An Analysis of Lead Pollution in Guiyu, China

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1. Introduction

Guiyu, a rural village in Guangdong Province, China, is considered to be one of the most polluted places in the world. As a major destination of the world's electronic waste, or e-waste, Guiyu is a source of worldwide controversy over how to address the growing problem of e-waste disposal. E-waste describes discarded electronic or electric devices—from cell phones and computers to televisions and refrigerators—and is the fastest growing segment of the waste stream. While e-waste does contain valuable materials and components which can be reclaimed, it also contains an assortment of toxins and heavy metals which, if not handled correctly, can result in severe environmental and human health damage. One particular pollutant—lead—is released in large quantities from processing activities and has had dramatic effects on the health of the villagers and the surrounding environment.

Despite national and international regulations outlawing the movement of hazardous electronic waste to informal recycling workshops in rural China, the e-waste industry continues to grow. In order to understand how to address the problem from a different angle, I examine the systemic forces which strongly support this industry. I then use this understanding to propose solutions that have the potential to improve environmental conditions in Guiyu.

2. Characterizing Lead Pollution in Guiyu

Among the damaging pollutants found in Guiyu, including dioxins, strong acids, and heavy metals, the presence of lead has been the most studied to date. River samples from the Lianjiang River in Guiyu have shown lead levels up to 2,400 times above the World Health Organization (WHO) Drinking Water Guidelines. The water is so contaminated that drinking water must be trucked in from villages 30 km away. Sediments are also highly polluted, with samples exhibiting levels of lead 212 times higher than is considered hazardous waste by the European Union.[1] To provide context, lead levels of dust inside e-waste workshops in

[1]Basel Action Network (BAN), & Silicon Valley Toxics Coalition (SVTC). (2002, February 25). *Exporting harm: The high-tech trashing of Asia.* Retrieved from `http://www.ban.org/E-waste/technotrashfinalcomp.pdf` on November 2, 2011. Pages 15, 22.

Guiyu are 29 times higher than those found in comparable operations in New Delhi, India.[2] Among children 6 or younger, 81.8% have blood levels of lead (BLLs) greater than 10 μg/dL, a level considered elevated by the U.S. Centers for Disease Control. The highest BLLs were found among children with parents who strip circuit boards.[3] Unfortunately, the extent of human health problems resulting from e-waste processing activities is largely unknown, as the local government does not permit such investigations.

Chronic (long-term) exposure to lead in humans affects the blood, central nervous system, reproductive systems, blood pressure, kidneys, and Vitamin D metabolism. Children under the age of 6 and developing fetuses face the greatest risk from chronic lead exposure due to their rapid neurological and physiological development, exhibiting slowed cognitive development and reduced growth, among other effects.[4] In the environment, lead accumulates within organisms, leading to stunted growth and premature aging in plants and death in both plants and animals. Aquatic organisms are particularly sensitive to low levels of lead due to faster absorption rates. Higher trophic level organisms are especially at risk from the consumption of lead in lower level organisms.[5]

3. Diagnosis of the Causes of Lead Pollution

Knowledge of the structure of the system which created and sustains the levels of lead pollution in Guiyu is necessary in order to identify possible points of intervention. I will diagnose the causes of the high levels of lead pollution in Guiyu by starting with the most immediate cause—the e-waste processing centers—and then work towards the root causes.

3.1. E-Waste Processing in Guiyu

The immediate cause of lead pollution in Guiyu is inarguably its e-waste processing centers. E-waste contains many materials and components of economic value due to their potential for re-use. The processing

[2]Gao, Y., Huang, C., Zhang, H., & Dong, Q. (2009, July/August). Heavy metal contamination from electronic waste recycling at Guiyu, southeastern China. *Journal of Environmental Quality*, 38, 1617-1627. Page 1618.

[3]Leung, A. O. W., Duzgoren-Aydin, N. S., Cheung, K. C., & Wong, M. H. (2008, March 4). Heavy metals concentrations of surface dust from e-waste recycling and its human health implications in southeast China. *Environmental Science and Technology*, 42(7), 2674-2680. Retrieved from `http://dx.doi.org/10.1021/es071873x` on November 2, 2011. Page 2674; Zheng, L., Wu, K., & Liu, J., et al. (2008, September). Blood lead and cadmium levels and relevant factors among children from an e-waste recycling town in China. Environmental Research, 108(1), 15-20. Retrieved from `http://dx.doi.org/10.1016/j.envres.2008.04.002`. Page 15.

