Life Cycle Comparison of Traditional Retail and E-commerce Logistics for Electronic Products: A Case Study of buy.com

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Executive Summary

Problem
Advances in information and communication technology have provided consumers the option of shopping on-line instead of driving to a traditional retail store for many products. E-commerce has now grown from less than 1% of retail sales in 2000 to 3% in 2008. The alternative retail channels have some distinct differences with regard to environmental costs, including overstock inventory, physical store space, and consumer transport in traditional retail stores and individual packaging and last mile delivery for e-commerce. We build on prior comparative research and conduct a streamlined Life Cycle Assessment (LCA) to quantify variations in energy use and carbon dioxide (CO₂) emissions for the alternative systems using data received from the e-commerce industry for an electronic product. This report reviews our assumptions and analysis and provides conclusions and offer recommendations to decrease logistics LCA uncertainties.

Differences in Logistics Networks
The major differences between the traditional retail model and the e-commerce model are the transportation from the warehouses to the retail store or the distribution center, data center energy usage, individual vs. bulk packaging, and the transportation, from the store or distribution center to the consumer, often called the “last mile” of delivery. These differences vary in energy usage and intensity. The objective of our work was to assess which network uses less energy and produces less greenhouse gas carbon dioxide (CO₂) equivalent emissions.

Results
Our results confirm prior findings that e-commerce delivery uses less primary energy and produces less CO₂ emissions than traditional retailing. Considering retail and e-commerce logistics differences, the three largest contributors were customer transport, packaging, and last mile delivery. Customer transport encompassed approximately 65% of the traditional retail primary energy expenditures and CO₂ equivalent emissions on average. For e-commerce, packaging and last mile delivery were responsible for approximately 22% and 32% of the e-commerce energy usage, respectively. Overall, e-commerce had about 30% lower energy consumption and CO₂ emissions compared to traditional retail using calculated mean values.

There was significant uncertainty and variability in many of the numbers used in the analysis, particularly in terms of customer transport to the retail store (i.e., fuel economy, trip length, purposes per trip, etc). We used Monte Carlo simulations and scenario analysis to estimate that e-commerce being the less energy-conservative option approximately 80% of the time with average delivery logistics and 50% with air-only delivery logistics for e-commerce. To make the LCA transportation model more robust, actual data from a traditional retail business and more detailed information on consumer shopping behaviors are necessary.
1.0 Introduction

Consumers now have the option of driving to a traditional retail store or shopping on-line for many products. E-commerce has grown from less than 1% of retail sales in 2000 to 3% in 2008 (Census 2008). The alternative retail channels have some distinct differences. Retail stores have overstock inventory and physical store spaces. The packaging of individual products and last mile delivery are energy intensive for e-commerce. Similarly, bulk packaging and primarily truck delivery can reduce energy use and cost for traditional retail, but individual consumer trips account for significant carbon dioxide (CO₂) equivalent emissions. We compare the differences of e-commerce and retail logistics using data received from buy.com for electronic products and building on prior logistics Life Cycle Assessment (LCA) research. This paper reviews our LCA analysis, provides conclusions and offer recommendations to decrease logistics LCA uncertainties.

The changes that information and communication technology (ICT) has brought to people’s lives are commonly thought to be wholly environmentally beneficial. Past work has discussed in general terms the energy and environmental benefits of telecommuting over traditional commuting. Several authors have compared the energy and environmental emissions associated with online retail (here forth, e-commerce) to traditional retail methods. Matthews (2001) reported a comparison of book purchasing via e-commerce and traditional retailing which was updated and summarized in Hendrickson (2006). Matthews (2002) completed an LCA study reviewing energy and cost impacts of logistics networks for the retail of books in Japan and the U.S. Abukhader (2004) proposed a methodology for assessing ‘green supply chains’ for e-commerce. Toffel (2004) examined delivery of print products by digital means. Sivaraman (2007) examined alternative logistics systems for DVD rental. Abukhader (2008) analyzed the eco-efficiency of e-commerce supply chains. Kim (2008) also examined book retailing logistics. This paper differs from past studies by focusing on electronic products and using data directly from an online retailer and wholesale supplier. Thus, while the results are robust, it is important to realize the context is on a specific company and a specific class of retail products. Results could differ significantly for other retail and e-commerce companies, and for other products.

