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Assessing Negative Externalities of E-Waste Exportation and the Potential Shift to Domestic Processing

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ABSTRACT

In this paper, I will discuss the prominence of informal e-waste management and the historical unidirectional export flow of e-waste from developed to developing countries. Focusing on the exportation of e-waste from the United States to China, this paper considers health studies from Chinese communities near informal e-waste treatment centers and the Japanese LIME externality model to estimate a quantitative value of the negative externalities caused by e-waste exportation. Conjoint survey results are subsequently implemented to approximate consumer willingness to reduce e-waste related externalities. Then, cost data from formal U.S. e-waste processing centers will be used to assess the expected cost of eliminating e-waste exportation in favor of domestic processing. The willingness to reduce e-waste externalities will be compared with the cost of reducing such externalities to provide insight into the potential benefits of eliminating e-waste exportation.

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Chapter 1
Introduction

Electronic death is anything but uncommon: batteries lose their lifespan, chargers fray, and laptop displays crack. A staple of consumption culture, the perpetual cycle of purchasing, trashing, and repurchasing our devices yields surprisingly devastating international consequences. According to sustainability expert Rick LeBlanc, e-waste, defined as “any discarded products with a battery or plug” amounts to an estimated $55 billion in material loss annually. While $55 billion is far beyond negligible, environmental researchers are now discovering that the negative impact of e-waste disposal may even be exponentially greater. LeBlanc estimates that, on average, every American produces roughly 44 pounds of e-waste annually, 40% of which is swiftly exported to toxic landfills in Asia. As e-waste generation continues to accelerate, individuals afflicted by e-waste-related environmental damages are susceptible to “severe damage to human blood and kidneys, as well as central and peripheral nervous systems,” (LeBlanc, 2018).

Unfortunately, there is no evidence that this trend is slowing; Americans have become accustomed to the vicious cycle of device turnover, as evidenced by their average phone ownership time of less than 34 months (Krouse 2018). While alarming, these numbers are hardly surprising. In the past several decades, many electronics companies have been accused of adopting a planned-obsolescence model that forces consumers to upgrade their “obsolete” devices after an artificially short period of time (Adorno, 2021). These companies rapidly churn out software updates and device iterations year after year, profiting from compliantly desensitized consumers eager to stay up to date.

One issue lies in visibility; when such a large quantity of waste is simply exported to another country, both consumers and corporations alike are often unaffected and unaware of the true cost of their actions. In economics, this phenomenon is called a negative externality: despite contributing to eventual health, environmental, and economic damages felt by others, neither the local consumer nor local producer bear a cost when they generate e-waste. Thus, when Americans produce e-waste, their private costs (costs that affect only Americans) are substantially lower than their social costs (costs that affect both Americans and anybody else down the line). Given the longstanding economic assumption that private actors maximize utility by increasing consumption until marginal benefit equals marginal cost, one of the implications of a negative externality with low private costs is a larger quantity of consumption than what is socially desirable. Thus, it is expected that Americans export a larger-than-optimal quantity of e-waste given they do not experience the associated negative externalities.

In theory, one can eliminate negative externalities by simply increasing marginal private costs to match marginal social costs; in practice, negative externalities have been reduced through regulation such as taxes, tariffs, and penalties. As discussed in the following chapter, economists have yet to quantify the difference in marginal private cost and marginal social cost (the externality) for e-waste. Additionally, discussion of rectifying said externality is rare in both American media and policy debates. This paper provides a quantitative estimate of the negative externalities of American e-waste exportation to China, as well as the cost to alternatively process e-waste domestically. This paper is the first step in bringing awareness to the e-waste problem with an action-oriented goal of eliminating externalities.

Chapter 2

Literature Review

2.1 E-Waste History and the Rise of Informality

In March of 1989, 35 states signed the Basel Convention on Transboundary Movements of Hazardous Wastes and Their Disposal ("Basel Convention") which required both importing and exporting countries to ensure that hazardous wastes are managed in accordance with environmentally sound procedure ("Basel Convention…" 1988). According to economist Rebecca Kirby (1994), the Basel Convention "strives to protect human health and the environment from the dangers presented by the mismanagement and careless disposal of hazardous wastes." However, a relatively strong consensus throughout the literature suggests that the Basel Convention and subsequent regulation have been largely ineffective. In his assessment of the Basel Convention on international trade in hazardous wastes, economist Olav Stokke (2013) sums up: "Clear indicators of the effectiveness of the Basel Convention remain scarce because of the lack of consistent, comparable, and robust data regarding total volumes of hazardous wastes that are traded as well as quantitative and qualitative changes in domestic waste-management strategies." Economist Alan Andrews (2009) shares a similar perspective in his *Law Environment and Development Journal* article, claiming "The Convention is currently failing to prevent the developing world from being used as a dumping ground for the industrialized nation's hazardous waste."