[4]U.S. Environmental Protection Agency. (2010, April 14). *Lead Compounds.* Retrieved from `http://www.epa.gov/ttnatw01/hlthef/lead.html` on November 2, 2011.; U.S. Department of Labor, Occupational Safety and Health Administration. *Lead.* Retrieved from `http://www.osha.gov/SLTC/lead/` on November 2, 2011.

[5]Greene, D. (1993, Winter). Effects of lead on the environment. LEAD Action News, 1(2). Retrieved from `http://www.lead.org.au/lanv1n2/lanv1n2-8.html` on November 3, 2011.

system in Guiyu is quite organizationally sophisticated, with each processing center specializing in maximizing the value reclaimed from a specific type of e-waste.[6] Migrant workers from poor, rural provinces work to separate materials and components from e-waste using crude, hazardous methods. The equipment and infrastructure necessary to safely reclaim value from e-waste is far beyond the means available to the rural workforce in Guiyu. Without adequate technology, the processing centers are not particularly efficient at reclaiming materials from the e-waste. The methods used are also the source of the high levels of lead pollution. Despite the inefficiencies, the low costs associated with an impoverished workforce and lax occupational and environmental standards allows the processors to operate profitably. The processing of printed circuit boards (PCBs) and cathode ray tube (CRT) monitors is responsible for most of the lead pollution.

(a) PCB processing (b) CRT processing

Figure 1: E-waste processing in Guiyu is performed in unsafe working conditions with minimal tools. After the materials and components of interest are extracted, the remaining material is discarded. *Images courtesy of the Basel Action Network (BAN) in Exporting Harm, 19.*

Processors of PCBs collect both the circuit components and the lead-tin solder which connects them to the board by cooking the PCB in a pan over a charcoal fire as shown in Figure 1a. The melted lead-tin solder is collected in the pan and electrical components of interest are removed and sorted for further material processing. Workers use no protection against the resulting lead vapors. The stripped PCBs are then collected in a pile for disposal through burning near the river, which releases the remaining lead into the environment. Processors of CRTs are typically only interested in the valuable copper yolk, which is broken off with a hammer as shown in Figure 1b. The remaining waste, including pounds of lead-infused

[6] Exporting harm, 15

glass, is simply dumped. These practices result in hazardous levels of lead release into the environment. When rated for disposal in landfills, CRTs and PCBs have expected levels of lead release 4 and 28-265 times greater than the regulatory level in the United States.[7] Given the conditions of handling and disposal in Guiyu, the levels of lead release will be much greater.

3.2. A Difficult Choice—Poverty or Poison

E-waste processing began at large in Guiyu in 1995. At the time, the majority of the villagers were impoverished rice farmers. E-waste processing, though dangerous to human health and the environment, offers much higher wages than rice farming.[8] The ability of villagers to participate in e-waste processing is not excludable, and its effects subtract from the ability of others to gain positive utility from other ecosystem services. We can treat the ability to participate in e-waste processing as a common-pool resource. Each individual obtains the entire positive utility of his or her participation in e-waste processing; the negative utility of environmental degradation is distributed among all of the villagers. As the net utility of e-waste processing is greater than that of other available options (rice farming), this structure encourages pollution. The resulting degradation of the land and water reduces the positive utility of other activities, causing e-waste processing to become an increasingly better option. The current state of Guiyu is the result of a tragedy of the commons, where each rational actor makes a decision which collectively leads to the destruction of the local environment.

Though the levels of lead pollution in Guiyu can be characterized as a tragedy of the commons, it is unclear whether a collective action to avoid pollution would be better from the perspective of the villagers. The rural farmer in China will consider the risks associated with this decision differently than someone in a higher socioeconomic setting. A family in extreme poverty with an uncertain continued survival will necessarily heavily discount the future. Though the hazards and exposures associated with unsophisticated e-waste processing are great, the worst effects will be delayed in time on the order of years or decades. The extent of the risks is also largely unknown to the workers due to the temporal distance between cause and effect. Some villagers have expressed a lack of knowledge of the causes of the local water pollution, the types of health problems which result from e-waste processing, and the activities that can result in harmful exposure.[9] A person placed in this difficult position is likely to choose the hazardous employment option that promises a higher income, despite the long-term health effects and environmental damage.