2.0 Study Scope and Boundary Description

In this study we specifically compare the energy use and CO₂ emissions associated with delivering a flash drive from the manufacturer to a home via retail or e-commerce. We included portions of the logistics chains that differed between retail and e-commerce in this study, such as product delivery. We excluded processes that were common to the two shopping modes, such as product manufacture. The energy associated with manufacturing and using products could be significantly larger than the delivery and purchase energy. We show a conceptualization of the transportation chains that the two delivery methods follow in Figures 1 and 2. The systems have similar processes in the early stages of product manufacturing and storage, but then differ later in the transportation chain.
Figure 1 shows a visual representation of the transportation chain for the traditional retail model. The product begins at the manufacturer from where it is assumed to be shipped by heavy-duty truck to the wholesale warehouse. The product sits in the warehouse (for simplicity we assume only one warehouse, owned by the retailer) for a certain amount of time until the product is in demand by the retail store, and we assume in the base case that it is then trucked directly to the store, packaged in bulk. Later we include the possibility for shipment to a secondary warehouse belonging to the retailer (or an intermediate distribution warehousing facility) before it is shipped to the actual store. Individual consumers drive by car from their homes to the nearest retail store to pick up the product and then return home. Of course the consumer trip to the retail store could include multiple stops or purposes, and this is discussed below in the methods and data section.

Figure 2 shows the transportation chain diagram for the e-commerce model. In the e-commerce model, the product begins at a manufacturer and is delivered to a distributor warehouse, again by heavy-duty truck\(^1\). While not shown as a part of the transportation flow in Figure 2, a customer shops for and buys a product on the e-commerce company website. After receiving information from the e-commerce company’s data center that the product has been ordered and needs to be shipped, the distributor warehouse individually packages and sends the product to the collecting and sorting distribution center via a parcel service, either by airplane and truck depending on the

\(^1\) We note that the company studied in this analysis, buy.com, does not have any warehouses. For electronic products their distributor is the only stock warehouse and provided data for this study. Other e-commerce companies having their own warehouses could have higher energy use than estimated here due to additional transportation and warehousing.
online consumer’s preferences for delivery time. The product, along with other products, is then taken to the individual homes via a light-duty (we assume a 20,000 lb) delivery truck.

![Figure 2: E-commerce Product Flow Diagram](image)

As can be seen in Figure 1 and Figure 2, the initial stages in the product delivery (manufacturing, transport to first warehouse, and storage at first warehouse) are similar for both retail models. We assumed that the first stage of transportation, from the manufacturer to the wholesale warehouse, was similar in both systems and could thus be ignored in a comparative analysis. The time spent for a package in collecting and sorting distribution center after the wholesaler warehouse and before the distribution center were assumed to be small relative to the time spent in a wholesaler’s warehouse and, therefore, their impacts were excluded from this study. The main differences in the transportation chains are from the warehouse to the retail store and distribution center and from the retail store or distribution center to the consumers. In addition, some potentially important non-transportation differences exist between the systems: energy usage in the data center to run the e-commerce web site, different uses of packaging (i.e., individual packaging vs. bulk packaging) from the wholesaler to the consumer, and energy use in the traditional retail store. We also modeled energy use and associated CO₂ emissions from wholesale warehousing, as sensitivity analysis and anecdotal evidence required a scenario where a traditional retail warehouse would exist between the wholesale warehouse and the retail store. For this scenario, we assumed that this retail warehouse (and transportation to it) had similar energy use as the wholesale warehouse where data existed.

