass, aluminum) that can produce an economic benefit as well as serve to return materials to the supply chain and reduce overall waste. It should be noted that many countries have their own definitions, policies, and laws regarding management of used electronics and e-waste, including import and export restrictions. [2]

According to the Partnership for Action on Computing Equipment (PACE) Working Group of the Basel Convention, "computing equipment contain[s] many types of metals, plastics, and other substances, some of which are hazardous, some of which are valuable resources, and some of which are both. To avoid exposure of people and communities to the hazardous substances, and reduce the use of resources, end-of-life computing equipment should be re-used—if possible—but if not it should be sent for material recovery/recycling at facilities that recycle electronics and that undertake environmentally sound management (ESM) in their operations, and only as a last resort be sent for final disposal" [3].

1.1 Previous Work

1.1.1 Phase I, II, and III Work under CEC

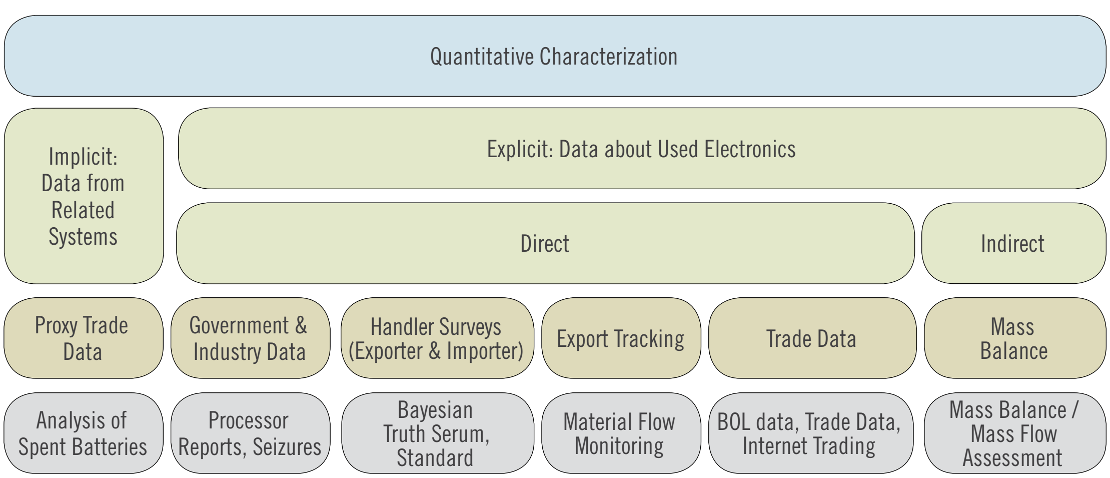
This report has been prepared for the Commission for Environmental Cooperation (CEC) with financial support from Canada, Mexico, and the United States and is part of a multiphase effort to understand the flow of used computers and computer monitors from North America to the rest of the world. Phase I, the Feasibility Study, concluded that it would be possible to characterize and quantify this flow. Phase II of this multiphase study, executed over nine months, developed and validated the Mass Balance method used in this study. The current study is the final phase (Phase III) and represents the implementation of the methods developed.

1.1.2 Overview of Characterization Approaches

The approaches pertinent to quantitative and qualitative characterization are described more extensively in a recent work by the authors of this study, "Characterizing Transboundary Flows of Used Electronics: Summary Report," which was completed for the Solving the E-Waste Problem Initiative (StEP) [4]. These approaches were gathered through a review of the relevant literature, discussion with stakeholders at a workshop in June 2011, and subsequent discussion among the report's authors. Figure 1 presents an overview of the hierarchy of methodologies that may contribute to quantitative characterization. Following the figure, each category of method is described.

- **Implicit methods** make inferences based on available data from related systems involving items similar in scope to used electronics.
  - **Proxy trade data** can be used to make inferences about unknown flows of targeted used electronics items by analyzing available trade data from related items. For example, flows of laptops may be inferred from data about circuit boards, hard drives, and LCD displays. Lepawsky and McNabb [5] studied spent battery data.
- **Explicit methods** derive estimates from data about the targeted used electronics items.
  - **Direct methods** use data about the exported used electronics under consideration.
    - **Government & Industry Data** encompass analysis of mandatory or voluntary exporter reports, extrapolations from government seizure reports, and monitoring of import country ports, as well as voluntary sharing of information from original equipment manufacturers (OEMs) and industry voluntary export standards organizations (including certifying organizations such as e-Stewards and R2).
    - **Handler surveys** include surveys of recyclers and collectors in both exporting and importing countries. Standard surveys and Bayesian Truth Serum surveys are options. The term "handlers" refers to both collectors and processors of used electronics.

Figure 1: Hierarchy of quantitative characterization approaches



- **Trade data** contain information on export or import flows of material or product streams. Bill of lading (BOL) data provide detailed accounts of each shipment, whereas other forms of trade data involve some level of aggregation. Internet trading platforms also give insight into the quantity and price of used electronics available and demanded around the world.

- **Indirect methods** use data about flows related to exported used electronics and infer the exported used electronics flows from these other flows.
  - **Mass balance** methods assume that exports are the unexplained portion of flows. **Trade data** can be used to inform these flows.

An ideal approach would require low effort, but yield high information quality (as illustrated by the matrix in Table 1), and would also provide information for qualitative characterizations. 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 of the data being collected and takes into account any sources of error in estimation, *Representativeness* refers to the ability of the sample data gathered to represent the range of used electronics exports, *Availability* refers to the existence and accessibility of data, and *Cost* refers to the financial resources needed to meet the research or political cost of diplomatic collaboration.

Another dimension not included in the table is *Comprehensiveness*, both in terms of quantifying generation, collection, and export and of achieving data scalability to an entire country. In this study, Trade Data were used within the Hybrid Sales Obsolescence-Trade Data Method (HSOTDM), and the Mass Balance approach was also used. Although these are expected to yield information of moderate quality, both have the benefit of comprehensiveness compared to approaches in the medium-high information quality category.

The HSOTDM methodology and the US results has been described similarly in the 2013 Solving the E-Waste Problem Initiative (StEP) report, "Quantitative Characterization of Transboundary Flows of Used Electronics: Methodology and Analysis of Generation, Collection, and Export in the United States." The trade data methodology was developed and applied to laptops in a recent Master's thesis [6].[1]

Table 1: Matrix of quantitative approaches by effort required and information quality yielded. Approaches attempted in this study are in bold.

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

1. Note that in the prior report, trade data were listed as having "low information quality," whereas in this report, they are listed as having "medium information quality." The change in assessment is due to two unanticipated advances: 1) researchers' access to more detailed trade data, and 2) development of the export method described in this report, which makes it possible to estimate the differentiation between used and new products using detailed trade data.

1.2 Scope of Study

1.2.1 Products Studied

Used, intact computers and computer monitors, excluding their derivative parts, were studied in this report. Desktop and laptop computers were studied, but more recent tablet technologies such as the iPad were excluded. Computer monitors were categorized as CRTs or flat panel monitors. The trade data include a category for video monitors, which are essentially special computer monitors that interface with security cameras through a computing device and, therefore, were included in this study. Due to resource limitations, a variety of used electronics and e-waste exports are not covered by this study, including separate whole and shredded circuit boards, printers, processed CRT glass, servers, gaming devices, cables, digital imaging devices, and audio and visual equipment.

1.2.2 Time Frame

The year 2010 was chosen as the time frame of this study for several reasons. Although sales and trade data are available quickly, other types of information about electronics flows typically lag by several months to several years. Several recent reports have focused on 2010, and hence by choosing it as the analysis year, the results can be compared to these other estimates. Moreover, both methods used in this report base some of their analyses on a set of surveys targeting computer equipment user behavior in 2010, and therefore it makes the most sense to apply the results to the intended year.

1.2.3 Geographic Region

The Commission for Environmental Cooperation is specifically interested in studying the export flows of used electronics among the North American countries of Canada, Mexico, and the United States and from these countries to other countries around the world. Re-exports, a subset of exports which do not originate in the exporting country [7], are assumed not to represent flows of used products from the exporting country and hence were excluded where possible.[2]

1.2.4 Flows of Used Electronics Estimated in This Study

In this study, the generation, collection, and export of used electronics are estimated. The term "generation" refers to electronics coming directly out of use, post-use storage, or informal reuse destined for collection for recycling and reuse or disposal. "Informal reuse" refers to small-scale exchanges of electronics between individuals without interaction with a firm that collects and aggregates used electronics for recycling or formal reuse. Generation is therefore consistent with the term "ready for end-of-life [EOL] management" [8,9]. The used electronics processor, having collected the used electronic unit as a whole, opts either to prepare it for reuse by a new user, to recover parts and materials from the item and transfer them to downstream vendors (some of which may be in foreign countries), or to export the used electronic product as a single unit.

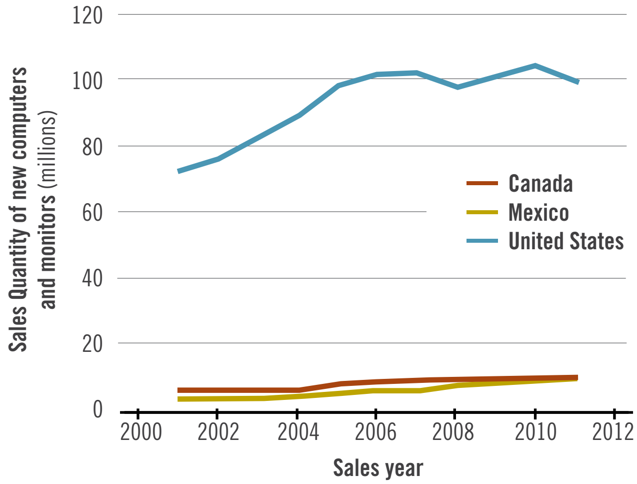
1.3 Country Comparison Overview

For the purpose of trade, used and waste electronics may be subject to control as "hazardous waste" or "other waste" under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel Convention). To date, 183 countries are parties to the convention, including Canada and Mexico. A party cannot export or import wastes determined to be hazardous to a non-party unless it has entered into a separate bilateral agreement governing such movements. This is the case with transboundary movements of hazardous wastes and other wastes between parties and the United States because the United States is a signatory to the Convention, but has not ratified it through domestic law. See Appendix 1 for more detail. Although this research estimates export flows of used computers and monitors from North America, characterizing potential illegal shipments of these materials is beyond the scope of this work.

To obtain an impression of how the three countries studied compare otherwise, Figures 2 through 5 present various parameters relevant to consumption and trade in new and used computers and monitors. Figure 2 presents the sales of new computers and monitors over time, as calculated for this study. See Appendix 1 for a more detailed sales chart. Figure 3 shows trends in population [10]. Figure 4 charts gross national income (GNI),[3] and Figure 5 shows GNI per capita. As expected, population, GNI, and GNI per capita correlate positively with sales of new computers and monitors [11]. The United States (US) is the highest across all categories, and although Mexico and Canada have a similar total GNI, Canada's GNI per capita more closely resembles that of the United States because Canada has a smaller population than Mexico.

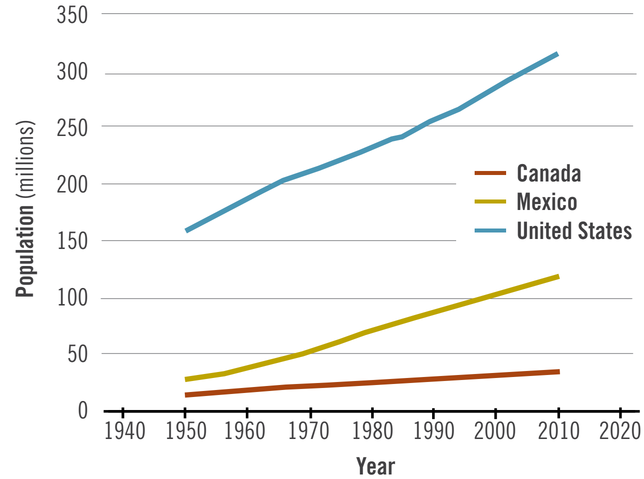
2. General exports are the sum of domestic exports and re-exports. The UN Statistics Division (2010) states that "goods that are not under 'in transit' or 'transshipment' customs procedure and change ownership after entering the economic territory of a country should be recorded as imports and re-exports if they leave the country in the same state as imported" [7 (UN Statistics Division, *International Merchandise Trade Statistics: Concepts and Definitions 2010*, in *Statistical Papers,* 2010)]. To identify exports of used exports from the United States, the portion that is re-exported in the same condition after import is excluded. Mexican trade data do not distinguish re-exports.
3. "GNI (formerly GNP) is the sum of value added by all resident producers plus any product taxes (less subsidies) not included in the valuation of output plus net receipts of primary income (compensation of employees and property income) from abroad. Data are in current US dollars." [11. (The World Bank, *World Development Indicators*, 2013, p. 25].

Figure 2: Comparison of total new computer and monitor sales



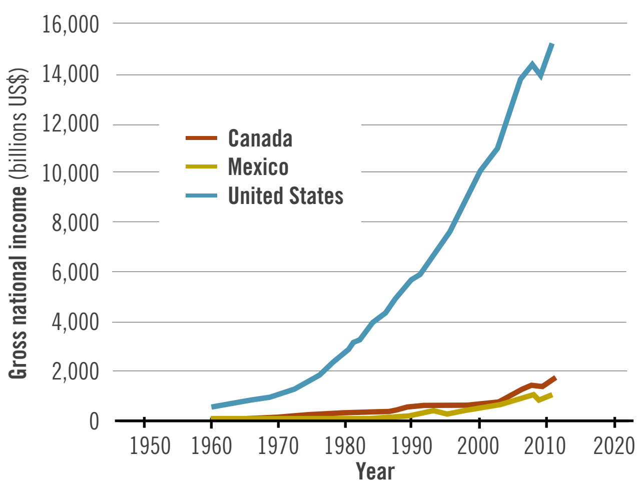
Source: International Data Corporation (IDC). See Table 4.
Note: The US sales quantity is much higher than those of Canada and Mexico, which are estimated to have similar sales quantities.

Figure 3: Comparison of population over time



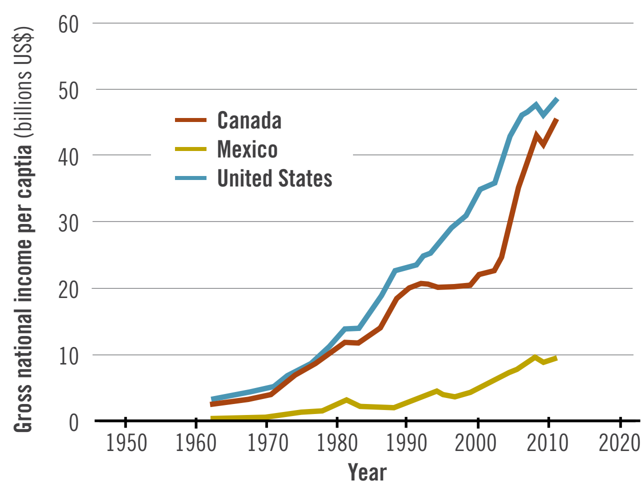
Source: UN Department of Economic and Social Affairs 2012 [10].
Note: The United States has a much larger population than Mexico, which has a larger population than Canada.

Figure 4: Comparison of gross national income (current US$)



Source: The World Bank 2013 [11].
Note: The US Gross National Income is much higher than those of Canada and Mexico, which are similar.

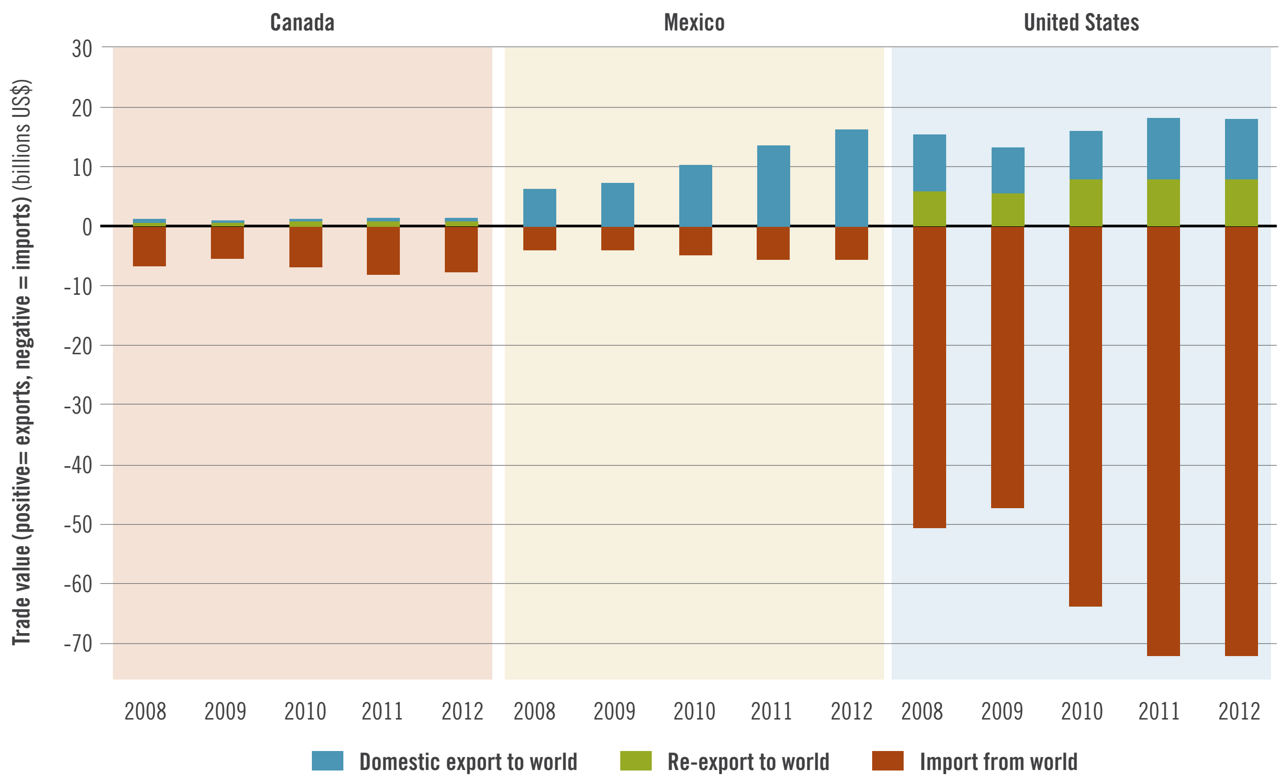
Figure 5: Comparison of Gross National Income per capita (current US$)



Source: The World Bank 2013 [11].
Note: The US Gross National Income per capita is slightly higher that of Canada, which has grown to be much higher than that of Mexico.

Aggregate trade data can lend some insight into consumption and flows of electronics. Figure 6 shows the trade balance for Canada, Mexico, and the United States from 2008 to 2012. Total exports are equal to the sum of domestic exports (originating in the country) and re-exports (which can be thought of as goods traveling through a country without use or a change in their condition). The United States is seen to import the most computers and monitors, although it is also seen to engage in considerable re-export, and re-exports are included in the import data, so that imports for consumption are less than total imports. This is consistent with the observation that the United States has the highest computer and monitor sales volume because it imports most of the new computers and monitors sold. As shown in a more detailed chart in Appendix 1, Mexico's domestic exports are largely to the United States.

Figure 6: New and used computer and monitor trade balance



Source: UN Statistics Division [12].
Note: Trade value calculated using UN Comtrade database. Positive values denote export, negative values denote import.

2. Methods

2.1 Comparison between Methods Used

Given the lack of ideal datasets to quantify used electronics flows, two separate approaches were undertaken to compare the results attained and provide a range for the estimates. Table 2 provides a summary comparison between the two methods used in this study. The Hybrid Sales Obsolescence-Trade Data Method (HSOTDM) quantifies generation using a modified sales obsolescence model involving survey and sales data, collection using trends in survey collection rates, and export using detailed trade data. The Mass Balance method uses extrapolated survey data to quantify the flows of electronics that are generated and collected and then estimates for three scenarios the fractions of the collected electronics which are subsequently exported in combination with balancing all flows.

Table 2: Summary comparison between methods used

Flow	HSOTDM	Mass Balance
Generation	***Residential:*** Combines product sales data with models of product lifespans based on survey data ***Business/Public:*** Similar to Mass Balance	***Residential and Business/Public***: Amplification of survey respondents' generation habits in 2010 based on sales data and purchase habits
Collection	***Residential:*** Combines generation results with models of collection rates from survey data ***Business/Public:*** Similar to Mass Balance	***Residential and Business/Public***: Amplification of survey respondents' collection habits in 2010 based on sales data and purchase habits
Export	Uses detailed export trade data and differentiates between used and new exports based on unit value. Results in a lower-bound estimate.	Mass balance of flows combined with estimates of post-collection destinations based on type of collection habit
Limitations	Inherent errors in sales and survey data, lifespans are approximations, used electronics are often classified differently at export	Inherent errors in survey data and extrapolation factors, estimates of fractions of collected electronics that are exported are highly uncertain

Figure 7 depicts the flows of electronics from the manufacturer (M) through residential households (H) and business/public (BP) users, to intermediaries (I). Purchase, use, and disposal habits are assumed to differ among these users, and hence generation and collection were modeled separately. Intermediaries also collect used imports (Im) and either redistribute them for reuse to households (H) and business/public (B/P) users, send them to landfill or incinerator (L), sell them domestically for parts and materials recycling (R), or export them to a foreign country (E). In the HSOTDM, the generation flows are estimated, as is the collected quantity (an aggregate of the flows after collection for reuse and recycling). In the Mass Balance method, each flow is estimated.

2.1.1 Overview of Hybrid Sales Obsolescence-Trade Data Method (HSOTDM)

This methodology has been described similarly in the 2013 Solving the E-Waste Problem Initiative (StEP) report, "Quantitative Characterization of Transboundary Flows of Used Electronics: Methodology and Analysis of Generation, Collection, and Export in the United States." The Hybrid Sales Obsolescence-Trade Data Method (HSOTDM) for residential generation and collection estimation follows a similar series of steps to those in many studies, which are listed below. The Business/Public estimates amplify survey respondents' habits in 2010 based on sales data and purchases.

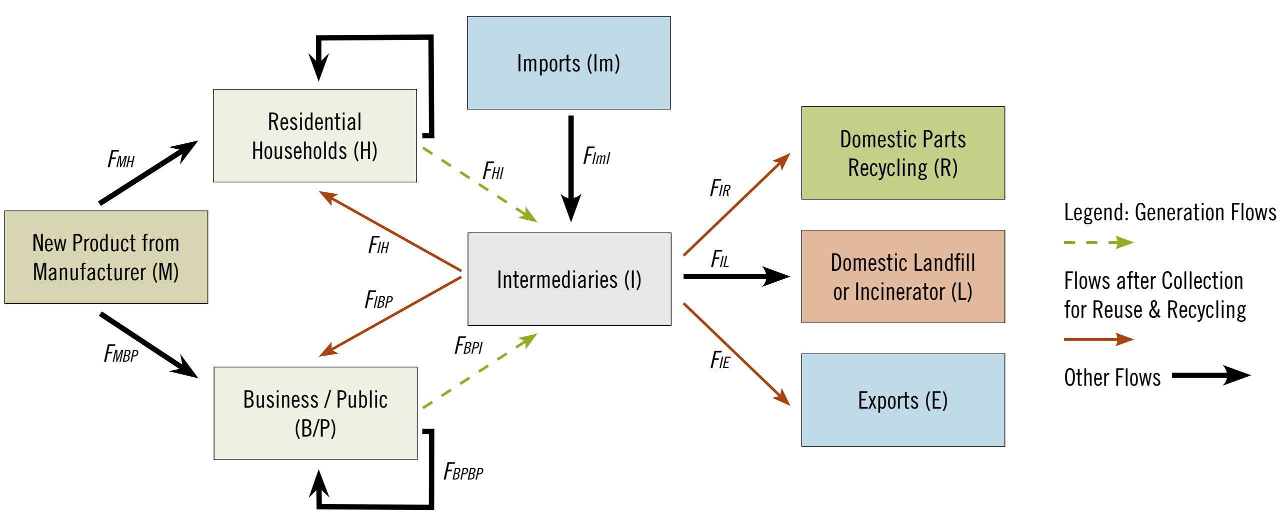
1. Determine the residential sales of a product in a region over a time period.
2. Determine the typical lifespan distribution for the product over a time period.
3. Calculate how many products are predicted to be generated in a given year using the sales and lifespan information.
4. Calculate how many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

The HSOTDM for export is to use detailed, disaggregated trade data to distinguish the quantity of used electronics exports. The steps to do this are as follows:

1. Collect and prepare disaggregated, detailed export trade data.
2. Estimate the threshold unit values that differentiate used and new goods for different world regions.
3. Sum the quantity of goods domestically exported from the United States to partner countries with a unit value below the threshold.

The advantage of this method is that trade data for all types of electronic products are widely available (including extensive historical data), are updated relatively frequently, and provide insight into product destinations. The disadvantages are that there are no specific trade codes for used

Figure 7: Export material flow analysis for the selected country



Source: Adapted and modified from Kahhat and Williams 2012 [13].
Note: The ordering of indices is from/to, i.e., FHI refers to flows from residential households (H) to intermediaries (I), and FIH refers to flows from intermediaries (I) to residential households (H).

electronics and that exporters may choose codes different from those used in this study to describe these exports. An analytical approach was used here to differentiate used products from new ones in the trade data, but the extent of differences in classification among exporters is unknown. Hence, it is not currently possible to say how much error exists in the export estimates as a result of differences in classification. Still, it is safe to assume that the estimates of export quantities are lower bounds of actual export quantities due to these likely differences in classification.

Another issue with the trade data approach is that the destination listed in the trade data may actually be an initial stopping point and not a final destination. After the initial stop, the products may then be re-exported to a final destination; re-exports and final destinations are not always reported in trade data. Hence, 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 re-export, the final destination is likely in the same region.

2.1.2 Overview of Mass Balance Method

The Mass Balance method makes it possible to calculate several flows of used electronics with few data inputs. The disadvantage is that exports are not calculated using data directly pertaining to exports, with the side effect that the destination countries cannot be identified. The description of the Mass Balance method throughout this report is excerpted and adapted from unpublished reports from previous phases of this work and on a recent journal article [13] with permission from authors Ramzy Kahhat and Eric Williams. Although the prior work includes three end-of-use scenarios (Intended end-of-use, Lower reuse, and Higher export) to capture uncertainty, this version of the method incorporates data uncertainty throughout. Survey results are scaled up using scaling factors based on comparison between sales data and reported purchases by survey respondents. Data uncertainty in the scaling factors is carried through the entire analysis.

Figure 7 depicts national material flows of computers or computer monitors beginning with manufacture, followed by use in different sectors, and then by end-of-life or export. The handling of end-of-use computers and monitors has been pulled out as an aggregated "intermediary" sector which engages in collection, sorting between re-usable or scrap equipment, preparation activities for reuse of computers and components (remanufacture, refurbishing, repair, or upgrade), reselling, donating, prepping computers or monitors for recycling, transportation to landfills, and import and export of used computers and monitors. An array of organizations acts as intermediaries in this process. These organizations include e-waste management companies (such as Intechra), brokers, resellers (such as Goodwill), donation agencies (such as Computers for Schools), Internet sales sites (such as eBay or Mercado Libre), and municipalities. From intermediaries, used computers and monitors flow back into residences, businesses, and public agencies and also to domestic landfills, domestic recycling, and export sectors. The flow of computers and monitors from one element to another can be denoted as F_{BPI} = Flow from Business/Public to Intermediaries.

In summary, the number of used and scrap computers and monitors exported from a country or region can be calculated by subtracting the flow of computers entering the intermediary sector from the consumer sectors with the flows exiting the intermediary sector to the consumer, domestic landfill, and domestic recycling. Moreover, in some countries, there could be a flow of imported used computers that can satisfy either the domestic reuse or recycling markets. This flow should be assumed to enter the intermediaries and is expressed as F_{ImI} in the equation in Figure 7.

2.2 Data Source Overview

2.2.1 Survey Data

Residential and business/public surveys were conducted in each country focusing on activity in 2010 (Table 3). The surveys were designed by Ramzy Kahhat and Eric Williams. The Mexican residential survey was conducted again in 2013 using a slightly updated survey to ensure a demographically representative survey sample. The 2011 Mexican residential survey was conducted online, and therefore a portion of Mexican computer users who do not have Internet access were not represented. To address this shortcoming, the 2013 survey was

Table 3: Survey Details

Country	Residential surveys	Business/public surveys
Canada	Year survey conducted: 2011 Method of survey: online Sample size: 600 adults Margin of error: ±4%	Year survey conducted: 2011 Method of survey: Online Sample size: 345 IT/ asset managers Margin of error: ±5.25%
Mexico	Year survey conducted: 2013 Method of survey: telephone/CATI Sample size: 1,200 adults Margin of error: ±3%	Year survey conducted: 2011 Method of survey: online Sample size: 257 IT/ asset managers Margin of error: ±4%
United States	Year survey conducted: 2011 Method of survey: online Sample size: 1,000 adults Margin of error: ±3%	Year survey conducted: 2011 Method of survey: online Sample size: 400 IT/ asset managers Margin of error: ±5%

conducted by telephone by the Mexican firm Grupo IDM, which has a broader penetration than the Internet. In addition, residential surveys conducted by others from other years were sought to create a time series trend of collection rates [14]. Additional survey details can be found in Appendix 2.

2.2.2 Sales Data

Sales data were used in both the residential and business/public steps (Table 4). Anticipating that some used electronics are generated decades after their purchase, time series sales data were sought from two decades before the year of prediction (1990 to 2010). Sales of desktops and monitors do not fit nicely into simple growth models, although laptop sales through 2010 could be modeled as exponential growth. Therefore, the sales data estimates themselves are used in the baseline analyses and are allowed to vary by ± 10% to capture error in the Monte Carlo simulation.

Table 4: Sales data sources

Country	Product	Sales years (data source)
Canada	Desktops	1994–2011 (IDC)
	Laptops	1994–2011 (IDC)
	CRTs and flat panel monitors	2000–2007 (GIA) 2008–2011 (IDC)
Mexico	Desktops	1994–2011 (IDC)
	Laptops	1994–2011 (IDC)
	CRTs and flat panel monitors	2008–2011 (IDC)
United States	Desktops	1990–1994 (IDC via EPAa, 2008) 1995–2011 (IDC)
	Laptops	1990–1994 (IDC via EPAa, 2008) 1995–2011 (IDC)
	CRTs and flat panel monitors	1990–1999 (IDC via EPAa, 2008) 2000–2007 (GIA) 2008–2011 (IDC)

Sources: International Data Corporation (IDC) sales data for computers and monitors. Global Industry Analysts, Inc. (GIA) data on computer monitors [55].

Sales data for each product were purchased from the International Data Corporation (IDC). Sales data were available for computers since 1996 and for monitors since 2008. The model begins with sales in 1990, so additional data sources were required for the missing information. When additional data sources did not distinguish between residential and business/public, the fraction of residential sales observed in the IDC data was allowed to vary by ± 10% to capture error and then applied to the additional sales data.

2.2.3 Unit Weight Data

The unit weight data for computers and monitors were estimated based on several thousand samples of collected used products in Oregon and Washington.[4] Although desktops and laptops were differentiated, monitors were combined, and hence the apparent bimodal distribution was assumed to differentiate CRT monitors and flat panel monitors. The Finite Mixture Models [15] (FMM) package embedded in the Stata data management software was used to differentiate the underlying lognormal distributions.[5] Oracle Crystal Ball confirmed that the lognormal function was a good fit for the distributions. Table 5 shows the resulting unit weights (kg per unit).

Table 5: Unit weights of used electronics (kg per unit)

Used electronics	Distribution fitted	Mean	Standard deviation
Desktops	Lognormal	10.6	3.3
Laptops	Lognormal	3.1	1.5
CRT monitors	Lognormal	15.4	1.2
Flat panel monitors	Lognormal	10.4	2.0

2.2.4 Trade Data

Trade data were used in the export portion of the HSOTDM, but not in the Mass Balance method. Although the UN Comtrade database maintains publicly available trade data for most countries in the world, it is too aggregated for the purposes of this method. Therefore, considerable efforts were undertaken to locate disaggregated trade data, which are shown in Table 6.

4. NCER Brand Data Management System, sampling share from computer and monitors (weight), Oregon and Washington Sampling Data: <www.electronicsrecycling.org/BDMS/AlphaList.aspx?sort=All>.
5. Partha Deb. 2008, Finite Mixture Models: <www.stata.com/meeting/snasug08/deb_fmm_slides.pdf>.

Table 6: Trade data sources

Country	Data source	Description of data
Canada	Statistics Canada	Port-level data with value and quantity. Export quantities of computers and some monitors not reported.
Mexico	Mexican Customs agency (*Aduanas Mexico*) via INFOMEX	Shipment-level records with value and quantity, screened for trade code classification accuracy.
United States	USA Trade Online, Quintero Hermanos Ltd. (sicex.com), Statistics Canada	Mathematical combination of district-level data containing value, quantity, and weight with port-level data containing only value and weight. Substitution of Mexican and Canadian import data for overland exports to those countries.

2.3 Generation

2.3.1 Hybrid Sales Obsolescence-Trade Data Method (HSOTDM)

The residential survey asked about each item, whereas the business/public survey asked about groups of items. Therefore, the residential generation and collection methodology followed the basic approach to determine generation and collection quantities consistent across most studies listed above, whereas the business/public methodology is a more simplistic amplification of results and will be described in this chapter after the residential method.

2.3.1.1 Residential Generation

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

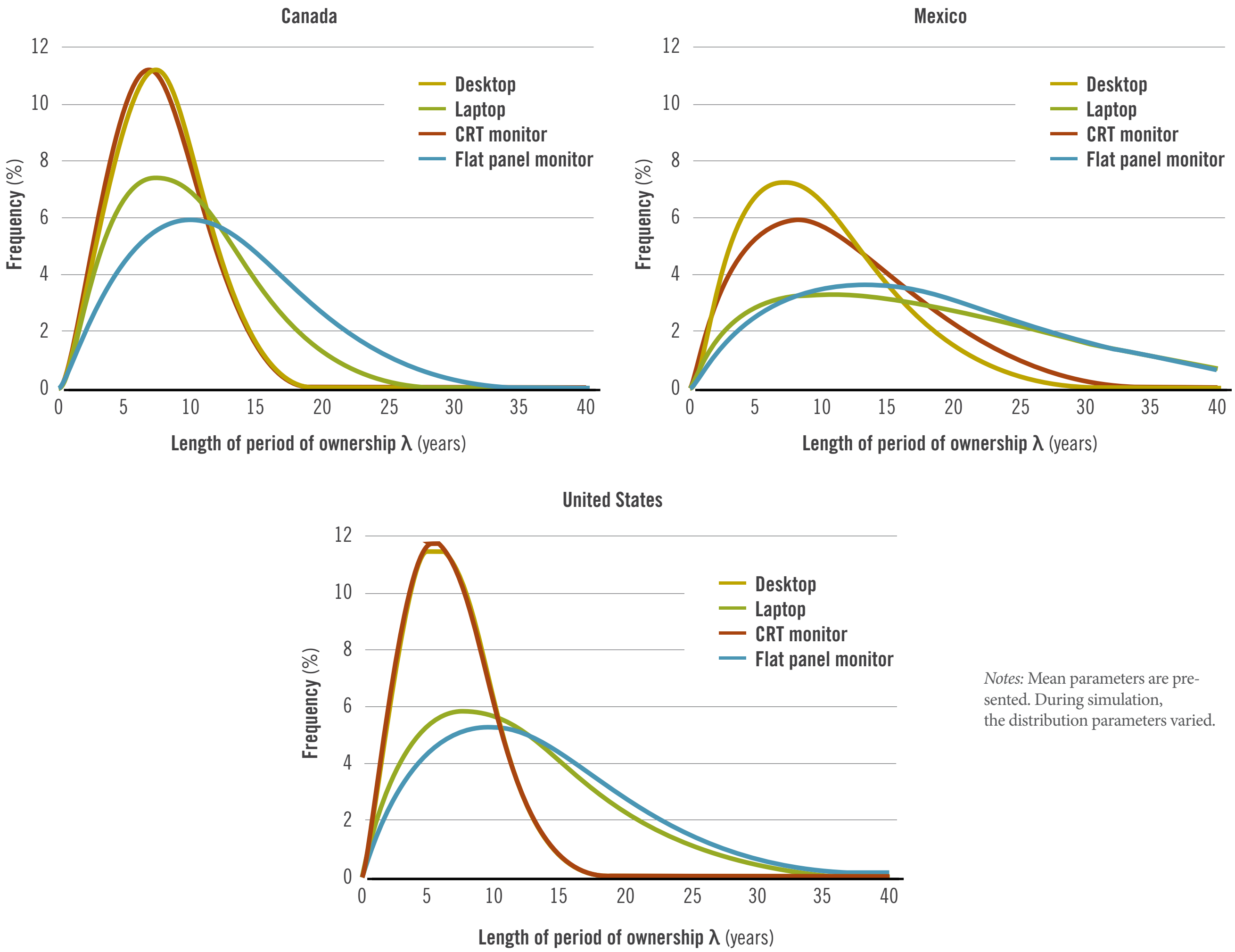
To compute the lifespan distributions for each residential product, survival analysis techniques were used [16]. Survival analysis is typically used in studies of patient survival of disease or of machine failure. Adapting that terminology to this study with the intent to understand the length of time that 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. The distribution of the length of one period of ownership is an input into the generation prediction model, which is why this quantity is sought instead of time until generation directly, as one might expect. Ideally, estimates would be made as a trend for each year, but that was not done due to data limitations. Moreover, ideally items would be separated into those purchased new and those purchased used because new products will probably last longer, but this was not possible with the survey dataset. The steps in estimating the distribution of the length of one ownership period λ are listed below and elaborated upon in Appendix 3.

i. Prepare the residential survey data from surveys described in Table 3.
ii. Determine the age of products either at the point of "failure" or at the time of "retirement" (a product is retired if it is still with the owner when surveyed). If possible, screen the responses by the respondent's precision in estimating the year of purchase in comparison to estimating the time in use and storage (a cutoff of one 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 products together. Use the same K-M curve and associated Weibull regression for all years of purchase.
v. Fit additional Weibull regression parameters to the K-M curves.
vi. Transform the results of the Weibull regression into a probability density function, which will be used as the length distribution of one period of ownership.
vii. During the Monte Carlo simulation, allow the regression parameters to vary within a 95% confidence interval and allow the entire distribution to shift left and right by one year to account for allowable error in the respondents' precision.

Figure 8 presents the mean lengths of period of ownership λ for Canada, Mexico, and the United States for each product. See Table 13 in Appendix 3 for the mean distribution parameters. Recall that these results were produced from independently conducted surveys and that therefore the similarity of the results supports the validity of the survey and modeling methodology.