Guiyu is quite prosperous relative to its neighboring villages. Many of the locals who worked in the industry as it first developed have earned enough money to start their own businesses and hire migrant

[7] Exporting harm, 29

[8] China Labour Bulletin. (2005, August 15). *The plight of China's e-waste workers.* Retrieved from `http://www.clb.org.hk/en/node/16058/print` on November 3, 2011.

[9] Greenpeace International. (2007, July 23). Toxic tea party. Retrieved from `http://www.greenpeace.org/international/en/news/features/e-waste-china-toxic-pollution-230707/` on November 3, 2011.

workers. It is estimated that approximately 100,000 migrants work as e-waste processors in Guiyu.[10] These migrants have found better economic opportunities in Guiyu than in their home provinces, lifting them out of extreme poverty. For the villagers of Guiyu, the preferred collective action is to continue participating in e-waste processing and polluting the environment. When operations in Guiyu were first exposed to the international community, regional environmental officials in Shantou, a city with jurisdiction over Guiyu, attempted to restrict e-waste operations in Guiyu. Local authorities and villagers resisted, re-opening closed workshops almost immediately. Reporters and journalists are no longer welcome in the area, as the villagers fear that increased exposure will threaten their livelihoods.[11] Such a situation is generally considered environmental injustice, where marginalized groups share a disproportionate environmental burden.

3.3. The Flow of E-Waste

A combination of several strong economic forces led to the creation of e-waste processing centers in Guiyu and continues to sustain it. The sources of the e-waste in Guiyu are both domestic and international, ultimately entering the same e-waste processing chain. Guiyu is but the last stop in a series of processing steps seeking to extract additional value out of discarded electronic products.

3.3.1. The E-Waste Processing Chain

The e-waste processing chain satisfies demands both from both industry and consumers. China is highly dependent on resource imports to feed its strong manufacturing sector. Compared to other countries in the world, China is resource poor, with only 58% of the average distribution of resources per capita.[12] Domestic recycling provides an opportunity to make up for this lack of internal resources.[13] In Asia, the largest market segment is the secondary market, where products are re-used, repaired, and built from recycled components.[14] Some of the e-waste produced by developed countries is functional or only slightly damaged and can address this demand with minimal cost. These factors create a very strong economic demand for e-waste, which can satisfy material, component, and product demands. Collection centers sort through e-waste separating out re-usable and repairable products for resale. The remaining waste is sold down the chain, where functioning components are extracted for the manufacturing of secondhand electronics. The

[10]Toxic tea party

[11]China Labour Bulletin

[12]Hicks, C., Dietmar, R., & Eugster, M. (2005). The recycling and disposal of electrical and electronic waste in Chinalegislative and market responses. *Environmental Impact Assessment Review*, 25, 459-471. Retrieved from `http://www.empa.ch/plugin/template/empa/*/51485/---/l=2\%20463` on December 12, 2011. Page 463.

[13]Yoshida, A. (2005). China: The world's largest recyclable waste importer. In *International trade of recyclable resources in Asia* (pp. 33-52). Retrieved from `http://www.ide.go.jp/English/Publish/Download/Spot/pdf/29/29_ch3.pdfonDecember12,2011.`

[14]Gadiesh, O., Leung, P., & Vestring, T. (2007, September). The Battle for Chinas Good-Enough Market. *Harvard Business Review*. Retrieved from `http://hbr.org/2007/09/the-battle-for-chinas-good-enough-market/ar/1`

remaining waste is then sold to rural processing centers, such as Guiyu, for final material recovery.[15] The sources of this e-waste are discussed below.

3.3.2. International Sources

When the processing centers first began in Guiyu in 1995, most of the e-waste came from illegal importation. To understand the process by which e-waste travels from international sources to rural China, I examine the practices of the United States, the world's top producer of e-waste. E-waste is presently the fastest growing segment of the waste stream in the U.S., and is one of the most costly for municipalities to manage. The hazards posed by e-waste require expensive equipment and infrastructure to manage properly. Unfortunately, exceptions to regulations exist in the U.S. that allow large volumes of e-waste to enter the main waste stream.[16] Each individual cannot be excluded from the use of the waste disposal service and contributing to the filling of the landfill. The potential costs from environmental damages will be shared by all users (tax-payers in the municipality), giving no incentive for the consumer to reduce his or her own e-waste disposal habits. As local solid waste agencies can be held liable for damages caused by leachate of toxins in landfills, risk managers of these agencies try to divert as much of the e-waste as possible to local recyclers, thus avoiding the externalities.