In summary, the systems under consideration included the following stages within the comparative study boundary:
• Warehouse Energy usage (in the retail warehouse scenario)
• Electricity use at home computer to place e-commerce order
• Transportation from the wholesale warehouse to the retail store, distribution center, or retail warehouse
• Last mile transportation from local distribution center to customer home or from retail store to customer home
• Data Center electricity usage to run e-commerce website
• Individual vs. bulk cardboard packaging
• Energy use in traditional retail store

In contrast, the following stages or parameters were assumed to be similar between the systems and were not included in this comparative study:

• Transportation from manufacturer to wholesale warehouse
• Wholesale warehouse energy usage
• Energy use of corporate headquarters of retail and e-commerce companies
• Non-cardboard packaging

3.0 Method

Each process included within the system boundary had different data requirements and assumptions. Thus we discuss each process individually in the following sections. In general uncertainty was modeled using probabilistic analysis (Monte Carlo simulation) using triangular distributions where the most likely value was estimated from existing data and minimum and maximum likely values were estimated or taken as the largest and smallest available data point. Our functional unit of all deliveries is one flash drive.

3.1 Fuel Carbon and Energy Intensity

Table 1 shows the assumed energy content and carbon content of different fuels. This data was used to estimate the CO₂ emissions associated with the energy consumption during the product flow stages of the retail models included in this study. In addition to the fuels listed in Table 1, electricity is used in various stages of the product flow. In the U.S., the average fuel mix for electricity generation is consists of 50% coal, 20% natural gas, 3% petroleum, and 27% zero-carbon sources (IEA 2008). Using this average mix, the average emissions from electricity generation are estimated to be 1,350 pounds of CO₂ equivalents per MWh of delivered electricity (170 gr CO₂e/MJₑ) (Jaramillo 2007). Electricity-based energy was converted to primary energy equivalents based on the IEA substitution method, which represents an adjustment for the initial amount of energy/fuels needed to generate electricity in our relatively inefficient electric power plants (IEA 2008).
Table 1: Carbon Content and Heat Content for Energy Fuels (EPA 2006)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Carbon Content (Tg C/QBTU)</th>
<th>Heat Content (MMBTU/bbl or BTU/ft³)</th>
<th>Oxidation Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finished Motor Gasoline</td>
<td>19.3</td>
<td>5.25</td>
<td>0.99</td>
</tr>
<tr>
<td>Finished Aviation Gasoline</td>
<td>18.9</td>
<td>5.05</td>
<td>0.99</td>
</tr>
<tr>
<td>Kerosene-Type Jet Fuel</td>
<td>19.3</td>
<td>5.67</td>
<td>0.99</td>
</tr>
<tr>
<td>Distillate Fuel Oil</td>
<td>20.0</td>
<td>5.83</td>
<td>0.99</td>
</tr>
<tr>
<td>Residual Fuel Oil</td>
<td>21.5</td>
<td>6.29</td>
<td>0.99</td>
</tr>
<tr>
<td>Liquefied Refinery Gases</td>
<td>17.0</td>
<td>3.85</td>
<td>0.99</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>14.5</td>
<td>1,030</td>
<td>0.995</td>
</tr>
</tbody>
</table>

3.2 Energy Use at Data Centers

Data center electricity use was taken from Buy.com’s data center, metered for around 3 years. The data covers 932 days from 1/12/2006 to 8/14/2008 with 28 readings. The electricity meter was read on non-uniform intervals but the average interval was around 35 days. Each reading was given in kilowatt-hours (kWh) for the time that had lapsed before the prior reading. This electricity consumption was converted to megajoules (MJ) per shipment to compare to other energy usage and other branches of the life cycle of the product. Since the data center electricity consumption was given on a non-uniform measurement of time, a value in terms of MJ/day was first calculated and then multiplied by 30 to achieve a monthly estimate of energy usage, around 23,700 MJₑ/month. To estimate the data center energy usage on a shipment-by-shipment basis, the MJₑ/month value was divided by the total number of shipments from 5/25/2008 to 6/28/2008 (283,000, as provided by buy.com). This results in an energy usage of approximately 0.25 MJ/shipment related to the data center. It should be noted this is a conservative measure of the importance of data centers, as we allocated all data center energy usage to the shipments from their wholesale supplier, which represents only a portion of total buy.com orders, due to missing data.