Note that the mean lengths of period of ownership λ for Canada and the United States are similar across the range of products, in contrast to Mexico. This is to be expected given the similar economics of the two countries, as pointed out in the introduction. Moreover, it is possible that because 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 8: Distribution of lengths of period of ownership λ for Canada, Mexico, and the United States for each product



Notes: Mean parameters are presented. During simulation, the distribution parameters varied.

Another lifespan input to the residential generation prediction model is the lognormal distribution of the length of time δ until an electronic device is reused. Because 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 device 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 Appendix 3). This does not capture electronics that were sent to recyclers and subsequently reused, nor electronics still in the home that were purchased used. Still, it is a reasonable approximation.

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. Therefore, which "disposal" activities lead to generation is defined first; as with the literature method, informal reuse is not considered generation (see Appendix 3). Next, the approach models the quantity of electronics that are used only 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 Equation 1, 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 device is reused. The same length of period of ownership λ was applied to used and new products given the data constraints related to the survey questions. Ideally, these would be separate distributions because used products are likely to have a shorter functional use period.

Equation 1: Generation in year y based on sales and periods of ownership

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

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 the 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 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 new purchases in a given year were assumed to undergo one use before generation (*O*), less those that are predicted to be informally reused in future years (*I*). A detailed description of this methodology is found in Appendix 3. The total of these three groups is shown simply in Equation 2.

Equation 2: Total Residential Generation of Used Electronics in Year y

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

2.3.1.2 Business/Public Generation

As a reminder, the residential survey asked about each item, whereas 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. In this approach, the responses to survey questions about the most recent purchases in 2010 were tabulated. Note that because these questions addressed only the most recent purchases, a full purchase time series could not be generated. A scale factor for 2010 was determined for each product (laptops, desktops, CRTs, and flat panel monitors) using Equation 3. Scale factors are found in Tables 15 and 16 of Appendix 3.

Equation 3: Scale Factor for Business/Public Generation and Collection steps

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

Both inputs to Equation 3 were allowed to vary in a Monte Carlo simulation; Sales varied by ± 10%, and Survey Purchases varied within the surveys' confidence interval (roughly ± 5%). Because the scale factors differed somewhat for each product due to inaccuracies in either the survey or the sales data, an average 2010 scale factor was determined and applied to all product estimates.

To arrive at 2010 generation and collection estimates, the reported 2010 generated products tabulated from the surveys were multiplied by the scale factors, as shown in Equation 4. The scale factors were allowed to vary within a 95% confidence interval in a Monte Carlo simulation. Details on the survey tabulation are found in Appendix 3.

Equation 4: Business/Public 2010 Generation

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

2.3.2 Mass Balance

To arrive at generation estimates, the reported 2010 generated products tabulated from residential and business/public surveys were scaled to each country's residential and business/public sectors. Referring back to the export material flow analysis illustrated in Figure 7, generation is approximately equivalent to the flows F_{HI} and F_{BPI} for residential households and the business/public sector respectively. As a reminder, the flow of computers and monitors from one element to another can be denoted as F_{BPI} = Flow from Business/Public to Intermediaries.

Slightly departing from the methodology established in previous work by Kahhat and Williams, the scaling of both residential and business/public flows was accomplished in this study by comparing survey purchases to sales data using Equation 3; the same business/public scale factors used in the HSOTDM were used in the Mass Balance Method. Previously, the number of people in the residential sector of respondents was scaled to the population because the sales data available to the researchers did not disaggregate the residential and business/public sectors. Once the population-based scale factor had been established, residential sales were estimated, and business/public sales were determined as the remainder.

In this study, disaggregated sales data made it possible to estimate both the residential and business/public scale factors directly from sales data. The scale factors were allowed to vary within a 95% confidence interval.

2.3.3 Comparison with Other Sources

2.3.3.1 Canada

PHA Consulting Associates (2006) applied US sales data from a 2003 report by IAER (International Association of Electronics Recyclers, since merged with ISRI, the Institute of Scrap Recycling Industries) to a model developed for estimating generated Canadian electronics. Although the collected electronics could have been calculated using the model, they were not reported. The model incorporated "annual sales data, expected life of the product, and unit weight data to estimate the weight of product flowing through various parts of the system from generation through first life, reuse, storage, recycling, and disposal," as detailed in [17]. The model assumes that of most electronics in 2010, 40% were reused informally (bypassing collectors) and 10% were stored. The remaining 50% was split between recycling and disposal. Use lifespan assumptions are derived from a variety of North American literature; desktop and laptop computers were assigned average first-use lifespans of 3.5 and 3.4 years respectively.

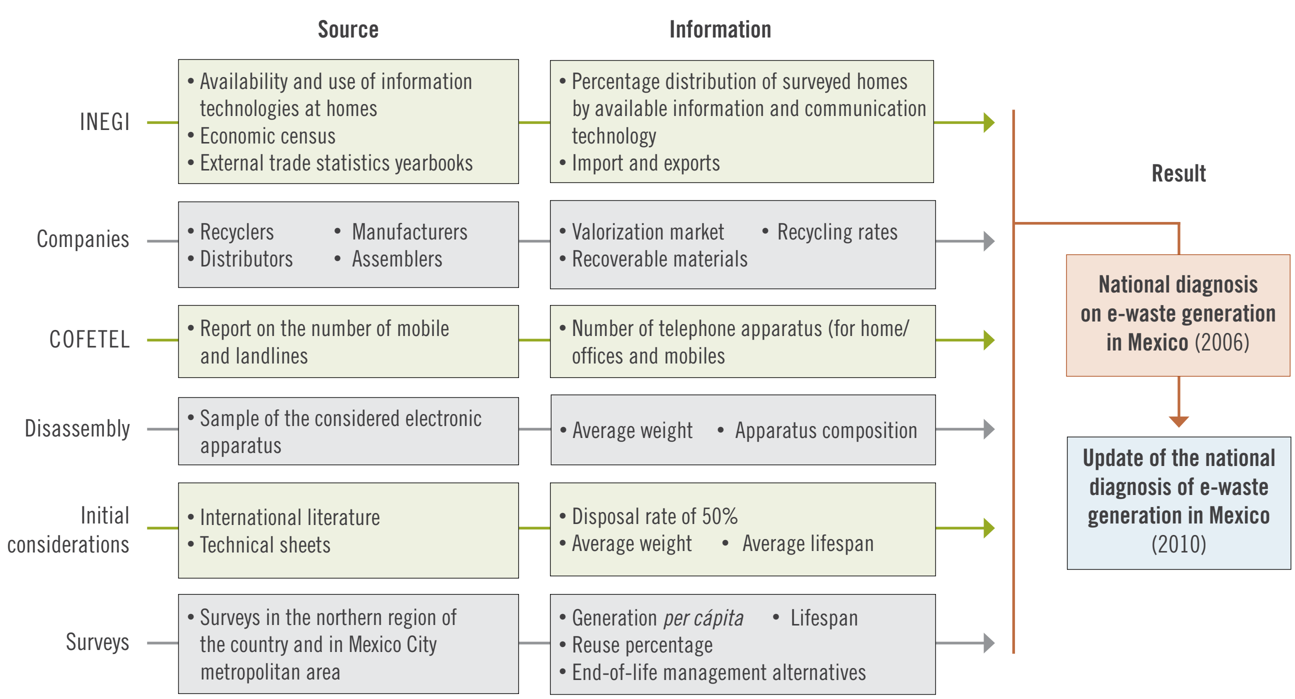
2.3.3.2 Mexico

In 2006, an assessment of electronic waste generation was prepared by the Mexican National Polytechnic Institute (*Instituto Politécnico Nacional*) for the National Institute of Ecology (*Instituto Nacional de Ecología*—INE) [18]. The author, Dr. Guillermo J. Román Moguel, prepared an update for 2010 [19]. Because the definition of generation included items going to reuse and storage (40% overall), the comparison figures were adjusted to 60% of the estimates. The average lifespans for desktop and laptop computers were found to be 5 years and 3 years respectively.

The first step in this project was to analyze information from national official reports, adoption data from countries with similar behaviors, surveys, and similar sources. These data were combined to generate inventories of used and discarded electronic equipment. Listed below are the main sources of information used in Mexico. Figure 9 shows the various sources of information used to obtain the amount of electronic waste generated in the country. These studies also validated the average weight and lifespan and the destination of this waste.

1. Official reports of generators (prior assumptions were made about the size of the system being analyzed, sample size, imports, exports, data available from government records, time reporting, and failure to report, among others).
2. Reports of e-waste processed by companies (special assumptions were made because the companies do not receive everything that is discarded, and sometimes they do not report everything they receive, similarly to the cases of municipal solid waste and other kind of waste).
3. Estimates were based on economic indicators and comparison between reports from other countries (number of employees, same processes = same residues).
4. Projections to the entire country based on information obtained for zones or geographic areas.
5. Calculations based on information technologies.
6. Calculations based on consumption (use) of the products before disposal.
7. Calculations based on the material balance in the country: Production + Imports – Exports = residue accumulation potential.
8. Use of population surveys on consumption and disposal of electronic products.

Figure 9: Methodological steps for developing the national diagnosis of e-waste in Mexico



2.3.3.3 United States

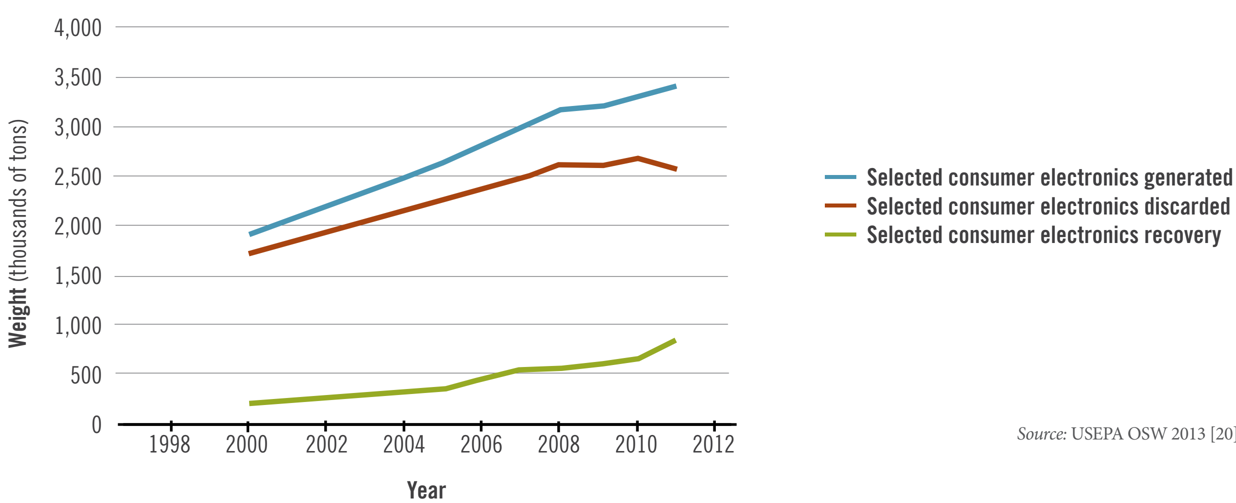
The US EPA has studied the generation and collection of used electronics on several occasions. The overall approach of ICF International, which prepared the document for the US EPA Office of Resource Conservation and Recovery, is to model the year in which an electronic item will be ready for end-of-life management based on the year that it was sold, the year it is expected to become obsolete, and expected storage habits [9]. This report updates earlier US EPA reports. Sales data were approximated by manufacturers' shipment data instead of retail sales; shipment data includes some items that were not finally sold to a customer. These figures were obtained from the International Data Corporation (IDC), the Consumer Electronics Association (CEA), and the literature. Gartner reports, IDC, and the literature were used to determine the share of sales in the commercial and residential markets. Average weight data were determined using Consumer Reports Buying Guides and equipment manufacturer specification sheets.

Lifespan estimates, here taken as age at end-of-life management, were differentiated between residential and commercial owners. A 2006 study from the Florida Department of Environmental Protection (DEP) was used in conjunction with industry surveys, expert interviews, and literature reviews to arrive at estimates of residential product lifespans and storage habits. For desktops, laptops, CRT monitors, and flat panel monitors, the average residential lifespans in years were estimated to be 12.25, 5.9, 9, and 9 respectively. For commercial electronics, these products were all assigned an average lifespan of 4.6 years based on the assumption that "desktop CPUs, portables, hard-copy

devices, and computer monitors are kept in use for three to five years, after which 20 percent are stored for up to two additional years. [They] believe a two-year storage estimate is conservative, but reflects the fact that commercial businesses are less likely than residential users to store products for long periods of time" [9].

In addition, a comprehensive study of municipal solid waste through 2011 by the US EPA Office of Solid Waste provides estimates for "selected consumer electronics" such as "television sets, videocassette recorders, and personal computers that are generated, "discarded," and "recovered" [20]. A form of sales obsolescence model is used and factored into the average product lifespans. Figure 10 shows trends in weight of selected consumer electronics generated, discarded, and recovered ("collection" in this study).

Figure 10: Trends in weight of selected consumer electronics generated, discarded, and recovered



Source: USEPA OSW 2013 [20].

2.4 Collection

2.4.1 Hybrid Sales Obsolescence-Trade Data Method (HSOTDM)

2.4.1.1 Residential Collection

To calculate the quantity of residential used electronics collected for processing, a collection rate is applied to the quantity generated over one year, *y*. The collection rate differentiates those generated used electronics that go to collection from those that are discarded in the garbage. Equation 5 presents the simple calculation used throughout this method, which essentially normalizes reported end-of-use fates to those that pertain to generation only. Therefore depending on the data source, several other end-of-use fates may be included, such as storage or informal reuse, which are ignored here. In Equation 6, the rate is applied to the quantity generated in the same year to arrive at the quantity collected.

Equation 5: Collection Rate from Survey Data

$$Collection\ Rate(y) = Collected\ \%\ (y)/(Collected\ \%\ (y) + Garbage\ \%(y))$$

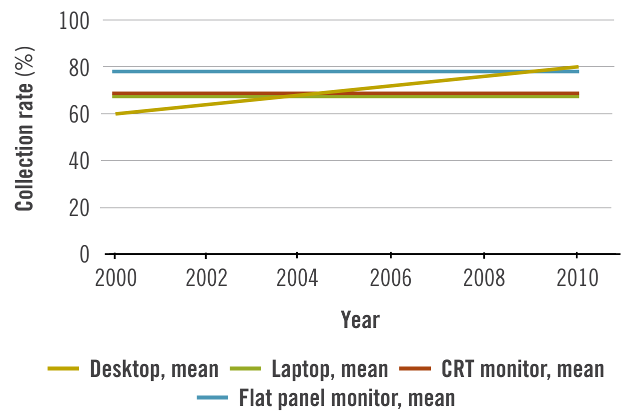
Equation 6: Collected Quantity

$$Collected(y) = Collection\ Rate(y) * Generated(y)$$

Canada

To estimate collection rates for each product over time, data from the Canadian residential survey conducted for this work were used. Moreover, in 2012, Samsung Canada provided a summary of the results of a survey of 1,004 randomly selected Canadian adults with a 3.1% margin of error. The results suggested that "Canadians may not know what to do with their old electronics or e-waste; 1 in 3 respondents (35%) say their old electronics are just gathering dust stored in their homes, while 1 in 10 admit to throwing their e-waste into the garbage" [21]. Using Equation 5 in combination with the data from that summary, the collection rate in 2012 was found to be 85%. There were sufficient data points to construct a time series trend for desktops, but insufficient data points resulted in the use of mean values with the standard deviation of the data for the other products. This Samsung data point is found to be very similar to the desktop collection rate extrapolated from this study's survey data. The Samsung data point was then incorporated into the collection rate estimate for all products. For the desktop time series, the estimated collection rate for a given year was allowed to vary by ± 10%. Figure 11 provides the mean of the estimated rates.

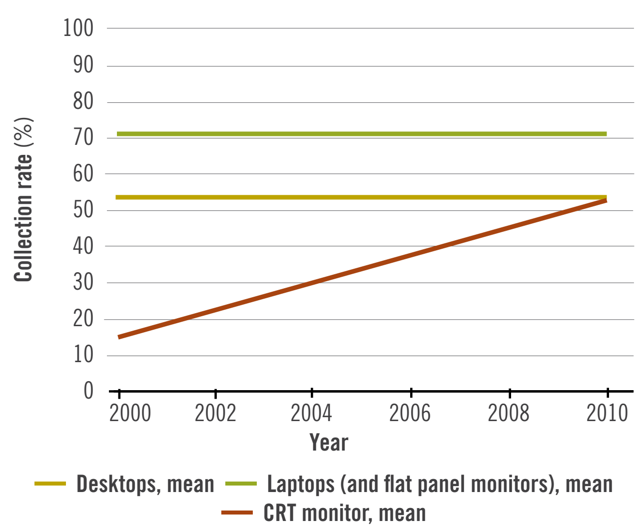
Figure 11: Estimated Canadian residential used electronics mean collection rates



Mexico

To estimate collection rates for each product over time, data from the Mexican residential survey conducted for this work were used. In 2007, a material balance of used electronics in Mexico resulted in estimates of 3% of used electronics going to recycling and 5% discarded, which suggests a collection rate of 60% using Equation 5 [18]. This data point was incorporated into the collection rate estimates for all products. Although the collection information in Figure 15 can be used for comparison purposes, the methodology is unclear, and therefore the data were not incorporated. There were sufficient data points to construct a time series trend for CRT monitors, but insufficient data points or trends resulted in the use of mean values with the standard deviation of the data for desktops and laptops, and the substitution of laptop collection rates for flat panel monitor rates due to the scarcity of data points. Figure 12 provides the mean of the estimated rates.

Figure 12: Estimated Mexican residential used electronics mean collection rates

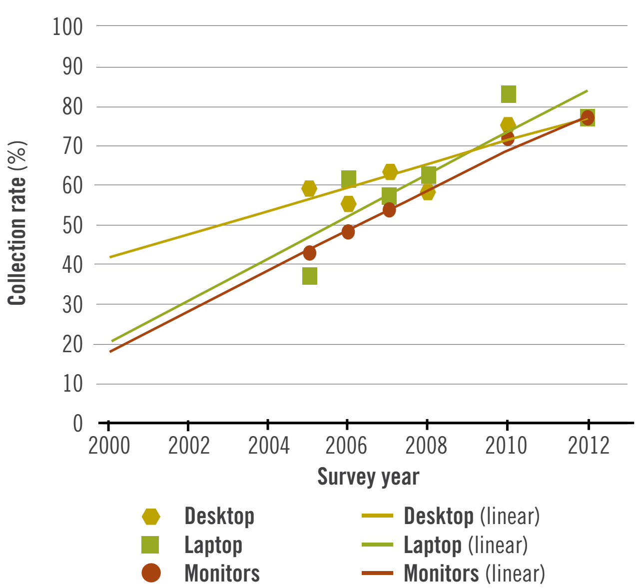


United States

Although the collection rates could have been inferred directly from the survey data used for the generation model, a more robust approach may be to use results from several surveys sampling five different representative groups of US residential computer owners (including the survey used in the generation model) from 2005 to 2012; some surveys covered two years [14, 22–24].

Figure 13 provides the estimated collection rates for monitors (not distinguishing between CRT and flat panel monitors), laptops, and desktops across all of the surveys. To account for uncertainty in the survey data and regression, the estimated collection rates for a given year were allowed to vary by ± 10% from the linear regression in the Monte Carlo simulation.

Figure 13: Estimated US residential used electronics collection rates across five surveys



2.4.1.2 Business/Public Collection

As with generation, to arrive at 2010 collection estimates, the reported 2010 collected products tabulated from the survey were multiplied by the scale factors, as shown in Equation 7. The scale factors were allowed to vary between their minimum and maximum values in a Monte Carlo simulation.

Equation 7: Business/Public 2010 Collection

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

2.4.2 Mass Balance

As with generation, to arrive at collection estimates, the reported 2010 generated products tabulated from residential and business/public surveys were scaled to each country's residential and business/public sectors. Referring back to Figure 7, collection is approximately equivalent to the sum of all flows from intermediaries, excluding flows to landfill, as shown in Equation 8. However, because the export flow F_{IE} is unknown, collection is instead determined by Equation 9. An equivalent quantity can be obtained by subtracting the flow to landfill from the generation quantity previously calculated. As a reminder, the flow of computers and monitors from one element to another can be denoted as: F_{IBP} = Flow from Intermediaries to Business/Public.

Equation 8: Collection of used electronics in Mass Balance Method, summation

$$Collection = \sum F_{IH} + F_{IBP} + F_{IR} + F_{IE}$$

Equation 9: Collection of used electronics in Mass Balance Method, subtraction

$$Collection = Generation - F_{IL}$$

To determine the proportion of used electronics from intermediaries that go to landfill, F_{IL}, survey responses about disposal of end-of-use products were analyzed. The flow to landfill was calculated for the residential and business/public sectors, and hence collection can be calculated separately as well. To capture uncertainty, three scenarios were developed about actual product destinations. Table 7 presents the end-of-use path specified by the survey respondent with the assigned end-of-use path for each scenario. Note that storage, donation to a friend/family within the household, and did not discard were not considered to be actual end-of-use paths and were excluded. Following the table are explanations of each scenario's assumptions. Also note that the HSOTDM differentiated between informal and formal reuse, as shown in Appendix 3.

(1) Intended end-of-use (EoU) scenario: Assumes a direct relationship between consumer intention at EoU and the actual EoU path:

   a) Computers sent for refurbishing, to leasing companies, or to charitable organizations are assumed to be reused with a 90% success rate. The remainder are recycled.
   b) 90% of used computers sold are reused, with the remainder recycled.
   c) 90% of computers returned to retailers, manufacturers, municipalities, or collection depot points are recycled and 10% reused, including reuse of parts.

Table 7: Comparison of user's intended end-of-use path and actual end-of-use path for three scenarios

	Intended end-of-use scenario (%)				**Lower reuse scenario** (%)				**High export scenario** (%)			
Storage	**Reuse**	**Recycle**	**Landfill**	**Export**	**Reuse**	**Recycle**	**Landfill**	**Export**	**Reuse**	**Recycle**	**Landfill**	**Export**
Donated to friend/family within household												
Did not discard												
Disposal via curbside garbage collection			100			20	80				100	
Recycled via curbside recycling program	10	90				100				70		30
Returned to collection depot for recycling	10	90				100				70		30
Returned to retailer	10	90				100				70		30
Returned to municipality during a collection event	10	90				100				70		30
Returned to manufactuer	10	90				100				70		30
Donated to friend/family outside of household	90	10			80	20			80			20
Donated to a charitable organization	90	10			60	40			60			40
Other donation	90	10			60	40			60			40
Returned to seller after lease expired	90	10			70	30			70			30
Sold online (e.g., eBay)	90	10			70	30			70			30
Sold locally	90	10			70	30			70			30
Sold to an acquaintance/friend/family	90	10			80	20			80			20
Other				100				100				100

Note: Colors refer to diagram in Figure 7.

d) All computers sent to curbside garbage collection are landfilled (assumes no informal street collection and absence of transfer stations that separate used computers for recycling).

(2) Lower reuse scenario: Modifies the previous intended end-of-use scenario by assuming lower rates for successful refurbishing and higher domestic recycling:

a) Computers sent to refurbishing and leasing companies are reused with a 70% success rate. The remainder are recycled.
b) Computers donated to charitable organizations are reused with a 60% success rate. The remainder are recycled.
c) 80% of computers donated or sold to family/friends/acquaintances are reused. The remainder are recycled.
d) 70% of used computers sold are reused. The remainder are recycled.
e) 100% of computers returned to retailers, manufacturers, municipalities, or collection depot points are recycled.
f) 80% of computers sent to curbside garbage collection are landfilled.
g) The remainder are recycled (e.g., via transfer stations or street collectors).

(3) Higher export scenario: Modifies intended end-of-use in preference of export:

a) Computers sent to refurbishment and leasing companies are reused domestically, assuming a 70% success rate. The remainder are exported.
b) Computers donated to charitable organizations are reused assuming a 60% success rate. The remainder are exported.
c) 80% donated or sold to family/friend/acquaintance are reused domestically. The remainder are exported.
d) 70% of used computers sold are reused domestically. The remainder are exported.
e) 70% of computers returned to retailers, manufacturer, municipality or collection depot points are recycled. The remainder are exported.
f) 100% of computers sent to curbside garbage collection are landfilled.

2.4.3 Comparison with Other Sources

2.4.3.1 Canada

In Canada, most provinces (Alberta, British Columbia, Manitoba, Newfoundland, Nova Scotia, Ontario, PEI, Quebec, and Saskatchewan) have instituted used electronics collection programs. These programs involve payments to used electronics processors, thus incentivizing collection and participation in the programs. Several provinces (Alberta, British Columbia, Nova Scotia, Ontario, and Saskatchewan) have begun programs since 2010, the year of focus. Annual reports differ in terms of the fiscal year start and end points, as well as the quantities (weight versus units) reported [25–33]. Some reports include total weight, some include weight by product, and others the quantity of products. To arrive at an overall total of computers and monitors collected, reasonable assumptions were made, such as:

- Reporting quantities for y2010 as the average of quantities from surrounding fiscal years, such as June 2009–July 2010 and June 2010–July 2011.
- Converting unit quantities into weights using the same unit weights as in the other models in this study included in Table 5, based on US empirical collection data.
- Assuming that the weight ratio of collected computers to total collected electronics from one province (12% in British Columbia) applies to all provinces. Before March 2011, only British Columbia included in its scope of obligated products a few additional obscure products like satellite dishes, handheld point-of-sale devices, and overhead projectors, and hence this assumption seems reasonable [34].
- Assuming that the weight ratio of collected monitors to collected computers averaged from a few provinces (1.9 in British Columbia assuming that one-third of the weight of the "TVs and Monitors" category is monitors, 1.3 in adjusted numbers from Ontario,[6] 1.5 in Saskatchewan) applies to all provinces.
- Following the US EPA (2011) in assuming that provinces without programs as of 2010 had a one pound per capita (or 0.45 kg per capita) collection rate. That collection rate was then multiplied by the population [35].

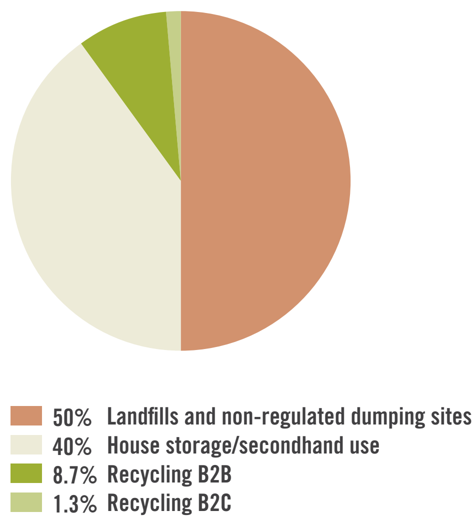
Note that considerable collection, especially from businesses, occurs outside of the official collection programs [36], and hence the collection figures are probably an underestimate of the total collection amount.

In addition, several provinces have reported landfill studies that estimated the amount of electronics included in the municipal solid waste stream [37–41]. Per capita computer and monitor landfill rates from two provinces (0.15 kg/person backcast for Nova Scotia and 0.13 kg/person in Alberta) were applied to provinces with collection programs in 2010. Because the collection rate for provinces with programs was about double the assigned 0.45 kg/person collection rate for provinces without programs, a landfill rate of about double, 0.30 kg/person, was assigned to provinces without **programs** in 2010.

2.4.3.2 Mexico

Collection was estimated by combining the generation estimates from Román Moguel (2012) with a pathway probability for general used electronics. Following the definitions of generation and collection used in this study, a ratio of recycling (collection) to landfill of 20% was determined and applied to the generation estimate. Figure 14 presents the end-of-use pathway probability.

Figure 14: End-of-use pathways for used electronics in Mexico



Source: Román Moguel 2012 [19].

2.4.3.3 United States

The same US EPA reports used to compare generation quantities as described above were used to compare collection quantities. The US EPA (2011) used data from states with used electronics recycling programs to estimate the share of residential generated electronics collected for processing versus disposal; low collection rates (one pound collected per capita) were assumed for states without programs. A survey of recyclers suggested that two-thirds of collected

6. The number of monitors reportedly collected was unreasonably high relative to computer collection (confirmed by program managers), and the total weight collected suggested much lower collection volumes; hence, monitor collection was set equal to units of desktop collection.

electronics originated from commercial sources; because the California state program included businesses, the residential figure was back-calculated, accounting for the two-thirds figure. An overall generated electronics recycling rate of 27% (by weight) was projected for 2010; the projected generated computer recycling rate was 40%. The authors recognize "considerable uncertainty" in this estimate [9].

As with generation, comparison was made with a comprehensive study of municipal solid waste in 2010 by the US EPA Office of Solid Waste that gave estimates for "selected consumer electronics" such as "television sets, videocassette recorders, and personal computers that are generated, "discarded," and "recovered" [20]. Figure 10 shows the trends in weight over time.

Daoud (2011) conducted a representative survey of 182 US electronics recyclers regarding practices in 2010 [8]. Recycling industry input weights were estimated for each product. In addition, the survey asked about the source of recycling inputs, whether residential or business/public, and therefore comparisons to this study's results could be made.

2.5 Export

2.5.1 Hybrid Sales Obsolescence-Trade Data Method (HSOTDM)

Because different agencies collect trade data for each country, the contents and level of disaggregation in the trade data vary for each country. The overall methodological approach will be discussed first, followed by its implementation based on data availability in each country. As a reminder, the HSOTDM for export uses detailed, disaggregated trade data to determine the quantity of used electronics exports. The steps are as follows:

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

2.5.1.1 Collect and prepare disaggregated, detailed export trade data

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, not the unit value of each individual piece of equipment. To model most accurately the value of the exported equipment, disaggregated, detailed export trade data are sought. When shipment-level data are 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, quantity of goods q, and weight w.
- Disaggregate domestic exports (originating in the exporting country) from re-exports (originating in a partner country).
- Disaggregate modes of transport.
- Provide trade codes at the 10-digit level.

Table 8 shows the export codes pertaining to computers and monitors. US export data at the 10-digit level were used to identify the quantities of desktops with CRTs (Schedule B Export Codes 8471410110 and 8471500110). Given that all CRTs exported were assumed to be used, desktops exported with CRTs were also assumed to be used. Mexican export data did not differentiate between desktops with and without CRTs, and hence CRTs are probably somewhat underestimated for Mexico.

Table 8: Export Codes by Product

Product	Specific product	Export code
Desktops	Desktops	847141
	Servers	847149
	Other desktops	847150
Laptops	Laptops	847130
CRT monitors	With desktop	8471410110 (US)
	With other desktop	8471500110 (US)
	PC monitors	852841
	Video monitors	852849
Flat panel monitors	PC monitors	852851
	Video monitors	852859

2.5.1.2 Estimate used-new threshold values, z, 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. An exception is made that no new CRT monitors are assumed to be exported from North America because very few are manufactured in the world currently, and none in 2010 from North America to our knowledge. Therefore, all CRT monitor exports are assumed to be used despite the average unit value.

The threshold approach assumes that the used-new threshold is consistent across a region for a given type of good. World regions were defined by World Bank country income groups [42] and UN macro-geographical region[7] [43]. US data were also disaggregated by vessel, air, and land transport. The threshold value z is the valley between the used and new distributions embedded in a bimodal distribution, as illustrated in Figure 15 with hypothetical data.

The threshold values were determined using two separate methods for comparison purposes. The first uses the Neighborhood Valley-Emphasis Method (NVEM) for each destination world region [44]. The assumption made is that export prices vary depending on the destination. NVEM finds the optimal threshold, , which simultaneously maximizes the variance between the modes (in this study, 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 using US export data is shown in Figure 16, with approximate distributions (means are known, variances are not known) superimposed on the histogram. There is a range of thresholds because there is uncertainty within the NVEM procedure.

The second threshold method (Pub.) takes advantage of published reference values for used goods and applies the same threshold to all world regions. These reference values were most readily available for the United States and hence were applied to each country. Figure 17 shows the thresholds used.

Figure 15: Approach for determining used-new threshold with hypothetical data

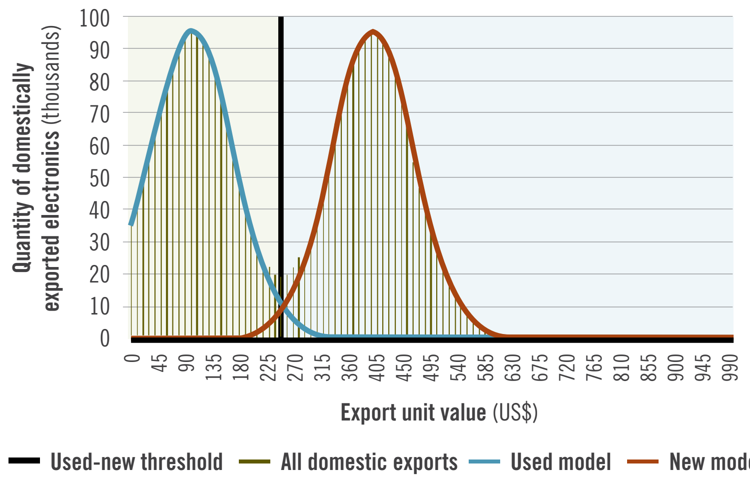
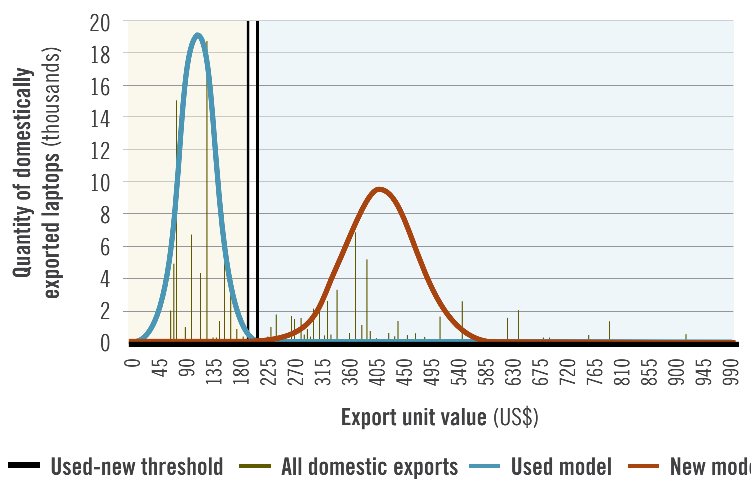
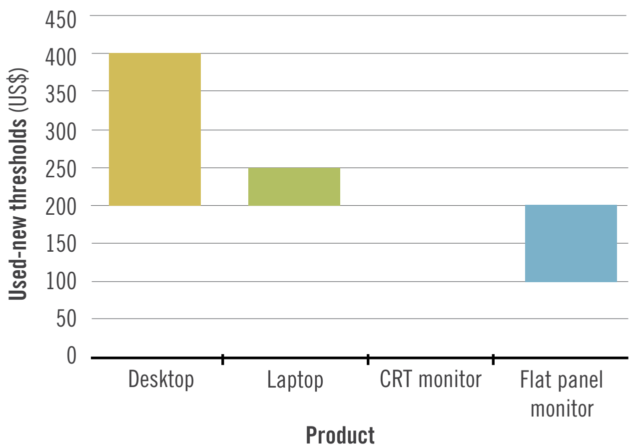


Figure 16: Example of export histogram with threshold range. 2010 export of laptops from the United States to upper middle-income countries in Latin America and the Caribbean



7. These regional designations are followed, with the exception of Mexico being assigned to North America in this study; its status is ambiguous in the UN classifications, and elsewhere Mexico is assigned to North America.

Figure 17: Used-new thresholds for each product (except CRT monitors, which are all assumed to be used), determined from published data (Pub.)



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.

2.5.1.3 Sum the quantity of goods domestically exported from the United States to partner countries with a unit value below a threshold

In this step, the quantities 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 export recipients are determined.

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

The domestic export data used contain detailed information about the export trade partner, but not necessarily the final destination, because some trade partners will then re-export the imports. Therefore, to approximate the potential of re-export after import from North America, ratios based on aggregate UN Comtrade data [12] were determined for laptops only. 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, and therefore ratios were developed comparing exports to imports for most countries. Some countries do not report trade data to the United Nations; for major US export destinations, trade flows were inferred from reporting countries' import and export flows with these countries. China was treated differently because it is a known major manufacturer and exporter. Using shipment-level Chinese export data (HS International Inc. 2012), re-export destinations of used laptops (under US$250) were determined.

2.5.1.5 Data and Methodological Variations by Country

Canadian export trade data

Port-level export data were available through a request from Statistics Canada. Unfortunately, for most of the products in the scope of this report, the Canada Border Services Agency does not record declarations of export quantities, although they do record import quantities for these items. Table 9 shows the availability of export quantity data from Statistics Canada port-level data and UN Comtrade aggregate trade data. Quantity is a key piece of information in the method, and therefore the method had to be modified for Canada.

Assuming that Canada and the United States have roughly similar per capita income as demonstrated in the introduction, United States export patterns were applied to the value of Canadian exports as follows for each trade code and destination country.

1. By combining the Canadian export value v_{CAN} to a destination country with the US average export unit value u_{US} to the same destination country *n*, the Canadian export quantity q_{CAN} was estimated (Equation 10).

Table 9: Availability of quantity data in Canadian trade data

Product	Specific product	Export code	Statistics Canada port-level data	UN Comtrade aggregate data
Desktops	Desktops	847141	No export quantity	No export quantity
	Servers	847149	No export quantity	No export quantity
	Other desktops	847150	No export quantity	No export quantity
Laptops	Laptops	847130	No export quantity	**Export quantity**
CRT monitors	PC monitors	852841	**Export quantity**	**Export quantity**
	Video monitors	852849	No export quantity	No export quantity
Flat panel monitors	PC monitors	852851	**Export quantity**	**Export quantity**
	Video monitors	852859	No export quantity	No export quantity

Equation 10: Canadian estimated total export quantity

$$q_{n,CAN} = v_{n,CAN} * \overline{u_{n,US}}$$

a. If the quantity is reported by Canada, that quantity is used instead.
b. In the case of exports to the United States, US imports are substituted.

2. By combining the estimated or reported Canadian export quantity q_{CAN} to a destination country with the used fraction of US exports to the same destination country $q_{US,Used}/q_{US}$, the Canadian used export quantity $q_{CAN,Used}$ can be estimated (Equation 11). The used fraction of US exports to each destination country is calculated as described in the following section.

Equation 11: Canadian estimated used export quantity

$$q_{n,CAN,Used} = q_{n,CAN} * q_{n,US,Used}/q_{n,US}$$

a. In situations in which Canada exports to a country to which the United States does not export, equation inputs from an appropriate country group (based on geographic region and income) are substituted.