Unfortunately, e-waste recyclers in the U.S. are often unable to process the waste profitably due to the expense of the equipment and infrastructure, despite the ability of modern recycling plants to recover 80% of material and use another 15% for heat generation.[17] In general, though e-waste does contain positive economic value, the negative value associated with the potential externalities both to the environment and human health is far greater. Thus, the net value of e-waste for recyclers in the U.S. is negative. Without an economic subsidy, recyclers must charge customers to process the e-waste profitably. Collectively, citizens are better off paying the recycling fees than paying for the potential environmental clean-up costs; individually, citizens are better off disposing of e-waste freely in a landfill. Rather than addressing this collective action problem, many recyclers take an easier, more profitable approach to handling the e-waste.

Though a net positive value cannot generally be obtained from e-waste in the United States, developing countries with lower costs of labor and lax occupational safety and environmental standards can by ignoring the negative externalities. International e-waste brokers offer to pay for the otherwise burdensome e-waste collected by recyclers, who then sell to e-waste traders and collection centers in developing countries.[18] In

[15] Anqi, C., & Nilsson, E. (2011, November 16). Wired for gold. Retrieved from `http://www.chinadaily.com.cn/cndy/2011-11/16/content_14101749.htm` on December 12, 2011.

[16] Exporting harm, 30

[17] Schwarzer, S., De Bono, A., Giuliani, G., Kluser, S., & Peduzzi, P. (2005, January). *E-waste, the hidden side of IT equipment's manufacturing and use.* Retrieved from United Nations Environment Programme website: `http://www.grid.unep.ch/product/publication/download/ew_ewaste.en.pdf` on November 2, 2011.

[18] Exporting harm, 34-37

attempting to avoid the externalities of e-waste, municipalities merely shift the externalities to the developed world.

The spatial distance between those who benefit from this externality and those who suffer from it complicates addressing the issue. The cost of properly managing the waste produced by electronic devices is not accounted for in the transaction between the manufacturer and the consumer, giving the manufacturer no incentive to use less toxic materials or design products for easier disassembly. The quick rate of obsolescence of electronic devices exacerbates the problems caused by this externality, encouraging frequent disposal. Neither the producer nor the consumer bears the negative utility of the waste. This complicates the possibility of an agreement to change behavior, as the creators of the problem would face increased expenses with no benefit.

3.3.3. Domestic Sources

Though international sources have traditionally been the primary source of e-waste, China is on pace to become the largest producer of e-waste in the world. Within China, the formal waste processing system cannot compete with the convenience and financial incentives offered by informal collectors. Most e-waste is disposed of through door-to-door collectors of the informal waste processing sector who will purchase the e-waste at good prices. These individual collectors bring the purchased e-waste to collection centers where it enters the e-waste processing chain.[19] As in the U.S., when given the option between a environmentally responsible option and a less expensive, more convenient option, most citizens choose the latter option.

3.4. Potential Non-Linear Effects and Discontinuities

In addition to the immediate human health effects on the villagers in Guiyu, its e-waste processing activities threaten local agricultural activity and downstream ecosystems. Approximately 30% of agriculture in the region around Guiyu is irrigated with water from the Liangjiang River. Over time, this will lead to the accumulation of lead, among other pollutants, in the soil. Elevated trace levels of lead have already been observed in these crops. At some level of accumulation, the crops will become too hazardous for consumption.[20] Without a way to easily remove the lead from the soils, these agricultural lands would be abandoned. Pollution has already rendered the Liangjiang River lifeless, and fishers in downstream Haimen Bay in the South China Sea have noted a sharp decrease in fish populations. It is unclear whether this is the result of pollution or over-fishing.[21] Lead levels in fish of the South China Sea will rise as pollution

[19] Chi, X., Streicher-Porte, M., Wang, M. Y. L., & Reuter, M. A. (2011). Informal electronic waste recycling: A sector review with special focus on China. *Waste Management*, 31, 731-742. doi:10.1016/j.wasman.2010.11.00. Pages 733-738.

[20] Huang et al, 1624

[21] Hofford, A. (2009, January 9). E-waste 'recycling' in Guiyu, China [Web log post]. Retrieved from Alex Hofford Photography: http://www.alexhofford.com/node/2238 on November 3, 2011.

continues to flow into the South China Sea. This effect threatens not only nearby sea life, but the health of the people which depend on the sea for food.