While concerns regarding a lack of data are expressed in much of the relevant literature, there is evidence that informal e-waste disposal is very prominent. In a comprehensive literature review assessing the scope of informality in Chinese waste management, researchers Linzner and Lange (2013) estimated the number of informal workers in China alone to be between 2,500,000 and 6,000,000. E-waste management is likely a large fraction of total informal employment within China; it is estimated that 40% of e-waste generated within China is dismantled by informal recycling facilities (Breivik et al., 2014). A contributing factor to such a large informal sector may be weak enforcement. While the Basel Convention explicitly bans e-waste exportation and informal disposal, critics have noted that “local governments often fail to accomplish their responsibility due to the lack of effective administrative mechanisms” and that “ineffective enforcement has been responsible for increased illegal e-waste activities,” (Ni & Zeng, 2009). Overall, while the Basel Convention attempted to reduce negative externalities by making dangerous practices illegal, the legislation failed to stifle the persistence of the inefficient and unsafe informal e-waste management sector.

2.2 Tracking Global E-Waste Flows

Current literature suggests a strong unidirectional flow of e-waste from developed to developing countries (Andrews, 2009). One study, measuring macroeconomic and social factors, sought empirical verification of this unidirectionality, as well as the potential influence of confounding variables (Efthymiou et al., 2016). To assess illegal e-waste industrial growth, Efthymiou and other researchers selected two potential confounding variables: macroeconomic and social. To measure macroeconomic factors, the researchers tracked GDP per capita and the

Open Markets Index (OMI). To measure social factors, the researchers tracked the Human Development Index (HDI) and the Social Progress Index (SPI). Then, the researchers divided their study into two categories: known and suspected routes of pollution and compared "sender" and "receiver" countries. The study assigned scores to each of the metrics in both developed "sender" developing "receiver" countries; a value of "1" was assigned if the sender country had a higher measurement of the above factors and "0" otherwise.

After running several statistical regressions on the known and suspected flow of illegal e-waste between the sending and receiving countries, Efthymiou identified a "strong connection between high scorings and sender countries in both known and suspected routes." This finding partially confirmed the initial suspicion that illegal e-waste trade flows from developed to developing countries despite several exceptions of high social scores such as Singapore (known route) and Chile, Malaysia, and the UAE (suspected). The study also found that while the average percentage differences between sender and receiver countries in GDP per capita, OMI, HDI, SPI, were all negative, GDP per capita had the strongest correlation. Overall, the study concluded that "illegal e-waste trade is not only a matter of economic evaluation, but further parameters need to be taken into account, such as social development, lack of or loose relevant legislation, and law enforcement efficiency."

Another publication, authored by Heacock (2016), aligns with Efthymiou's findings. In addition to citing several additional articles affirming Efthymiou's findings that e-waste flows mostly from developed to developing countries, Heacock notes that the negative externalities from this unidirectional flow are amplified, given that "in many low- and middle-income countries, handling and disposal of electrical or electronic equipment (EEE) [is] frequently unregulated." In developing countries, e-waste recycling is primarily conducted in the informal sector—a sector characterized by loose and unaccountable labor regulations. Common labor practices include “acid baths, burning cables, breaking apart toxic solders, and dumping consequent waste material,” all of which yield a high risk for chemical injury (Heacock, 2016).

It is imperative to note that much of the current discourse on informal e-waste management is not yet supported by empirical analysis. Because informal sectors are unregulated and poorly managed, researchers must analyze suspected illegal activity in which there is an inherent lack of data. In fact, Efthymiou (2016) states that there is “no quantitative data available” and that “further statistical analysis using the actual flows of e-waste trade is not possible.” Additionally, Efthymiou outlines several other questions requiring follow-up, such as an interest in “the analysis of the illegal e-waste trade occurring between developing countries, countries that act as transit points of e-waste, and what circumstances illegal e-waste trade takes place between developed country.” Nonetheless, Efthymiou acknowledges these weaknesses and provides all underlying assumptions and the data they are based on, which would allow for simple recalculations in the future should more data be collected.