Mexican export trade data

Information on trade of products and goods to/from Mexico is offered to the general public in two forms: aggregate data and shipment-level data. The Mexican Ministry of Economy (*Secretaria de Economía*) manages a dynamic online database that offers information about trade (import and export) for the various trade codes, including computers. This database offers two aggregate parameters for each trade code: shipment value (dollars) and shipment volume (units). The information is accessible to the general public and is free of charge.

Mexican shipment-level trade data was available for this study. The Mexican Customs agency (*Aduanas México*), managed by the Mexican Service for Tax Administration (*Servicio de Administración Tributaria* (SAT)), has extensive data on import and export of goods and products, including computers; however, accessing this data requires a special request to INFOMEX, the government entity in charge of facilitating access to public information to Mexican citizens.

Taking advantage of the descriptions available in shipment-level trade data, each shipment was screened and classified as one of the products in this study or as "other." Key words such as "accessories" were used to assign a shipment to "other," whereas "data processing unit" suggested a desktop. See Appendix 4 for a detailed description [45].

Unfortunately, domestic exports are not differentiated from re-exports in Mexican trade data, and therefore the export estimates are likely to be overestimates in the sense that re-exports are included. For Canada and the United States, only domestic exports are considered.

US export trade data

After comparing all the publically available US export trade datasets that we were able to locate, three were selected. Because the ideal US export trade dataset of detailed shipment-level reporting is not available in full[8], nor is the ideal set of port-level data, a method was developed to approximate port-level domestic export unit values and quantities. See Appendix 4 for calculation details.

Port-level weight (or quantity) data are needed to calculate the approximate port-level unit value, which is available through USA Trade Online. Unfortunately, the datasets used do not contain this information for land shipments, and therefore alternatives were sought for exports to Canada and Mexico from the United States. "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" [1]. Therefore, for laptops, port-level Canadian import data from STATCAN were used for US domestic export data to Canada. For other products, SICEX[46] district level data were used. Quantity data are available through SICEX [46] for US exports to Mexico as well as for Mexican imports with the United States as country of origin at the district level. Due to considerable discrepancies in Mexican import data, US domestic export data to Mexico at the district level were used.

2.5.2 Mass Balance

To estimate exports of used electronics, the Mass Balance method conserves the quantity of product going into and leaving the intermediaries. Referring back to Figure 7, Equation 12 finds the unknown export quantity by subtracting the estimated flows, F. As a reminder, the flow of computers and monitors from one element to another can be denoted as: F_{BPI} = Flow from Business/Public to Intermediaries.

8. This type of data is potentially available from the Census Research Data Centers as Restricted-Use Transactions Microdata: <www.census.gov/ces/rdcresearch/>. However, one must go through an extensive application process, which takes roughly six months, to access the data.

Equation 12: Export Flow in Mass Balance Method

$$Export = F_{IE} = F_{HI} + F_{BPI} + F_{ImI} - F_{III} - F_{IBP} - F_{IR} - F_{IL}$$

As with the generation and collection steps, residential and business/public scale factors were used which scale survey responses to the total in the country. The scale factors were allowed to vary within a 95% confidence interval.

2.5.3 Comparison with Other Sources

Few comprehensive export comparisons exist for the countries studied. For the United States, comparisons were made with a recent 2013 report on Used Electronic Products (UEP) from the US International Trade Commission (USITC) [47]. According to the News Release [48]:

> The USITC recently concluded the investigation for the US 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 US 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.

For purposes of comparison with this study's investigation into exports of used whole units, survey results for refurbished, remanufactured, and repaired products were obtained. 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 other electronic products." Although whole units are exported 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 on exports of several products. Although the present study focuses on 2010, the comparison is made because many survey respondents reported that exports in 2011 and previous years were about the same [47]. The USITC study does not define a used-new threshold, but it does provide statistics for the lowest 10%, 25%, and 50% of trade by average unit value. Because the thresholds used in the present study were most similar to the average unit value of the lowest 10% of shipment-level trade, this was used as a point of comparison, with the exception of CRT monitors, in which case 100% of trade was used because no new CRT monitors are assumed to be exported. Note that for desktops, export code 847150 was not used, unlike the approach used here (see Table 8).

2.6 Uncertainties

As described in the preceding sections, uncertainties were captured at every stage of estimation. Table 10 summarizes key sources of uncertainty in generation, collection, and export estimates as they pertain to the HSOTDM and Mass Balance methods.

Table 10: Sources of uncertainty in estimates

Source of Uncertainty	Generation	Collection	Export
Accuracy of survey data and their extrapolation	HSOTDM & mass balance	HSOTDM & mass balance	Mass balance
Assumptions about intended end-of-use, lower reuse, and higher export scenarios	Mass balance	Mass balance	Mass balance
Estimation of product lifespans from survey responses and literature	HSOTDM		
Estimation of collection rates from survey responses and literature		HSOTDM	
Accuracy of new product sales data	HSOTDM & mass balance	HSOTDM & mass balance	
Accuracy of product weight estimates	HSOTDM & mass balance	HSOTDM & mass balance	
Accuracy of trade data, including exporter's choice of trade code and final versus reported destination			HSOTDM

3. Results

This section presents the results of this study's analysis of generation, collection, and export of used computers and monitors in 2010 and provides comparison with other estimates. The results are presented for each country separately (Canada, Figures 18–26; Mexico, Figures 27–36; the United States, Figures 37–48), and then a cross-country comparison is made (Figures 49 and 50). The raw data used to derive these figures for each of the three countries are included in Appendix 5. Generation and collection results are presented for the residential and business/public sectors first; the combined results are compared with export results in the subsequent section. Results are presented in quantity of units and weight in metric tons. In addition, the fraction of each downstream stage is determined in comparison with the upstream stage; collection is compared to generation, and export is compared to collection. In each chart showing HSOTDM and Mass Balance results, the error bars correspond to the bounds of a 95% confidence interval. Key observations from the results are presented below.

3.1 Key Observations

3.1.1 Comparison between Methods

3.1.1.1 Generation and Collection

- HSOTDM and Mass Balance are methodologically similar in calculating generation and collection from the business/public sector, and therefore their results are similar, as expected.
- HSOTDM yields consistently higher residential generation and collection results than Mass Balance. This could have occurred because HSOTDM residential results are based on sales data for each product, whereas the scale factors for the Mass Balance method are based on an average scale factor across all products. Because sales data produce lower CRT monitor sales estimates than those reported from the surveys, the average scale factor is less than that for computers and flat panel monitors, likely resulting in underestimated flows for these products.

3.1.1.2 Export

- The export results from HSOTDM can be expected to be a lower-bound estimate due primarily to intentional or unintentional misclassification of exported goods. For most products in Canada and the United States, the HSOTDM export estimate is lower than that from the Mass Balance method, as expected. Combination and comparison of these methods is useful for estimating the range of used computers and monitors exported from these countries. However, the HSOTDM estimated much higher export quantities from Mexico than did Mass Balance. Overall Mexican export quantities and values have been shown to be higher than corresponding US imports for many years. It is likely that the HSOTDM overestimates Mexican export quantities for this reason.
- HSOTDM can predict the destinations of used electronic exports because it uses trade data. Domestic export data report the export trade partner, but not necessarily the final destination, because some trade partners will re-export the imports. Miller (2012) demonstrated from a US export perspective that some of the top used laptop destination countries were expected to export much of their imported used laptops, whereas others exported very little [6]. Of the top 10 recipients of used laptops in 2010 from the United States, Lebanon, Hong Kong, the United Arab Emirates, the United Kingdom, and China were estimated to re-export between 20% and 48% of their imported used laptops. The remaining top 10 recipients of used laptops in 2010 from the United States, Argentina, Canada, Chile, Bolivia, and Mexico, were estimated to re-export only between 0.1% and 1.8% of their imported used laptops. These findings fit with expectations that known trading hubs, especially those with relatively small populations like Hong Kong, can be expected to re-export a portion of their imports to regional destinations. Given this reality, export results to specific destination countries known for re-export are likely to overestimate the quantity of used electronics that remain in that country.

3.1.2 Country Comparison

3.1.2.1 Generation and Collection

- The generation and collection of used computers and monitors are roughly proportional to the population of the countries and per capita income; the United States has the largest population and by far the largest estimated generation and collection. Although Mexico has a larger population than Canada, Canada has a much higher per capita income and hence purchasing power, which likely explains why generation and collection in these two countries are roughly the same.

3.1.2.2 Export

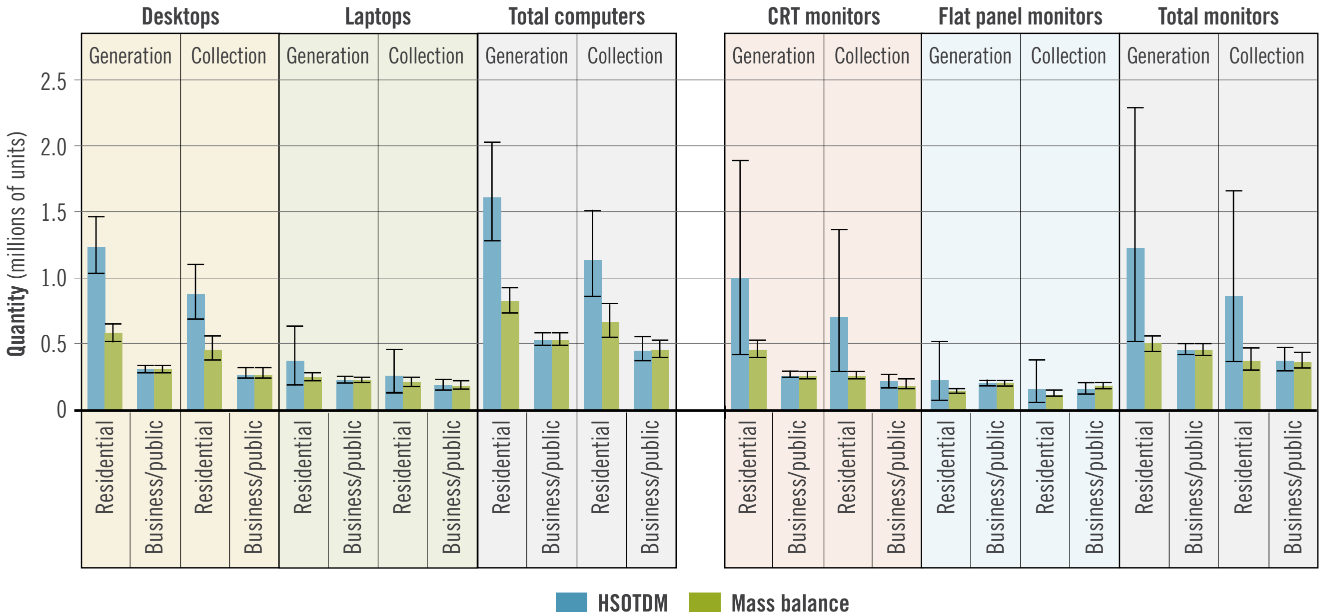
- The HSOTDM export estimates do not predict very large differences in used computer and monitor export quantities among the countries studied, whereas the Mass Balance method estimates a higher export quantity for the United States that is more in proportion with its higher generation and collection quantities. Several factors could account for this. Some used electronics exporters, especially in the United States and Canada, in an effort to contravene restrictions, have possibly intentionally misclassified some used computers and monitor exports, leading to a lower HSOTDM export estimate. Enhanced recycling efforts in the United States and Canada could have led to increased domestic processing and fewer exports, as well as contractual agreements which specify no export of used electronics.

3.2 Canada

- The quantities of used computers and monitors generated and collected are similar, with slightly more computers generated and collected than monitors. The weight of generated and collected monitors, however, is greater than that of computers due to their higher unit weights.
- The weight of generated used computers is lower than a forecast from 2006, but the weight of generated used monitors is very similar to that forecast. The weight of collected and landfilled used computers and monitors is very similar to rough estimates of these figures made from a combination of empirical estimates. These estimates included annual reports from several provinces' used electronics collection programs, as well as landfill audits.
- The estimated fraction of collected used computers and monitors compared to that of generated computers and monitors is quite high, roughly 70–80%. The estimated export fraction of collected used computers is 4–10% on average and 1%–30% on average for used monitors.
- The major destinations of used computer and monitors were high-income OECD countries (63%), as well as upper middle-income countries (14–17%). The main destination regions were Europe (29–32%) and North America (31–34%), followed by Asia (21–24%) and Latin America (11–13%).
- Top used computer and monitor export destination countries include the United States, France, Italy, the United Arab Emirates, Sri Lanka, Germany, the United Kingdom, Chile, China, and Peru.

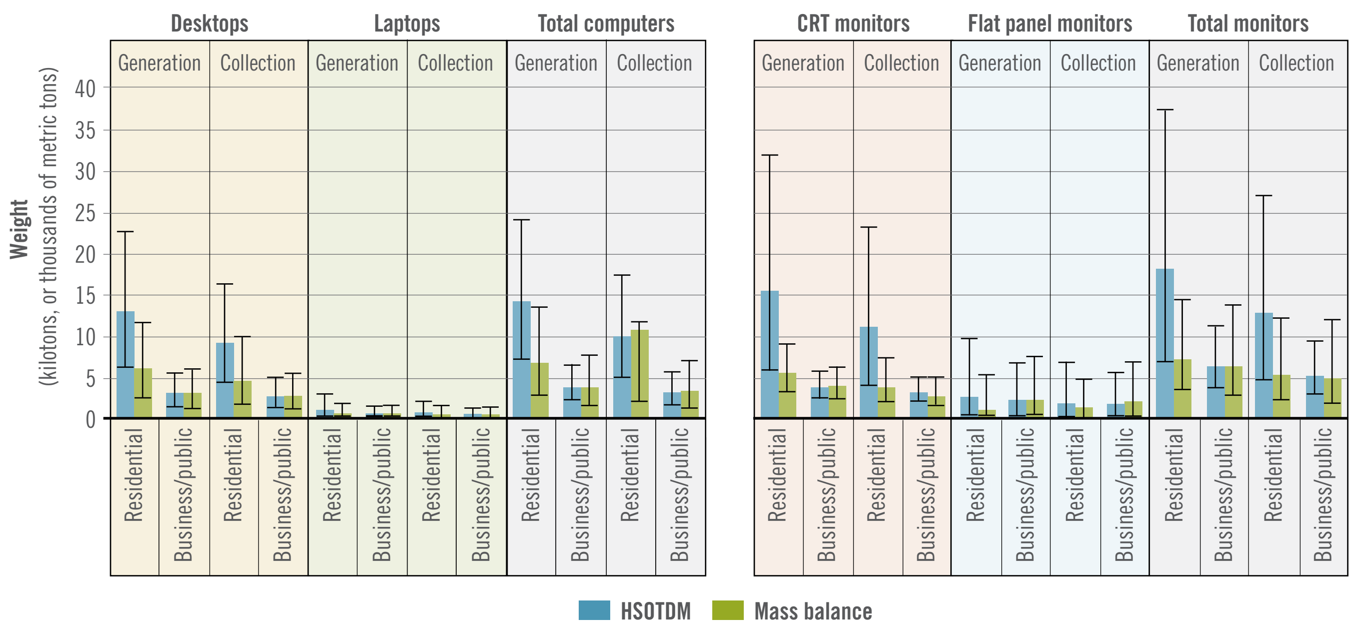
3.2.1 Generation and Collection

Figure 18: Comparison of Canadian generation and collection quantities by product, residential and business/public sectors, and method



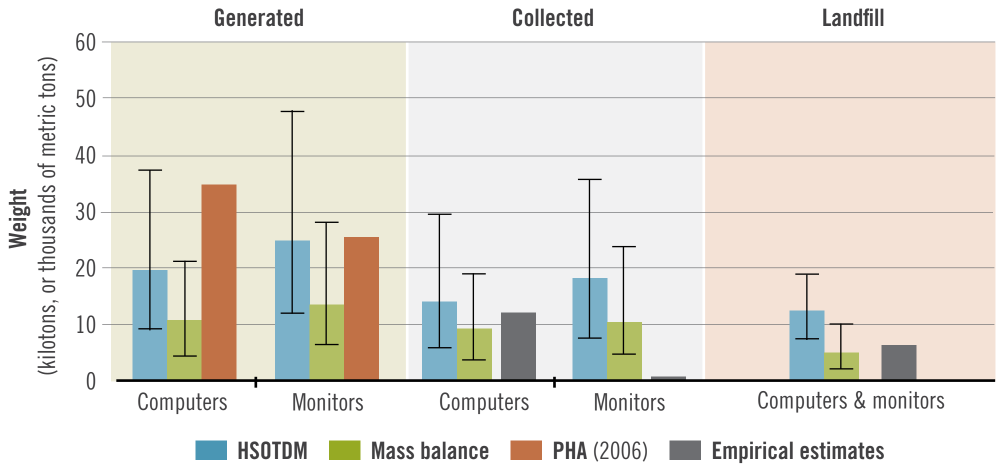
Note: Columns represent means, and error bars represent the 95% confidence interval.

Figure 19: Comparison of Canadian generation and collection weight by product, residential and business/public sectors, and method



Note: Columns represent means, and error bars represent the 95% confidence interval.

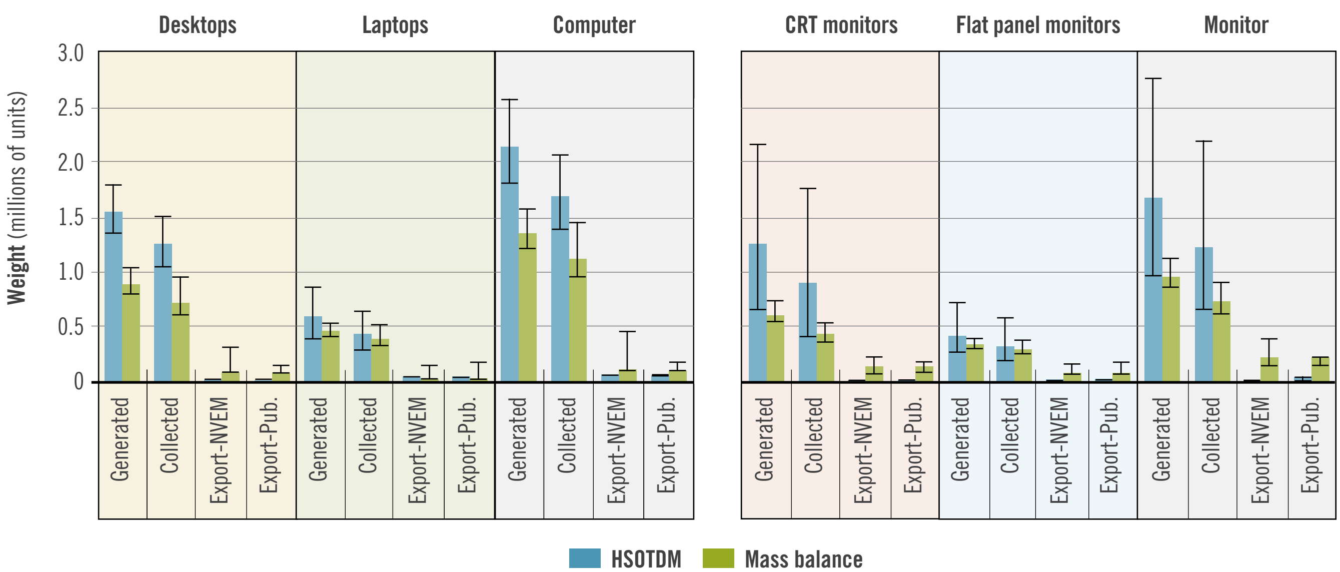
Figure 20: Comparison of Canadian generation and collection weight by product and estimation method



Source: Empirical estimates compiled from provincial programs and forecasts from PHA Consulting Associates (2006) [49].
Note: Columns represent means, and error bars represent the 95% confidence interval

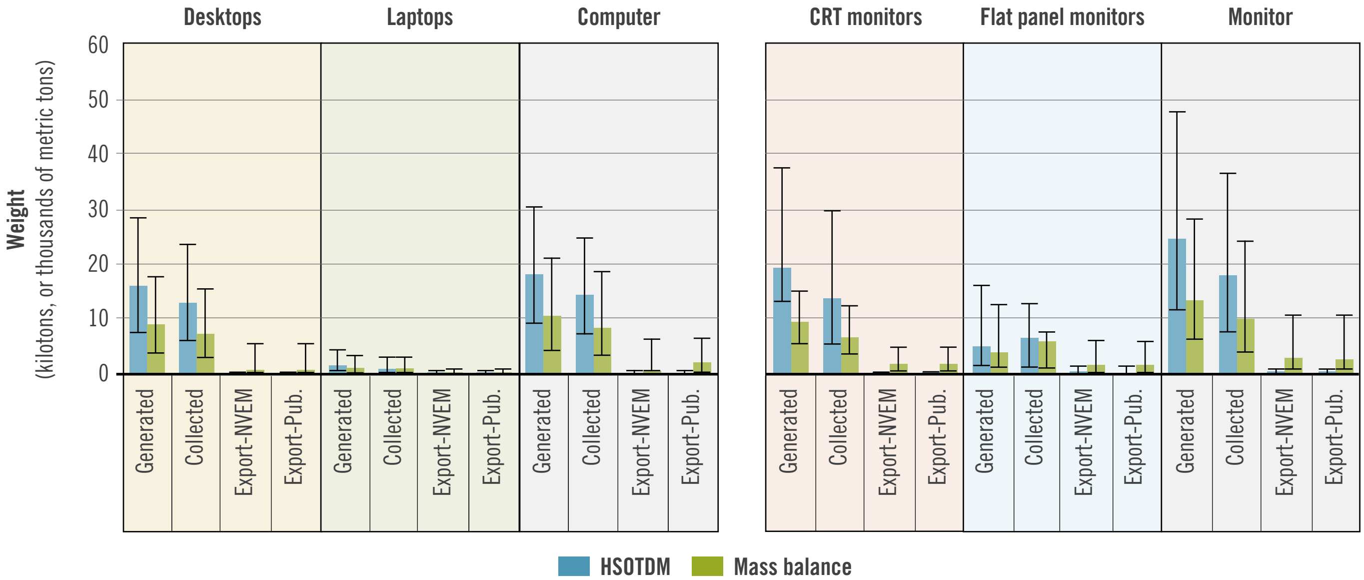
3.2.2 Generation, Collection, and Export

Figure 21: Comparison of Canadian generation, collection, and export quantities by product, residential and business/public sectors, and estimation method



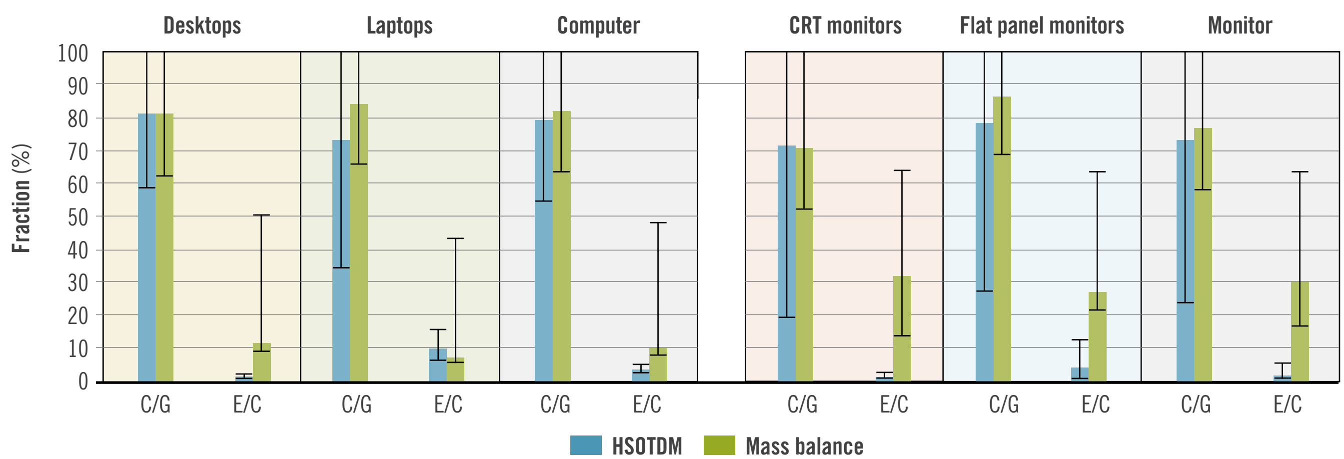
Notes: For HSOTDM, export quantities are determined using both NVEM and thresholds from published data.
Columns represent means, and error bars represent the 95% confidence interval.

Figure 22: Comparison of Canadian generation, collection, and export weight by product, residential and business/public sectors, and estimation method



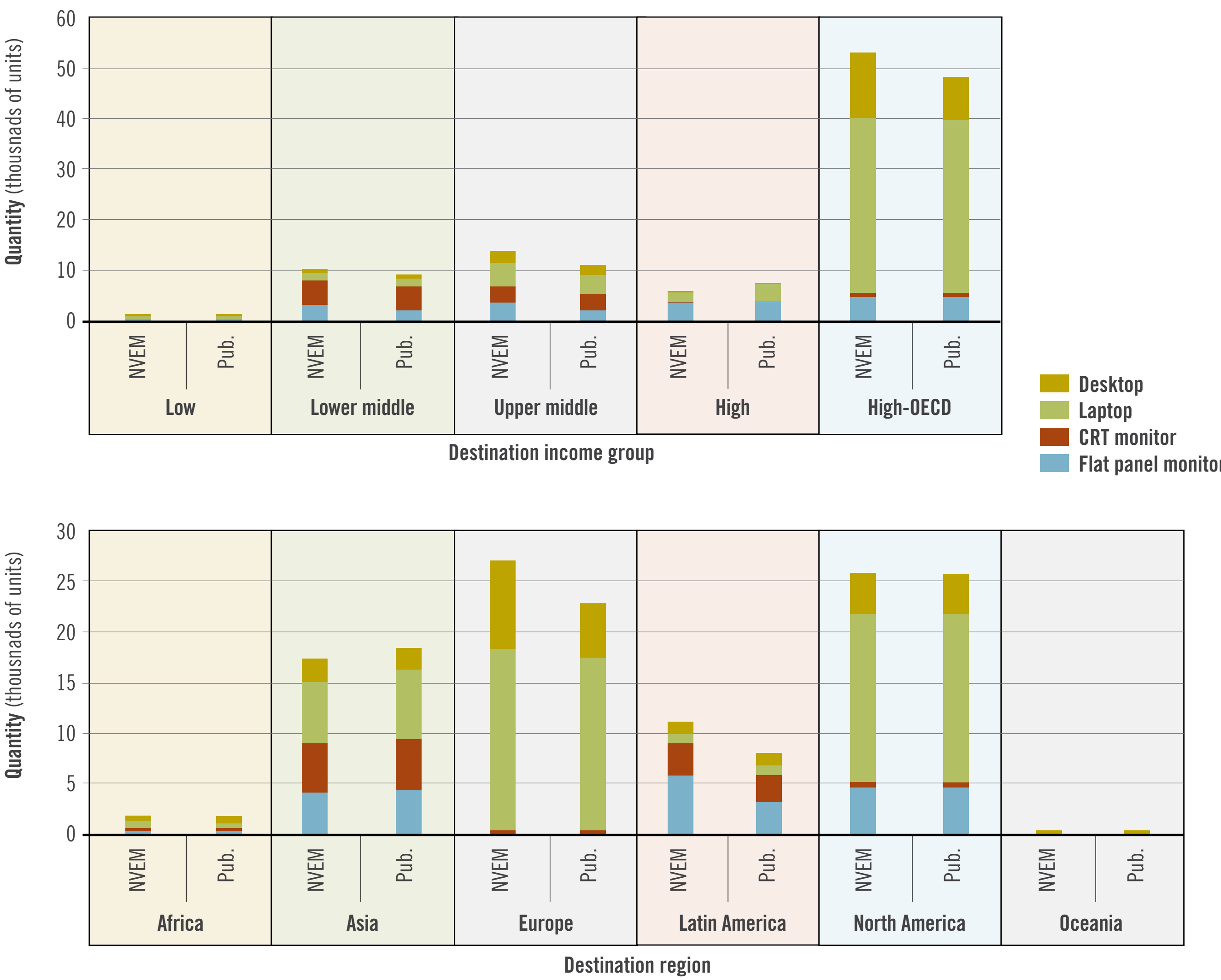
Notes: For HSOTDM, export quantities are determined using both NVEM and thresholds from published data.
Columns represent means, and error bars represent the 95% confidence interval.

Figure 23: Fractions of Canadian downstream stage as compared to upstream stage. Comparison of collection/generation and export/collection fractions by product and estimation method



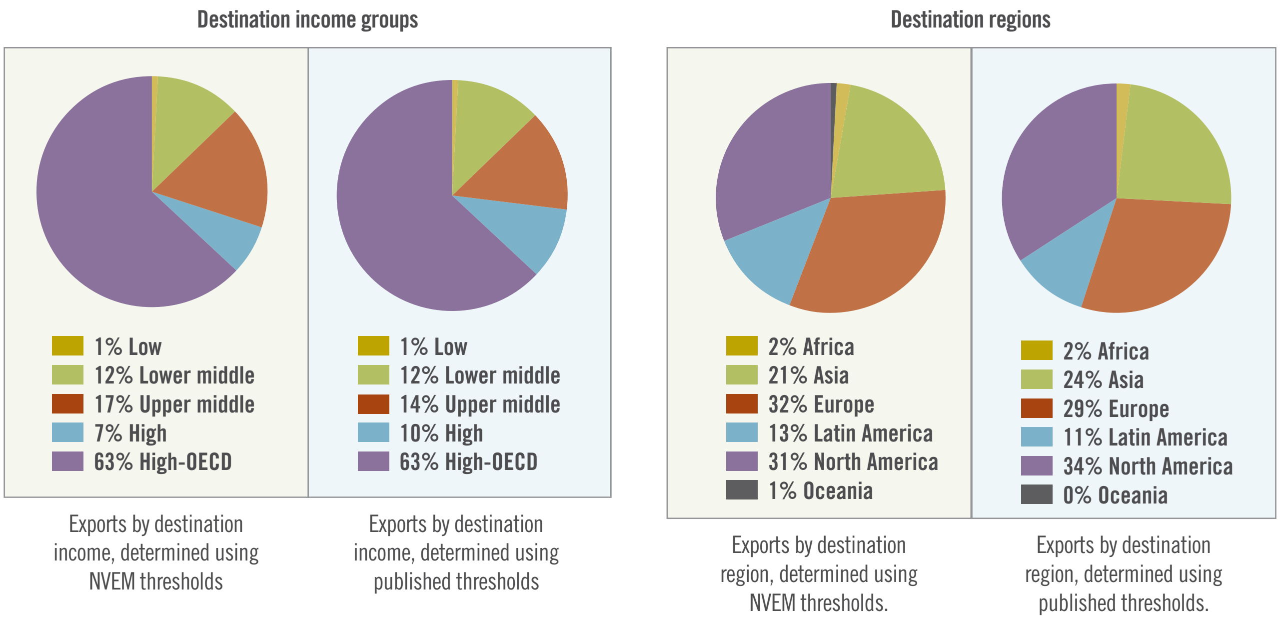
Notes: For HSOTDM, export quantities are determined by combining both methods. Columns represent means, and error bars represent the 95% confidence interval based on quantity. Weights have the same mean fractional values, but larger confidence intervals due to uncertain unit weights.

Figure 24: Comparison of Canadian used exports to destination income groups (top) and destination regions (bottom) by product



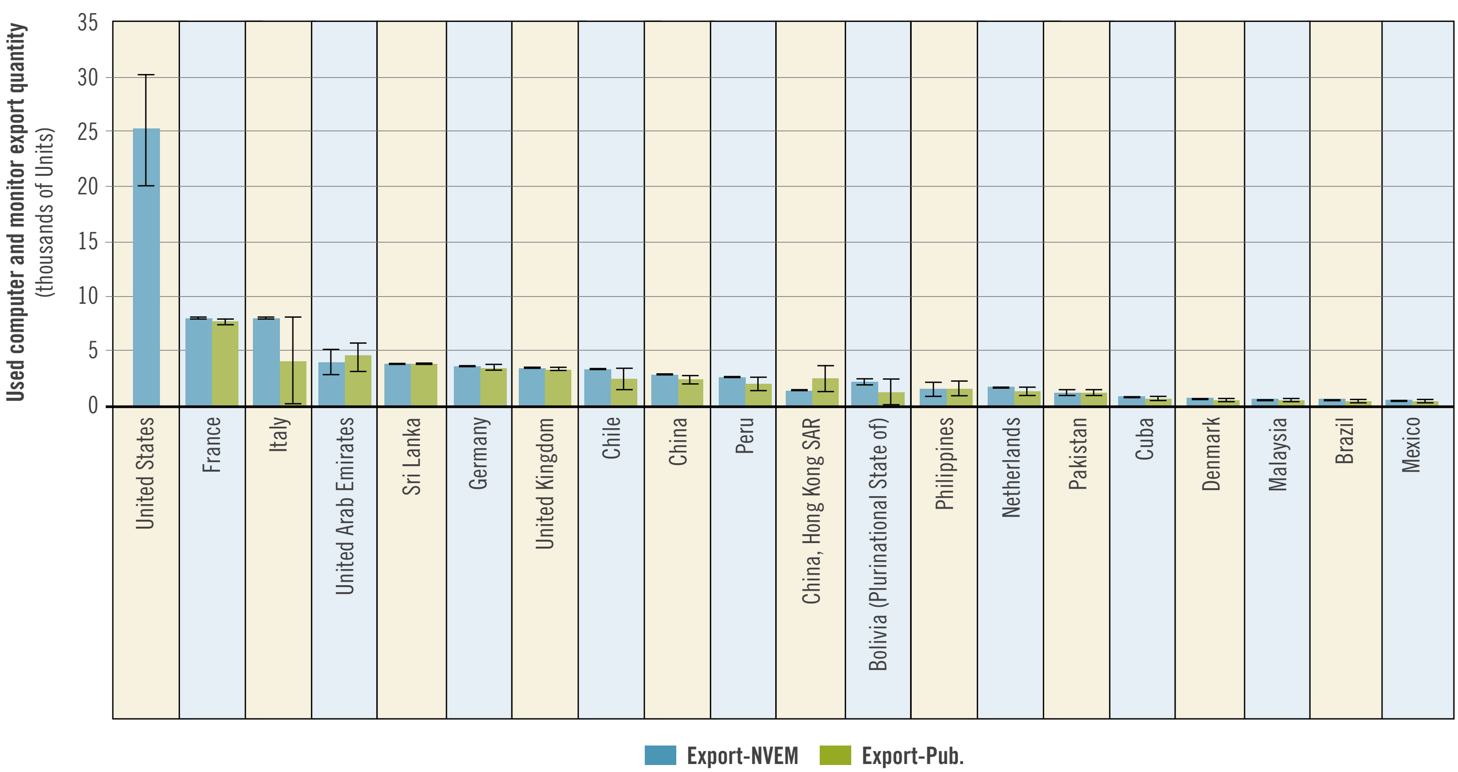
Note: Using HSOTDM, export quantities are determined using both NVEM and thresholds from published data (Pub.).

Figure 25: Comparison of Canadian exports of used computers and monitors to destination income groups (left) and destination regions (right)



Note: Using HSOTDM, exports are determined using both NVEM (left) and thresholds from published data (right).

Figure 26: Top 20 Canadian used computer and monitor destination countries



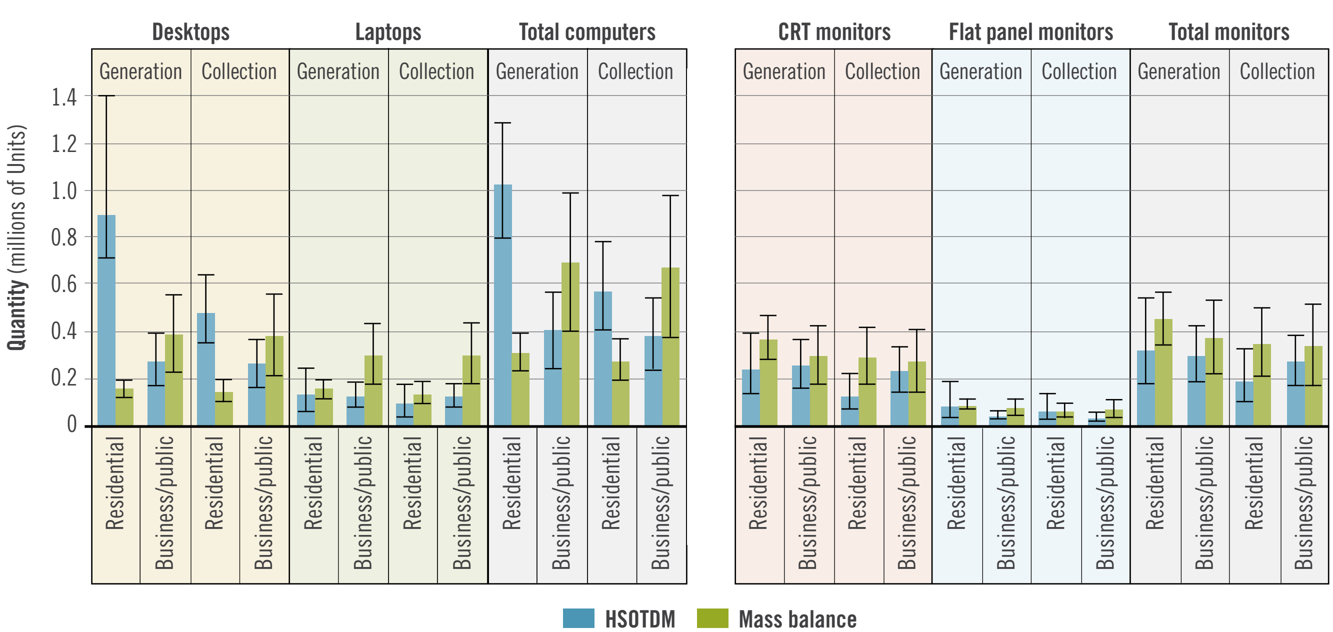
Note: Canadian destination countries, determined using US HSOTDM values, are applied to Canadian export data due to data constraints. Error bars reflect the range of thresholds for each threshold method, Export-NVEM and Export-Pub.

3.3 Mexico

- As with Canada, the quantities of used computers and monitors generated and collected are similar, with slightly more computers generated and collected than monitors. The weight of generated and collected monitors, however, is greater than that of computers due to their higher unit weights.
- Although the HSOTDM and Mass Balance generation estimates for laptops and desktops are much lower than estimated in a study by Román Moguel (2012), applying the estimated collection fraction to the generation quantities results in collection figures on par with the estimates from this study.
- The collection rate of 20% estimated from Román Moguel (2012) is much lower than those estimated in this study, which range from 70% to 100%. Different assumptions and methodologies must account for the large differences.
- Using HSOTDM, the fraction of collected used computers and monitors that is exported is unreasonably high, almost 100%, but using the Mass Balance method, it is 31%–33%.
- For exports of used desktops and flat panel monitors, the HSOTDM estimates greatly exceed the Mass Balance estimates. Factors which could account for this include:
    - Mexican export trade data do not differentiate between domestic exports and re-exports, meaning that much of the trade captured could be re-exports.
    - There is a general issue, described previously, with a trend across all trade categories, for the reported export trade quantities from Mexico to the United States to be larger than the reported imports to the United States from Mexico.
    - Mexico is involved in manufacturing and assembly of computers and flat panel monitors. Perhaps the used-new thresholds used are too high and capture lower-value new exports.
- The United States is the major destination for exports as determined by the HSOTDM, which determines that high-income OECD and North American countries are the major export destinations. Exports to the Netherlands make Europe the second-largest destination.