4. Addressing the Causes of Lead Pollution

Market rationality encourages the movement of e-waste from developed countries to China and from its urban citizens to its marginalized rural migrants. National and international efforts have been made in attempts to stop this environmental injustice to little success. I examine why present regulations have not produced the desired results and how progress can be made to reduce lead pollution in Guiyu and other similar operations operating in rural China.

4.1. Existing Regulations

4.1.1. International: The Basel Convention

In 1989, 175 parties participated in the Basel Convention on the Control of the Trans-boundary Movement of Hazardous Waste and Their Disposal. The convention and subsequent amendments prohibit the export of waste from developing to developed countries and require domestic handling of waste whenever possible. If domestic handling is not possible, the importing country must explicitly approve the action and handle the wastes in such a way as to minimize human health and environmental risks. To encourage participation, parties to the convention are barred from trading with non-parties.[22] The Basel Ban Amendment was made to the convention in 1995, banning the export of waste from developed countries to developing countries.

The U.S. is one of only three countries which has signed the convention but has yet to ratify it. Several other large producers of e-waste, such as Japan, South Korea, Australia, and Canada, have ratified the convention, but have been known to subvert it.[23] Large producers of e-waste have significant economic incentive to subvert the convention as the domestic handling of e-waste is more costly due to strict environmental and human health standards. Conversely, developing countries have incentive to subvert the convention as it provides an immediate positive economic utility. The same economic pressures which create the environmental injustice act against the solution by undermining collective action to ban waste export. The policy is most commonly subverted by exploiting uncertainty in the definition of waste. Discarded devices can often be re-used in secondary markets or recycled, and can justifiably be labeled as a resource rather than e-waste.

[22]Basel Convention, Basel Convention on the Control of the Trans-boundary Movement of Hazardous Waste and Their Disposal. Retrieved from `http://archive.basel.int/text/con-e-rev.pdf` on November 3, 2011.

[23]Exporting harm, 33

4.1.2. United States: The Resource Conservation and Recovery Act

Parties to the Basel Convention identify complete domestic recycling of waste as the solution to the environmental injustices caused by the international waste trade. The U.S. approach, according to Bob Tonetti of the EPA, is that there is no intention to regulate the export of electronics in the U.S. The EPA policy "is that none of [the e-waste] should be hazardous waste; we want it recycled." The Resource Conservation and Recovery Act (RCRA) prohibits the exports of hazardous wastes and controls its disposal. However, small volume generators and households are exempt from regulations, and e-waste can be exempted if it is contains an undefined "minimal quantity" of scrap or precious metals. Export controls are also lifted if the intended recipient simply claims that the materials will be recycled. The U.S. has developed a set of minimal ESM criteria that recipients must follow before they can receive e-waste.[24] The loopholes in this policy allow e-waste to enter U.S. landfills and to be exported to China. Proponents of the approach point out that the extraction of virgin materials creates much more environmental damage than recycling. Critics of the approach of the U.S. point out that the impacts are still shifted unfairly to developing countries.[25]

4.1.3. European Union: WEEE and RoHS Directives

The European Union passed and implemented the Waste Electrical and ELectronic Equipment (WEEE) and Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) directives in an attempt to reduce the environmental impacts of e-waste generation. The WEEE directive requires that EU member nations:

- Apply the extended producer responsibility (EPR) principle by requiring manufacturers to offer options to customers to return waste to them for environmentally safe disposal at least free of charge
- Manufacturers must use certified waste management companies to dispose of wastes which follow a defined set of best practices
- Meet re-use, recycling, and recovery target goals for e-waste

The WEEE directive changes the issue structure by making the provision of waste disposal services excludable, requiring manufacturers to pay for disposal.[26] The RoHS directive restricts the use of six hazardous materials above a low concentration, including lead, in products manufactured after July 1, 2006.[27] Though this will reduce the lead pollution resulting from e-waste processing in the future, there is a time delay between products entering the market and those entering the waste stream. Large volumes of lead-containing e-waste will continue to enter Guiyu despite these changes.

[24] Exporting harm, 28-30

[25] Danigelis, A. (2010, July 30). *Revenge of the tv monitor zombies.* Retrieved from Discovery News website: `http://news.discovery.com/tech/revenge-of-the-tv-monitor-zombies.html` on November 3, 2011.

[26] Full text available at `http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0019:0023:en:PDF`

[27] Full text available at `http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0024:0038:EN:PDF`.