2.2 Negative Externalities of E-Waste Exportation and Informal Processing

Since e-waste is a relatively recent phenomenon, there is little empirical data regarding the true extent of associated negative externalities. However, it is generally accepted within the scientific community that the current improper treatment of e-waste is incredibly harmful to local populations and environments. To date, there have been several observational case studies providing significant evidence of the negative externalities caused by e-waste exportation and its disposal.

One such study analyzed the effects of e-waste disposal on residents and e-waste workers in Guiyu, China (Xing et al., 2009). Specifically, the researchers zeroed in on PCB levels in fish, atmosphere, and human milk. PCBs, or polychlorinated bophenyls, are highly toxic industrial compounds that can build up in our bodies. PCBs are commonly used as coolants and lubricants in transformers and capacitors in electronic products; dismantling PCB-containing wastes or engaging in combustion processes could release PCBs into the atmosphere ("What Are…" 2014). Given that PCBs are given off in high concentrations during e-waste treatment (Xing et al., 2009), they can be a reliable measure to assess the larger effects of all chemicals released during the process. While the researchers note that several chemicals such as polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyls ethers (PBDEs), polychlorinated dibenzo-*p*-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) have been proven to also cause pollution in air, dust, soil, river water, and sediment, they focused specifically on PCBs.

The study aimed to "investigate PCB concentrations and congener profiles in environmental media, food samples and human specimens from the e-waste scrapping center" to "assess human health risk at the e-waste recycling site due to exposure to PCBs, including food and inhalation exposure." To do so, the researchers collected seven species of commonly consumed freshwater fish, eighteen air samples near the burning sites and within the surrounding area, and nineteen human milk samples from local doctors. The researchers measured the PCB levels in each sample using the standard GC/MS and QA/QC analyses. The researchers found that all of the fish samples contained "at least one order of magnitude higher than those collected from other locations in China" which was likely due to bioaccumulation near the e-waste treatment site. Additionally, the researchers found "large amounts of PCBs were released from the open burning of circuit boards and cable wires, and atmospheric transport could be a possible source for PCB pollution in the vicinity." Lastly, the researchers noted that the human milk samples also had elevated levels of PCB samples, which "were significantly correlated to the frequency of fish consumption of the donors." The researcher's conclusion outlined that PCBs impacted both the surrounding environment and its organisms both directly and indirectly with the ultimate recommendation that "further detailed investigations on human exposure and epidemiological studies of health impacts due to PCBs released in e-waste sites should be carried out."

Another study, conducted in response to reports of abnormal fertility rates in the Taizhou area, also found correlation of negative health externalities with proximity with e-waste treatment centers (Chen, 2012). In this study, the researchers chose to focus on the Taizhou area in Zhejiang Province, East China, given that it is one of the two largest e-waste disassembly centers of China. Past research has already revealed the presence of "PBBs, PBDEs, and PCBs with high concentrations" in local hair samples, indicating that there may be a correlation between e-waste treatment and chemical releases. Here, the researchers focused on the Nanguan River of Taizhou area, which is a water source for locals as well as downstream occupants. The objective of analyzing this river was to "investigate the possible incidence of e-waste recycling process on the local reproduction based on the detection of the (anti)estrogenic effects in surface sediments by using yeast estrogen screen assay (YES)."

In addition to the Nanguan River, the researchers also selected a control site, DG, that they believed was not in close proximity to an e-waste treatment site. The researchers described their method of taking 10g samples which were Soxhlet-extracted with 200mL high purity acetone/hexane (1:1, v/v) for 48 hours at four to six cycles per hour. By using a yeast estrogen screen assay, the researchers accounted for both unanalyzed chemicals and potential non-additive interactions among compounds that could imitate an estrogenic response. The researchers then created a curve to calculate the EEQ values for the sedimentary samples as well as a correlation between the samples and the proximity to the research site.

After testing all their samples and running several statistical regressions, the researchers concluded that the water near the e-waste treatment site contained “significant synergistic and anti-estrogenic effects, respectively.” Additionally, when compared to a control site with negligible readings, the researchers found that e-waste recycling sites ranged from 6.01 to 29.31 nmol/kg dw E2 equivalents by water extraction and 20.47 to 135.02 nmol/kg dw by water extraction. The researchers did not interact with humans to confirm the effects of water consumption; the researchers only focused on the chemicals present in the sediment that are known to be damaging to the environment and humans.