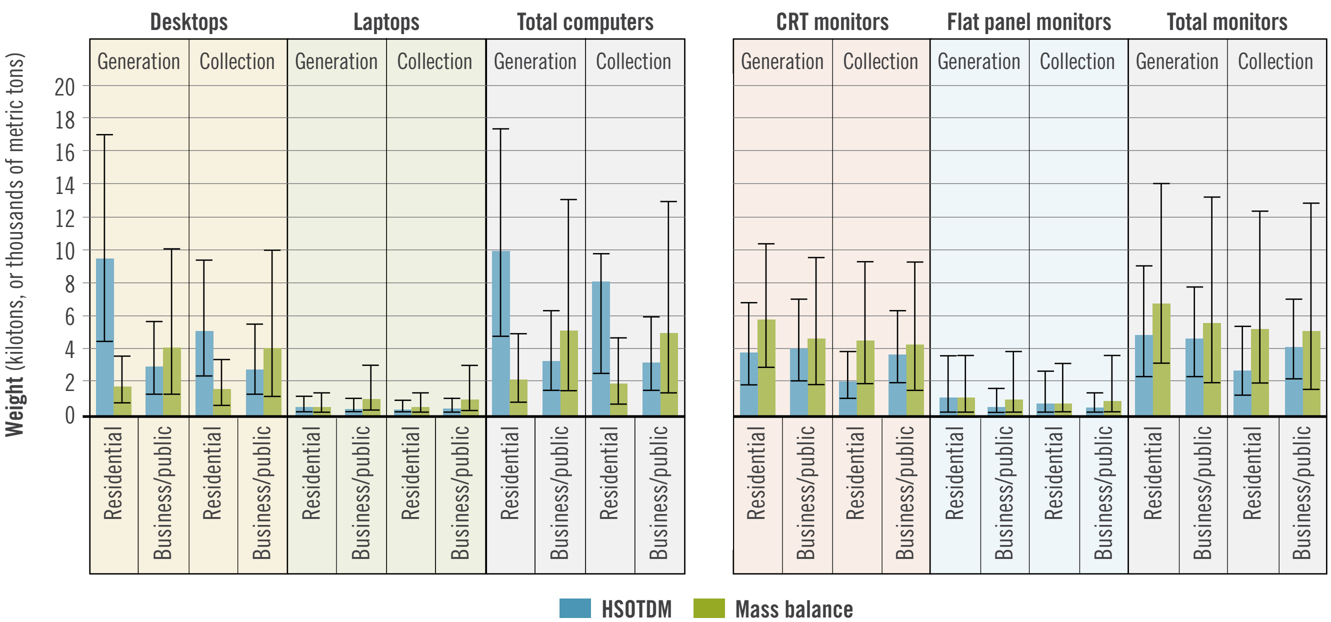
3.3.1 Generation and Collection

Figure 27: Comparison of Mexican generation and collection quantities by product, residential versus business/public sectors, and estimation method



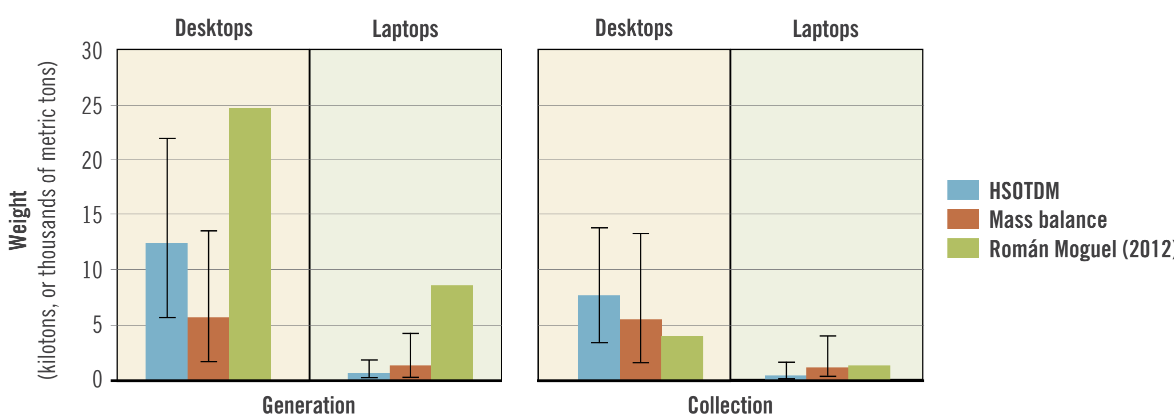
Note: Columns represent means, and error bars represent the 95% confidence interval.

Figure 28: Comparison of Mexican generation and collection weights by product, residential versus business/public sectors, and method



Note: Columns represent means, and error bars represent the 95% confidence interval.

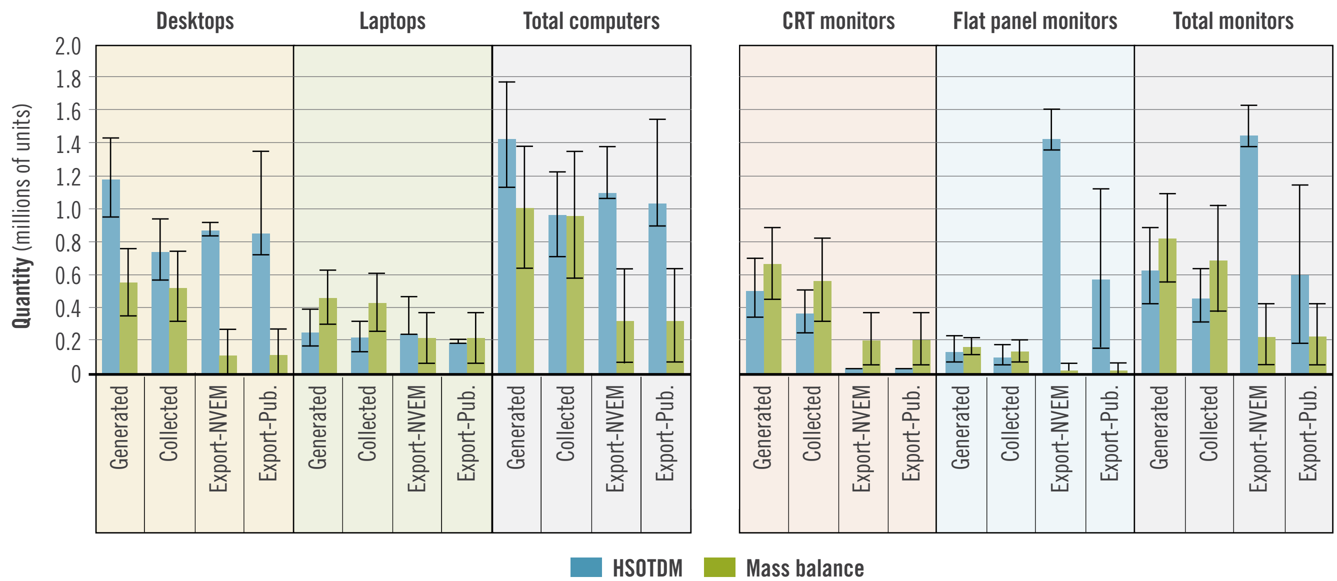
Figure 29: Comparison of Mexican generation and collection weights by product and estimation method



Source: Estimates derived from related work reported in [19].
Note: Columns represent means, and error bars represent the 95% confidence interval.

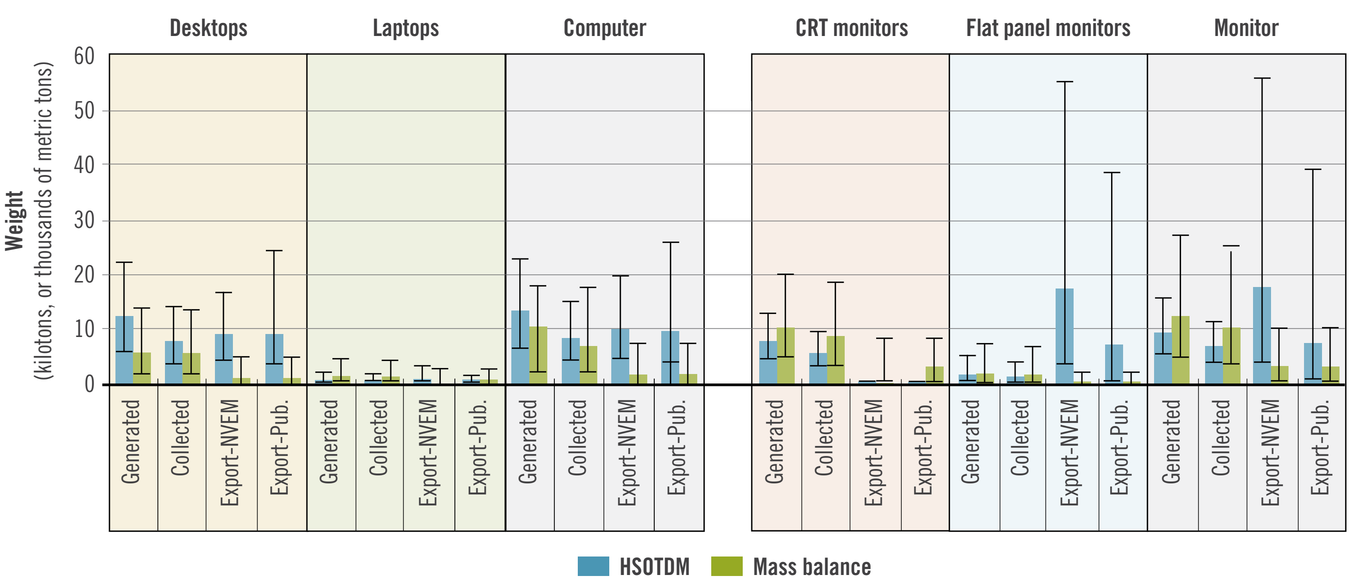
3.3.2 Generation, Collection, and Export

Figure 30: Comparison of Mexican generation, collection, and export quantities by product, residential versus business/public sectors, and method



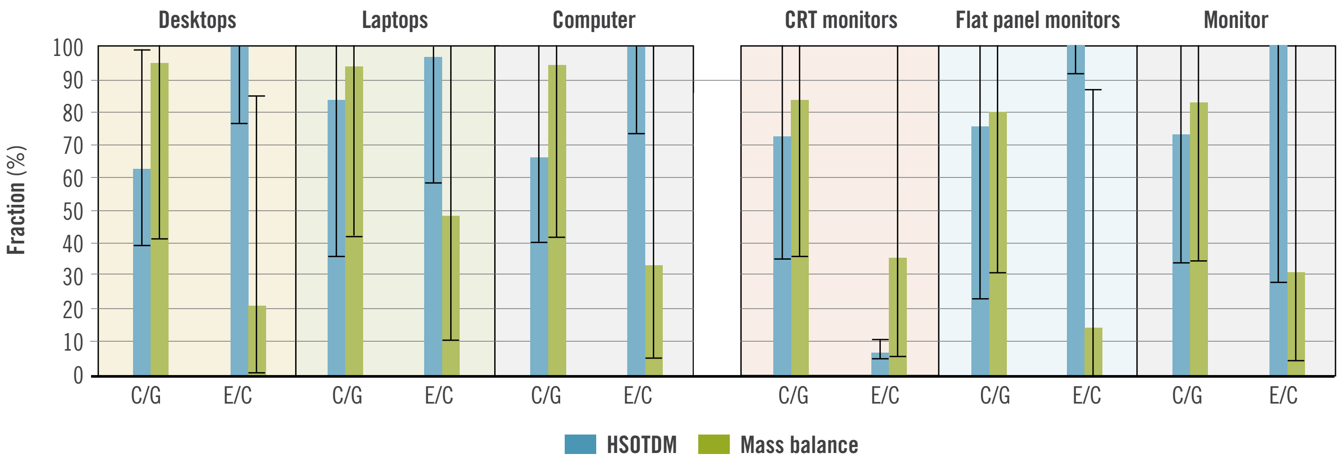
Notes: For HSOTDM, Export was determined using both NVEM and thresholds from published data.
Columns represent means, and error bars represent the 95% confidence interval.

Figure 31: Comparison of Mexican generation, collection, and export weights by product, residential versus business/public sectors, and method



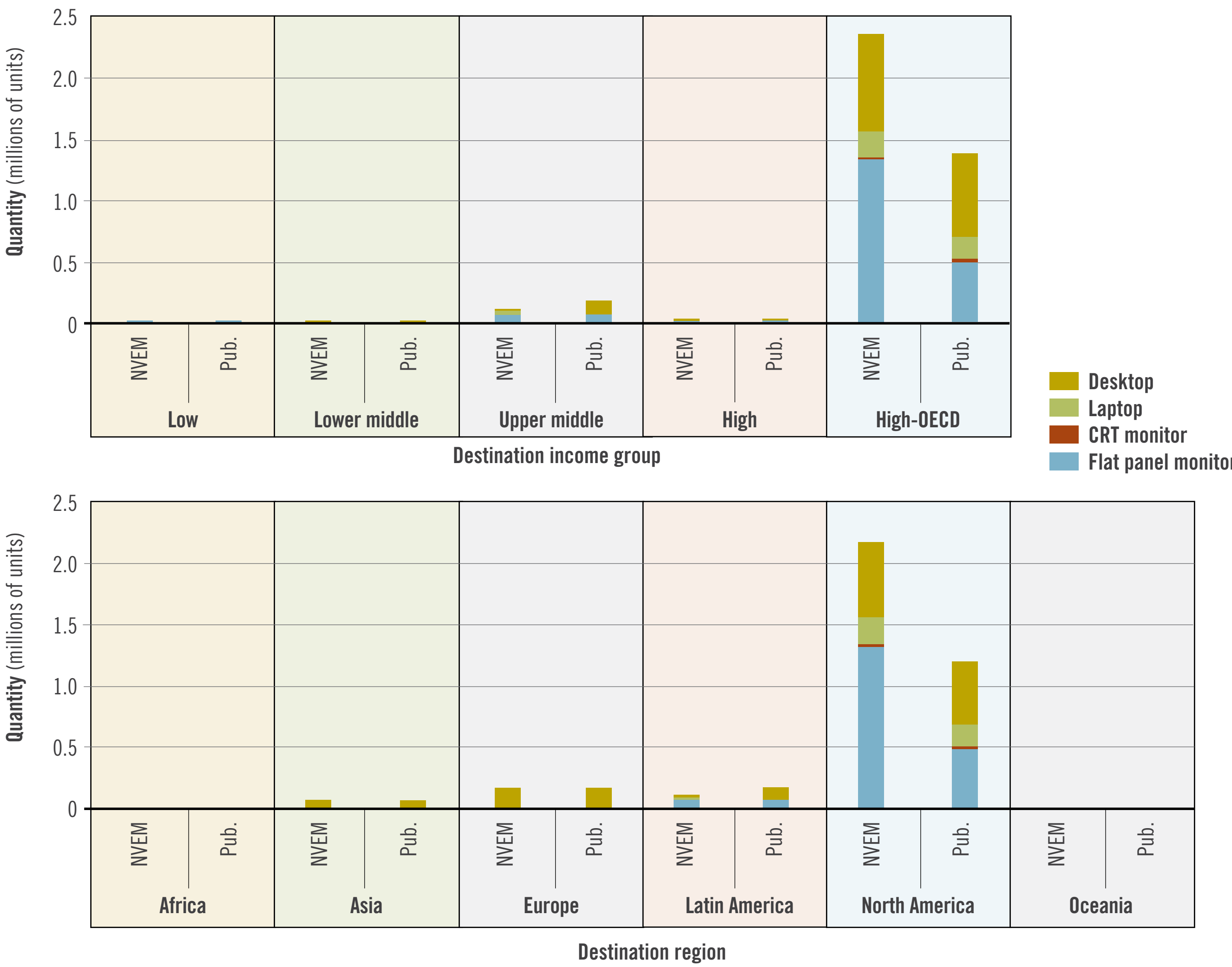
Notes: For HSOTDM, export quantities are determined using both NVEM and thresholds from published data.
Columns represent means, and error bars represent the 95% confidence interval.

Figure 32: Comparative fractions of Mexican downstream and upstream stages: collection/generation and export/collection fractions compared by product and method



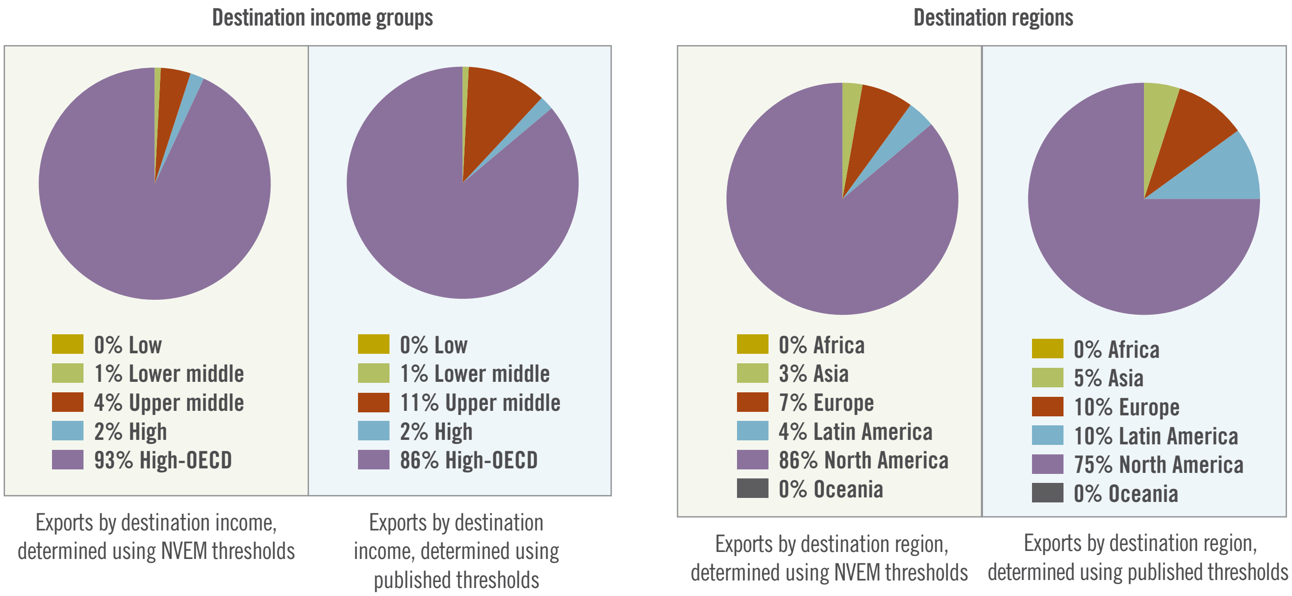
Notes: For HSOTDM, Export was determined by combining both methods. Columns represent means, and error bars represent the 95% confidence interval based on quantity. Weights have the same mean fractional values, but larger confidence intervals due to uncertain unit weights.

Figure 33: Comparison of Mexican used exports to destination income groups (top) and destination regions (bottom) by product



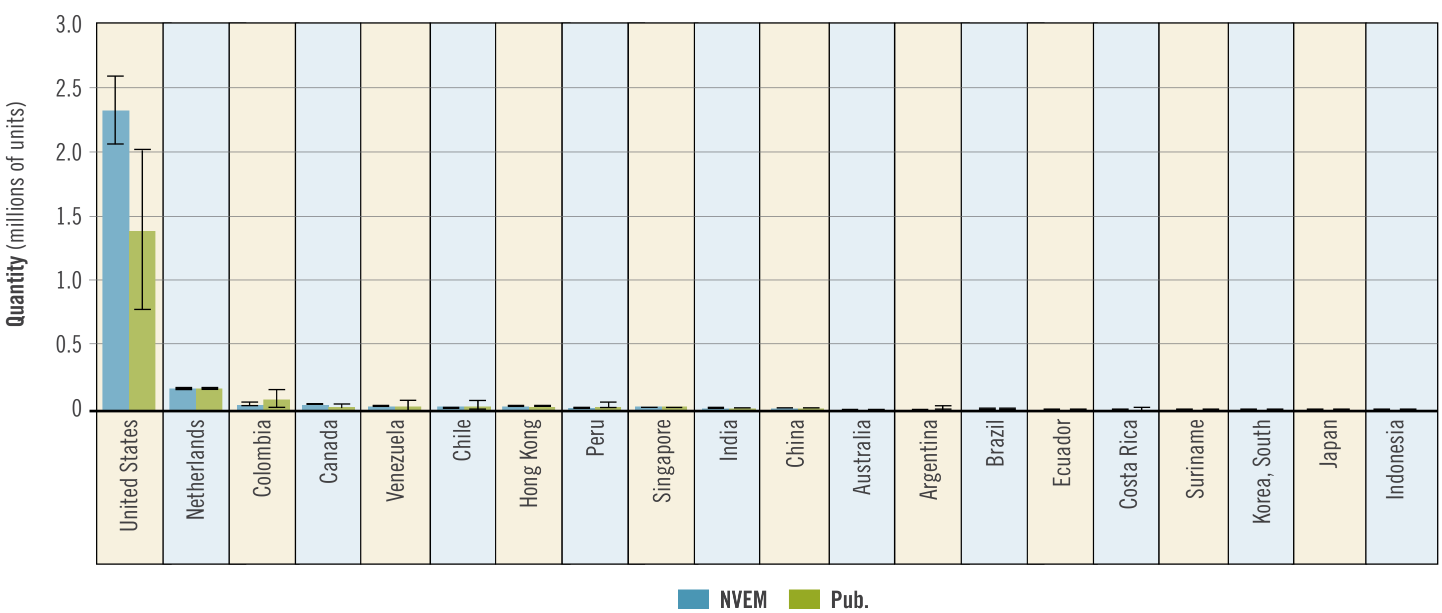
Note: Using HSOTDM, exports were determined using both NVEM and thresholds from published data.

Figure 34: Comparison of Mexican exports of used computers and monitors to destination income groups and destination regions



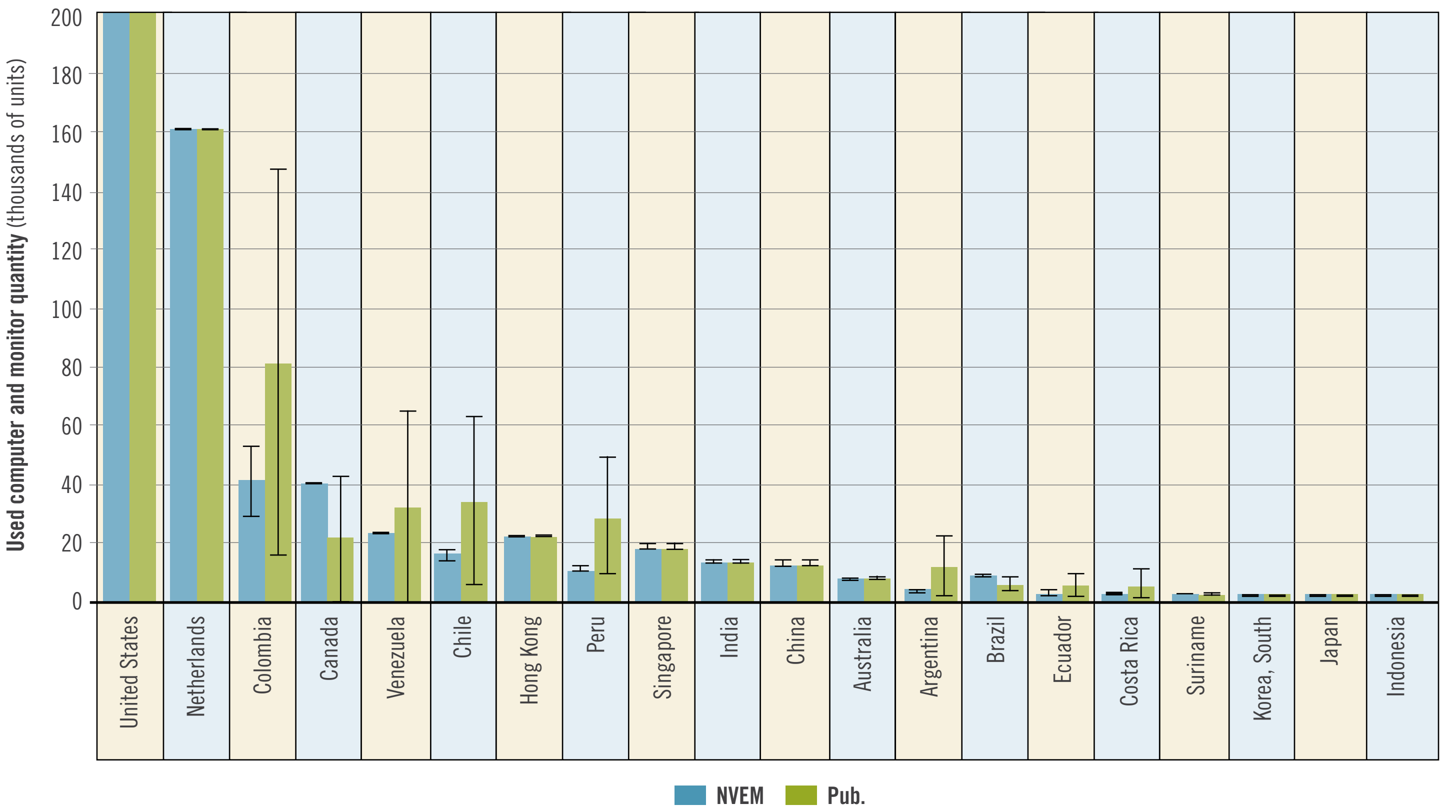
Note: Using HSOTDM, exports were determined using both NVEM (left member of each pair) and thresholds from published data (right member).

Figure 35: Top 20 destination countries for Mexican used computers and monitors, determined using HSOTDM and sorted by NVEM threshold method



Note: Figure 36 truncates the y-axis to enable observation of smaller export quantities.

Figure 36: Top 20 destination countries for Mexican used computers and monitors, determined using HSOTDM and sorted by NVEM threshold method



Note: The y-axis is truncated to enable observation of smaller export quantities.

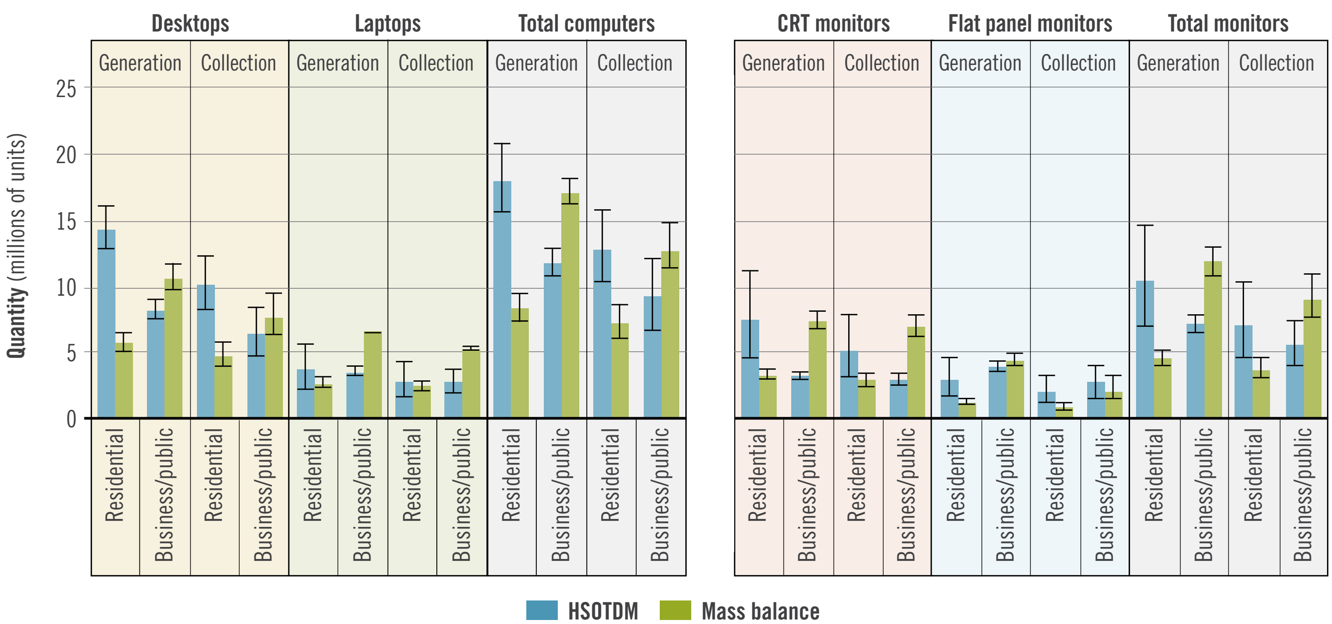
3.4 United States

- As with Canada and Mexico, the quantities of used computers and monitors generated and collected are similar, with slightly more computers generated and collected than monitors. The weight of generated and collected monitors, however, is greater than that of computers due to their higher unit weights
- Although the generation and landfill estimates in the US EPA ORCR study [9] exceed those from both methods in this study, the collection estimates are similar. The US EPA ORCR study assumed lower collection rates and made different lifespan assumptions, although the sales data used were very similar. Although the US EPA OSW study [20] [50] is not directly comparable to this study because it tracks only aggregate electronics, it does suggest that the US EPA ORCR estimate is reasonable in comparison.
- The collection estimates from Daoud (2011) are greater than both the generation and collection estimates from this study [8]. This suggests that either both methods in this study provide underestimates or that extrapolation from the recycler survey resulted in an overestimated quantity.
- In the Mass Balance method, the share of collection quantity from the business/public sector is closer to the estimate from recycler surveys in Daoud (2011) than to that from the HSOTDM. The Mass Balance method used a similar approach for both sectors, whereas the HSOTDM followed the mass balance approach for the business/public sector, but used a much more complex sales obsolescence model for the residential sector due to greater data availability. This suggests that the HSOTDM as executed somewhat underestimates the business/public sector or overestimates the residential sector, but could be improved with better surveys.
- The overall export/collection fraction varies from 5% to 35% for computers and 6% to 44% for monitors. Considering that the HSOTDM collection and export estimates were calculated independently, it is surprising how similar the export/collection fractions are for computers and monitors.

- As expected, due to the regional proximity and relatively lower per capita income of Mexico, which suggests greater demand for used electronics, Mexico is the top destination for US used computer and monitor exports.
- Upper middle-income countries are the largest export destination (47–49%), followed by high-income OECD countries (23–27%) and high-income countries generally (11–17%). Noting that Mexico is considered part of North America in this study, the top destination region is Latin America (28–32%), followed by Asia (25–29%) and then North America (25–26%).
- Top destination countries include Mexico, Canada, Hong Kong, the United Arab Emirates, Lebanon, Argentina, Chile, Colombia, Italy, and Bolivia.
- Comparing 2010 used computer and monitor exports from this study to those estimated for 2011 using survey results and trade data by USITC (2013), there is reasonable agreement for the desktop, laptop, and CRT monitor export estimates. The survey, conducted in 2012, suggests much higher flat panel monitor exports than expected from this study's 2010 estimates or the USITC 2011 trade data estimate. It could be that with the growth in sales of flat panel monitors, their export has grown considerably in the past few years.

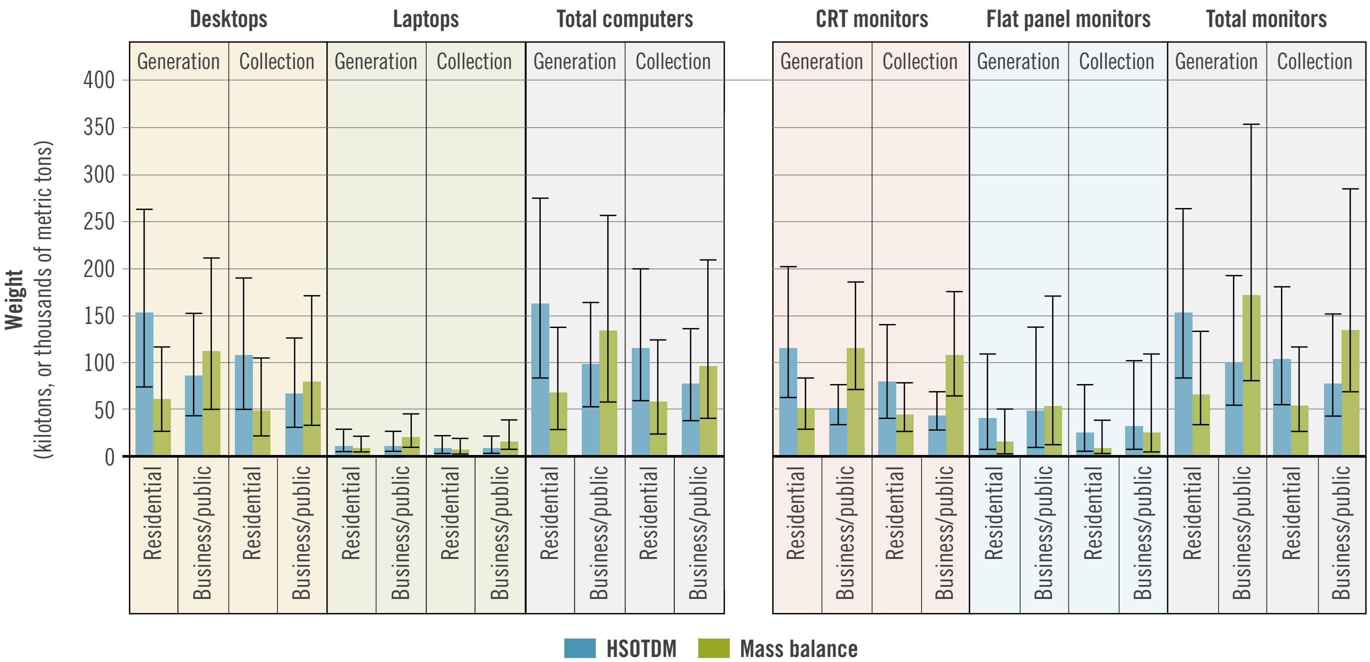
3.4.1 Generation and Collection

Figure 37: Comparison of United States generation and collection quantities by product, residential versus business/public sectors, and method



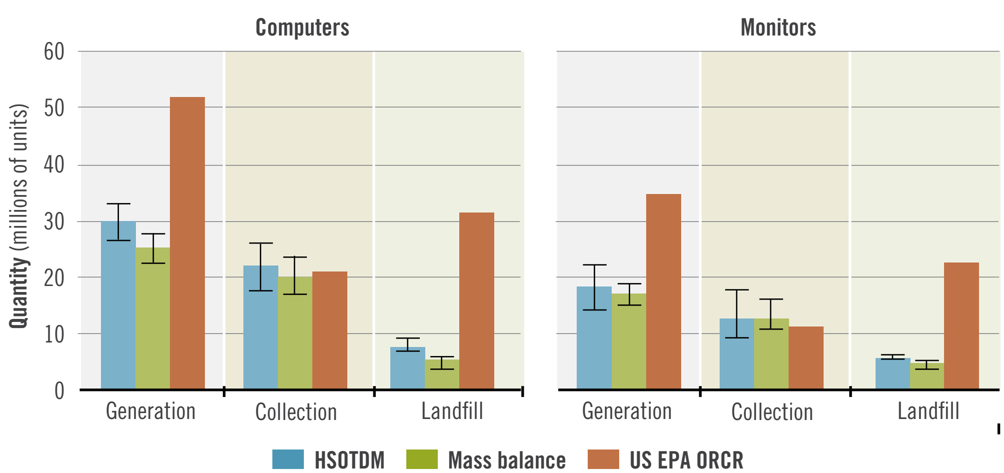
Note: Columns represent means, and error bars represent the 95% confidence interval.

Figure 38: Comparison of United States generation, collection, and landfill quantities by product and method



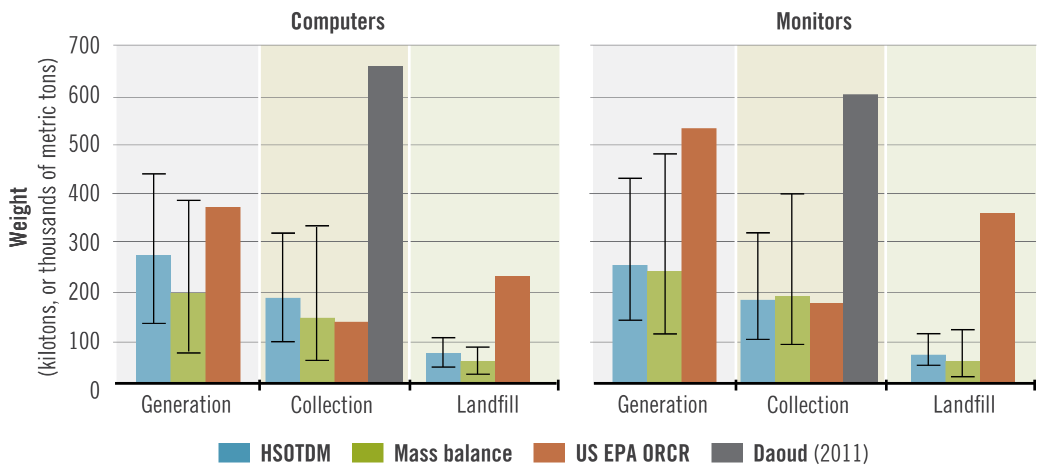
Source: Estimates from US EPA ORCR [9].
Note: Columns represent means, and error bars represent the 95% confidence interval.

Figure 39: Comparison of United States generation, collection, and landfill quantities by product and method



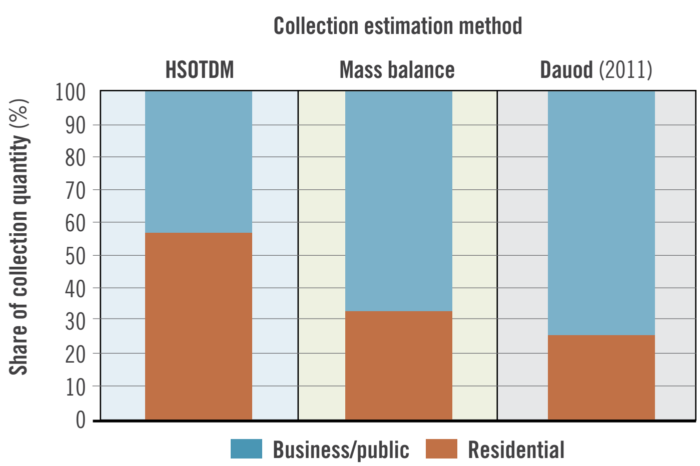
Source: Estimates from US EPA ORCR [9].
Note: Columns represent means, and error bars represent the 95% confidence interval.