3.3 Packaging

For packaging it was assumed that the main difference between systems was in the amount of cardboard used in both systems. Differences in plastic and paper packaging materials were assumed to be small. The traditional bulk retail box was assumed to be a 36”x36”x24” box, which was estimated to hold approximately 195 flash drives at a volume of 160 in³ (assumed to be 2” x 10” x 8”). The e-commerce shipping method was assumed to be flexible form corrugated foldable to a surface area of 396 in² (12” x 10” x 2” with some overlap). Both standard box sizes

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2 The wholesale supplier for buy’s operations will stay anonymous and be referred to as “the wholesale supplier”
and the average density of corrugated were taken from a commercial shipping box website (URI 2008).

Data on the energy and CO$_2$ intensities of corrugated cardboard were taken from the U.S. EPA’s Waste Action and Reduction Model (EPA 2008), which specializes in providing estimates of the energy and greenhouse gas emissions of various types of materials that become municipal waste. The mean value was taken to represent the case of source reduction in the usage of cardboard where reduction in demand for cardboard directly translates into reduced tree harvesting. Thus, forest carbon sequestration is counted in the mean assumed value. For the high value for energy and carbon intensity, forest carbon sequestration was counted and the reduction in demand was assumed to displace all virgin production as opposed to the average mix of virgin and recycled production. The low value was taken to displace the average mix and forest carbon sequestration was not counted, under the assumption that reduction in demand for cardboard would not affect tree harvests on the margin.

### 3.4 Distribution and Final Delivery

While the distance from warehouse to local distribution center or retail store was assumed to be similar given no better information, the distance is still relevant since the model energy intensity varies between road and air transport, as shown in Table 2 (Fachana 2006, Burnham 2006). The distance was taken from data provided by a major distributor of electronics to both retail and e-commerce systems. The distribution was fit to the monthly data (ZIP code to ZIP code, distances calculated as great circle distances multiplied by circuitry factors of 1 for air and 1.3 for road) given for the distributor to yield a 10$^{th}$, 50$^{th}$, and 90$^{th}$ percentile for air and ground shipping, which were assumed to represent the mean and extremes of a triangular distribution. This procedure yielded distributions of (164 mi, 1,177 mi, 2,814 mi) for air delivery and (79 mi, 410 mi, 1,270 mi) for ground shipping. The base case for traditional retail was assumed to be 100% ground delivery, while the base case for e-commerce was assumed to be the average mix of 12% air, 88% ground from provided data for the wholesale supplier. The flash drive was assumed to weigh 1 lb with packaging.

**Table 2: Modal Energy Intensity (Fachna 2006, Burnham 2006)**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Energy Intensity of Freight Modes (MJ/tonne-km)</th>
<th>Fuel Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Duty Truck (25 ton cargo)</td>
<td>0.74</td>
<td>100% Diesel</td>
</tr>
<tr>
<td>Medium Duty Truck (8 ton cargo)</td>
<td>1.58</td>
<td>100% Diesel</td>
</tr>
<tr>
<td>Air Carrier</td>
<td>9.93</td>
<td>100% Jet Fuel</td>
</tr>
</tbody>
</table>

For the final delivery (last mile) portion of the logistics chain, data on total system energy per package was taken from a large commercial delivery company (UPS 2006). The system-wide energy use per package was 28.1 MJ/package from this data set, but this represented all energy, not just last mile energy. We used the percentage of energy use from diesel to approximate the
last mile energy intensity (10 MJ/package). To check this assumption, data was also gathered from local interviews of delivery truck drivers, who gave a distribution of packages delivered per day and miles driven from the local distribution center. This data (ranging from 0.1 to 1 miles/package delivered) was combined with the energy efficiency of a 20,000 lb delivery truck from (Davis 2008), given as 18 MJ/mile.