Chapter 3

Methods

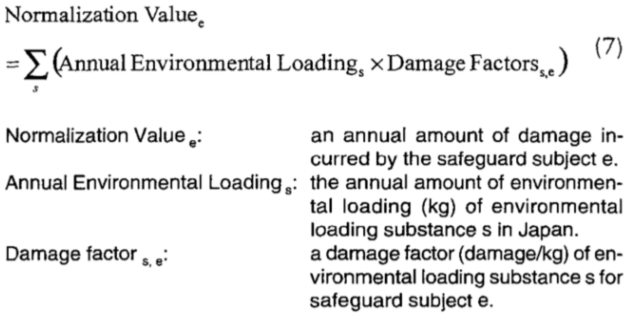
This paper implements methodology from the Life-cycle Impact Assessment Method based on Endpoint Modeling (LIME). Conjoint data from the original application of the LIME model was extrapolated to obtain a social estimation of the cost of damage associated with e-waste exportation to China. Then, cost data from domestic e-waste processing centers was obtained to approximate the required cost to transfer from exportation to domestic processing, which was compared to the results of the LIME model.

3.1 Introduction to LIME Life-Cycle Impact Assessment

A common way to quantify negative externalities is a life-cycle impact assessment (LCIA). Many economists have developed their own rendition of a LCIA; to date, there is no international consensus on which LCIA index is universally applicable. Nonetheless, most LCIA models follow similar theory and methodology. Generally, potential drivers of externalities are separated into categories, with individual weight assigned to each driver as an indication of scope and severity. Each factor is then normalized (the process where the most substantial deviation between methods occurs) to determine a uniform impact measurement of the externality. The LIME model is a variation of LCIA developed by the Japanese Ministry of Economy, Trade, and Industry in 2003. The LIME model was chosen for three key reasons: applicability to e-waste pollution analysis, normalization metrics in units of monetary value, and potential for future conjoint analysis.

Although developed to assist in “quantifying environmental impacts that are induced by the occurrence of environmental loading in Japan,” the Japanese national project of life cycle assessment (LCA Project) was designed to provide both economic valuations and dimensionless indexes that will “contribute greatly to increasing the level of research into weighting methodology,” (Itsubo et. al 2004). The model categorized its assessment around four “safeguard subjects,” or “endpoints” affected by an externality: human health, social assets, biodiversity, and primary production. The model then considered damage factors relating to safeguard subjects, such as years of human life lost relating to human health or incremental risk of extinction relating to biodiversity. As discussed above, existing research on safeguard subjects affected by informal e-waste processing indicates a strong fit within this framework, supporting the use of LIME over other LCIA frameworks.

A key feature of the LIME model is the integration of normalization values to non-dimensionalize impact categories under a common standard. Normalization allows for a quantitative valuation of fundamentally different metrics; for example, years of human life lost and incremental risk of species extinction can be normalized into monetary damages and thus compared. To conduct normalization, measurements of environmental loadings discharged by subject products during their life cycles (measured in kgs) are multiplied by the damage to the subject per unit of environmental loading, or damage factors, according to the following equation in Figure 1:



$$\text{Normalization Value}_e = \sum_s \left(\text{Annual Environmental Loading}_s \times \text{Damage Factors}_{s,e}\right) \quad (7)$$

Normalization Value $_e$: an annual amount of damage incurred by the safeguard subject e.

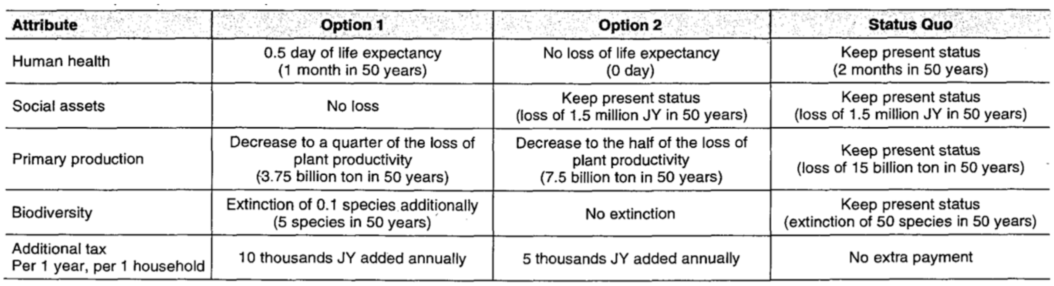
Annual Environmental Loading $_s$: the annual amount of environmental loading (kg) of environmental loading substance s in Japan.