Figure 40: Comparison of United States generation, collection, and landfill weights by product and method



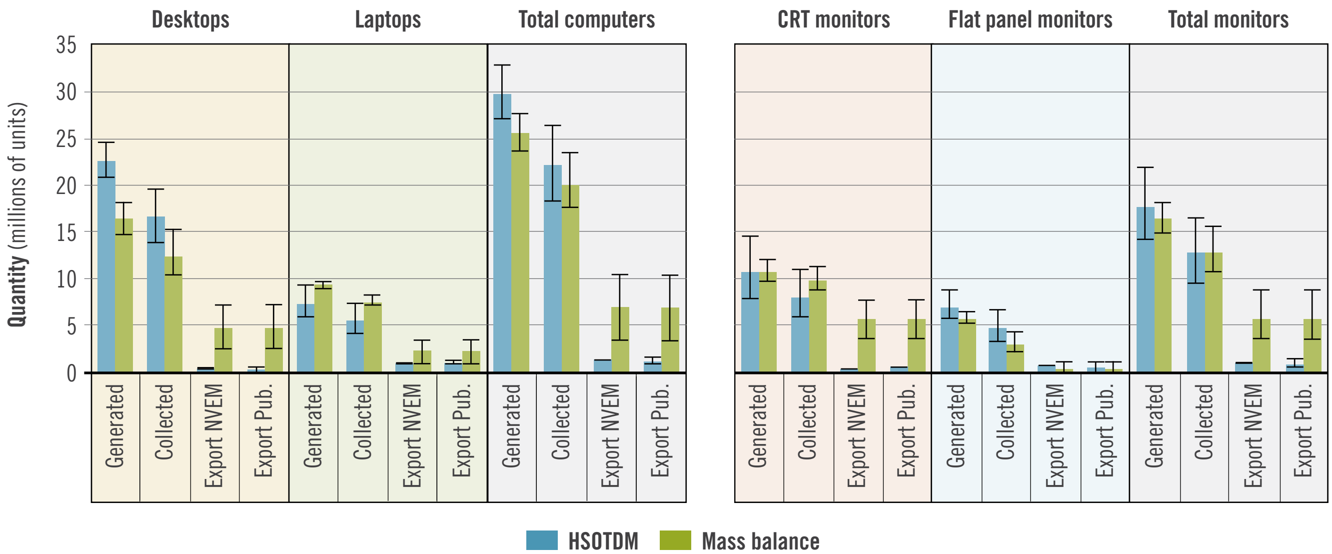
Source: Estimates from US EPA ORCR [9] and collection estimates from Daoud (2011) [8].
Note: Columns represent means, and error bars represent the 95% confidence interval.

Figure 41: Share of collection quantity for residential and business/public sectors by method



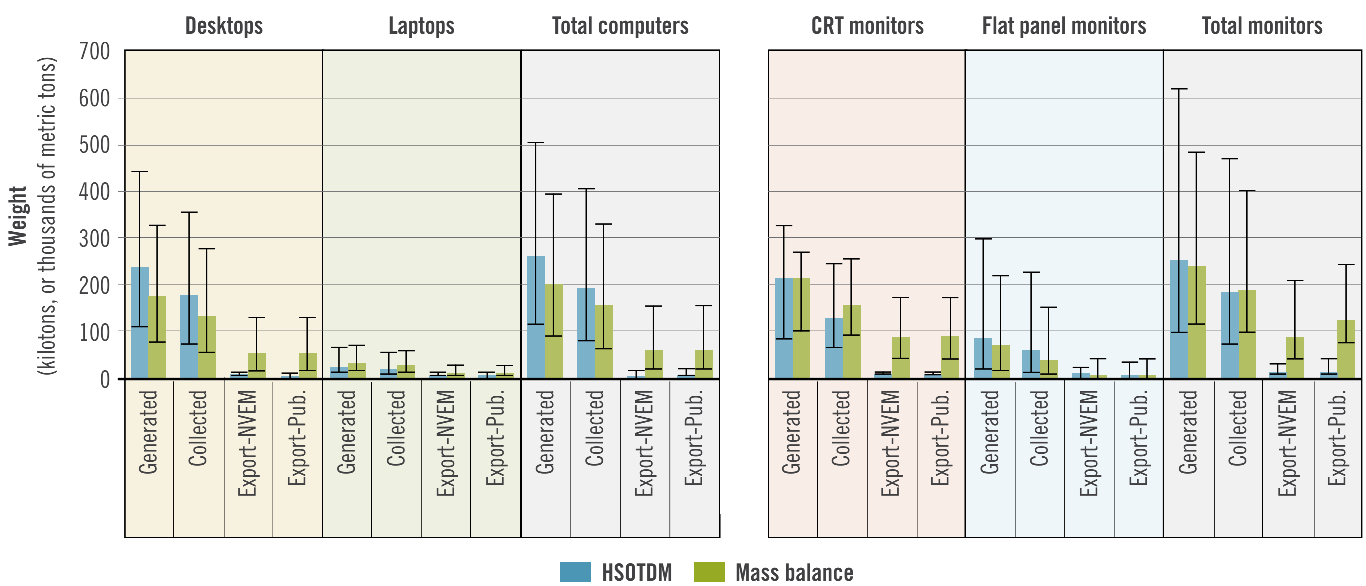
3.4.2 Generation, Collection, and Export

Figure 42: Comparison of United States generation, collection, and export quantities by product, residential versus business/public sectors, and method



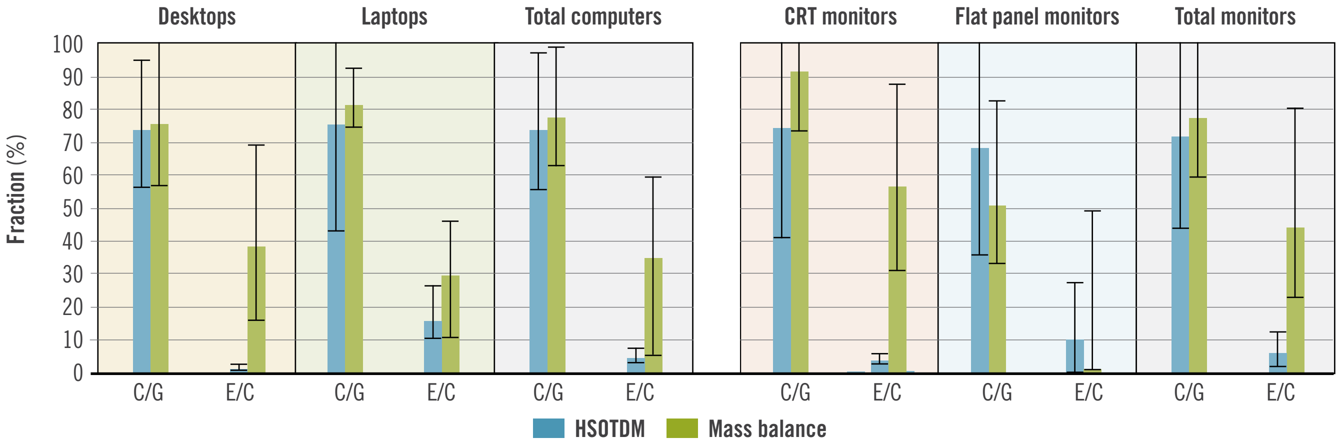
Source: For HSOTDM, Export was determined using both NVEM and thresholds from published data.
Note: Columns represent means, and error bars represent the 95% confidence interval

Figure 43: Comparison of United States generation, collection, and export weights by product, residential versus business/public sectors, and method



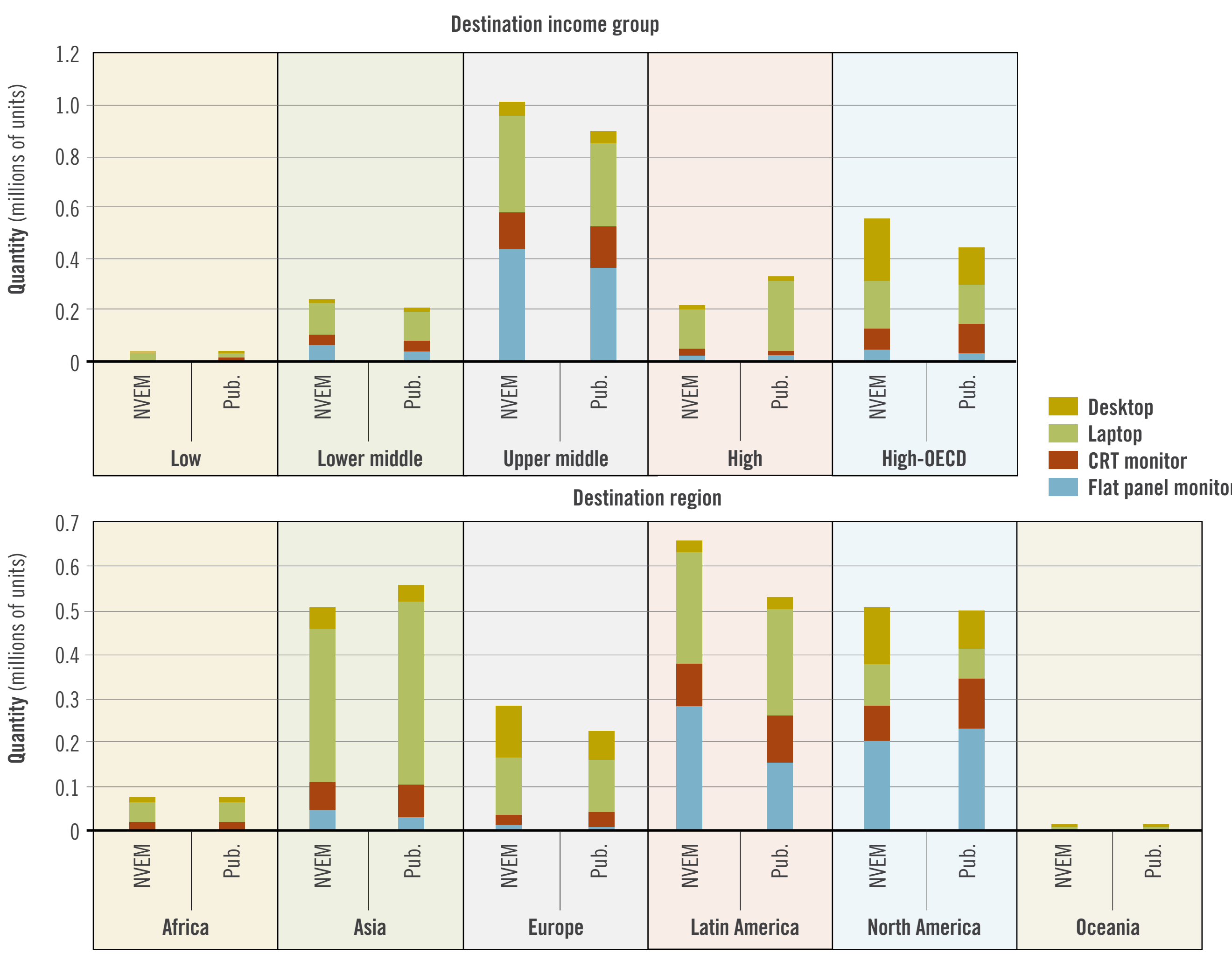
Source: For HSOTDM, Export was determined using both NVEM and thresholds from published data.
Note: Columns represent means, and error bars represent the 95% confidence interval.

Figure 44: Fractions of US downstream stage as compared to upstream stage.
Comparison of collection/generation and export/collection fractions by product and method



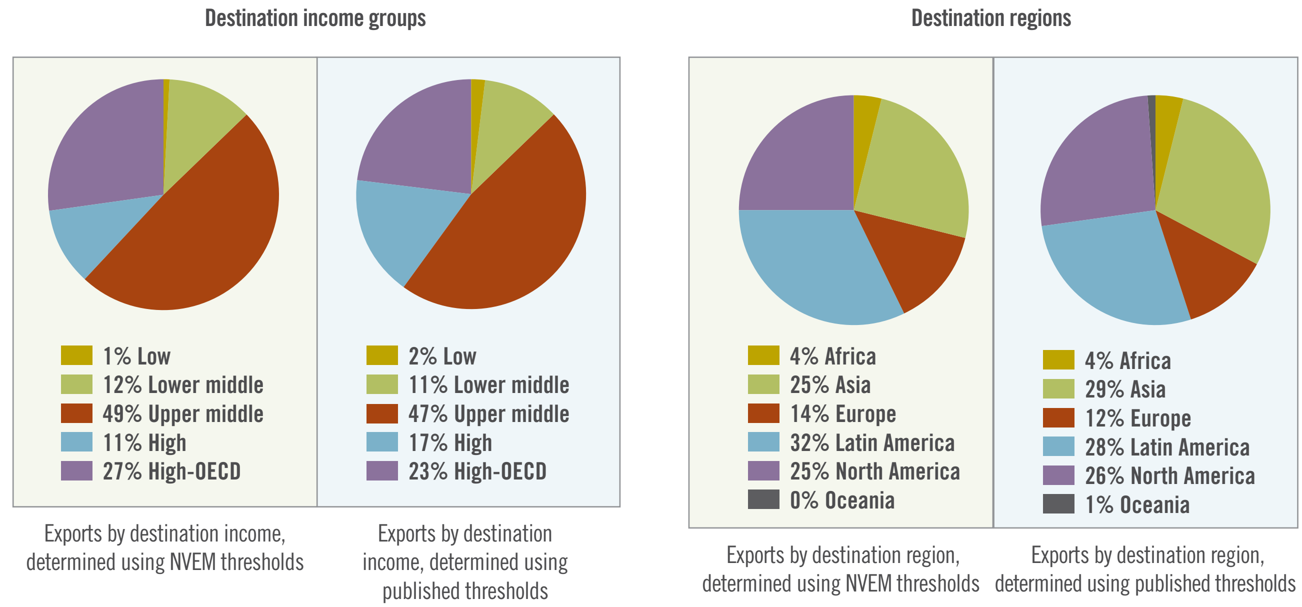
Source: For HSOTDM, Export was determined by combining both methods.
Notes: Columns represent means, and error bars represent the 95% confidence interval based on quantity. Weights have the same mean fractional values, but larger confidence intervals due to uncertain unit weights.

Figure 45: Comparison of Canadian used exports
to destination income groups (top) and destination regions (bottom) by product



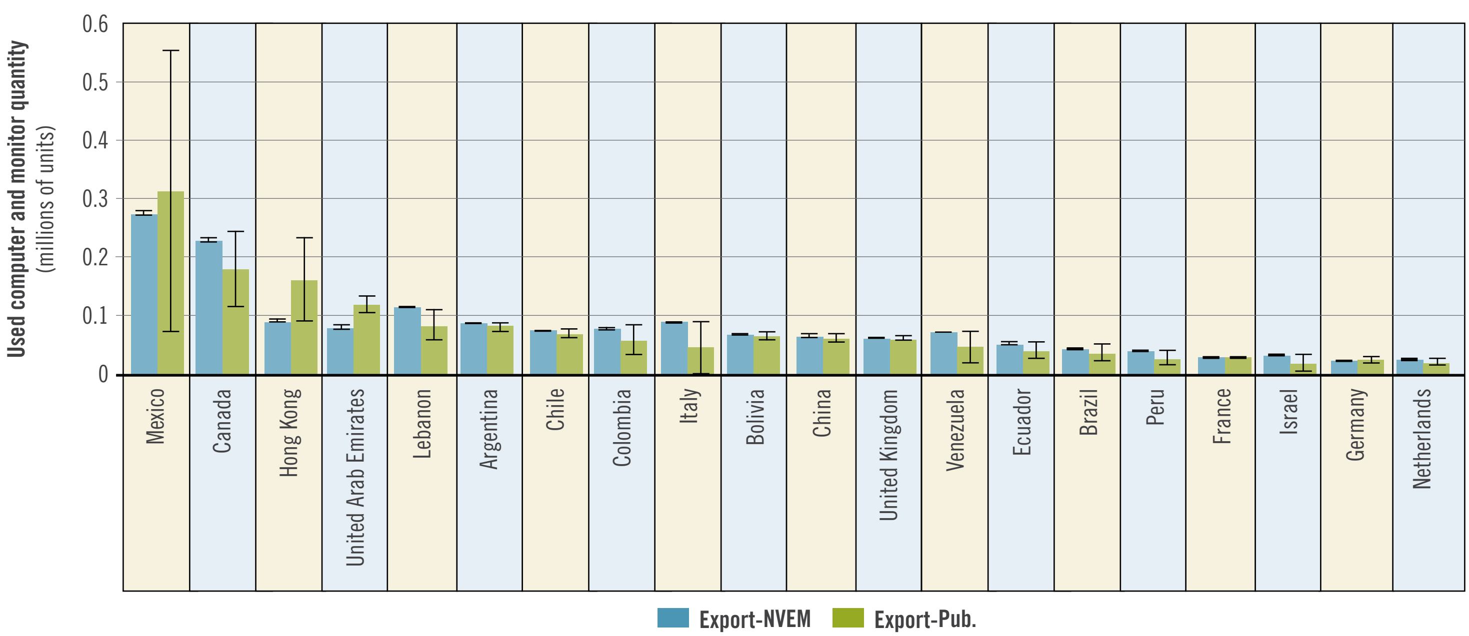
Source: Using HSOTDM, exports were determined using both NVEM and thresholds from published data.

Figure 46: Comparison of United States exports of used computers and monitors to destination income groups and destination regions



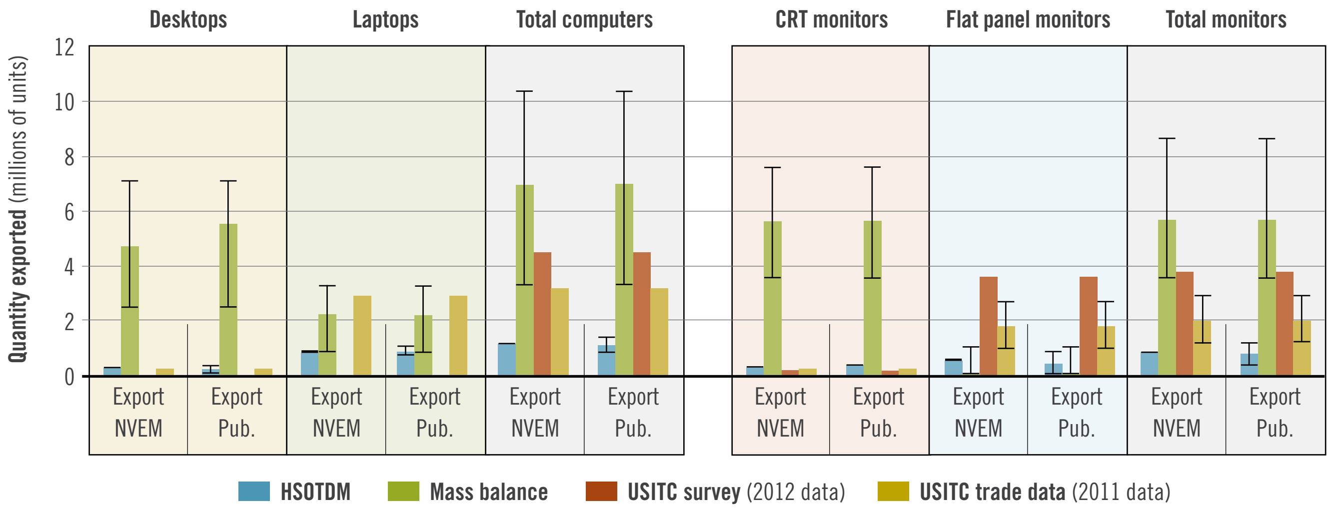
Source: Using HSOTDM, exports were determined using both NVEM (left member of each pair) and thresholds from published data (right member).

Figure 47: Top 20 United States used computer and monitor destination countries, determined using HSOTDM and sorted by NVEM threshold method



Note: Several destination countries are known commonly to re-export goods regionally, including Hong Kong, the United Arab Emirates, and Lebanon and therefore are not likely to be final destinations.

Figure 48: Comparison of United States export quantities by product and method as determined in this study with USITC results



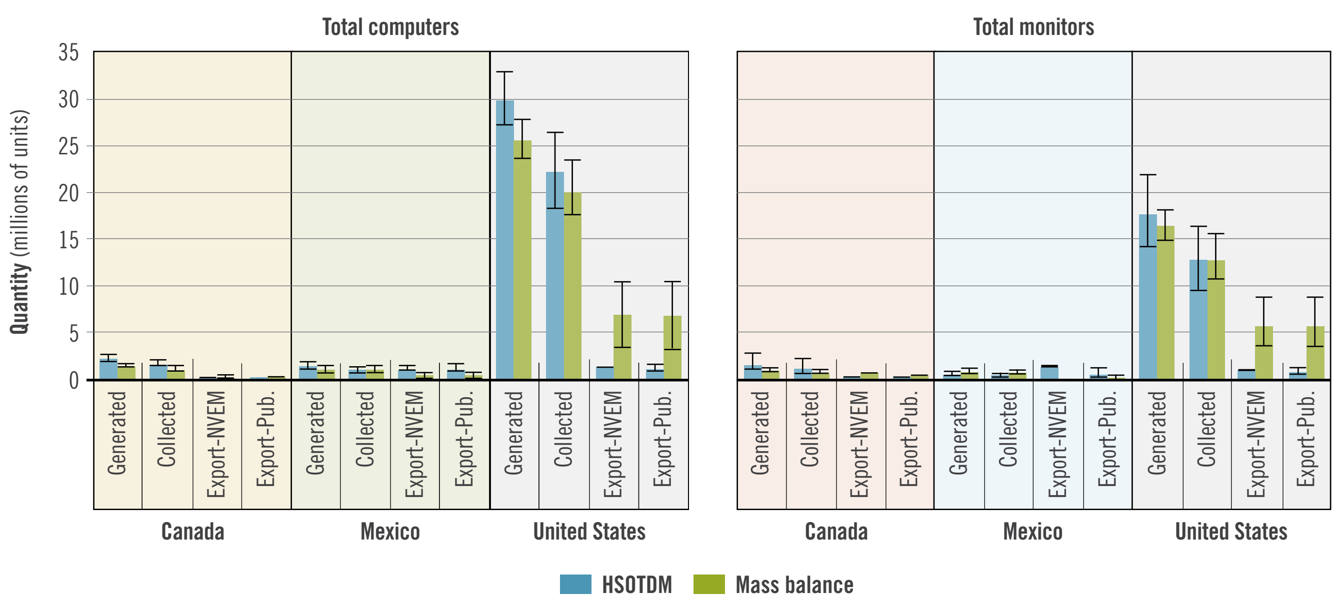
Source: US International Trade Commission 2013 [47].

Notes: For HSOTDM, Export quantities were determined using both NVEM and thresholds from published data. Columns represent means, and error bars represent the 95% confidence interval. Note that the 2013 USITC study included two estimates (one, from trade data, for 2011 and a survey, for 2012) and hence the results are not directly comparable to this study's Export NVEM and Export Pub (with estimates for 2010). The survey data on computers have not been further segregated here by desktops versus laptops.

3.5 Country Comparison

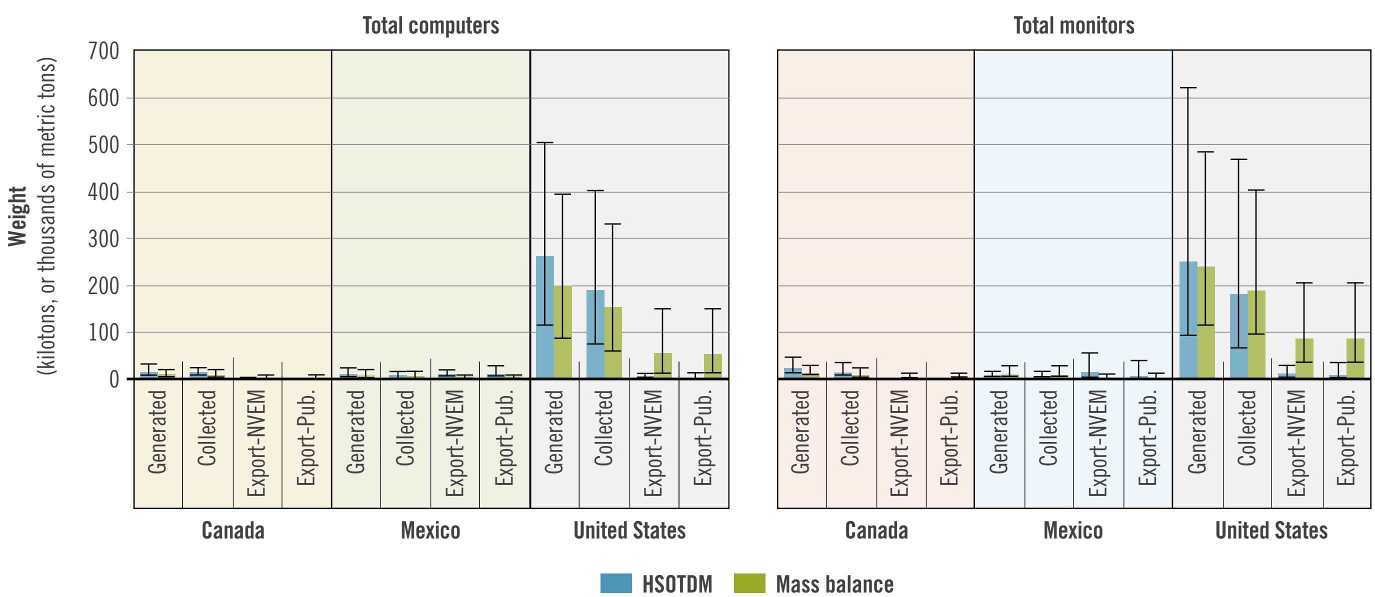
3.5.1 Generation, Collection, and Export

Figure 49: Comparison of generation, collection, and export quantities across countries by product and method



Notes: For HSOTDM, Export was determined using NVEM for all countries and also thresholds from published data. Columns represent means, and error bars represent the 95% confidence interval.

Figure 50: Comparison of generation, collection, and export weights across countries by product and method



Note: For HSOTDM, Export was determined using NVEM for all countries and also thresholds from published data. Columns represent means, and error bars represent the 95% confidence interval.

4. Conclusions and Recommendations

4.1 Quantitative Conclusions

4.1.1 Generation and Collection

Comparing the products for all three North American countries investigated, slightly more computers were generated and collected than monitors. The weight of generated and collected monitors, however, was greater than that of computers due to their higher unit weights. As discussed in the results, the generation and collection of used computers and monitors are roughly proportional to the population of the countries and to per capita income; the United States has the largest population and by far the largest estimated generation and collection. Although Mexico has a larger population than Canada, Canada has a much higher per capita income and hence purchasing power, which probably explains why its generation and collection are roughly the same as Mexico's.

4.1.2 Export

The quantities and weight of used computer and monitor exports from Canada, Mexico, and the United States in 2010 were estimated using two methods, HSOTDM and Mass Balance. According to the two methods, on average Canada exported 55 to 114 thousand used computers and 22 to 218 thousand used monitors. Citing only the Mass Balance results because of outlier HSOTDM results for Mexico, on average Mexico exported 315 thousand used computers and 215 thousand used monitors. Finally, according to the two methods, on average the United States exported 1,122 to 6,992 thousand used computers and 779 to 5,669 thousand used monitors.

Also according to the two methods, the overall fraction of used computer and monitor export quantities as compared to collection quantities is estimated to be on average 1% to 30% for Canada, 3% to 47% for the United States, and for Mexico using the HSOTDM over 100%, but using the Mass Balance method 31% to 33%. Issues with Mexican trade data overestimation and capture of low-value newly manufactured goods may account for the overestimation of the Mexican export fraction using HSOTDM. The other estimates are reasonable considering other domestic processing options for used electronics such as reuse and recycling.

4.2 Methodological Conclusions

4.2.1 Generation and Collection

Both HSOTDM and the Mass Balance method seem to be capable of producing a quality range of estimates for generation and collection of used electronics. The HSOTDM for residential generation requires a more complex model and dataset to model lifespans in a sophisticated sales obsolescence model incorporating reuse. The Mass Balance method requires few data inputs aside from sales and simple survey data and therefore is a more streamlined approach to obtaining a snapshot of flows, whereas a sales obsolescence model can produce a time series. To improve on these estimates and reduce uncertainty, better historical sales data and more complex business/public surveys from a broader range of businesses and institutions are needed.

As discussed in the results, HSOTDM and Mass Balance are methodologically similar in calculating generation and collection in the business/public sector, and therefore these results are similar, as expected. HSOTDM produced consistently higher residential generation and collection results than Mass Balance. This could have been because HSOTDM residential results are based on sales data for each product, whereas the scale factors for the Mass Balance method are based on an average scale factor across all products. Because the sales data produced lower CRT monitor sales estimates than those reported in the surveys, the average scale factor was lower than those of computers and flat panel monitors, resulting in a likely underestimate of flows for those products.

4.2.2 Export

With few exceptions, the methods attempted in this study seem to represent reasonably he likely range of used computer and monitor exports from Canada, Mexico, and the United States. The juxtaposition of the HSOTDM and Mass Balance methods has proven useful for estimating the lower and upper bounds of export quantities, and comparison with the collection estimates makes it possible to check the validity of the export estimates. The HSOTDM, because it uses trade data, has the advantage of giving insight into export destinations.

4.3 Recommendations

Several recommendations have arisen from this work to improve on the generation, collection, and export estimates and reduce the associated uncertainty:

- Flows could be analyzed across multiple years to discern trends. The methods proposed in this study can be used to model generation, collection, and export across several years.
- More accurate sales data, especially for Mexico, would enable more accurate generation estimates.
- Additional annual detailed surveys of business/public firms could enhance the accuracy of business/public generation and collection estimates.
- Creation of trade codes for used products would enable explicit tracking of these products (to the extent that these codes are properly used).
- Allowing more open access to Canadian and US shipment-level trade data would enable more accurate analyses of export flows.
- Canada Border Services Agency could record the quantity of all exported electronics to enable more accurate analyses of export flows.
- Domestic exports and re-exports could be differentiated in Mexican trade data.
- Other approaches could be used to estimate export flows of used electronics to understand the impact on the quantity estimates of the limitations in all approaches.
- Although cumbersome to record, increased reporting of re-export destinations would greatly improve the accuracy of final destinations for trade flows because it would provide a more realistic depiction of transactions. The current trade code system denotes only two trade partners.

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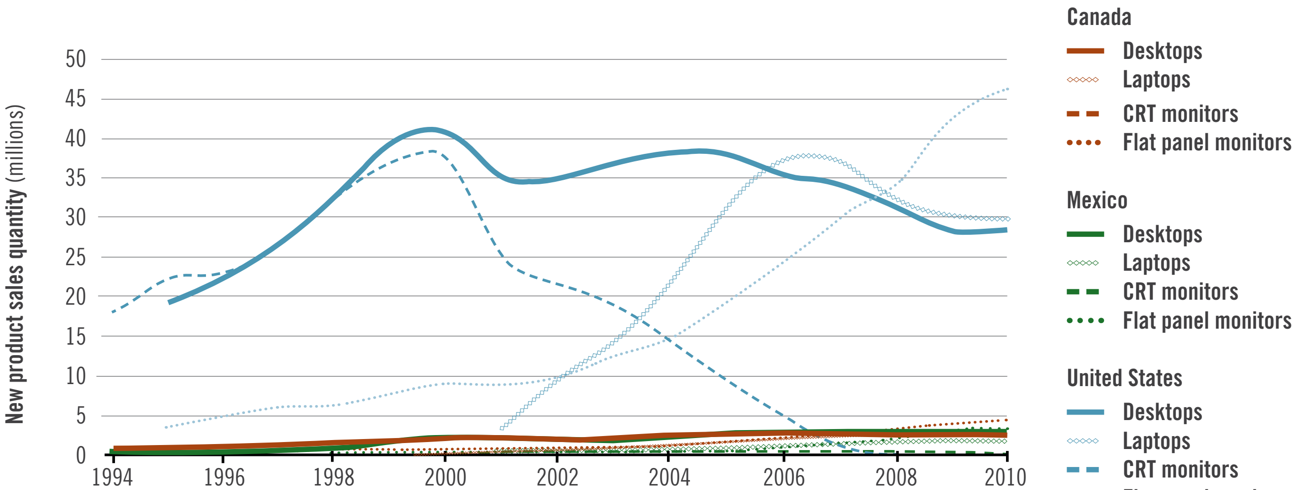
Appendices

Appendix 1. Country Comparison Overview

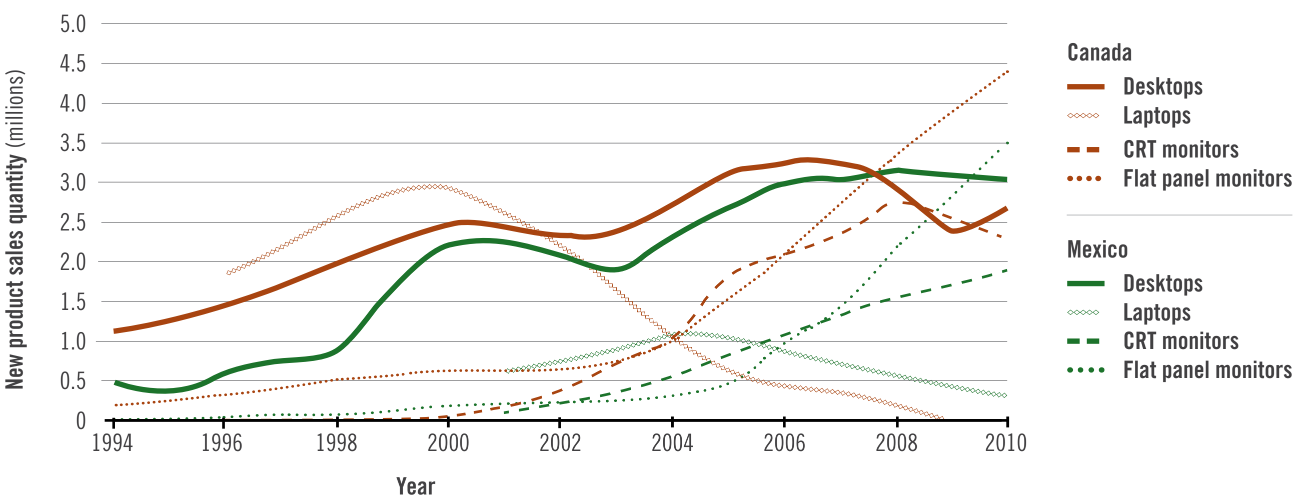
Comparing the North American countries studied with regards to international agreements on transboundary flows of used electronics, Canada and Mexico are both parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel Convention), whereas the United States is a signatory, but has not ratified it [51]. Wastes within the scope of the Basel Convention are therefore subject to transboundary movement provisions for hazardous wastes and other wastes as defined in Article 1 of the Convention. Non-Parties "cannot participate in waste transfers with Basel Parties without a separate and equivalent bilateral or multilateral agreement"; "the United States has entered into several bilateral agreements and one multilateral agreement" with OECD members [52].

Figure 51: Comparison between sales by country and product



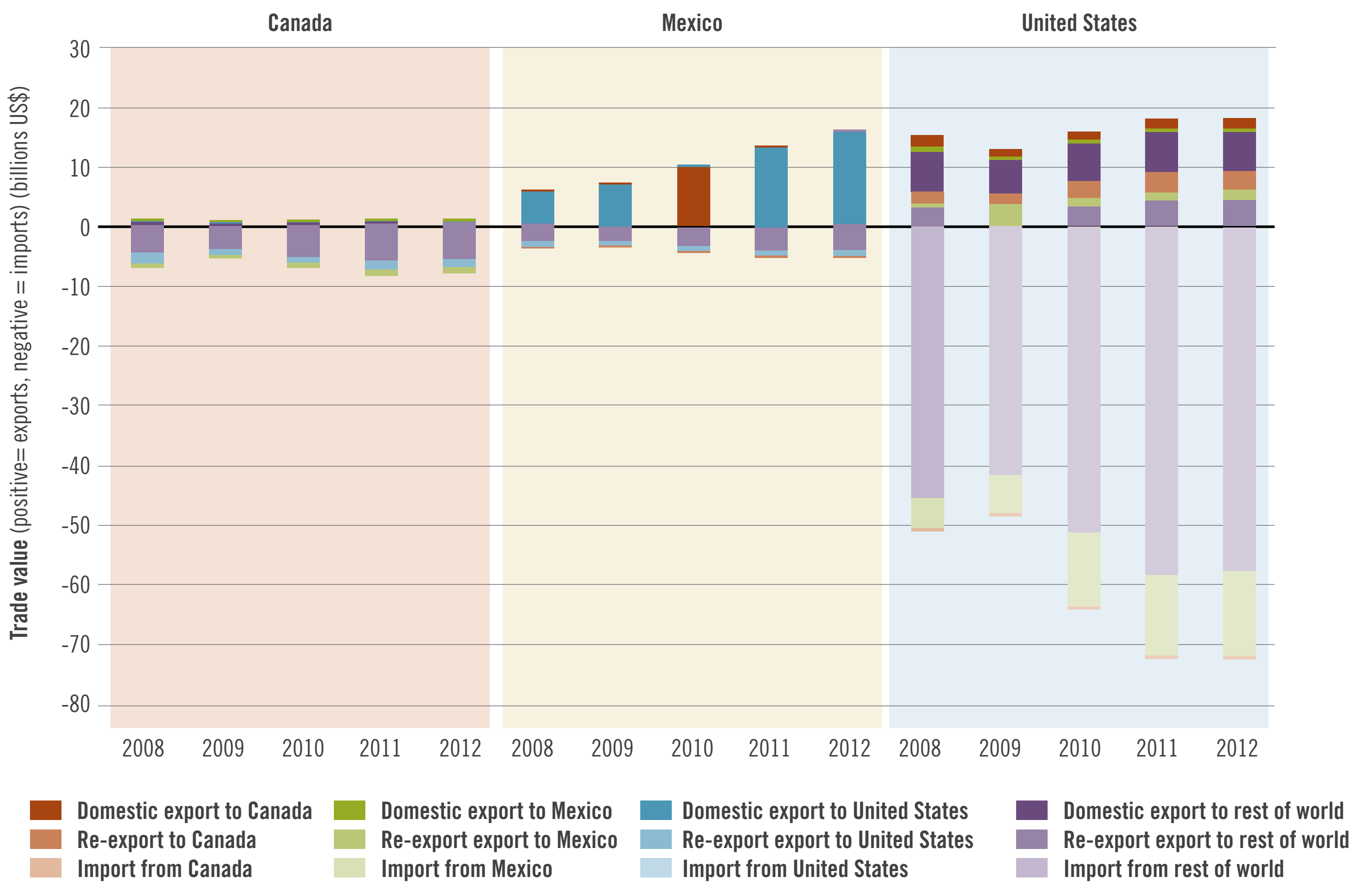
Note: Lines smoothed to protect proprietary data.