3.5 Customer Transport to the Retail Store

The energy and emissions associated with customer transport to the retail store was modeled using the Equation 1.

\[
\text{Equation 1: Energy Consumption for Customer Transport} \\
E_{\text{item}} = \frac{(mi)(E_{\text{gal}})}{(mi/gal)(p_{\text{veh}})(items/p)} \\
\]

Each of the parameters in Equation 1 was treated parametrically or probabilistically. The distribution for miles driven was to have a minimum of 2 miles and a maximum of 20 miles, by assumption. The mean value was taken from the 2001 National Household Travel Survey (NHTS), which gave a round trip of 14 miles for shopping purposes (DOT 2004). The average fuel economy of the US fleet was taken from the US EPA, and assumed to be 22 mi/gal, with a minimum of 10 and a maximum of 30. The persons per vehicle was also taken from the NHTS, which gave a mean estimate of 1.5 person-trips/vehicle-trip for shopping purposes with a minimum of 1 and a maximum of 2. The same distribution was assumed for items/person on each trip, given no better data immediately available.

For the probabilistic analysis it was assumed that the different items purchased in a trip was correlated with distance the customer had to drive to the store, with a correlation coefficient of 0.7. It was also assumed that the customer driving distance was correlated with the distance of the last mile delivery for e-commerce shipments (since those households living further from a retail store likely also live further from a distribution center). The correlation coefficient was again assumed to be 0.7.

3.6 Warehouse Energy Usage

Buy.com utilizes their wholesale supplier for five regional distribution warehouses. The Commercial Buildings Energy Consumption Survey CBEC is a large survey done by the Department of Energy that estimates energy intensities for various types of commercial businesses, including retail stores. These data sources summarize the average sales (in dollars) and size (in square feet) for many types of businesses. In order to quantify the energy and CO₂
equivalent, monthly electricity bills were received from the wholesale supplier outlining their electricity consumption, and CBECS (2003) data was used for the average warehouse natural gas use. In the distribution warehouse, the electricity was assumed to be used for lighting, while natural gas was used for heating. Given that Buy.com approximately distributes 300,000 packages per month through all five warehouses, calculations were made to associate the energy use to each package.

In terms of electricity, monthly bills were analyzed per warehouse and allocated in terms of percent of buy.com business versus total wholesale supplier sales which is on average 11%. It was assumed that each warehouse distributed one fifth of the 300,000 packages sold in June. From the calculations, the average electricity contribution is 1 kWh/shipment. For natural gas consumption, the CBECS annual warehouse data was used in each climate zone. These natural gas energy intensities were correlated to the five warehouses and allocated per package. From the calculation, the monthly natural gas contribution on average is 0.2 MJ/shipment. Therefore, the total contribution of primary energy consumption and greenhouse gas emissions is 11 MJ/shipment or 675 gCO$_2$/shipment.

3.7 Energy Usage in Retail Stores

Data on energy use of retail stores came from HDL Companies and the Commercial Buildings Energy Consumption Survey. HDL Companies suggests the average retail sales are $250 to $900 per square foot (Bizstats 2008). Note that given the case of flash drives used in this study, the retail sales per square foot for Best Buy ($900/square foot) was used. For energy use, the Commercial Buildings Energy Consumption Survey (CBECS 2003) was used. From CBECS, the total energy use for retail (non-mall) stores ranges from 31 to 130 megajoules per square foot (MJ/sf) (25$^{th}$ to 75$^{th}$ percentile values). For retail stores in malls the energy use ranges from 60 to 153 MJ/sf. Given our data needs we allocate energy use instead by dollars of sales, resulting in an estimated energy use value in MJ/$, which ranges from .03 to .14 MJ/$ for non-mall stores (at $900/sf) and .07 to .17 MJ/$ for retails stores in malls (CBECS 2003). We assume a retail price of $10 to convert these intensities into MJ of energy uses in the retail phase.