Damage factor $_{s,\,e}$: a damage factor (damage/kg) of environmental loading substance s for safeguard subject e.

Figure 1: LIME Normalization Value Calculation

This normalization factor captures the extent of environmental externalities for each safeguard subject in terms of quantitative damages.

Unlike other life-cycle impact assessments, LIME also integrates conjoint analysis. Conjoint analysis is a survey-based measurement method used originally in marketing research to measure consumer preferences via questionnaire surveys. Conjoint analysis is a generic methodology of preference assessment for several attributes. Typically, conjoint analysis includes the use of profiles to bind attributes, thus representing specific products or scenarios (e.g. utility for a vehicle is an aggregate of attribute-specific utility for the engine, wheels, capacity, etc.). Conjoint analysis is not typically applied within life cycle assessment frameworks; however, LIME integrates conjoint analysis as an environmental economic valuation method. When presented with normalization values as the status quo, respondents are asked to choose between a range of options, each with ascending values of taxation to reduce damages. Figure 2 depicts a sample of the original conjoint analysis survey questions provided by the Japanese Ministry to respondents:



Attribute	Option 1	Option 2	Status Quo
Human health	0.5 day of life expectancy (1 month in 50 years)	No loss of life expectancy (0 day)	Keep present status (2 months in 50 years)
Social assets	No loss	Keep present status (loss of 1.5 million JY in 50 years)	Keep present status (loss of 1.5 million JY in 50 years)
Primary production	Decrease to a quarter of the loss of plant productivity (3.75 billion ton in 50 years)	Decrease to the half of the loss of plant productivity (7.5 billion ton in 50 years)	Keep present status (loss of 15 billion ton in 50 years)
Biodiversity	Extinction of 0.1 species additionally (5 species in 50 years)	No extinction	Keep present status (extinction of 50 species in 50 years)
Additional tax Per 1 year, per 1 household	10 thousands JY added annually	5 thousands JY added annually	No extra payment

Figure 2: Conjoint Survey Sample

Upon application, researchers incorporate survey responses with the normalization values to measure the social valuation of safeguard subjects such as biodiversity and human health. Subsequently, generalized willingness to pay to reduce negative environmental factors is used to weight impact factors that cause damage to the safeguard subjects. The integration conjoint analysis into the LIME framework yields a “willingness to pay for annual damage” estimation, accounting for both the scope and perceived severity of damages. In the original application of LIME, Japanese economists used conjoint analysis to assess nationwide willingness to pay for varying levels of safeguard subject protection.

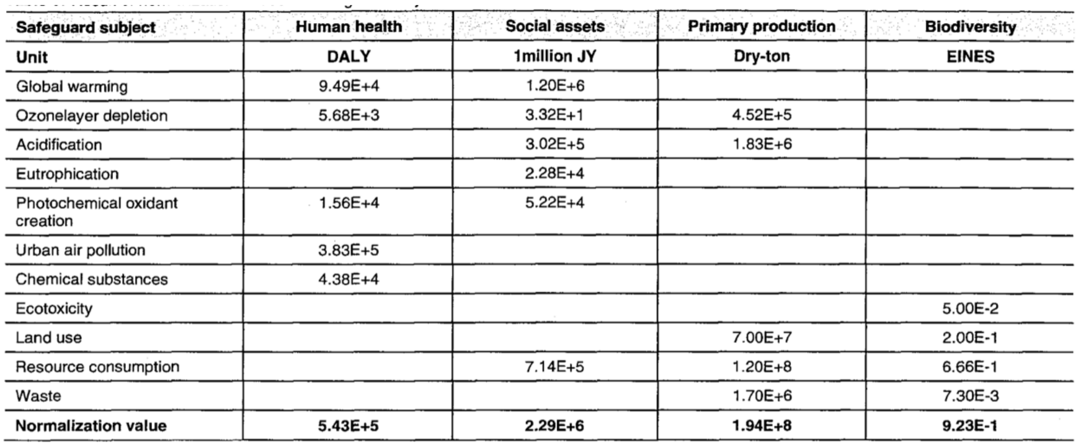
3.2 Application of LIME Life-Cycle Impact Assessment

To apply the LIME framework to an e-waste externality analysis in China, the research studies on communities near informal e-waste treatment centers discussed in Chapter 1 were considered to select safeguard subjects. The three safeguard subjects based on the studies were: human health (measured in incremental years of life lost), social assets (measured in dollars), and biodiversity (measured in incremental increase in chance of pollution). Due to the current limitations on Chinese data availability, heightened by the lack of reporting on the informal sector, this paper uses the baseline damage normalization data from the Japanese LCA National

Project LIME development, which was then scaled using aggregate emissions ratios between China and Japan as proxies for emissions gaps. Limitations of using proxy data are discussed below.