Figure 52: Comparison between new product sales by country and product



Note: Canada and Mexico only are presented to show detail. Lines smoothed to protect proprietary data.

Figure 53: New and used computer and monitor trade balance



Source: Trade value calculated using UN Comtrade database [12].

Appendix 2. Data Collection on National Patterns of Computer Use and End-of-Life Management

The surveys designed by Kahhat and Williams and used in this study are available in the following section about the United States, and are also available in the supplemental data to their article about the United States and are generally applicable to the other countries [13].

Canada

The following section, written by Ramzy Kahhat and Eric Williams, describes the methodology used for the online surveys implemented in the Canadian residential, business, and public sectors. Survey questionnaires were made available in both English and French.

Residential Sector

Participants: Survey participants (referred to as "respondents") consisted of 791 adult residents of Canada who owned a home computer. Of the 791 respondents who began the survey, 191 did not complete the survey, and 600 completed the survey. All further details are for the 600 respondents who completed the survey. Respondents were members of a survey research panel pool of approximately 25,000 eligible persons under the jurisdiction of the survey-hosting site Opinionology (Orem, Utah, USA). All respondents received payment in the form of electronic credit for survey completion. All respondents were treated according to the ethical principles of the American Psychological Association and the Arizona State University Institutional Review Board (IRB).

Sample demographics: To ensure that any required extrapolation about the use and disposal of computers and monitors in the residential sector was accurate for the overall population, the sample had to be as representative as possible of the actual population. Hence, the sample chosen was representative of the Canadian adult public according to the following parameters (with caveats listed where applicable), as compared to the population of Canada in 2006 (Canadian Census, 2010): gender, location/province, age, household income, and educational attainment. Deviations from national representativeness are described in more detail below. In addition, it is important to note that the quota system used for online surveys is controlled by invitations and not by completed surveys. This means that the system accepted completed surveys from participants that initiated the survey before the particular quota was reached. There are no options for researchers to reject a survey while it is being completed by a specific individual.

Gender: Of the 600 survey respondents, 293 (48.83%) were males, and 307 (51.17%) were females. This is consistent with the breakdown of gender in the adult population in Canada.

Location: Responses were solicited from all 13 provinces/territories in accordance with 2006 Canadian Census data; however, due to low population, responses were solicited but not received from the following jurisdictions: Northwest Territories, Nunavut, Prince Edward Island, and Yukon. (The online panel contained very few members from these low-population jurisdictions. These panel members were invited but did not respond to the invitation). Responses from the highly populated provinces of Alberta, British Columbia, and Ontario were increased accordingly to account for the difference. The only populous province that had a lower-than-expected response rate was Quebec, due to a lower volume of French-language panelists available.

Age: Respondents ranged in age from 18 to 85, in accordance with 2006 Canadian census data. The only deviation from Canadian census proportions in the survey response solicitation is the collapse over age groups above age 65 (the proportions of each sub-group over 65 were included in the "over 65 category" and then counted as one large group). This collapse accounts for the lower Internet activity of older generations. Responses by age breakdown correspond to census data, except for the four non-responsive jurisdictions noted above.

Household Income: Respondents from all household income levels responded to the survey, in accordance with the 2006 Canadian census data, with two exceptions:

1) Those with household incomes in the highest category (above $150,000/year Canadian) responded at a lower rate than their proportion of the population according to the census, due to a lower proportion of wealthy individuals in the respondent pool than in the general population; and
2) Those with household incomes in the lowest category (below $25,000/year Canadian) responded at a slightly lower rate than their census population proportion due to lower rates of computer ownership among those with low income.

Educational Attainment: Respondents from all levels of secondary and post-secondary education responded to the survey in accordance with data from the 2006 Canadian census. The authors added the categories "some college/university" and "some graduate school" to the list of options in addition to those offered by the census to account for responses by current students. However, these were not used by respondents and were therefore omitted from the data presentation. Actual educational attainment by sample respondents is nationally representative [over-representation of high school graduates (HS diploma) and post-graduate degree recipients is <2% and hence statistically negligible].

Sample selection: The sample of respondents was chosen from a pool of 25,000 prospective survey respondents maintained by the third-party survey-hosting site Opinionology (Orem, Utah, USA). Respondents were screened for demographic suitability and record of honesty (e.g., participants that had a bad history of filling out surveys were eliminated post-hoc) in survey participation before initiating the survey itself. The prospective respondent pool is generally representative of the Canadian adult public.

Materials: Materials consisted of a single Web-based survey presented in Canadian English or Canadian French. The survey was translated and back-translated twice to ensure that content was identical in each version. A letter of informed consent was presented at the beginning of the survey and required a button press by the respondent for questions to begin.

The survey consisted of 22 questions covering six topic areas plus desired language: demographic questions (age, gender, location (province and type of area), household income, educational attainment, status, length of time in storage); monitors at home (same as computers at home); computer disposal (type of computers disposed of, number disposed of, disposal method, date of disposal); monitor disposal (same as computer disposal); and other electronics disposal.

Procedure: All respondents were screened by Opinionology, based on the authors' demographic requirements before participation. Demographically suitable respondents received a survey invitation from Opinionology.com by email and followed the link to the survey itself. After choosing the preferred language (English or French), respondents read an informed consent letter. Consent was considered granted if respondents chose the "Next" button to begin the survey at the end of the informed consent letter. If consent was not given, the survey was terminated (listed as incomplete).

Once respondents completed the survey, they were directed to a disclosure page that repeated contact information for the research group. Respondents received payment from Opinionology after completing the survey through the Opinionology website. The survey took an average of eight minutes to complete, and data were collected between December 23, 2010 and January 25, 2011.

Business and Public Sector

Participants: Survey participants (referred to as "respondents") consisted of 350 adult Information Technology (IT) and/or Asset Managers in the Canadian business and public sector, including both for-profit and non-profit organizations. Of the 350 respondents who began the survey, five did not complete it, and 345 completed the survey. All further details are for the 345 respondents who completed the survey. Respondents were members of a survey research panel pool of approximately 25,000 eligible persons under the jurisdiction of the survey-hosting site Opinionology (Orem, Utah, USA). All respondents received payment in the form of electronic credit for survey completion. All respondents were treated according to the ethical principles of the American Psychological Association and the Arizona State University Institutional Review Board (IRB).

Sample Demographics: The sample chosen was representative of the Canadian business and public sectors according to the following parameters (with caveats listed where applicable), as compared to the 2009 Canadian Industry Statistics (Canadian Industry Statistics, 2010): business location/province and business size. Business and public sector (and specific industry) information was collected and reported, but was not solicited by the authors. Deviations from national representativeness are described in more detail below.

Location: location details were recorded for the respondent's facility and for all possible locations of the respondent's organization. Details reported below are only for respondent facility location. Responses were solicited from all 13 provinces/territories in accordance with 2009 Canadian Industry Statistics. However, due to low population, responses were not received from the following three jurisdictions: Northwest Territories, Nunavut, and Yukon. Responses from the highly populated provinces of Alberta, British Columbia, Ontario, and Quebec were increased accordingly to account for the difference. Note that 350 responses were solicited, but only 345 complete surveys were achieved.

Number of Employees in the Business and Public Sectors: There were four size categories in the business and public sector, defined by Canada Industry Statistics as number of employees per business across locations: 1–4 employees, 5–99 employees, 100–499 employees, and 500+ employees.

Business size was intentionally modified by the authors to deviate from representativeness to include larger business organizations in the analysis. This change was made by the authors because larger businesses represent significantly more computers per company than do the more prevalent small (1–4) and medium-size (5–99) businesses. As in the 2009 Industry Statistics, small businesses represented a plurality of the sample, followed by medium-size businesses.

Industry Classification in the Business and Public Sector: The authors did not solicit responses based on business and public agency sector (goods versus services) or for specific industries. However, the collected data indicate that the actual responses are nationally representative, with the following two exceptions: construction is under-represented, and science/technology/professional organizations are over-represented. This makes sense in the context of computer-heavy versus computer-light industries and is accounted for in the model.

Sample Selection: The sample of respondents was chosen from a pool of 25,000 prospective survey respondents maintained by the third-party survey-hosting site Opinionology.com (Orem, Utah, USA). Respondents were screened for demographic suitability and record of honesty in survey participation before initiating the survey itself. The prospective respondent pool is generally representative of the Canadian business sector.

Materials: Materials consisted of a single Web-based survey presented in Canadian English or Canadian French. The survey was translated and back-translated twice to ensure that content was identical in each version. A letter of informed consent was presented at the beginning of the survey and required a button press by the respondent for questions to begin.

The survey consisted of 18 questions covering six topic areas: business demographic questions (business size, business industry, business province or location, duties of respondent); computers at facility (laptop versus desktop, purchase condition and current condition, year of most recent bulk computer purchase, average lifespan of computers, use status, storage time); monitors at facility (same as computers at facility); computer disposal in the last 12 months (type of computer disposed of, number disposed of, disposal method, date of disposal); monitor disposal in the last 12 months (same as computer disposal); and other electronics disposal.

Procedure: All respondents were screened by Opinionology based on the authors' demographic requirements before participation. Demographically suitable respondents received a survey invitation from Opinionology.com by email and followed the link to the survey itself. After choosing the preferred language (English or French), respondents read an informed consent letter. Consent was considered granted if respondents chose the "Next" button to begin the survey at the end of the informed consent letter. If consent was not given, the survey was terminated (listed as incomplete).

Once respondents completed the survey, they were directed to a disclosure page that repeated contact information for the research group. Respondents received electronic credit from Opinionology after completing the survey through the Opinionology website. The survey took an average of 9.5 minutes to complete, and data were collected between January 21 and February 21, 2011.

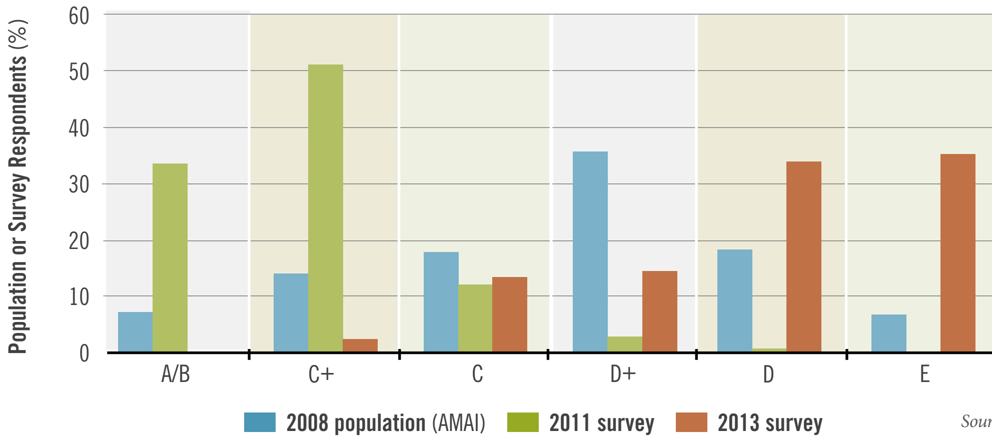
Mexico

The Mexican residential survey was re-done in 2013 by telephone due to low participation by computer users without Internet. The following section regarding the business/public survey was written by Ramzy Kahhat and Eric Williams.

Residential Sector

The survey was completed in spring 2013 by the Mexican firm Grupo IDM using computer-assisted telephone interviewing (CATI). In Mexico, the NSE Socioeconomic Level indicator is used to classify segments of the population by income and other metrics of purchasing power. The most recently published NSE distributions found were from 2008 [54], but they showed little change from previous years, suggesting that there was little change from 2008 to 2010. The previous survey completed in spring 2011 was done online and resulted in much higher participation of respondents from higher NSE levels who had greater Internet access. During the 2013 CATI survey, no rewards were offered for

Figure 54: Comparison between Mexican socioeconomic levels nationwide and in two surveys related to this report



Source: Romo 2008 [54].

participation, and therefore many more phone calls were made than completed surveys. Perhaps due to the use of CATI, the 2013 survey under-represents the higher NSE levels and over-represents the lower NSE levels. Figure 54 compares the national NSE distribution to that of the survey respondents. Table 11provides the sample size and associated confidence intervals by Mexican geographical area.

Business and Public Sector

Participants: Survey participants (referred to as "respondents") consisted of 496 adult IT and/or asset managers for Mexican organizations, including both for-profit businesses and non-profit organizations. Of the 496 respondents who began the survey, 239 did not complete the survey, and 257 completed the survey. All further details are for the 257 respondents who completed the survey. Respondents were members of a survey research panel pool of approximately 5,000 eligible persons under the jurisdiction of survey-hosting site Research Now (Dallas, Texas, USA). All respondents received payment in the form of electronic credit for survey completion. All respondents were treated according to the ethical principles of the American Psychological Association and the Arizona State University Institutional Review Board (IRB).

Sample demographics: The sample chosen was representative of Mexican business and public organizations according to the following parameters (with caveats listed where applicable), as compared to the 2011 Mexican Industry Statistics (SIEM 2011): location/state and size. Business and public sector (and specific industry) information was collected and reported, but was not solicited by the authors. Deviations from national representativeness are described in more detail below.

Location: Details on location were recorded both for the respondents' own facility and for all possible locations of the respondents' organization. Details reported below are only for respondent facility location. Responses were solicited from all 32 states and the Distrito Federal in accordance with 2010 Mexican Industry Statistics.[9] Responses were consistent with census figures. Note that 250 responses were solicited, but 257 completed surveys were received.

Number of Employees in the Business and Public Sectors: INEGI defines four categories of business/public entity size according to number of employees per business/public entity across locations: less than 10 employees, 11–50 employees, 51–250 employees, and 250+ employees. Note that these categories differ slightly from the sizes used for Canadian organizations because fewer multinational corporations are headquartered in Mexico than in Canada. Business and public sector size was intentionally modified by the authors to deviate from representativeness to

Table 11: Sample size and confidence level of respondents by Mexican geographical area

Area	Sample	95% Confidence Level
Distrito Federal	300	±5.65
Noreste	200	±7.07
Norte	200	±7.07
Bajío	150	±8.16
Centro	200	±7.07
Sureste	150	±8.16
Total	**1200**	**±2.88**

9. Sistema de Información Empresarial Mexicano, 2011. Estadísticas. <www.siem.gob.mx/>. (Accessed 01/2011) (In Spanish)

include larger business organizations in the analysis. This change was requested because larger businesses represent significantly more computers per company than do the more prevalent small (1–10) and medium-size (11–50) businesses. As in the 2010 Industry statistics, small organizations represent a plurality of the sample, followed by medium-size businesses.

Business and Public Sector/Industry: The authors did not solicit responses based on business sector (goods versus services) or specific industry. The industry list is based on the Mexican Industry Statistics.

Sample Selection: The sample of respondents was chosen from a pool of 5,000 prospective survey respondents maintained by the third-party survey-hosting site e-rewards.com, owned by Research Now (Texas, USA). Respondents were screened for demographic suitability and record of honesty in survey participation before initiating the survey itself. The prospective respondent pool is generally representative of the Mexican business sector.

Materials: Materials consisted of a single Web-based survey presented in Spanish. The survey was translated from English to Spanish and back-translated twice to ensure that content was identical in each version. A letter of informed consent was presented at the beginning of the survey and required a button press by the respondent for questions to begin.

The survey consisted of 18 questions covering six topic areas: business demographic questions (business size, business industry, business province or location, duties of respondent); computers at facility (laptop versus desktop, purchase condition and current condition, year of most recent bulk computer purchase, average lifespan of computers, use status, length of time in storage); monitors at facility (same as computers at facility); computer disposal in the last 12 months (type of computer disposed of, number disposed of, disposal method, date of disposal); monitor disposal in the last 12 months (same as computer disposal); and other electronics disposal.

Procedure: All respondents were screened by Research Now, based on the authors' demographic requirements before participation. Demographically suitable respondents received a survey invitation from e-rewards.com by email and followed the link to the survey itself. Respondents read an informed consent letter written in Spanish. Consent was considered granted if respondents chose the "Next" button to begin the survey at the end of the informed consent letter. If consent was not given, the survey was terminated (listed as incomplete).

Once respondents completed the survey, they were directed to a disclosure page that repeated contact information for the research group. Respondents received electronic credits from Research Now after completing the survey through the Research Now website. The survey took an average of 9.5 minutes to complete, and data were collected between February 1 and February 11, 2011.

United States

Data used for many steps in both methods are from US residential and business/public surveys conducted in 2011 by Kahhat and Williams [13]. The following excerpt describes the survey methodology used:

> 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, residential 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 were 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 being 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. [13]

US Residential Survey

User Profile

1.) Please select your gender

( ) Male ( ) Female

Objective: Participant profile (Important for sample characterization).

2.) What is your age? _____

Objective: Participant profile (Important for sample characterization).

3.) Where do you reside? ___________________

Options: All states in the United States

Objective: Participant/Household location (Important for sample characterization).

4.) Which best describes the area in which you live?

( ) Urban ( ) Suburban ( ) Rural

Objective: Participant location

5.) Including yourself, how many people live in your home?

Adults (18 years and above) ______ Children (Below 18 years) ______

Objective: Computers/monitors per capita. Divide total number of computers in the household by total number of people.

6.) Please select your occupation

( ) Agriculture, forestry, fishing, and hunting ( ) Mining, quarrying, and oil and gas extraction
( ) Utilities ( ) Construction ( ) Manufacturing ( ) Wholesale trade ( ) Retail trade
( ) Transportation and warehousing ( ) Information (e.g., publishing, recording, broadcasting, telecommunications, etc.)
( ) Finance and insurance ( ) Real estate and rental and leasing ( ) Professional, scientific, and technical services
( ) Management of companies and enterprises ( ) Administrative and support, waste management and remediation services
( ) Educational services ( ) Health care and social assistance ( ) Arts, entertainment, and recreation
( ) Accommodation and food services ( ) Other services, except public administration ( ) Public administration
( ) Student ( ) Homemaker ( ) Unemployed

Objective: Participant occupation.

7.) What's the highest educational level that you have achieved or are enrolled in?

( ) Some high school ( ) Graduated high school or equivalent ( ) Some college ( ) Associate degree
( ) Bachelor's degree ( ) Some graduate school ( ) Post-graduate degree

Objective: Participant profile.

8.) What is your annual household income in dollars (before taxes)? _________________

Objective: Household profile.

9.) Are you the primary income earner? ( ) Yes ( ) No

Objective: Participant Profile

10.) Do you have a computer at your home (in use or not in use)? ( ) Yes ( ) No

Objective: The answer to this question decides if the participant should continue with the survey or not. If the participant answers "No," the survey ends.

Computers at home

11.) How many computers (desktops or laptops not including monitors) do you have at home (in use or not in use)? _____

Objective: Computers per capita. Divide total number of computers in the household by total number of people.

12.) For your computers currently at home (in use or not in use), **please provide the following information.**

Type (laptop, desktop)	**Condition of computer when bought/acquired** (new, used)	**Year computer was bought or acquired** (years)	**Current status of the computer** (in use, not in use)	**Current condition of the computer** (working, not working)	**Number of years computer was/is in use by you or a member of your household**	**Number of years computer has been in storage at your home**
1						
2						
3						

Objective: Computer storage time, life span, buying patterns, number of used and new computers in US households.

Monitors at Home

13.) How many external monitors (not including laptop screens) do you have at home (in use or not in use)? ___

Objective: Monitors per capita. Divide total number of monitors in the household by total number of people.

14.) For your external monitors currently at home (in use or not in use), please provide the following information.

External monitor type (flat panel or liquid crystal display (LCD), traditional monitor or cathode-ray tube (CRT))	**Condition of monitor when bought/acquired** (e.g., new, used)	**Year monitor was bought or acquired**	**Current status of the monitor** (in use or not in use)	**Current condition of the monitor** (working or not working)	**Number of years monitor was/is in use by you or a member of your household**	**Number of years monitor has been in storage at your home**
1						
2						
3						

14a) If you have more than 5 monitors at home, please use the space below to answer all the above questions regarding your monitors

Objective: monitor storage time, life span, Buying patterns, number of used and new computers in US households.

Computer Disposal Methods

15.) Have you previously discarded a computer? ( ) Yes How many? Desktop _______ Laptop ______ ( ) No

Objective: Quantification of discarded computers. “Yes” prompts user to next question. “No” skips two questions.

16.) Please estimate the average lifespan of the computer (s) you have previously discarded. (For current purposes, lifespan is defined as time from purchase to physical removal from household) Desktop _______ Laptop ______

Objective: Computer lifespan.

17.) Please specify how each home computer was discarded.

Dropdown menu options (one per computer):

Option	Type (Desktop, laptop)	Year it was discarded
Disposed of via curbside garbage collection		
Recycled via curbside recycling program		
Returned to collection depot for recycling		
Returned to retailer		
Returned to municipality during a special collection event		
Returned to manufacturer		
Stored off-site		
Donated to friend/family within household		
Donated to friend/family outside of household		
Donated to a charitable organization		
Other donation		
Returned to seller after lease expired		
Sold online (e.g., Mercado Libre)		
Sold locally		
Sold to an acquaintance/friend/family		
Other		
NA Did not discard		

Objective: Characterize end-of-life patterns for computers in the US household sector.

18.) Have you previously discarded a monitor? ( ) Yes
How many? ____
Traditional monitor or cathode ray tube (CRT) _______ Flat panel or liquid crystal display (LCD) ______ ( ) No

Objective: Quantify discarded monitors. "Yes" prompts user to next question. "No" skips it.

19.) **Please estimate the average lifespan of the monitors (s) you have previously discarded.**
(For current purposes, lifespan is defined as time from purchase to physical removal from household)
Traditional monitor or cathode ray tube (CRT) _______ Flat panel or liquid crystal display (LCD) ______

Objective: Monitor lifespan.

20.) Please specify how each external monitor was discarded. **Dropdown menu options (one per computer):**

Option	**Type** (Traditional monitor or cathode ray tube (CRT), Flat panel or liquid crystal display (LCD))	Year discarded
Disposed of via curbside garbage collection		
Recycled via curbside recycling program		
Returned to collection depot for recycling		
Returned to retailer		
Returned to municipality during a special collection event		
Returned to manufacturer		
Stored off-site		
Donated to friend/family within household		
Donated to friend/family outside of household		
Donated to a charitable organization		
Other donation		
Returned to seller after lease expired		
Sold online (e.g., e-Bay)		
Sold locally		
Sold to an acquaintance/friend/family		
Other		
NA Did not discard		

Objective: Characterize end-of-life patterns for monitors in the US household sector.

21.) For the electronic equipment listed below, how many items did you discard in 2010 and what was the method of disposal? Please give your best estimate

	Number of items discarded	Disposal Method
Option 1: Reuse (e.g., donate, sell)		
Option 2: Recycle (e.g., curbside recycling)		
Option 3: Storage (e.g., closet, basement)		
Option 4: Landfill (e.g., throw away in the common garbage)		
Option 4: Other		
Option 5: Not Applicable		
Computer-related electronics (e.g., printers, scanners)		
Facsimile machines (fax machines)		
Televisions (CRT)		
Televisions (non-CRT)		
Telephones and mobile phones		
Small kitchen appliances (e.g., toaster, blender)		
Large kitchen appliances (e.g., refrigerator, dishwasher, microwave)		
Small household appliances (e.g., clock radio, answering machine)		
Large household appliances (e.g., washer, dryer, vacuum cleaner)		
Small audio/visual equipment (e.g., MP3 player, VCR, DVD player, camera, small stereo system)		
Large audio/visual equipment (e.g., large home theater system, large speakers)		

Thank you for taking our survey. Your response is very important to us.

Please feel free to contact us in case of questions, concerns or comments.

US Business/Public Survey

General Business Information

1.) **How would you classify the size of the organization you work for?**
[ ] 1 to 4 employees [ ] 5 to 9 employees [ ] 10–19 employees [ ] 20–49 employees [ ] 50–99 employees
[ ] 100–299 employees [ ] 300–499 employees [ ] More than 500 employees

Objective: Business profile and size

2.) **Please classify the industry of the organization you work for:**
( ) Agriculture, forestry, fishing, and hunting ( ) Mining, quarrying, and oil and gas extraction ( ) Utilities
( ) Construction ( ) Manufacturing ( ) Wholesale trade ( ) Retail trade ( ) Transportation and warehousing
( ) Information (e.g., publishing, recording, broadcasting, telecommunications, etc.) ( ) Finance and insurance
( ) Real estate and rental and leasing ( ) Professional, scientific, and technical services
( ) Management of companies and enterprises ( ) Administrative and support, waste management and remediation Services
( ) Educational services ( ) Health care and social assistance ( ) Arts, entertainment, and recreation
( ) Accommodation and food services ( ) Other services, except public administration ( ) Public administration

Objective: Business profile (important for sample characterization). Based on United States NAICS.

3.) **In what state is your office/organization located?**

	Facility at which you are located *(Please select only one)* Only one option	**Entire organization** *(Please select all that apply)* All options that apply
Options: All States		

Objective: Location of facility and organization.

4.) **What are the kinds of duties you perform in the organization? (Please select all that apply)**
[ ] IT decision making [ ] Acquisition and purchasing [ ] Service and maintenance
[ ] Asset replacement and disposal [ ] Others

Objective: Employee duties.

5.) **Please answer the following questions that refer to computer equipment used by your organization for business use only (not including general retail stock and others) and that are or have been present at the specific facility at which you are located within your organization.** [ ] I have read the instructions above.

Objective: Instructions for participant.

Computer stock and purchase information

6.) **How many of the following types of computer equipment are currently in use for business purposes at the facility at which you are located? "Currently in use" means both functioning physically and used for business purposes, but not stored away.**

Equipment at the facility at which you are located	Number
Desktop computers	
Laptop or portable computers	
CRT (cathode ray tube) monitors or traditional monitors (includes monitors associated with desktop computers and any extra monitors)	
LCD (liquid crystal display) monitors (includes, but is not limited to, flat-panel monitors)	

Objective: Quantification of equipment. Find ratio of devices per employee.

7.) How many of the following types of computer equipment that were used for business purposes at the facility at which you are located are currently in on-site storage (not in use)?

Equipment at the facility at which you are located	Number
Desktop computers	
Laptop or portable computers	
CRT (cathode ray tube) monitors or traditional monitors (includes monitors associated with desktop computers and any extra monitors)	
LCD (liquid crystal display) monitors (includes, but is not limited to, flat-panel monitors)	

Objective: Quantification of equipment. Find ratio of devices per employee.

NOTE: (If the quantities of similar equipment in Q7 and Q8 add up to zero, this needs to be reflected in the following related questions Q10–Q13).

8.) How many employees currently work at the facility at which you are located? Please give your best estimate.

Facility at which you are located ______________________________ Number of employees _______

Objective: Quantification of employees. Find ratio of devices per employee.

9.) For the equipment listed above, please specify the preferred purchase/acquisition method and the year that the most recent "bulk" purchase/acquisition was made in the facility at which you are located. (Rows need to add to the number of equivalent pieces of equipment in Q7 and Q8)

Purchased (number)	**Leased** (number)	**Free** (e.g., donation) (number)	**Year that most recent "bulk" purchase/ acquisition was made**
Laptop or portable computers			
Desktop computers			
CRT (cathode ray tube) monitors or traditional monitors			
LCD (liquid crystal display) monitors			

Objective: Characterize purchase preferences in the business sector.

10.) For computer equipment currently in business use and in-site storage at the facility at which you are located, what was the condition (new/used) of the following types of equipment at the time of original purchase/lease/donation? (Rows need to add up to the number of pieces of equivalent equipment in Q7 and Q8)

Purchase/lease/donation New (number)	**Leased** (number)	**Purchase/lease/donation Used** (number)
Portable or laptop computers		
Desktop computers		
CRT (cathode ray tube) monitors or traditional monitors		
LCD (liquid crystal display) monitors		

Objective: Characterize condition, when purchased, of equipment in the business sector.

Computer lifespan and storage information

11.) For the last five years, please estimate the typical lifespan of the computer equipment at the facility at which you are located. For current purposes, lifespan is defined as time from purchase to physical removal from the facility at which you are located.

	Typical Lifespan (years)
Portable or laptop computers	
Desktop computers	
CRT (cathode ray tube) monitors or traditional monitors	
LCD (liquid crystal display) monitors	

Objective: Understand typical life span of devices.

12.) For the last five years, please estimate the average storage time, in months, of the following computer equipment at the facility at which you are located. *Storage time is defined as the time from when equipment is deemed obsolete and is no longer in use by the company to physical removal from facility for an end-of-life management option.*

	Storage time in your office (months)
Portable or laptop computers	
Desktop computers	
CRT (cathode ray tube) monitors or traditional monitors	
LCD (liquid crystal display) monitors	

Objective: Understand storage time.

Computer disposal information

13.) How many pieces of computer equipment went through asset disposal at the facility at which you are located in 2010? Please give your best estimate.

Equipment	**Number**
Portable or laptop computers	
Desktop computers	
CRT (cathode ray tube) monitors or traditional monitors	
LCD (liquid crystal display) monitors	

Objective: Quantify the disposal of obsolete equipment in 2010.

14.) For the above equipment that went through asset disposal at the facility at which you are located in 2010, please identify the chosen option(s) for asset disposal. (The sum of columns needs to match the numbers for specific pieces of equipment in Q14).

	Laptop or portable computers (number)	**Desktop computers** (number)	**CRT monitors** (number)	**LCD monitors** (number)
Returned to leasing company				
Refurbished under contract to private service provider				
Recycled under contract to private service provider				
Disposed of under contract to private service provider				
Returned to manufacturer				
Stored off-site				
Sold				
Donated				
Disposed of via curbside garbage collection				
Recycled via curbside recycling program				
Returned to retailer				
Returned to municipality during a special collection event				
Returned to collection depot for recycling/				
Returned to collection depot for refurbishing				
Other				

Objective: Identify the end-of-life management options in the US business sector.

15.) For the electronic equipment listed below, how many items went through asset disposal at the facility at which you are located in 2010 and what was the method of disposal?

	Reuse (e.g., donation, sale) (number)	**Recycle** (e.g., curbside recycling) (number)	**Storage** (e.g., closet, basement) (number)	**Landfill** (e.g., disposal in the common garbage) (number)	**Other** (number)
Computer-related electronics (e.g., printers, scanners)					
Facsimile machines (fax machines)					
Televisions (CRT – cathode ray tube)					
Televisions (non-CRT – non-cathode ray tube)					
Telephones and mobile phones					
Small kitchen appliances (e.g., toaster, blender)					
Large kitchen appliances (e.g., refrigerator, dishwasher, microwave)					
Small business appliances (e.g., clock radio, answering machine, fan)					
Large business appliances (e.g., photocopier, vacuum cleaner)					
Audio/visual equipment (e.g., VCR, DVD player, camera, small stereo system, projector)					
Large audio/visual equipment (e.g., large home theater system, large speakers)					

Objective: Understand the share of end-of-life of computer equipment in the data for general e-waste.

Appendix 3. Generation and Collection of Survey Data

Hybrid Sales Obsolescence-Trade Data Method (HSOTDM)

Residential Generation with US Laptops as Case Study

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

The first step was to prepare the survey data received from the survey firm, which needed to be consolidated because the data were originally arranged by respondent instead of by type of electronic device. There were two sets of relevant questions, each requiring separate preparation: questions pertaining to items that had been "discarded," and those pertaining to electronics that were still in the home ("retired"). Some of the "discarded" items were considered to be "failures" and others "retired" in Table 12.

The second step was to determine the age of products either at the point of "failure" or at the time of "retirement" (a product is retired if it is still with the owner when surveyed). Where possible, screen the responses by the respondent's precision in estimating the year purchased in comparison to estimating time in use and storage (a cutoff of one year was deemed reasonable).

Equation 13 illustrates how the precision metric was calculated. Note that this metric cannot be calculated for electronics that were "discarded" because the survey asked solely about lifespan in the home, not about year of purchase. 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 "method of disposal," the type of electronic device matched across the two questions (e.g., laptop and laptop, not laptop and desktop). Mismatches were excluded.

Table 12: Designation of failure, generation, and collection by discard type

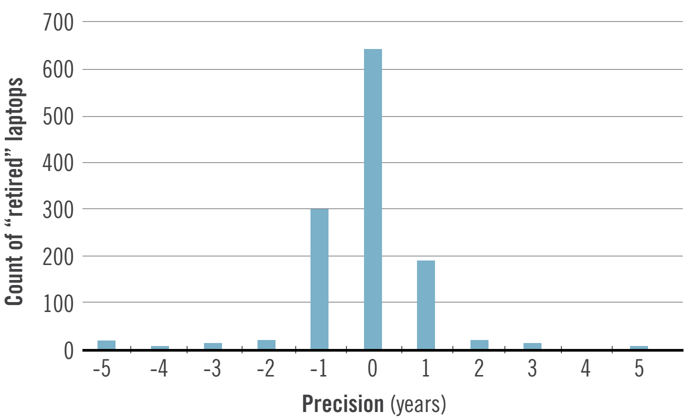
Discard Type	**Failure** [?]	Category	**Generated** [?]
Stored off-site	Retire	Not included	Not generated
Donated to friend/family within the residential category	Fail	Informal reuse	Not generated
NA Did not discard	Retire	Not included	Not generated
Disposed of via curbside garbage collection	Fail	Trash	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
Donated to friend/family outside of the residential category	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	Retire	Not included	Not generated

Equation 13: Determination of Precision of Responses on "Retired" Electronics

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

Figure 55 shows that the vast majority of US respondents reported both the year purchased and the corresponding time in use and time in storage of laptops quite precisely. A one-year cutoff was chosen as reasonable for all products.

Figure 55: Respondents' precision in estimating US laptop age and time at home



Next, it was necessary to determine the year that the product was purchased. For "retired" electronics still in the home, the year purchased was given directly by the respondents. For "discarded" electronics, Equation 14 was used.

Equation 14: Determination of Year of Purchase of "Discarded" Electronics

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

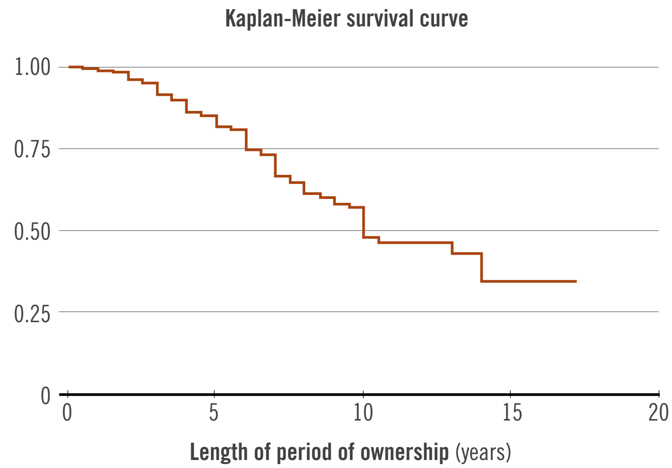
The Stata® 12.1 model was used to produce Kaplan-Meier (K-M) survivor curves and, subsequently, Weibull regressions for all products together, using the same K-M curve and associated Weibull regression for all years of purchase.

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

- *stset age, failure(failure)*
  Set data for suvival analysis
- *stdescribe*
  Describe data to ensure that they were processed correctly
- *sts list* and *sts graph*
  Derive K-M Survival Analysis

These data, which consist of the K-M curve data for the modeled survival curve and the 95% confidence interval, are copied into Microsoft Excel® for the next step.

Figure 56: Kaplan-Meier survival curve for US residential laptops

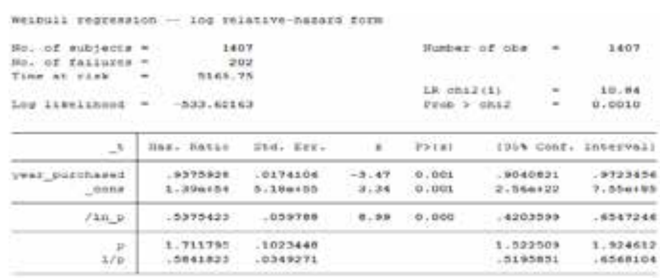


Generate Weibull Regression

- *streg year, dist(weibull)*

This returns information about the Weibull regression for the laptop dataset (Figure 57). Note that p is the scale factor used to model Weibull distributions.

Figure 57: Stata® Weibull regression analysis for US residential laptops



Weibull regression — log relative-hazard form

No. of subjects = 1407 Number of obs = 1407
No. of failures = 202
Time at risk = 5165.75
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

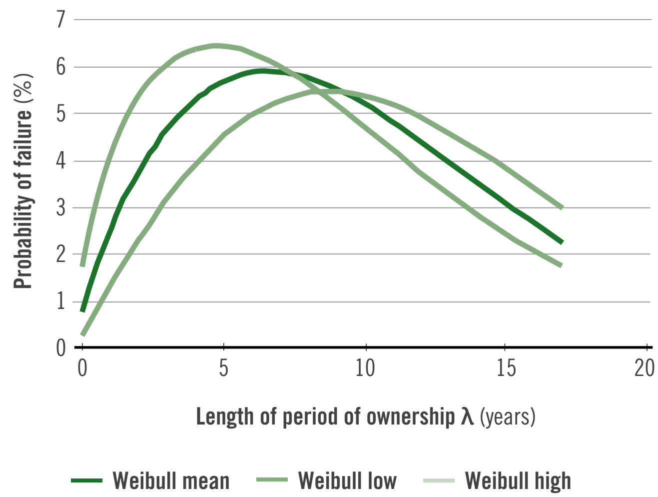
- *stcurve, surviv*

This graphs the survival curve based on the Weibull regression (Figure 58). It also models the K-M survival curve (Figure 56) with the parameters used (Figure 57).

The next step was to fit additional parameters for the Weibull regression to the K-M curves.

Figure 58: Graph of Weibull regression model for US residential laptops

Figure 60: Distribution of length of period of ownership for US residential laptops



To define a Weibull distribution, both the scale and shape parameters are needed. It would perhaps be possible, but difficult, to extract the shape parameters from the Weibull regression data, and therefore the data from *sts list* are copied into Microsoft Excel® and the Solver add-in used to find the shape parameters that minimize the squared error between an inverse cumulative Weibull model and the K-M survivor curves (Figure 59).

The results of the Weibull regression were transformed into a probability density function, which will be used as the length distribution of one period of ownership. Using the parameters found through the Weibull regression (scale parameters) and the least-squares error fit (shape parameters), the lifespan distributions for the length of one period of ownership are modeled using the Microsoft® Excel Weibull Dist function. Note that the typical length is considerably longer than that modeled using the Literature method, as shown in Figure 60. This likely occurs due to underestimation of storage time in the literature.