3.8 Energy Usage in Homes for Placing E-commerce Orders

The consideration of home computer energy use has varied over time and our method is inspired by but not repetitive to these methods (Sivaraman 2007, Toffel 2004, Williams 2004). Past work has included the energy of the computer and monitor (often desktop computers despite the high prevalence of laptops today), lighting and heating/cooling within the room, and the network energy overhead for the transaction. We assume a range of 60 W-100 W for an average computer, representing reasonable values for current laptops and desktops with monitors. We further assume a person spends an average of 15-30 minutes shopping online for the flash drive and that all energy use by the computer during this time can be allocated to the purpose of buying the flash drive. This represents an upper bound estimate, though often computer users are performing multiple tasks at once. We also include an allocated share of the production energy of the computer (.004 kWh/minute), using an assumed lifetime of 3 years, since previous work has shown the importance of the production phase for computers (Williams, 2004; Toffel, 2004). Although we specifically included buy.com's data centers, there is further energy use upstream of
the buyer in the non-Buy.com internet infrastructure. We take numbers from Taylor and Koomey (2008) which estimates average energy usage of Internet traffic around 9-16 kWh/GB of data. We assume an upper bound value of 1 MB data usage for the online purchase. These ranges lead to an estimate of 1-2 MJ of primary energy use from the consumer placing the order online.

4.0 Results and Discussion

4.1 Average Results

Results are shown first in terms of mean estimates for energy and CO₂ emissions, then in terms of probabilistic assessment of the difference between the systems. Figures 3 and 4 show the base case results for total primary energy (MJ/item) and CO₂ emissions (g CO₂/item) for the two systems, and we estimate that e-commerce performs better than retail. The results look similar due to the close correlation of energy and CO₂ emissions. Thus for all other results only CO₂ emissions are shown.

![Figure 3: Total Primary Energy associated with Retail and E-commerce systems by stage](image-url)
The e-commerce delivery system studied here delivers the flash drive from manufacturer to consumer with less CO₂ emissions (2200 g CO₂/delivery compared to 2800 g CO₂/delivery for traditional retail). In general there are 5 major contributions to the differential life cycle CO₂ emissions of the two systems: customer transport to and from the retail store (65% of retail), wholesale warehousing (26% of retail and 31% of e-commerce), cardboard individual packaging (22% of e-commerce), and last mile delivery (32% of e-commerce). Freight transport between the wholesale warehouse and distribution center or store, energy use in the retail store, customer computer and network use, and data center electricity use made minor contributions to the overall results.

Customer transport in the retail system is the most important parameter to the overall results, being similar in scale to the overall emissions related to the e-commerce system (~2000 g CO₂). This is consistent with past findings (Hendrickson 2006; Matthews 2002; Abukhader 2004; Toffel 2004). Error bars representing the 90th percentile range of the Monte Carlo results show the relatively large amount of variability and uncertainty in the calculation, ranging from around 1600-3600 g CO₂ for retail and 1600-2600 g CO₂ for e-commerce. Thus a quantitative assessment of the importance of the different parameters to the overall results would clearly be valuable.