3.3 Selection and Approximation of Safeguard Subject Normalization Values

As discussed in Chapter 1, high concentrations of PCBs are associated with adverse human health effects, such as abnormal fertility, childhood mortality, etc. Although the list and scope of the harmful chemicals released by informal e-waste processing still remains uncertain, case studies have revealed a direct correlation between PCB levels in both fish and humans with proximity to e-waste treatment sites (Xing, 2009). Given the informal nature of e-waste management in China, yearly PCB emissions are unknown. Thus, to estimate the amount of PCB emissions (and generalized human health effects) in China, the normalization value for human health and biodiversity derived by the Japanese Ministry (Itsubo et. al. 2004) were multiplied by the ratio of mean annual air particulate exposure data (Brauer, 2017) between Japan and China. Figure 3 depicts the Japanese normalization values used, while the scaling and calculations for this paper are depicted in Appendix A.



Safeguard subject	**Human health**	**Social assets**	**Primary production**	**Biodiversity**
Unit	**DALY**	**1million JY**	**Dry-ton**	**EINES**
Global warming	9.49E+4	1.20E+6		
Ozonelayer depletion	5.68E+3	3.32E+1	4.52E+5	
Acidification		3.02E+5	1.83E+6	
Eutrophication		2.28E+4		
Photochemical oxidant creation	1.56E+4	5.22E+4		
Urban air pollution	3.83E+5			
Chemical substances	4.38E+4			
Ecotoxicity				5.00E-2
Land use			7.00E+7	2.00E-1
Resource consumption		7.14E+5	1.20E+8	6.66E-1
Waste			1.70E+6	7.30E-3
Normalization value	**5.43E+5**	**2.29E+6**	**1.94E+8**	**9.23E-1**

Figure 3: Japanese Ministry LIME Normalization Values

In addition to affecting both human health and biodiversity, emissions associated with e-waste treatment centers have a negative effect on the general environment. According to the "social assets" column in Figure 3, these chemicals have effects on global warming, ozonelayer depletion, acidification, eutrophication, and resource consumption. To obtain an estimate on the generalized effects of e-waste externalities in China, the social assets normalization value depicted in Figure 3 was multiplied by the ratio of total carbon dioxide emissions data reported by the Climate Watch (Climate Watch, 2021) between Japan and China. Scaling and calculations are depicted in Appendix A.

3.4 Approximation of Conjoint Analysis Willingness to Pay for E-Waste Externalities

Once normalization values depicting the extent of environmental damage were obtained, conjoint analysis was implemented to assess citizens' willingness to pay to reduce such damages. Ideally, a conjoint analysis survey regarding U.S. citizens' willingness to pay would be conducted; however, such research is beyond the scope of this paper and is grounds for future research. For this analysis, the conjoint results for Japanese consumers' willingness to pay to reduce each respective unit of damage to safeguard subjects (used by the Japanese Ministry in the initial implementation of the LIME model) were used as a substitute. To estimate the willingness to pay for annual e-waste related externalities, the scaled Chinese normalization values were multiplied by the Japanese conjoint results, which were then converted from Japanese Yen to USD. Calculations are depicted in Appendix A.

3.5 Estimation of Required Cost to Eliminate E-Waste Exportation

While a large amount of U.S. generated e-waste is exported to China, domestic processing does occur in several states. To assess the cost to conduct all e-waste processing within the United States in lieu of exportation, data from the State of Connecticut ("2019 Status Report," 2020), the State of California ("Covered Electronic…," 2022), and two large e-waste processing centers, GreenCitizen (Kao, 2018), and ElectroRecycle ("ElectroRecycle Annual Report 2020," 2020) were obtained. Publicly reported cost data of these four geographically unique domestic e-waste processing centers were averaged to estimate the cost of e-waste processing in the United States. The average was then multiplied by the reported amount of e-waste exported from the United States to estimate the cost of transitioning e-waste exports to internal processing. The data and subsequent calculations for this estimate are captured in Appendix B. Inherently, the use of this calculation requires several assumptions. First, while the four selected processing centers manage different types of metal scrap and e-waste subcategories, it is assumed that the reported costs are representative of domestic e-waste processing as a whole. Additionally, marginal cost for each additional unit of e-waste is assumed to be constant. Third, this analysis assumes a frictionless transition to internal e-waste management, thus not considering the requirements for additional infrastructure investment, training, and regulatory revisions associated with a shift away from waste exportation.