Figure 61 shows a histogram of the distribution of the length of time δ until an electronic device is reused. The mean was allowed to vary by ± 2 years, and the standard deviation was allowed to vary by ± 10% in the Monte Carlo simulation. The survey data represent the 100 laptops that

Figure 59: Comparison between K-M curves and OLS fit Weibull regression curves for means and low and high bounds of the 95% confidence interval for US residential laptops

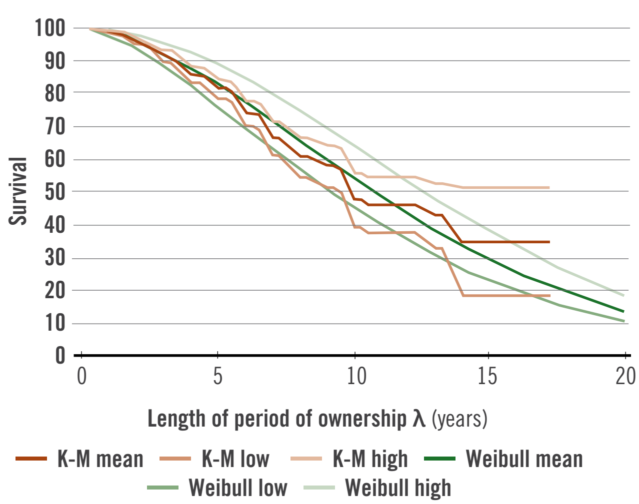


Figure 61: Histogram and fitted lognormal distributions of the length of time **δ** that a US residential laptop remains with an owner until informal reuse

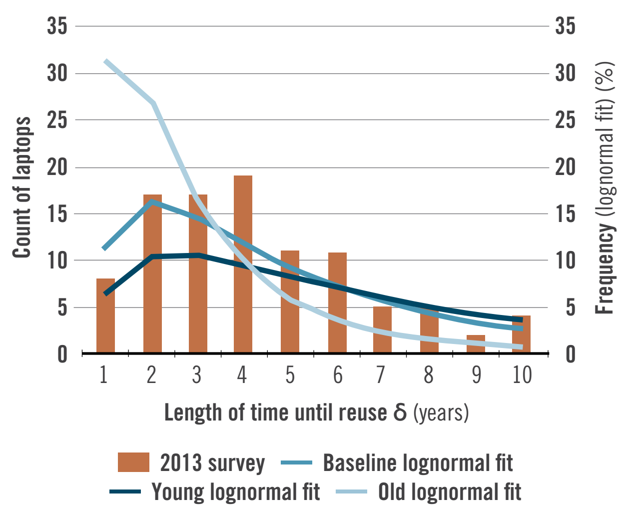
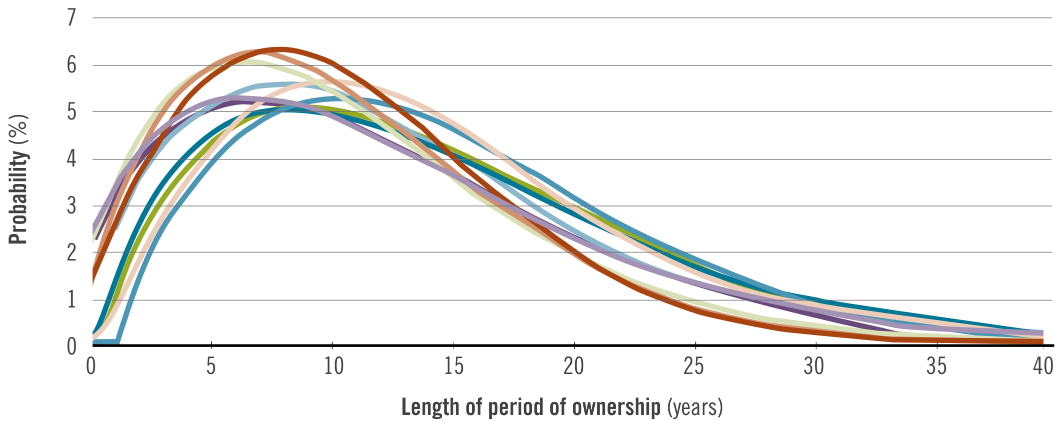


Figure 62: Distributions of length of period of ownership λ for US laptops (random sample)



were "discarded" for informal reuse. This information is entered into the generation prediction model.

During the Monte Carlo simulation, the regression parameters were allowed to vary over a 95% confidence interval and the entire distribution to shift left and right by one year to account for allowable error in the response precision. Figure 62 shows some of the 10,000 distributions modeled during the Monte Carlo simulation.

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

The following series of equations were used to model the quantity of electronics that are used only once before generation (O), those that are informally reused before generation (I), and those that are formally reused after a first round of generation and collection (C).

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 the 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 to capture this phenomenon, as shown in Equation 15.

Equation 15: Ratio $\boldsymbol{\beta}$ of used to new purchases

$$\beta = \frac{Sales_{Used}(s)}{Sales_{New}(s)}$$

Table 13: Mean Weibull distribution parameters for length of period of ownership λ

Country	Product	Weibull Distribution Scale Parameter	Weibull Distribution Shape Parameter
Canada	Desktops	2.45	8.84
	Laptops	1.91	11.16
	CRT Monitors	2.35	8.53
	Flat Screen Monitors	1.97	14.23
Mexico	Desktops	1.80	11.13
	Laptops	1.52	22.16
	CRT Monitors	1.72	13.26
	Flat Screen Monitors	1.72	21.31
United States	Desktops	2.09	7.61
	Laptops	1.71	13.28
	CRT Monitors	2.10	7.46
	Flat Screen Monitors	1.77	15.05

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*). The survey questions asked whether electronics still in the home were purchased used or new, and separately asked whether "discarded" electronics were managed in ways that were classified as informal reuse and collection (Equation 16). The difficulty in estimating α is that the probability of domestic formal reuse after collection is unclear. Because far more "discarded" electronics went to informal reuse than to collection, a wide range of 0.2 to 1 was assigned to α.

Equation 16: Fraction **α** of used purchases that occurred through informal reuse (I) compared to formal reuse after generation and subsequent collection (C)

$$\alpha = \frac{Sales_I(s)}{Sales_I(s) + Sales_C(s)}$$

Lastly, all new purchases in a given year were assumed to undergo one use before generation (*O*), less those which were originally bought in year *s* and predicted to be informally reused before generation (*I*) in future years $s + \delta$, starting one year after the current sales year, as shown in the equivalent versions of Equation 17. Because sales of used electronics are modeled in relation to the sales of new electronics (see Equation 15), the quantity of electronics informally reused in future years can be estimated. However, that estimate requires forecasting of sales data. This is accomplished by using an annual sales growth rate and allowing it to vary within the range of rates from prior years. In some periods when early historic sales data were not available (e.g., 1990–1994), a backcast annual sales growth rate was used and allowed to vary within the range of growth rates in subsequent years.

In cases where the product initially experienced exponential growth in sales (laptops and flat panel monitors), the model for purchases that undergo one use before generation *(O)* is insufficient. In the early years of product sales, the quantity of purchases *(O)* was often found to be negative. This occurs because the demand for reused items in future years was larger than could be supplied by the small number of sales in early years. To account for this in a robust manner, the model could include an increasing α over time, or a more complex model could be built in which where the mean of δ grows older over time. Here, an approximation was used. The number of purchases that undergo one use before generation *(O)* during the first few years of exponential growth of a product was based on the range of proportions of total residential sales to those purchases in subsequent years (roughly 10), as shown in Equation 18. An interpretation of this approximate method could be that the reused items purchased in subsequent years were also purchased from the business/public sector to meet demand, a phenomenon which is not explicitly captured here.

Equation 17: Purchases of electronics that undergo one use before generation (***O***)

$$Sales_O(s) = Sales(s) - \sum_{s+1} P(\delta, s+\delta) \cdot Sales_I(s+\delta)$$

$$Sales_O(s) = Sales(s) - \sum_{s+1} P(\delta, s+\delta) \cdot \beta \cdot \alpha \cdot Sales(s+\delta)$$

Equation 18: Approximate number of electronics purchases that undergo one use before generation (O) during the initial years of exponential growth in sales

$$Approximate\ Sales_O(s) = Sales(s) \cdot \frac{1}{9} \sum_{s+1}^{10} \frac{Sales_O(s)}{Sales(s)}$$

Expanding on Equation 18, the total generation in year *y* is the sum of applications of these formulae to the three groups, as shown in Equation 19.

Equation 19: Detailed expression of total generation of used electronics in year *y*

$$Generated(y) = \sum_{s}^{y} Sales_O(s) \cdot \lambda(y-s) + \sum_{s}^{y} Sales_I(s) \cdot \lambda(y-(s+\delta)) + \sum_{s}^{y} Sales_I(s) \cdot \lambda(y-(s+\delta))$$

Business/Public Generation

Unlike the residential case, the business/public "discard" options do not include informal reuse. Therefore, all relevant "discard" options are assumed to be generated, as shown in Table 14. The assumptions from Kahhat and Williams [13] are included and served as the basis for the Collection classification. Many electronics were said to have been "discarded" under "Disposal under contract to private service provider." It is possible that these electronics were actually collected, rather than sent to the landfill, by the service provider. Therefore, in the analysis, the fraction of electronics "discarded" under "Disposal under contract to private service provider" that were classified as Collected versus Trash was allowed to vary from 0% to 100%. If this proves to be a driver of uncertainty, it would make sense to seek ways to refine this fraction.

The 2010 business/public scale factors used are the same as those used in the Mass Balance method, described in the next section.

Table 14: Classification of business/public "discard" types

Type	Table 4.4*	Category	Generated [?]
Returned to leasing company	Reuse	Generated	Collected
Refurbished under contract to private service provider	Reuse	Generated	Collected
Recycled under contract to private service provider	Recycle	Generated	Collected
Disposal under contract to private service provider	Landfill	Generated	Trash or Collected?
Returned to manufacturer	Recycle	Generated	Collected
Storage off-site	NA	NA	NA
Sold	Reuse	Generated	Collected
Donated	Reuse	Generated	Collected
Disposal via curbside garbage collection	Landfill	Generated	Trash
Recycled via curbside recycling program	Recycle	Generated	Collected
Returned to retailer	Recycle	Generated	Collected
Returned to municipality during a special collection event	Recycle	Generated	Collected
Returned to collection depot for recycling/refurbishing	Recycle	Generated	Collected
Other	Landfill/ Recycle/ Reuse	Generated	NA

* *Source:* The data in the column headed "Table 4.4" come from Kahhat and Williams 2012 [13].

Mass Balance

The 2010 scale factors relating the survey values to the national statistics were found in Monte Carlo simulations and are shown below in Table 15. The business/public scale factors are much smaller than the residential scale factors because the residential sample sizes were much smaller relative to the survey population than for the business/public case.

Table 16 presents the detailed scale factors for each product and sector that were used to arrive at the overall average product scale factors. Recall that the same scale factors were used to scale up each product for a given country and sector. For comparison purposes, a US business/public scale factor based on the number of employees in the facilities of the businesses surveyed was compared with the number of employees in the country in 2010. The employee scale factor is likely higher than those based on sales because the survey is representative only of the subset of businesses with computers, whereas the employee-based estimate refers to employees in all businesses. Similarly, a scale factor based on US population compared to the people represented by survey respondents' households was compared with the residential scale factor. It was most similar to the laptop scale factor, but certainly higher than that for all products. This could suggest that the sales estimates are too low, or that the survey respondents purchase more than the average household.

Table 15: Summary of 2010 scale factors by country and sector

Country	Sector	Mean	Low	High
Canada	Business/Public	233	212	254
	Residential	11,561	10,228	12,894
Mexico	Business/Public	115	67	164
	Residential	11,891	8,982	14,801
United States	Business/Public	799	726	873
	Residential	45,801	40,217	51,385

Table 16: 2010 product scale factors used to arrive at overall product average scale factors by country and sector

Country	Sector	Scale Factors	Mean	Min	Max
Canada	Business/Public	Desktop	242	219	264
		Laptop	453	412	495
		CRT Monitor	0	0	0
		Flat Panel Monitor	237	215	259
		Product Average	233	212	254
	Residential	Desktop	15,019	13,146	16,893
		Laptop	17,969	15,727	20,210
		CRT Monitor	0	0	0
		Flat Panel Monitor	13,256	10,142	16,369
		Product Average	11,561	10,228	12,894
Mexico	Business/Public	Desktop	85	75	96
		Laptop	180	158	202
		CRT Monitor	87	4	169
		Flat Panel Monitor	109	5	213
		Product Average	115	67	164
	Residential	Desktop	14,845	13,052	16,639
		Laptop	10,833	9,524	12,142
		CRT Monitor	9,193	4,783	13,603
		Flat Panel Monitor	12,693	6,604	18,783
		Product Average	11,891	8,982	14,801
US	Business/Public	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
	Residential	Desktop	37,001	32,022	41,980
		Laptop	80,587	70,686	90,488
		CRT Monitor	0	0	0
		Flat Panel Monitor	65,616	57,684	73,547
		Product Average	45,801	40,217	51,385
		Population	93,902	91,144	96,660

Appendix 4. Generation of Computer and Related Electronics Export Data: Assumptions and Calculations

Hybrid Sales Obsolescence-Trade Data Method (HSOTDM)

Mexican Export Trade Data

The following list describes the assumptions made in the classification process for Mexican shipment-level data, as detailed in CIPREC (2013) [45]. Any differences between this study and the CIPREC (2013) study are noted. For the purposes of this study, CPUs were classified as desktops.

General Assumptions

The assumptions used in interpreting the descriptions of the products in the databases are presented in this section. These are presented in list form, including explanations where relevant. The general assumptions applied to all categories are:

- When the word "Accessories" appears, it was assumed that monitors were not included, at least unless explicit descriptions stated otherwise.
- Commonly, in the categories of monitors, desktops, or laptops, the corresponding items also include some peripheral devices. Hence, it should be assumed that the weight and price data for each item also include these materials; however, the marginal share can be negligible. Weight data were not available in the dataset provided.
- On the other hand, if peripheral devices such as keyboards, mice, or others appeared as separate items, they were included as "other."

Assumptions about Central Processing Units

The presence of words such as "unit" and "processing" was the principal criterion used in determining that a description referred only to a CPU. Hence, the following descriptions were taken as CPUs:

a) data processing unit,
b) data processor,
c) data processing server,
d) central unit,
e) processing unit,
f) digital processing unit,
g) data digital processing unit and
h) digital processing units.

Assumptions about Desktops

- The above descriptions of CPUs could be taken as desktops only if words such as apparatus, system, machine, or computer appeared instead of the word "unit." Hence, descriptions such as "processing machine" and "data processor in the form of a system" were categorized as desktops. (Note that in this study, all CPUs were considered as desktops).
- When in the descriptions the word "computer" appears without further qualification, it was taken to be a desktop (CPU + monitor) unless the description stated explicit conditions such as CPU or portable. (Note that in this study, the code 847130 overrode that assumption and assigned those computers as laptops).
- The description "work station for computer" was categorized as "other," but if the words "for computer" were lacking, it was considered as a "desktop."
- All server devices were categorized as desktops. Only a few exceptions were considered, which are presented in the section of assumptions about the "other" category.
- The description "print server" was considered as a "desktop" unless a brand of printer was specified, in which case it was considered "other."

Assumptions about Monitors

- All items explicitly described as such were classified as flat panel monitors, for example, flat monitors or liquid crystal monitors. Moreover, if the description stated only "color monitor," the item was considered as an LCD monitor.
- Simple descriptions such as "monitor" were assumed to refer to CRT monitors. (Note that in this study, flat panel monitor export codes overrode this assumption).
- Descriptions referring only to flat screens were considered as "other" because of the high probability that they referred to TV devices.
- Descriptions of 19-inch monitors were considered as LCD monitors if and only if they were specified as containing accessories.
- Every monitor larger than 27 inches was assigned to the "other" category even though use with a computer was specified because the most common application of these devices is in industrial plants.

- Monitors from 19 to 27 inches were categorized as LCD monitors even though in the descriptions, no accessories were included.

Assumptions about Laptops

- There were several items with descriptions such as "portable machine for data processing with scanner," which were identified (by brand, model, and designation as a scanner) as referring to hand-held devices for recording bar codes or registering bank cards; these were classified as "other."
- Items described as "data processing machines," which could be categorized as desktops, were categorized as "laptops" when the corresponding customs code of the item was 847130.
- Items described as "network servers" were categorized as desktops.

Assumptions about Hand-held and Pocket Devices

This category includes products such as Palm Pilots®, tablets, and electronic organizers. The numbers of items with this description were very few compared to the other categories, and therefore fewer difficulties in identifying these devices from the descriptions were encountered.

Assumptions about "Other"

The most common descriptions considered as "other" were:

- All devices related to cellular phones, such as mobile smart devices, iPhones, and iPods.
- Radio navigation devices.
- Monitors explicitly described as televisions, as well as monitors with any use not related to the household or to office computer systems. Video monitors and those used in closed-circuit television (CCTV) systems fall into this class.
- Items described as "input-output units."
- Items described as "control units."
- Cathode ray tubes and kinescopes were categorized as "other" because they are only part of a complete monitor device.
- Items described as CPU parts were not included in the category of complete CPUs and were therefore classified as "other": for example: microprocessors, motherboards, hard disks, and input devices.
- Every computer device related to industrial and production use was categorized as "other."
- Items described as computer (CPU, monitor, desktop) wastes were classified as "other."
- Items described as touch screens were considered to be industrial and therefore classified as "other."
- Rack servers.
- Host servers.
- Security servers.
- Crimpador servers.
- Certain companies were identified with devices not related to the object of this study, and therefore all these products were considered as "other": ELO, Tyco, Intermec, Avaya, Blackberry, Symbol, Pelco, Top, B-K Medical, Cardio Theater, Blaupunkt, GE Medical Systems Information Technologies, UniOp, Biotronix, Datex-Ohmeda, Waveric.
- In the case of Motorola, although most of the devices encountered were identified as mobile communication devices, some were identified as "laptops" after checking the model.
- Items described as "video monitors" were classified as "other" unless their brand and model were identified as computer devices.

US Export Trade Data

First, all data used were aggregated to annual scale, all transport modes, and the partner country level to check for consistency across *v*, *q*, and *w* and for comparison with UN Comtrade data. Minor issues were encountered with inconsistencies in country classification (e.g., Sudan, Curacao) across datasets; however, trade with these countries was very small. (See Tables 17 and 18 for explanation of data and variable symbols.)

Table 17: Export trade data symbols and terms

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

Table 18: Datasets used for US export calculations

Database	1. USA Trade Online	2. SICEX (US Exports)	3. STATCAN (CA 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*	$w_1(f_g,m,n,r_p,t)$	$w_2(f_e,m,n,r_d,t)$	--

Note: Some datasets do not report quantity or weight.

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 the fact 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, and hence district-level results were determined to check that the approximate port-level results were reasonable. At the approximate port level, Canadian import data were substituted for US domestic export data, and district-level export data were used for exports to Mexico.

An example of the approximate port-level calculations for laptop exports from the US to Argentina is shown in Table 19. The district-level US domestic export unit value $u_2(f_e,m,n,r_d)$ was calculated using SICEX data, as shown in Equation 20. Because SICEX does not provide quantities disaggregated by transport mode, the export unit value was disaggregated to each month, partner nation, and district.

Equation 20

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

To arrive at approximate port-level data for non-North American countries, the general export port-level value per weight was 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 Equations 21 and 22.

Equation 21

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

Equation 22

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

To estimate the approximate port-level quantity $q_{1-2}(f_e,m,n,r_p,t)$, the ratio of district-level domestic export weight to district-level general export weight is multiplied by port-level general export weight and then divided by the corresponding district average unit weight, as shown in Equation 23.

Equation 23

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

To calculate both North American import unit values for trade with the United States as country of origin *n*, the value is simply divided by the quantity for each month, port or district, and transport mode. The Canadian import unit value calculation is shown in Equation 24.

Equation 24

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

Table 19: Example approximate port-level calculations for laptop exports from the United States to Argentina in 2010

Trade partner Nation *n* and 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 Intercontinental Airport, TX	Miami International Airport, FL	Miami International Airport, FL	Miami, FL	Port Everglades, FL	JFK International Airport, NY
$v_2\ (f_{g\text{-}e},m,n,r_d)$	$634,444	$634,444	$3,389,603	$3,389,603	$3,389,603	$-
$q_2\ (f_{g\text{-}e},m,n,r_d)$	912	912	5,742	5,742	5,742	-
$w_2\ (f_{g\text{-}e},m,n,)$	$5,877	$5,877	$27,842	$27,842	$27,842	$-
$(,m,n,)$	-	-	350	350	350	-
$(,m,n,)$	$113,541	$113,541	$4,099,759	$4,099,759	$4,099,759	$56,440
$(,m,n,r_d)$	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
$u_{1\text{-}2}\ (f_e,m,n,r_p,t_{air})$	**$293**	**$-**	**$339**	**$-**	**$-**	**$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	-
$u_{1\text{-}2}\ (f_e,m,n,r_p,t_{ves.})$	**$-**	**$378**	**$-**	**$206**	**$197**	**$-**
$w_2\ (f_e,m,n,r_d,t_{air})$ $w_2\ (f_g,m,n,r_d,t_{air})$	0%	0%	49%	49%	49%	100%
$w_2\ (f_e,m,n,r_d,t_{ves.})$ $w_2\ (f_g,m,n,r_d,t_{ves.})$	100%	100%	63%	63%	63%	0%
$q_{1\text{-}2}\ (f_{g\text{-}e},m,n,r_p,t_{air})$	912	-	5,671	-	-	-
$q_{1\text{-}2}\ (f_{g\text{-}e},m,n,r_p,t_{ves.})$	-	-	-	45	27	-
$q_{1\text{-}2}\ (f_e,m,n,r_p,t_{air})$	-	-	**10,704**	-	-	**208**
$q_{1\text{-}2}\ (f_e,m,n,r_p,t_{ves.})$	-	**300**	-	**149**	**88**	-

Note: Results from equations 22 and 23 shown in bold.

Export Trade Data Threshold Calculations

Thresholds were calculated at the approximate port level for each world region (World Bank country income group and U.N. macro-geographical region) and for both vessel and air transport (and land transport for North America). These thresholds were applied to the district-level distributions as well, in part for consistency of comparison. Because the datasets used mainly report export values that do not include freight costs, it may seem superfluous to determine different thresholds for different transport modes. Still, considerable differences in unit value distributions have been observed for this dataset based on mode of transport, and hence the exercise may be useful.

The neighborhood valley-emphasis method (NVEM) was used to determine the used-new threshold value z for the first threshold method. Fan and Lei (2012) described their approach for determining the threshold of differentiation between modes in a distribution, which they developed for finding the threshold of a bimodal histogram of a grayscale image. They demonstrated the wider applicability of their neighborhood valley-emphasis method versus the Otsu and valley-emphasis methods, which they modified. This method was chosen because the z[10] values are not easily distinguished by the eye and because Fan and Lei (2012) convincingly demonstrated the superiority of their method. Because this approach requires a histogram with a developed distribution, the method was applied only to suitable datasets with considerable trade quantities (here, greater than 10,000 units). These calculated thresholds were substituted for missing thresholds in world regions with low trade quantities.

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 a particular threshold value bin (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 v is evaluated as a possible threshold z, and hence its neighborhood probability $\bar{h}(u)$ is calculated. Equation 25 is used to sum the neighborhood unit value probabilities 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 the reasonableness of the results in terms of avoiding 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 25

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

Modes (or classes) are defined as $c_0 = [0, \ldots, z]$ and $c_1 = [z+1, \ldots, B-1]$, where $B-1$ is the maximum unit value bin. The total probabilities of each class are found using simple summations, as shown in Equations 26 and 27. The means of each class are shown in Equations 28 and 29.

Equation 26

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

Equation 27

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

Equation 28

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

Equation 29

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

The optimal threshold, z, corresponds to the maximum across all value bins of the objective function of the neighborhood valley-emphasis function, $\xi(z)$, in Equation 30.

Equation 30

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

10. Notation used here differs from that presented in Fan and Lei (2012).

Appendix 5. Computer and Related Electronics Supply and Export Data: Results

Canada

Hybrid Sales Obsolescence-Trade Data Method (HSOTDM)

Table 20: Quantities of Canadian generation, collection, and export of used computers and monitors in 2010, as mean and low and high bounds of the 95% confidence interval (thousands of units)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	1,237	1,037	1,468	309	282	336	1,547	1,344	1,780
	Collected	995	789	1,235	262	211	317	1,256	1,040	1,506
	Export-NVEM							17	16	18
	Export-Pub.							13	7	20
Laptops	Generated	374	178	627	221	202	240	595	397	849
	Collected	251	112	445	185	149	224	436	290	634
	Export-NVEM							43	43	43
	Export-Pub.							42	40	45
Computers	Generated	1,611	1,269	2,014	530	484	577	2,141	1,792	2,548
	Collected	1,246	952	1,597	447	360	541	1,692	1,379	2,056
	Export-NVEM							60	58	61
	Export-Pub.							55	47	64
CRT Monitors	Generated	1,002	410	1,890	256	234	278	1,258	664	2,150
	Collected	684	197	1,531	214	171	260	898	407	1,748
	Export-NVEM							9	9	9
	Export-Pub.							9	9	9
Flat Panel Monitors	Generated	224	68	519	198	181	216	422	264	717
	Collected	175	51	419	157	117	200	332	195	575
	Export-NVEM							15	8	22
	Export-Pub.							13	3	23
Monitors	Generated	1,226	514	2,298	454	415	494	1,680	965	2,751
	Collected	859	291	1,815	371	289	460	1,230	650	2,188
	Export-NVEM							24	17	31
	Export-Pub.							22	11	32

Table 21: Weights of Canadian generation, collection, and export of used computers and monitors in 2010, as mean and low and high bounds of the 95% confidence interval (metric tons)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	13,125	6,217	22,779	3,277	1,580	5,615	16,402	7,826	28,329
	Collected	10,551	4,901	18,759	2,774	1,287	4,877	13,325	6,283	23,486
	Export-NVEM							182	81	333
	Export-Pub.							141	36	353
Laptops	Generated	1,153	345	2,860	683	270	1,512	1,836	659	4,263
	Collected	773	219	1,980	571	223	1,274	1,344	477	3,098
	Export-NVEM							132	54	293
	Export-Pub.							130	50	306
Computers	Generated	14,278	7,133	24,210	3,960	2,147	6,389	18,238	9,354	30,334
	Collected	11,324	5,557	19,598	3,345	1,746	5,522	14,669	7,449	24,886
	Export-NVEM							313	134	625
	Export-Pub.							271	86	658
CRT Monitors	Generated	15,696	5,791	32,577	4,003	2,623	5,782	19,699	9,084	37,387
	Collected	10,723	2,827	25,528	3,346	2,073	5,047	14,069	5,609	29,604
	Export-NVEM							134	89	193
	Export-Pub.							134	89	193
Flat Panel Monitors	Generated	2,778	334	10,064	2,452	489	7,019	5,230	945	16,241
	Collected	2,170	259	7,967	1,939	372	5,680	4,108	728	12,957
	Export-NVEM							188	21	775
	Export-Pub.							160	6	810
Monitors	Generated	18,474	6,842	38,615	6,455	3,790	11,334	24,929	11,794	47,621
	Collected	12,892	3,847	29,718	5,285	2,955	9,391	18,177	7,872	36,564
	Export-NVEM							322	109	968
	Export-Pub.							294	95	1,003

Table 22: Top 20 destination countries for Canadian used computers and monitors

Average Export Quantity Rank	Destination Country	Export-NVEM Mean and Range		Export-Pub. Mean and Range	
1	United States	N/A	N/A	25.3	± 5.2
2	France	7.9	± 0	7.7	± 0.3
3	Italy	8.0	± 0	4.1	± 3.9
4	United Arab Emirates	4.0	± 1.1	4.6	± 1.4
5	Sri Lanka	3.9	± 0	3.9	± 0
6	Germany	3.7	± 0	3.5	± 0.2
7	United Kingdom	3.5	± 0	3.4	± 0.1
8	Chile	3.4	± 0	2.5	± 1
9	China	2.8	± 0	2.4	± 0.3
10	Peru	2.6	± 0	2.0	± 0.6
11	China, Hong Kong SAR	1.4	± 0	2.5	± 1.2
12	Bolivia (Plurinational State of)	2.2	± 0.2	1.2	± 1.2
13	Philippines	1.6	± 0.6	1.6	± 0.6
14	Netherlands	1.7	± 0	1.3	± 0.4
15	Pakistan	1.2	± 0.2	1.2	± 0.3
16	Cuba	0.8	± 0	0.7	± 0.2
17	Denmark	0.6	± 0	0.6	± 0
18	Malaysia	0.5	± 0	0.6	± 0.1
19	Brazil	0.6	± 0	0.5	± 0.1
20	Mexico	0.5	± 0	0.5	± 0.1

Note: Determined using US HSOTDM values applied to Canadian export data for most countries as well as US import data, due to data constraints, as mean export quantities (thousands of units) and range of thresholds for each threshold method. All other countries received less than 500 units of used computers and monitors. Several destination countries are known commonly to re-export goods regionally, including Hong Kong, United Arab Emirates, and Lebanon and therefore are not likely final destinations.

Table 23: Top 19 destination countries for Canadian used computers and monitors

Average Export Quantity Rank	Destination Country	Export Method: NVEM	Mean Uncertainty	Export Method: Pub.	Mean Uncertainty
1	United States	N/A	N/A	156	+363 / -115
2	Italy	84	+102 / -43	42	+100 / -42
3	Sri Lanka	59	+47 / -21	59	+27 / -21
4	United Arab Emirates	40	+138 / -33	43	+113 / -35
5	Chile	41	+77 / -25	30	+64 / -18
6	Peru	37	+57 / -20	29	+46 / -15
7	France	26	+46 / -15	26	+32 / -15
8	Philippines	21	+53 / -12	21	+42 / -13
9	Bolivia (Plurinational State of)	27	+78 / -22	15	+68 / -15
10	United Kingdom	15	+24 / -8	14	+18 / -8
11	Germany	13	+23 / -8	12	+16 / -8
12	China, Hong Kong SAR	10	+19 / -6	15	+41 / -12
13	China	10	+18 / -6	9	+12 / -6
14	Cuba	9	+11 / -5	7	+8 / -5
15	Malaysia	6	+6 / -3	7	+6 / -4
16	Pakistan	6	+18 / -4	6	+14 / -4
17	Kenya	5	+27 / -5	5	+22 / -5
18	Lebanon	5	+11 / -3	5	+8 / -3
19	Netherlands	5	+10 / -3	4	+8 / -3

Note: Determined using US HSOTDM values applied to Canadian export data for most countries as well as US import data due to data constraints, as mean export weight (metric tons) and range of thresholds for each threshold method. All other countries received less than 5 metric tons of used computers and monitors. Several destination countries are known commonly to re-export goods regionally, including Hong Kong, United Arab Emirates, and Lebanon and therefore are not likely final destinations.

Table 24: Quantities of Canadian generation, collection, and export of used computers and monitors in 2010, as mean and low and high bounds of the 95% confidence interval (thousands of units)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	578	511	645	309	281	337	887	793	982
	Collected	451	370	555	270	238	308	721	608	863
	Export							87	78	304
Laptops	Generated	243	215	271	221	201	241	464	416	512
	Collected	208	176	246	182	158	212	390	334	459
	Export							28	25	144
Computers	Generated	821	726	915	530	483	578	1,351	1,209	1,494
	Collected	659	546	801	452	397	521	1,111	942	1,322
	Export							114	103	448
CRT Monitors	Generated	358	317	400	256	233	279	614	550	679
	Collected	254	201	326	182	152	225	437	353	551
	Export							138	74	225
Flat Panel Monitors	Generated	139	123	155	198	180	216	337	303	371
	Collected	116	97	138	176	156	200	292	253	338
	Export							80	72	159
Monitors	Generated	497	440	554	454	413	495	951	853	1,050
	Collected	370	298	464	358	308	425	728	606	890
	Export							218	146	384

Table 25: Quantities of Canadian flows quantified using the mass balance method (thousands of units)

Product	Flow	Intended End-of-Use Scenario			Lower Reuse Scenario			Higher Export Scenario		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	FMH	728	644	812	728	644	812	728	644	812
	FMBP	1,380	1,256	1,505	1,380	1,256	1,505	1,380	1,256	1,505
	FHI	578	511	645	578	511	645	578	511	645
	FBPI	309	281	337	309	281	337	309	281	337
	FIH	231	205	258	231	205	258	231	205	258
	FIBP	112	102	122	112	102	122	112	102	122
	FIR	291	260	322	360	321	399	183	163	202
	FHR	203	180	226	252	223	281	136	120	152
	FBPR	88	80	96	109	99	118	47	42	51
	FIL	167	148	185	133	119	148	167	148	185
	FHL	127	113	142	102	90	113	127	113	142
	FBPL	39	36	43	32	29	34	39	36	43
	FIMI	0	0	0	36	31	40	80	71	89
	FIE	87	78	95	87	78	95	275	247	304
Laptops	FMH	1,491	1,319	1,663	1,491	1,319	1,663	1,491	1,319	1,663
	FMBP	805	732	877	805	732	877	805	732	877
	FHI	243	215	271	243	215	271	243	215	271
	FBPI	221	201	241	221	201	241	221	201	241
	FIH	335	297	374	335	297	374	335	297	374
	FIBP	71	65	78	71	65	78	71	65	78
	FIR	118	106	130	172	154	190	78	70	86
	FHR	68	61	76	95	84	106	45	40	51
	FBPR	50	45	54	77	70	84	33	30	36
	FIL	74	67	82	59	53	65	74	67	82
	FHL	35	31	39	28	25	31	35	31	39
	FBPL	39	36	43	32	29	34	39	36	43
	FIMI	162	143	182	202	178	226	226	200	252
	FIE	28	25	30	28	25	30	131	118	144

Table 25: (continued)

Product	Flow	Intended End-of-Use Scenario			Lower Reuse Scenario			Higher Export Scenario		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
CRT Monitors	FMH	81	72	90	81	72	90	81	72	90
	FMBP	108	98	118	108	98	118	108	98	118
	FHI	358	317	400	358	317	400	358	317	400
	FBPI	256	233	279	256	233	279	256	233	279
	FIH	46	41	52	46	41	52	46	41	52
	FIBP	14	13	15	14	13	15	14	13	15
	FIR	238	214	263	330	295	364	173	155	191
	FHR	134	119	150	184	163	205	97	86	108
	FBPR	104	95	114	146	133	159	76	69	83
	FIL	178	159	197	142	127	157	178	159	197
	FHL	104	92	116	83	74	93	104	92	116
	FBPL	74	67	81	59	54	64	74	67	81
	FIMI	0	0	0	0	0	0	0	0	0
	FIE	138	124	152	82	74	91	204	182	225
Flat Panel Monitors	FMH	751	665	838	751	665	838	751	665	838
	FMBP	1,100	1,001	1,200	1,100	1,001	1,200	1,100	1,001	1,200
	FHI	139	123	155	139	123	155	139	123	155
	FBPI	198	180	216	198	180	216	198	180	216
	FIH	220	194	245	220	194	245	220	194	245
	FIBP	78	71	85	78	71	85	78	71	85
	FIR	90	80	99	123	110	136	64	57	70
	FHR	52	46	58	65	57	72	39	34	43
	FBPR	38	34	41	58	53	63	25	23	27
	FIL	45	41	50	36	33	40	45	41	50
	FHL	23	20	26	18	16	21	23	20	26
	FBPL	22	20	24	18	16	20	22	20	24
	FIMI	175	155	195	199	177	222	214	190	238
	FIE	80	72	87	80	72	87	145	130	159

Note: Flows pertain to Figure 7, which presents a schematic drawing of the flow analysis for the selected country.

Flows are from manufacturers (M) through residential households (H) and business/public (BP) users, to intermediaries (I). Intermediaries also collect used imports (Im) and either redistribute them for reuse to households (H) and business/public (B/P) users, send them to landfill or incinerator (L), sell them domestically for parts and materials recycling (R), or export them to a foreign country (E). The ordering of indices is from/to, i.e., FHI refers to flows from residential households (H) to intermediaries (I), and FIH refers to flows from intermediaries (I) to residential households (H).