Two other scenarios warrant attention: a second warehouse stage in retailing and an express (air) delivery in the e-commerce system. Figure 5 shows the results assuming 2 warehousing stages and 2 freight stages occur in the delivery for the traditional retail system. Emissions per item increase to 3400 g CO₂/item, doubling the difference between systems from 600 g to 1200 g CO₂. This scenario could be seen as the maximum likely difference between the systems (for mean values). In contrast, to investigate the minimum likely difference a full air delivery for e-commerce is shown in Figure 6. The (air) freight emissions from wholesale warehouse to distribution center is now much more substantial, at 400 g CO₂, bringing the difference in systems down to 300 g CO₂.
4.2 Uncertainty and Variability: Probabilistic Results

Up until now results have been discussed in terms of mean values (or values of maximum likelihood). However, substantial uncertainty exists in many of the parameters of the model and significant variability exists between different individual users of the different systems. Thus we show the results of a joint probability assessment of the difference between the two systems in several figures to follow. As discussed above, all parameters were assumed to be independent except the customer driving distance, which was assumed to be correlated with both the number
of purposes per trip as well as the energy intensity of last mile delivery. We use the base scenario and the express air delivery scenario to examine quantitatively the likely range of differences between systems and the most important model parameters for the difference.

Figure 7 shows the cumulative distribution of the difference between CO$_2$ emissions associated with the E-commerce and retail systems (e-commerce CO$_2$/item – retail CO$_2$/item). The important thing to note is that although the 90th percentile ranges overlap significantly (see Figure 4). It is somewhat unlikely for the retail system to ever have lower emissions than the e-commerce system (only 20% probability, represented as a negative difference in Figure 7). This is due to both the assumed correlation between driving distance and last mile energy intensity as well as the relatively low probability of drawing several low CO$_2$ values for retail and high CO$_2$ values for e-commerce. The category importance graph, showing the correlation of individual parameters with the difference, shows the most important parameters of the model are, in order: distance driven to retail store, fuel economy of consumer auto, last mile energy intensity, individual cardboard packaging used in e-commerce, and retail store electricity usage. However, the importance of these top parameters is not the same; driving distance is roughly 7 times as important as retail electricity usage, and fuel economy is roughly 5 times. Thus, it is clear that consumer transport in the retail system is very important to the overall comparison, which is intuitive given the overall importance to the retail value as well as its large variability.
Similar results are seen for the express air delivery scenario in Figure 8, though with the expected result that there is a higher probability (around 50%) of the retail system having less CO₂ emissions and the difference between systems is smaller at all probability values. Similarly, the important parameters change slightly, with the delivery distance (e-commerce Air ton-mi) a much more important parameter when express air service is used.
Figure 8: Cumulative distribution of difference between systems (g CO2/item) for express air delivery scenario and importance analysis (using correlation coefficients) of individual model parameters

Acknowledgments
We acknowledge the Green Design Consortium for support, buy.com (and an anonymous buy.com partner) for providing unprecedented access to data needed to complete this study. This material is based partly upon work supported by the U.S. National Science Foundation under grant #0755672. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.
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Errata

March 8, 2011 edits: Section 3.6 on Warehousing incorrectly reported values and units used in the model, and were updated. The model was correct but the reported values were transcribed incorrectly. The old paragraph excerpt read:

From the calculations, the average electricity contribution is 3.7 MJ/month/shipment. For natural gas consumption, the CBECS annual warehouse data was used in each climate zone. These natural gas energy intensities were correlated to the five warehouses and allocated per package. From the calculation, the monthly natural gas contribution on average is 0.2 MJ/shipment. Therefore, the total monthly contribution of primary energy consumption and greenhouse gas emissions is 3.9 MJ/shipment or 13.5 gCO$_2$/shipment.

The revised paragraph excerpt reads:

From the calculations, the average electricity contribution is 1 kWh/shipment. For natural gas consumption, the CBECS annual warehouse data was used in each climate zone. These natural gas energy intensities were correlated to the five warehouses and allocated per package. From the calculation, the monthly natural gas contribution on average is 0.2 MJ/shipment. Therefore, the total contribution of primary energy consumption and greenhouse gas emissions is 11 MJ/shipment or 675 gCO$_2$/shipment.