Chapter 4

Results and Limitations

4.1 Results

The aggregate willingness to pay to reduce negative externalities in China (represented by the summation of the scaled safeguard subject willingness to pays) was approximated to be $353.66 billion. The aggregate cost to process e-waste domestically instead of through exportation was calculated to be $15.35 billion. At face value, the willingness to pay for a complete transfer to domestic processing far exceeds the cost to do so, suggesting that it is economically desirable to do so. However, such a conclusion cannot be made; due to the vastly limited nature of the data and series of assumptions required as compensation, additional research and data collection is necessary to effectively conduct the LIME analysis and influence policy behavior.

4.2 Limitations

Several limitations hindered the validity of this analysis and could be overcome with additional research. First, one of the major limitations of this analysis was the reliance on Japanese research conducted for the development of the LIME model. Little documentation exists on total pollution levels in China, with even less on the informal e-waste sector. While used as a substitute in this paper, future implementation of such data would provide for a much more accurate analysis.

Despite being in close proximity to China, Japan is not a global destination for e-waste exportation. In fact, Japan is considered a “sending” country of e-waste instead of a “receiving” country (Takayoshi & Nguyen, 2009). Since Japanese citizens do not directly experience the physical effects of e-waste processing in their hometowns, it is likely that the Japanese willingness to pay to reduce environmental externalities would be substantially lower than Chinese willingness to pay. Additionally, it is unknown if the impact categories used to calculate Japanese normalization values (ozonelayer depletion, urban air pollution, etc.) are reflective of impacts related to e-waste treatment. The data used in this analysis was based on aggregate levels of pollution; in reality, e-waste makes up only a fraction of total Chinese pollution. For example, if e-waste is only attributed to half of the effects on biodiversity, the willingness to pay relating to e-waste would be 50% of $161 billion. The lack of inclusion of this variable may justify the continued reliance on exportation of e-waste, as the fractional willingness to pay may be less than the cost of domestic processing.

Another limitation was the use of proxies as scaling factors between China and Japan. Although Chinese case studies demonstrate the presence of PCBs in fish and humans who consumed those fish, the scaling proxy relied upon in this paper for Biodiversity and Human concerned atmospheric particulate levels. Such a proxy is likely an oversimplification of the true differences between China and Japan; however, the directionality of the effect is unknown. Similarly, the use of CO_2 as a scaling proxy for environmental damage may also be an oversimplification. As shown in the case studies, several complex chemicals are correlated with e-waste treatment, many of which are damaging to the environment; thus, it is unlikely that the ratio of CO_2 emissions between Japan (low levels of informal e-waste processing) and China (high levels of informal e-waste processing) is a precise indicator of the true differences in environmental damages.

Regarding the estimation of transfer cost from exportation to domestic processing, the use of several assumptions raises doubts of the accuracy of the estimation. For example, as mentioned above, the assumption was made of frictionless transfer between exportation and domestic processing. In reality, there are several frictions expected with such a shift, such as infrastructure adjustments, marginal scaling, and public pushback. All of these frictions would result in a greater total cost to switch to domestic processing, which is likely another explanatory factor regarding the continued reliance on e-waste exportation.

Appendix A

LIME Estimation of E-Waste Externalities

Scaling of Japanese Normalization Values to Chinese Normalization Values

Safeguard Subject	*Scaling Factor*	*Scaling Value*	*Japanese Normalization Value*	*Scaled Chinese Normalization Value*
Biodiversity	World Bank PM2.5 air pollution (mg/m3)	4.49	0.923	4.144
Human Health	World Bank PM2.5 air pollution (mg/m3)	4.49	543,000	2,438,070
Social Assets	Climate Watch CO_2 emissions (kt)	8.97	2,290,000	20,541,300

Implementation of Conjoint Survey Data to Estimate E-Waste Related Willingness to Pay

Safeguard Subject	*Scaled Chinese Normalization Value*	*Japanese Conjoint Weighting Factor*	*Scaled Willingness to Pay (USD)*
Biodiversity	4.144	4.80e+12	$161 billion
Human Health	2,438,070	9.70e+6	$191 billion
Social Assets	20,541,300	1.00e+4	$1.66 billion