Table 26: Weights of Canadian generation, collection, and export of used computers and monitors in 2010, as mean and low and high bounds of the 95% confidence interval (metric tons)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	6,135	2,619	11,624	3,281	1,441	6,077	9,416	4,059	17,702
	Collected	4,785	1,892	10,002	2,863	1,221	5,561	7,648	3,113	15,562
	Export							919	399	5,481
Laptops	Generated	748	270	1,850	682	253	1,647	1,430	523	3,496
	Collected	642	221	1,682	560	199	1,451	1,202	420	3,133
	Export							85	32	984
Computers	Generated	6,883	2,889	13,474	3,963	1,693	7,724	10,846	4,582	21,198
	Collected	5,426	2,114	11,684	3,424	1,420	7,011	8,850	3,533	18,695
	Export							1,005	431	6,466
CRTs	Generated	5,608	3,280	9,006	4,007	2,411	6,289	9,614	5,691	15,295
	Collected	3,980	2,080	7,347	2,851	1,577	5,078	6,830	3,657	12,425
	Export							2,161	764	5,064
Flat panels	Generated	1,705	313	5,339	2,436	460	7,458	4,141	772	12,797
	Collected	1,421	247	4,774	2,162	397	6,897	3,582	644	11,671
	Export							977	183	5,483
Monitors	Generated	7,312	3,593	14,345	6,443	2,870	13,748	13,755	6,463	28,093
	Collected	5,400	2,327	12,121	5,012	1,975	11,975	10,413	4,302	24,096
	Export							3,138	946	10,546

Mexico

Hybrid Sales Obsolescence-Trade Data Method (HSOTDM)

Table 27: Quantities of Mexican generation, collection, and export of used computers and monitors in 2010, as mean and low and high bounds of the 95% confidence interval (thousands of units)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	899	714	1,107	276	167	387	1,175	945	1,420
	Collected	478	348	637	261	157	365	739	559	934
	Export-NVEM							865	828	913
	Export-Pub.							849	711	1,345
Laptops	Generated	128	55	241	127	76	177	255	156	379
	Collected	91	38	171	123	74	172	214	134	310
	Export-NVEM							230	227	459
	Export-Pub.							187	181	196
Computers	Generated	1,027	795	1,295	403	243	564	1,430	1,125	1,759
	Collected	569	404	774	384	231	537	953	705	1,217
	Export-NVEM							1,095	1,055	1,372
	Export-Pub.							1,035	892	1,541
CRT Monitors	Generated	325	173	539	300	181	420	625	415	873
	Collected	187	95	322	271	163	380	458	300	632
	Export-NVEM							1,446	1,380	1,619
	Export-Pub.							597	174	1,136
Flat Panel Monitors	Generated	240	131	391	259	156	362	499	334	687
	Collected	127	66	216	235	142	330	362	240	495
	Export-NVEM							23	23	23
	Export-Pub.							23	23	23
Monitors	Generated	85	30	180	41	25	57	126	66	222
	Collected	60	21	129	36	21	51	96	51	165
	Export-NVEM							1,423	1,358	1,597
	Export-Pub.							574	151	1,114

Table 28: Weights of Mexican generation, collection, and export of used computers and monitors in 2010, as mean, and low and high bounds of the 95% confidence interval (metric tons)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	9,514	4,364	16,902	2,927	1,161	5,696	12,440	5,757	21,915
	Collected	5,065	2,225	9,287	2,759	1,096	5,360	7,824	3,508	13,971
	Export-NVEM							9,179	4,238	16,466
	Export-Pub.							9,008	3,641	24,244
Laptops	Generated	398	108	1,046	393	131	951	790	275	1,873
	Collected	281	75	742	381	127	924	663	231	1,581
	Export-NVEM							709	285	3,136
	Export-Pub.							575	227	1,340
Computers	Generated	9,912	4,725	17,340	3,319	1,415	6,217	13,231	6,414	22,736
	Collected	5,346	2,434	9,650	3,141	1,344	5,898	8,487	4,046	14,732
	Export-NVEM							9,887	4,523	19,602
	Export-Pub.							9,583	3,868	25,585
CRT Monitors	Generated	4,798	2,253	9,025	4,556	2,304	7,669	9,354	5,179	15,376
	Collected	2,718	1,196	5,352	4,118	2,081	6,976	6,836	3,747	11,144
	Export-NVEM							17,840	3,691	55,606
	Export-Pub.							7,411	618	38,944
Flat Panel Monitors	Generated	3,752	1,806	6,750	4,051	2,028	6,912	7,803	4,367	12,709
	Collected	1,979	923	3,712	3,681	1,839	6,283	5,660	3,151	9,187
	Export-NVEM							352	233	507
	Export-Pub.							352	233	507
Monitors	Generated	1,046	141	3,562	505	92	1,514	1,551	257	4,850
	Collected	739	99	2,516	437	78	1,308	1,176	199	3,655
	Export-NVEM							17,487	3,458	55,099
	Export-Pub.							7,058	385	38,437

Table 29: Top 28 destination countries for used computers and monitors from Mexico, expressed as mean export quantities (thousands of units) and range of thresholds for each threshold method

Average Export Quantity Rank	Destination Country	Export-NVEM Mean and Range		Export-Pub. Mean and Range	
1	United States	2151.1	± 102.9	1210.4	± 436.4
2	Netherlands	160.8	± 0	160.8	± 0
3	Colombia	29.2	± 0	65.4	± 49.7
4	Canada	40.3	± 0.1	11.1	± 11
5	Venezuela	23.3	± 0	24.1	± 24.1
6	Hong Kong	22.2	± 0	22.2	± 0
7	Singapore	18.8	± 0.8	18.8	± 0.8
8	Chile	14.5	± 0	22.5	± 16.6
9	China	13.6	± 1.1	13.6	± 1.1
10	India	13.1	± 0	13.1	± 0
11	Peru	10.7	± 0	15	± 5.9
12	Argentina	3.3	± 0	17.1	± 15
13	Australia	8	± 0	8	± 0
14	Brazil	8.9	± 0	4.8	± 1.5
15	Ecuador	2.2	± 0	4.7	± 2.3
16	Costa Rica	2.5	± 0.2	2.2	± 1
17	Surinam	2.3	± 0	2.3	± 0
18	Korea, South	2.1	± 0	2.1	± 0
19	Japan	2	± 0	2	± 0
20	Indonesia	2	± 0	2	± 0
21	New Zealand	2	± 0	2	± 0
22	Taiwan	1.4	± 0	1.4	± 0
23	Romania	1	± 0	1	± 0
24	Guatemala	1	± 0	1	± 0
25	Paraguay	1	± 0	1	± 0
26	Cuba	0.9	± 0.1	0.7	± 0.2
27	Spain	0.7	± 0	0.7	± 0
28	Uruguay	0	± 0	0.6	± 0.6

Notes: All other countries received less than 500 units of used computers and monitors. Several destination countries are known commonly to re-export goods regionally, including Hong Kong, United Arab Emirates, and Lebanon and therefore are not likely final destinations.

Table 30: Top 27 destination countries for Mexican used computers and monitors, expressed in mean export weight (metric tons) and range of thresholds for each threshold method

Average Export Quantity Rank	Destination Country	Export Method: NVEM Mean	Export Method: NVEM Uncertainty	Export Method: Pub. Mean	Export Method: Pub. Uncertainty
1	United States	23,555	+42243 / -16917	12,390	+38069 / -9299
2	Netherlands	1,707	+1194 / -883	1,707	+1194 / -883
3	Colombia	270	+897 / -208	710	+2191 / -645
4	Canada	496	+895 / -393	137	+1192 / -136
5	Venezuela	275	+495 / -217	293	+1226 / -293
6	Hong Kong	255	+330 / -170	255	+330 / -170
7	Singapore	200	+147 / -107	200	+147 / -107
8	Chile	104	+216 / -73	242	+947 / -219
9	China	149	+139 / -88	149	+139 / -88
10	Peru	120	+212 / -89	172	+826 / -144
11	India	139	+120 / -72	139	+120 / -72
12	Argentina	25	+31 / -14	182	+225 / -172
13	Australia	85	+59 / -44	85	+59 / -44
14	Brazil	108	+195 / -86	59	+197 / -50
15	Ecuador	22	+58 / -17	53	+136 / -44
16	Costa Rica	28	+47 / -22	27	+195 / -23
17	Surinam	24	+17 / -12	24	+17 / -12
18	Korea, South	22	+16 / -11	22	+16 / -11
19	Japan	21	+15 / -11	21	+15 / -11
20	Indonesia	21	+15 / -11	21	+15 / -11
21	New Zealand	21	+15 / -11	21	+15 / -11
22	Guatemala	12	+28 / -10	12	+28 / -10
23	Paraguay	12	+23 / -10	12	+25 / -10
24	Taiwan	12	+9 / -6	12	+9 / -6
25	Romania	11	+9 / -6	11	+9 / -6
26	Cuba	9	+14 / -7	8	+12 / -6
27	Spain	8	+14 / -6	8	+14 / -6

Table 31: Quantities of Mexican generation, collection and export of used computers and monitors in 2010, expressed as mean, and low and high bounds of the 95% confidence interval (thousands of units)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	155	117	192	392	228	558	547	345	750
	Collected	143	102	185	378	208	551	521	309	736
	Exported							107	3	262
Laptops	Generated	155	117	192	300	174	427	455	291	619
	Collected	131	87	178	297	170	425	428	257	603
	Exported							208	59	365
Computers	Generated	309	234	385	692	402	984	1,001	636	1,369
	Collected	274	189	363	675	378	976	948	567	1,340
	Exported							315	62	627
CRT Monitors	Generated	369	278	459	294	171	418	663	449	877
	Collected	285	175	409	271	138	407	556	313	816
	Exported							197	41	360
Flat Panel Monitors	Generated	83	63	104	76	44	108	159	107	211
	Collected	59	33	89	67	32	104	127	65	193
	Exported							18	0	57
Monitors	Generated	452	341	562	370	215	526	822	556	1,088
	Collected	345	208	498	338	170	511	683	378	1,009
	Exported							215	41	416

Table 32: Mexican flows of used electronics, as quantified by the mass balance method (thousands of units)

		Intended End-of-Use Scenario			Lower Reuse Scenario			Higher Export Scenario		
Product	Flow	Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	FMH	1,819	1,374	2,265	1,819	1,374	2,265	1,819	1,374	2,265
	FMBP	1,643	957	2,343	1,643	957	2,343	1,643	957	2,343
	FHI	155	117	192	155	117	192	155	117	192
	FBPI	391	228	558	391	228	558	391	228	558
	FIH	297	225	370	297	225	370	297	225	370
	FIBP	23	14	33	23	14	33	23	14	33
	FIR	92	58	127	198	109	304	29	18	50
	FHR	24	18	30	39	29	61	7	5	10
	FBPR	69	40	98	159	80	244	22	13	39
	FIL	26	17	35	21	14	28	26	17	35
	FHL	12	9	15	10	7	12	12	9	15
	FBPL	14	8	20	11	7	16	14	8	20
	FIMI	0	0	0	0	20	0	14	43	0
	FIE	106	31	184	6	3	14	184	114	262
Laptops	FMH	2,878	2,174	3,582	2,878	2,174	3,582	2,878	2,174	3,582
	FMBP	635	370	905	635	370	905	635	370	905
	FHI	155	117	192	155	117	192	155	117	192
	FBPI	299	174	427	299	174	427	299	174	427
	FIH	131	99	163	131	99	163	131	99	163
	FIBP	10	6	14	10	6	14	10	6	14
	FIR	80	53	106	175	112	239	34	24	43
	FHR	40	31	50	58	44	73	25	19	31
	FBPR	39	23	56	117	68	166	9	5	12
	FIL	27	20	34	21	16	27	27	20	34
	FHL	24	18	30	19	14	24	24	18	30
	FBPL	3	2	4	2	1	3	3	2	4
	FIMI	0	0	0	0	0	0	0	0	0
	FIE	207	114	302	117	59	176	253	143	365

Table 32: (continued)

Product	Flow	Intended End-of-Use Scenario			Lower Reuse Scenario			Higher Export Scenario		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
CRT Monitors	FMH	321	243	400	321	243	400	321	243	400
	FMBP	147	86	210	147	86	210	147	86	210
	FHI	369	278	459	369	278	459	369	278	459
	FBPI	293	171	418	293	171	418	293	171	418
	FIH	250	189	311	250	189	311	250	189	311
	FIBP	3	1	4	3	1	4	3	1	4
	FIR	107	71	143	238	157	319	50	33	67
	FHR	52	40	65	108	82	135	25	19	31
	FBPR	55	32	78	129	75	184	25	14	35
	FIL	106	76	136	85	61	109	106	76	136
	FHL	83	63	104	67	50	83	83	63	104
	FBPL	23	13	33	18	11	26	23	13	33
	FIMI	0	0	0	0	0	0	0	0	0
	FIE	196	111	283	87	41	134	254	150	360
Flat Panel Monitors	FMH	1,498	1,132	1,865	1,498	1,132	1,865	1,498	1,132	1,865
	FMBP	755	440	1,077	755	440	1,077	755	440	1,077
	FHI	83	63	104	83	63	104	83	63	104
	FBPI	75	44	108	75	44	108	75	44	108
	FIH	71	54	89	71	54	89	71	54	89
	FIBP	18	10	25	18	10	25	18	10	25
	FIR	20	12	27	44	28	64	5	3	7
	FHR	6	4	7	17	13	21	0	0	0
	FBPR	14	8	20	27	15	42	5	3	7
	FIL	32	23	42	26	18	33	32	23	42
	FHL	24	18	30	19	14	24	24	18	30
	FBPL	8	5	12	7	4	10	8	5	12
	FIMI	0	0	0	0	4	0	9	10	8
	FIE	18	7	28	0	0	0	42	27	57

Notes: Flows pertain to Figure 7, which presents a schematic drawing of the flow analysis for the selected country.

Flows are from manufacturers (M) through residential households (H) and business/public (BP) users, to intermediaries (I). Intermediaries also collect used imports (Im) and either redistribute them for reuse to households (H) and business/public (B/P) users, send them to landfill or incinerator (L), sell them domestically for parts and materials recycling (R), or export them to a foreign country (E). The ordering of indices is from/to, i.e., FHI refers to flows from residential households (H) to intermediaries (I), and FIH refers to flows from intermediaries (I) to residential households (H).

Table 33: Weights of Mexican generation, collection, and export of used computers and monitors in 2010 as mean, and low and high bounds of the 95% confidence interval (metric tons)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	1,641	598	3,469	4,163	1,167	10,057	5,803	1,765	13,526
	Collected	1,514	522	3,340	4,011	1,063	9,937	5,525	1,585	13,277
	Exported							1,139	18	4,723
Laptops	Generated	477	147	1,314	925	219	2,914	1,401	366	4,228
	Collected	403	110	1,216	916	214	2,904	1,319	323	4,120
	Exported							640	74	2,495
Computers	Generated	2,117	745	4,784	5,088	1,386	12,971	7,205	2,130	17,754
	Collected	1,918	632	4,556	4,927	1,276	12,841	6,844	1,908	17,397
	Exported							1,779	92	7,218
CRTs	Generated	5,768	2,881	10,338	4,600	1,767	9,419	10,368	4,648	19,757
	Collected	4,465	1,809	9,205	4,241	1,429	9,178	8,706	3,238	18,383
	Exported							3,081	425	8,103
Flat Panel Monitors	Generated	1,023	160	3,575	930	112	3,712	1,952	272	7,287
	Collected	731	85	3,079	826	81	3,577	1,557	166	6,656
	Exported							219	0	1,950
Monitors	Generated	6,791	3,041	13,913	5,529	1,879	13,131	12,320	4,920	27,044
	Collected	5,196	1,894	12,284	5,067	1,511	12,756	10,263	3,404	25,039
	Exported							3,300	425	10,053

United States

Hybrid Sales Obsolescence-Trade Data Method (HSOTDM)

Table 34: Quantities of United States generation, collection, and export of used computers and monitors in 2010, as mean, and low and high bounds of the 95% confidence interval (thousands of units)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	14,385	12,823	16,049	8,219	7,501	8,938	22,604	20,773	24,481
	Collected	10,181	8,322	12,249	6,473	4,698	8,404	16,654	13,821	19,584
	Export-NVEM							331	319	344
	Export-Pub.							226	101	351
Laptops	Generated	3,728	2,203	5,627	3,570	3,258	3,883	7,298	5,731	9,233
	Collected	2,727	1,575	4,243	2,790	2,005	3,645	5,517	4,013	7,252
	Export-NVEM							871	865	878
	Export-Pub.							896	748	1,044
Computers	Generated	18,113	15,673	20,843	11,789	10,759	12,821	29,902	27,145	32,878
	Collected	12,908	10,346	15,817	9,263	6,703	12,049	22,171	18,237	26,301
	Export-NVEM							1,203	1,184	1,222
	Export-Pub.							1,122	849	1,395
CRT Monitors	Generated	7,485	4,631	11,188	3,264	2,979	3,550	10,750	7,872	14,446
	Collected	5,122	3,081	7,864	2,896	2,454	3,369	8,018	5,897	10,782
	Export-NVEM							288	288	288
	Export-Pub.							343	343	343
Flat Panel Monitors	Generated	2,953	1,690	4,596	3,968	3,622	4,316	6,921	5,571	8,602
	Collected	2,020	1,115	3,224	2,730	1,554	4,009	4,750	3,101	6,536
	Export-NVEM							553	527	579
	Export-Pub.							436	23	848
Monitors	Generated	10,439	7,007	14,615	7,232	6,601	7,865	17,671	14,171	21,910
	Collected	7,142	4,629	10,397	5,626	4,035	7,359	12,768	9,523	16,421
	Export-NVEM							841	815	867
	Export-Pub.							779	367	1,192

Table 35: Weights of United States generation, collection, and export of used computers and monitors in 2010 as mean, and low and high bounds of the 95% confidence interval (metric tons)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	152,660	65,660	289,377	87,224	38,409	161,160	239,884	106,367	441,413
	Collected	108,046	42,612	220,860	68,695	24,056	151,531	176,740	70,770	353,116
	Export-NVEM							3,515	1,633	6,194
	Export-Pub.							2,396	516	6,327
Laptops	Generated	11,493	2,769	38,437	11,006	4,095	26,524	22,499	7,203	63,068
	Collected	8,407	1,979	28,983	8,601	2,520	24,898	17,008	5,043	49,537
	Export-NVEM							2,687	1,087	5,999
	Export-Pub.							2,763	940	7,132
Computers	Generated	164,153	68,428	327,814	98,230	42,503	187,683	262,383	113,570	504,481
	Collected	116,453	44,592	249,843	77,296	26,576	176,429	193,748	75,813	402,653
	Export-NVEM							6,202	2,720	12,193
	Export-Pub.							5,159	1,456	13,458
CRT Monitors	Generated	117,114	47,913	252,077	51,070	30,821	79,985	168,200	81,444	325,483
	Collected	80,141	31,876	177,184	45,312	25,389	75,907	125,454	61,011	242,929
	Export-NVEM							4,506	2,980	6,489
	Export-Pub.							5,374	3,554	7,739
Flat Panel Monitors	Generated	36,285	4,305	158,583	48,757	9,226	148,922	85,042	14,191	296,809
	Collected	24,821	2,840	111,243	33,545	3,958	138,329	58,366	7,899	225,522
	Export-NVEM							6,796	1,343	19,971
	Export-Pub.							5,355	60	29,264
Monitors	Generated	153,399	52,218	410,660	99,827	40,047	228,907	253,242	95,635	622,291
	Collected	104,962	34,716	288,427	78,857	29,348	214,236	183,819	68,910	468,451
	Export-NVEM							11,302	4,323	26,460
	Export-Pub.							10,729	3,614	37,003

Table 36: Top 100 destination countries for US used computers and monitors

Average Export Quantity Rank	Destination Country	Export-NVEM Mean and Range		Export-Pub. Mean and Range	
1	Mexico	273.8	± 3.4	312.4	± 239.4
2	Canada	229.1	± 2.4	180.1	± 63.9
3	Hong Kong	90.8	± 1	161.8	± 69.7
4	United Arab Emirates	79.7	± 3	118.9	± 13.3
5	Lebanon	114.3	± 0	83.2	± 23.4
6	Argentina	87.2	± 0.3	81.3	± 6.3
7	Chile	74.5	± 0.1	69.7	± 7.1
8	Colombia	79.2	± 1.8	57.8	± 25.3
9	Italy	89.8	± 0	46.5	± 43.7
10	Bolivia	68.5	± 0.5	65.4	± 5.4
11	China	65.9	± 1.6	61.2	± 5.7
12	United Kingdom	61.5	± 0.3	60.2	± 3.3
13	Venezuela	71.9	± 0	46.0	± 26.3
14	Ecuador	51.6	± 1.5	39.8	± 13.8
15	Brazil	44.6	± 0.9	35.4	± 13.9
16	Peru	39.3	± 0	27.7	± 13.3
17	France	28.4	± 0	28.5	± 0.9
18	Israel	34.1	± 0.2	19.9	± 13.8
19	Germany	23.4	± 0.3	24.7	± 4
20	Netherlands	26.0	± 0.1	20.5	± 5.9
21	Egypt	22.7	± 0.4	22.2	± 0.5
22	Paraguay	23.5	± 0.7	17.0	± 8.2
23	Pakistan	15.9	± 0.9	15.6	± 1.3
24	Guatemala	18.3	± 1.7	12.9	± 7.1
25	Dominican Republic	18.0	± 0	13.0	± 5.3
26	Taiwan	16.7	± 1.2	12.5	± 6.9
27	Singapore	12.5	± 0.1	16.1	± 4.1
28	Uruguay	14.5	± 0.8	11.4	± 4.3
29	Ireland	14.3	± 0.2	11.6	± 3
30	Costa Rica	15.0	± 0.1	9.6	± 6.3
31	Kenya	11.4	± 0	11.7	± 0.1
32	Russia	11.5	± 0.1	10.8	± 0
33	El Salvador	12.8	± 0.2	9.5	± 3.9
34	Australia	10.7	± 1	9.6	± 2.4
35	Malaysia	12.9	± 0.8	7.3	± 2.9
36	Ghana	10.0	± 1.1	9.3	± 1.6
37	Japan	8.9	± 2	9.1	± 2.4
38	Nigeria	7.6	± 0.8	6.7	± 0.9
39	India	6.5	± 0.1	7.0	± 0.3
40	Korea, South	6.5	± 0.6	6.2	± 1.1
41	Philippines	6.1	± 0.1	6.4	± 0.3
42	Barbados	5.9	± 0.2	6.0	± 0.2
43	Honduras	9.4	± 0.8	2.5	± 1.7
44	Saudi Arabia	5.0	± 0.7	6.3	± 0
45	Kuwait	5.5	± 0.2	5.6	± 0.2
46	Trinidad and Tobago	5.4	± 3.4	5.3	± 3.6
47	Afghanistan	5.2	± 1.9	5.2	± 1.7
48	Panama	5.9	± 1.3	4.1	± 3.2
49	Jordan	5.3	± 0.1	4.6	± 0.7
50	Thailand	4.8	± 0.1	4.8	± 0.1

Table 36: (continued)

Average Export Quantity Rank	Destination Country	Export-NVEM Mean and Range		Export-Pub. Mean and Range	
51	Morocco	4.8	± 0.2	4.6	± 0.4
52	Bermuda	3.8	± 0.4	3.9	± 0.4
53	Jamaica	3.7	± 0	3.0	± 1
54	Finland	3.2	± 0.2	3.1	± 0.3
55	Vietnam	3.1	± 0	3.1	± 0
56	South Africa	3.1	± 0.3	2.6	± 0.8
57	Tanzania	1.9	± 0	3.6	± 0
58	Poland	2.8	± 0	2.7	± 0.1
59	Ukraine	2.5	± 0.1	2.5	± 0.1
60	Norway	2.4	± 0.3	2.6	± 0.3
61	Netherlands Antilles	2.5	± 0.6	2.5	± 0.9
62	Belgium	2.3	± 0	2.7	± 0.3
63	Spain	2.5	± 0	2.3	± 0.3
64	Denmark	2.0	± 0	2.1	± 0.1
65	Mozambique	1.7	± 0	2.1	± 0.1
66	Bahamas	2.0	± 0	1.7	± 0.2
67	Nicaragua	1.8	± 0.2	1.5	± 0.6
68	Hungary	1.9	± 0	1.4	± 0.6
69	Sweden	1.7	± 0	1.3	± 0.5
70	Czech Republic	1.1	± 0	1.3	± 0.1
71	Qatar	1.1	± 0	1.2	± 0
72	Aruba	1.0	± 0.5	1.0	± 0.5
73	Austria	1.1	± 0	0.9	± 0.2
74	Angola	0.9	± 0.6	1.0	± 0.6
75	Turkey	0.9	± 0.1	1.0	± 0.1
76	Benin	0.9	± 0	0.9	± 0
77	Haiti	0.8	± 0.3	0.8	± 0.3
78	Switzerland	0.5	± 0	1.0	± 0.3
79	Suriname	0.8	± 0	0.7	± 0.2
80	New Zealand	0.7	± 0.1	0.6	± 0.1
81	Guyana	0.7	± 0	0.6	± 0.5
82	Sri Lanka	0.7	± 0	0.7	± 0
83	Bulgaria	0.6	± 0	0.6	± 0
84	Rwanda	0.6	± 0	0.6	± 0
85	Madagascar	0.5	± 0	0.6	± 0.1
86	Chad	0.6	± 0	0.6	± 0
87	Algeria	0.6	± 0	0.6	± 0
88	Senegal	0.6	± 0	0.5	± 0
89	Bangladesh	0.5	± 0	0.5	± 0
90	Gabon	0.5	± 0	0.5	± 0
91	Montenegro	0.5	± 0	0.5	± 0
92	Cayman Islands	0.5	± 0.2	0.5	± 0.2
93	St Lucia	0.6	± 0	0.4	± 0.3
94	Nepal	0.5	± 0	0.5	± 0
95	Belize	0.5	± 0	0.5	± 0.1
96	Maldives	0.6	± 0	0.4	± 0.1
97	St Vincent and the Grenadines	0.5	± 0	0.5	± 0.1
98	Djibouti	0.5	± 0	0.5	± 0
99	Dominica	0.5	± 0	0.4	± 0.1
100	Sierra Leone	0.5	± 0	0.4	± 0

Table 37: Top 90 destination countries for US used computers and monitors

Average Export Quantity Rank	Destination Country	Export Method: NVEM Mean	Uncertainty	Export Method: Pub. Mean	Uncertainty
1	Mexico	3,088	+7042 / -2192	3,655	+13454 / -3158
2	Canada	2,250	+2743 / -1087	2,003	+2377 / -1141
3	Colombia	967	+1936 / -612	706	+1641 / -458
4	Venezuela	940	+1955 / -623	622	+1657 / -436
5	Italy	952	+1154 / -489	493	+1130 / -475
6	China	611	+731 / -262	606	+482 / -261
7	Ecuador	674	+1152 / -375	534	+925 / -292
8	Hong Kong	463	+859 / -286	648	+1377 / -478
9	Brazil	521	+983 / -325	434	+832 / -266
10	United Arab Emirates	353	+622 / -204	484	+646 / -294
11	Argentina	405	+769 / -251	336	+586 / -219
12	Chile	388	+780 / -249	320	+616 / -210
13	Peru	394	+908 / -285	256	+809 / -205
14	Bolivia	333	+678 / -214	287	+522 / -188
15	United Kingdom	313	+531 / -178	305	+403 / -172
16	Lebanon	356	+644 / -211	261	+477 / -184
17	Israel	340	+616 / -214	187	+553 / -171
18	Egypt	247	+234 / -95	246	+138 / -94
19	Paraguay	268	+524 / -170	189	+444 / -132
20	Taiwan	206	+472 / -139	155	+432 / -113
21	Netherlands	189	+304 / -104	156	+246 / -89
22	France	154	+204 / -74	164	+143 / -78
23	Costa Rica	185	+434 / -135	122	+381 / -94
24	Guatemala	184	+487 / -144	117	+410 / -106
25	Germany	137	+201 / -71	162	+269 / -99
26	Ireland	157	+229 / -88	127	+173 / -81
27	Uruguay	155	+365 / -113	119	+296 / -92
28	Dominican Republic	162	+322 / -105	110	+275 / -80
29	Australia	121	+158 / -58	116	+119 / -60
30	Singapore	93	+128 / -47	110	+136 / -59
31	Japan	95	+216 / -56	107	+166 / -60
32	El Salvador	112	+254 / -79	71	+219 / -59
33	Kuwait	82	+77 / -30	84	+50 / -31
34	Pakistan	76	+116 / -39	78	+80 / -40
35	Malaysia	73	+140 / -41	76	+136 / -46
36	Philippines	70	+70 / -27	73	+50 / -30
37	Trinidad and Tobago	63	+250 / -49	65	+202 / -50
38	Korea, South	61	+97 / -29	64	+71 / -30
39	Thailand	60	+65 / -26	61	+39 / -26
40	India	55	+76 / -27	64	+56 / -30
41	Panama	69	+192 / -52	48	+164 / -39
42	Bermuda	57	+64 / -23	58	+42 / -23
43	Afghanistan	48	+131 / -32	52	+99 / -33
44	Russia	45	+72 / -25	48	+46 / -25
45	Nigeria	47	+88 / -27	46	+59 / -26

Table 37: (continued)

Average Export Quantity Rank	Destination Country	Export Method: NVEM Mean Uncertainty		Export Method: Pub. Mean Uncertainty	
46	Saudi Arabia	41	+52 / -19	50	+34 / -22
47	Ghana	45	+120 / -31	44	+90 / -31
48	Morocco	44	+50 / -19	45	+32 / -20
49	Honduras	59	+138 / -42	26	+89 / -21
50	Kenya	39	+68 / -22	40	+47 / -23
51	Jamaica	39	+80 / -26	32	+68 / -20
52	Poland	34	+34 / -13	33	+21 / -13
53	Norway	28	+42 / -13	32	+31 / -14
54	Belgium	24	+25 / -10	29	+23 / -13
55	South Africa	27	+40 / -14	26	+27 / -14
56	Barbados	23	+46 / -14	25	+33 / -15
57	Netherlands Antilles	22	+55 / -14	26	+43 / -16
58	Bahamas	25	+37 / -13	22	+25 / -12
59	Vietnam	19	+23 / -9	21	+15 / -9
60	Nicaragua	22	+53 / -15	18	+44 / -12
61	Jordan	20	+35 / -11	18	+26 / -11
62	Finland	18	+30 / -10	17	+20 / -10
63	Spain	17	+20 / -8	17	+14 / -8
64	Mozambique	15	+37 / -11	17	+27 / -12
65	Qatar	14	+25 / -9	15	+18 / -9
66	Hungary	17	+21 / -9	11	+19 / -8
67	Sweden	14	+27 / -9	11	+22 / -7
68	Czech Republic	10	+12 / -5	15	+10 / -6
69	Haiti	11	+23 / -6	12	+17 / -6
70	Tanzania	8	+13 / -4	14	+15 / -8
71	Angola	10	+25 / -8	11	+17 / -8
72	Aruba	10	+39 / -9	10	+30 / -9
73	Switzerland	7	+7 / -3	13	+23 / -8
74	Surinam	9	+16 / -5	9	+13 / -5
75	Austria	9	+10 / -4	9	+8 / -4
76	Denmark	8	+14 / -5	9	+13 / -6
77	Guyana	9	+23 / -7	7	+23 / -6
78	Ukraine	8	+15 / -5	8	+10 / -5
79	New Zealand	7	+10 / -3	7	+7 / -3
80	St Vincent and the Grenadines	6	+6 / -2	7	+6 / -3
81	Djibouti	6	+5 / -2	6	+3 / -2
82	St Lucia	7	+17 / -5	5	+17 / -5
83	Turkey	6	+9 / -3	7	+7 / -4
84	Sri Lanka	6	+7 / -3	6	+4 / -3
85	Algeria	6	+7 / -3	6	+4 / -3
86	Iraq	6	+5 / -2	6	+3 / -2
87	Cambodia	6	+5 / -2	6	+3 / -2
88	Montenegro	6	+7 / -3	6	+4 / -3
89	Dominica	6	+5 / -2	5	+4 / -2
90	Cayman Islands	5	+17 / -4	6	+13 / -4

Table 38: Quantities of United States generation, collection, and export of used computers and monitors in 2010, as mean, and low and high bounds of the 95% confidence interval (thousands of units)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	5,725	5,027	6,423	10,704	9,722	11,690	16,429	14,749	18,113
	Collected	4,763	3,948	5,747	7,636	6,371	9,461	12,399	10,319	15,209
	Exported							4,746	2,489	7,102
Laptops	Generated	2,702	2,373	3,032	6,531	6,531	6,531	9,233	8,904	9,563
	Collected	2,427	2,064	2,839	5,090	5,090	5,379	7,518	7,155	8,217
	Exported							2,247	855	3,260
Computers	Generated	8,427	7,400	9,455	17,235	16,253	18,221	25,662	23,653	27,676
	Collected	7,191	6,013	8,586	12,726	11,462	14,840	19,917	17,474	23,426
	Exported							6,992	3,344	10,362
CRT Monitors	Generated	3,298	2,896	3,700	7,465	6,780	8,153	10,763	9,676	11,853
	Collected	2,885	2,433	3,410	6,985	6,256	7,804	9,871	8,689	11,215
	Exported							5,622	3,497	7,585
Flat Panel Monitors	Generated	1,237	1,086	1,387	4,494	4,082	4,908	5,730	5,167	6,295
	Collected	824	623	1,098	2,086	1,452	3,159	2,911	2,075	4,256
	Exported							47	43	1,008
Monitors	Generated	4,534	3,981	5,087	11,959	10,862	13,061	16,493	14,843	18,148
	Collected	3,710	3,057	4,508	9,072	7,708	10,963	12,782	10,765	15,471
	Exported							5,669	3,540	8,593

Table 39: US flows of end of use computers and monitors, as quantified by the mass balance method

		Intended End-of-Use Scenario			Lower Reuse Scenario			Higher Export Scenario		
Product	**Flow**	**Mean**	**Low**	**High**	**Mean**	**Low**	**High**	**Mean**	**Low**	**High**
Desktops	FMH	6,962	6,113	7,811	6,962	6,113	7,811	6,962	6,113	7,811
	FMBP	16,236	14,753	17,740	16,236	14,753	17,740	16,236	14,753	17,740
	FHI	5,725	5,027	6,423	5,725	5,027	6,423	5,725	5,027	6,423
	FBPI	10,699	9,722	11,690	10,699	9,722	11,690	10,699	9,722	11,690
	FIH	1,374	1,207	1,542	1,374	1,207	1,542	1,374	1,207	1,542
	FIBP	905	823	989	905	823	989	905	823	989
	FIR	5,373	4,803	5,946	8,179	7,326	9,037	3,658	3,267	4,051
	FHR	2,592	2,276	2,908	3,435	3,016	3,854	1,860	1,633	2,086
	FBPR	2,781	2,526	3,038	4,744	4,310	5,183	1,798	1,634	1,965
	FIL	4,028	3,631	4,430	3,223	2,905	3,544	4,028	3,631	4,430
	FHL	962	845	1,079	769	676	863	962	845	1,079
	FBPL	3,067	2,786	3,351	2,453	2,229	2,680	3,067	2,786	3,351
	FIMI	0	0	0	0	0	0	0	0	0
	FIE	4,744	4,286	5,207	2,744	2,489	3,002	6,459	5,822	7,102
Laptops	FMH	14,519	12,749	16,289	14,519	12,749	16,289	14,519	12,749	16,289
	FMBP	9,554	9,554	9,554	9,554	9,554	9,554	9,554	9,554	9,554
	FHI	2,702	2,373	3,032	2,702	2,373	3,032	2,702	2,373	3,032
	FBPI	6,531	6,531	6,531	6,531	6,531	6,531	6,531	6,531	6,531
	FIH	2,153	1,890	2,415	2,153	1,890	2,415	2,153	1,890	2,415
	FIBP	603	603	603	603	603	603	603	603	603
	FIR	2,515	2,364	2,667	4,096	3,903	4,290	1,578	1,469	1,688
	FHR	1,241	1,090	1,393	1,589	1,396	1,783	898	788	1,007
	FBPR	1,274	1,274	1,274	2,507	2,507	2,507	681	681	681
	FIL	1,715	1,682	1,749	1,372	1,346	1,399	1,715	1,682	1,749
	FHL	275	241	308	220	193	247	275	241	308
	FBPL	1,441	1,441	1,441	1,152	1,152	1,152	1,441	1,441	1,441
	FIMI	0	0	0	0	0	0	0	0	0
	FIE	2,247	2,364	2,129	1,009	1,162	855	3,184	3,260	3,108

Table 39: (continued)

Product	Flow	Intended End-of-Use Scenario			Lower Reuse Scenario			Higher Export Scenario		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
CRT Monitors	FMH	275	241	308	275	241	308	275	241	308
	FMBP	1,206	1,096	1,317	1,206	1,096	1,317	1,206	1,096	1,317
	FHI	3,298	2,896	3,700	3,298	2,896	3,700	3,298	2,896	3,700
	FBPI	7,462	6,780	8,153	7,462	6,780	8,153	7,462	6,780	8,153
	FIH	412	362	462	412	362	462	412	362	462
	FIBP	302	274	330	302	274	330	302	274	330
	FIR	3,534	3,162	3,908	5,470	4,904	6,040	2,247	2,006	2,489
	FHR	1,608	1,412	1,804	2,162	1,898	2,425	1,154	1,013	1,295
	FBPR	1,926	1,750	2,105	3,308	3,006	3,615	1,093	993	1,194
	FIL	892	798	986	713	638	789	892	798	986
	FHL	412	362	462	330	290	370	412	362	462
	FBPL	479	436	524	384	348	419	479	436	524
	FIMI	0	0	0	0	0	0	0	0	0
	FIE	5,620	5,080	6,166	3,862	3,497	4,231	6,907	6,235	7,585
Flat Panel Monitors	FMH	8,244	7,239	9,249	8,244	7,239	9,249	8,244	7,239	9,249
	FMBP	16,827	15,290	18,385	16,827	15,290	18,385	16,827	15,290	18,385
	FHI	1,237	1,086	1,387	1,237	1,086	1,387	1,237	1,086	1,387
	FBPI	4,492	4,082	4,908	4,492	4,082	4,908	4,492	4,082	4,908
	FIH	1,466	1,287	1,644	1,466	1,287	1,644	1,466	1,287	1,644
	FIBP	1,542	1,401	1,685	1,542	1,401	1,685	1,542	1,401	1,685
	FIR	989	888	1,090	1,812	1,632	1,993	665	597	733
	FHR	330	290	370	469	412	526	231	203	259
	FBPR	659	599	720	1,343	1,220	1,467	434	394	474
	FIL	2,819	2,549	3,092	2,255	2,039	2,474	2,819	2,549	3,092
	FHL	412	362	462	330	290	370	412	362	462
	FBPL	2,407	2,187	2,629	1,925	1,749	2,104	2,407	2,187	2,629
	FIMI	1,134	1,001	1,267	1,393	1,234	1,552	1,680	1,493	1,867
	FIE	47	43	52	47	43	52	917	827	1,008

Notes: Flows pertain to Figure 7, which presents a schematic drawing of the flow analysis for the selected country.

Flows are from manufacturers (M) through residential households (H) and business/public (BP) users, to intermediaries (I). Intermediaries also collect used imports (Im) and either redistribute them for reuse to households (H) and business/public (B/P) users, send them to landfill or incinerator (L), sell them domestically for parts and materials recycling (R), or export them to a foreign country (E). The ordering of indices is from/to, i.e., FHI refers to flows from residential households (H) to intermediaries (I), and FIH refers to flows from intermediaries (I) to residential households (H).

Table 40: Weights of United States generation, collection, and export of used computers and monitors in 2010 as mean, and low and high bounds of the 95% confidence interval (metric tons)

Product		Residential			Business/Public			Total		
		Mean	Low	High	Mean	Low	High	Mean	Low	High
Desktops	Generated	60,758	25,741	115,814	113,595	49,780	210,787	174,352	75,522	326,601
	Collected	50,550	20,216	103,632	81,037	32,624	170,594	131,588	52,840	274,226
	Exported							50,363	12,743	128,059
Laptops	Generated	8,331	2,982	20,709	20,134	8,208	44,612	28,465	11,190	65,321
	Collected	7,484	2,595	19,390	15,693	6,398	36,740	23,177	8,992	56,130
	Exported							6,926	1,075	22,265
Computers	Generated	69,088	28,723	136,523	133,729	57,988	255,399	202,817	86,712	391,922
	Collected	58,034	22,810	123,022	96,730	39,021	207,334	154,764	61,832	330,356
	Exported							57,289	13,818	150,324
CRTs	Generated	51,597	29,958	83,358	116,801	70,148	183,694	168,398	100,106	267,052
	Collected	45,147	25,174	76,834	109,297	64,728	175,842	154,444	89,902	252,677
	Exported							87,960	36,181	170,896
Flat Panel Monitors	Generated	15,195	2,766	47,872	55,218	10,397	169,349	70,413	13,163	217,220
	Collected	10,130	1,588	37,880	25,635	3,699	108,988	35,765	5,287	146,868
	Exported							579	109	34,796
Monitors	Generated	66,792	32,724	131,230	172,019	80,544	353,043	238,811	113,269	484,273
	Collected	55,277	26,762	114,715	134,932	68,427	284,830	190,209	95,189	399,544
	Exported							88,539	36,290	205,692

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