Appendix B

Estimating Domestic Cost of E-Waste Processing

Domestic E-Waste Processing Center	*Reported Processing Cost ($/lb)*
State of California	$0.87
State of Connecticut	$0.378
Green Citizen	$0.75
Electrocycle	$0.626
Average	$0.656

Average Cost of Domestic E-Waste Processing	$0.656/lb.
Total U.S. E-Waste Export Volume	3,400,000,000 lbs.
Cost Estimate to Replace Exports With Domestic Processing	$15.35 billion

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ACADEMIC VITA

DANIEL COHEN

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EDUCATION

The Pennsylvania State University | Schreyer Honors College **University Park, PA**
College of Liberal Arts, College of Information Sciences and Technology *Graduation: May 2022*
Majors in Economics and Security and Risk Analysis

PROFESSIONAL EXPERIENCE

Deloitte Government & Public Services **Harrisburg, PA**
Virtual Summer Scholar *June 2021 – Present*

- Aligned with USAID Human Resource Transformation project with a focus on Performance Management and Awards redesigns
- Facilitate client testing sessions with various USAID stakeholders and communicate functional requirements to developers
- Create over ten job aids and micro-learning video scripts for new Awards product as part of the change management process
- Conduct Performance Management current state analysis and assist two team members with onboarding and project transitions

Archbow Consulting **Orlando, FL**
Information Management Intern *May 2020 – August 2020*

- Researched and tested remote video conferencing/slide management platforms and reduced annual software costs by over $5000
- Executed pandemic adaptation training and implementation of Google Meet and TeamSlide Slide Management packages
- Collaborated with consulting teams to identify Dropbox organization deficiencies and establish standardized filing procedures
- Drafted and presented cyber risk reference guide to improve risk awareness standardize company-wide security protocols

Cancer Support Community Greater Philadelphia **Warminster, PA**
Summer Youth Corps Intern *June 2019– August 2019*

- Studied and assisted ten nonprofit organizations in the Bucks County area to understand 501(c)(3) administration and operations
- Directed a two-week summer camp to support children affected by cancer through teambuilding exercises and homemaking classes
- Created a transitional database containing intern records and supporting documents to streamline future onboarding processes

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LEADERSHIP

Penn State Mock Trial Association **State College, PA**
President *April 2020-Present*

- Act as the primary representative of a 60-member, top 1% competition team and conduct 9-person Executive Board meetings
- Manage communication with mock trial's governing body to enable nationwide travel and competition in monthly tournaments
- Serve as a member on the Internal Mediation and Arbitration Committee to resolve internal complaints and disputes

Administrative Director *April 2019-April 2020*

- Oversaw organizational communications, reports, documents, and official Executive Board meeting minute releases
- Cooperated with team captains to regulate material assignments and compile competition recordings, feedback, and results
- Advocated at Penn State budget allocation meetings to secure over $4000 in additional funding

Delta Sigma Pi, Professional Business Fraternity **State College, PA**
Founder of Diversity and Inclusion Committee *January 2019 – Present*

- Communicated with underrepresented members to design committee focused on inclusive outreach and cultural awareness
- Compile and disseminate lists of diverse literature, articles, and video resources to expand the fraternity's intercultural competence
- Attend regular professional development, community service, and social events to improve personal and professional presence

Penn State Learning **State College, PA**
Microeconomics Guided Study Group Leader *August 2019 – Present*

- Coordinate with faculty to attend microeconomics lectures and facilitate group-based content review and practice sessions
- Apply concepts from Bloom's Taxonomy of Questions to guide students through example problems and solidify comprehension
- Mentor other Guided Study Group Leaders through observation and provision of constructive feedback

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AWARDS & INTERESTS

Awards: Salutatorian of Central Bucks High School South, Paterno Fellows Academic Honors Fellow, All National Mock Trial Attorney, 6x Deans List Member, Doylestown Rotary Service Scholarship Recipient, Bucks County Bar Association William Penn Scholarship Recipient
Additional Experience: Schreyer Honors Orientation Mentor, Penn State THON Rules and Regulations Pass Leader, Gamma Tau Phi IST Honors Society, Senior Class President, MiniTHON Fundraiser Founder, SAT and middle-school math tutor
Interests: Broadway Theatre, Baking, Gymnastics