4.1.4. Chinese Policy

In addition to strongly supporting the Basel Convention and Basel Ban Amendment, the Chinese government has declared a strict policy banning the import of *any* used electronic devices.[28] Unfortunately, the economic demands of secondary markets and manufacturers have made this regulation difficult to enforce. The amount of e-waste which enters China illegally is unknown. China is already the second largest producer of e-waste, and is projected to become the largest by 2020.[29] Once e-waste enters Chinese ports, often through the bribing of port officials, it is difficult to trace back to its original source, obscuring the scale of the problem.[30]

As the European Union is a large market for Chinese manufacturers, China has implemented its own versions of the WEEE and RoHS directives to ensure industry conforms to EU regulations. Recent policies have called for mandatory e-waste recycling, extended producer responsibility (EPR) and the creation of an e-waste recycling fund, and requirements for environmental performance of recyclers, but many of these policies have yet to be successfully defined or implemented. This is partly due to the difficulties encountered by pilot programs attempting to compete with the robust informal recycling sector.[31]

4.2. Analysis of the Solution Space

The Coasian framework for addressing externalities states that because externalities are reciprocal—one party benefits while another suffers. Given perfectly defined property rights, complete information, and no transaction costs, the parties can come to an agreement as to the optimal level of the behavior which caused the externality. The most direct reciprocal externality occurs between the owners of the processing workshops who benefit economically from the hazardous processing performed by the migrant laborers. Though the health of the environment and the worker is nominally protected under Chinese law, enforcement of these rights is practically non-existent.[32] Most of the workers are migrants without the full legal standing of local citizens of the province of Guangdong, despite recent reforms.[33] Providing legal recourse for migrant workers experiencing adverse health effects from e-waste processing would force employers to improve standards. Even without a system of legal protection, workers are unable to make informed decisions as to the acceptable level of hazard without knowledge regarding the health damages

[28] China Labour Bulletin; Exporting harm, 30-31; Yoshida, 42-43

[29] United Nations Environmental Programme. (n.d.). Urgent need to prepare developing countries for surge in e-wastes. Retrieved from `http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=612&ArticleID=6471&l=en&t=longonNovember3,2011`.

[30] 60 Minutes. (2008, November 9). *The Electronic Wasteland*. CBS. Retrieved from http://www.cbsnews.com/video/watch/?id=4586903n on November 2, 2011.

[31] Chi et al., 734-740

[32] China Labour Bulletin

[33] Chan, K. W., & Buckingham, W. (2008, September). Is China abolishing the hukou system? *The China Quarterly*, 195, 582-606. `doi:10.1017/S0305741008000078`

of e-waste processing. Unfortunately, even with this knowledge, a particular worker is likely to settle for a level of hazard than is acceptable. With a large supply of impoverished migrants, employers need only negotiate with the subset of workers willing to accept the worst conditions. As the work requires little skill or experience, existing workers have almost no leverage over employers in a bargain. A collective bargaining group, or union, among the workers would work to define a minimally acceptable set of working conditions. Unfortunately, none of these solutions fit into the social planning scheme which the communist government has designed, marginalizing large portions of the population in attempts to grow the economy without causing social turmoil. Within China and internationally, NGOs provide the best opportunity to address the reciprocal externalities upstream—from the sources of the e-waste. Exposing activity in Guiyu to international media can bridge the spatial distance between cause and effect which reduces the likely of a mutual agreement. By speaking on behalf of the victims of the e-waste trade, the transaction costs for reaching an acceptable agreement amongst parties are also reduced.

As the effects of e-waste processing are very harmful and directly affect the villagers of Guiyu, we might expect the behavior of lead pollution to follow the mechanism of the Environmental Kuznet's Curve. Unfortunately, several factors strongly counteract this mechanism. Development within Guiyu is unlikely to result in an improvement in environmental conditions. There is little investment occurring to improve living conditions within the village with the wealth resulting from the e-waste processing. Without another source of income to replace the e-waste processing, it is likely that increased development will lead only to an increase in processing capacity. The primary beneficiaries of development—the owners of the processing workshops—have no reason to improve conditions because they can afford to live away from the most polluted areas of the town. Though increased income among the workers could result in environmental improvements, the abundance of cheap labor makes this scenario unlikely. As political activism is stifled by the communist system, only large-scale protests might lead to improvements. Increased development in China will actually exacerbate the problem as the level of domestically-produced e-waste will increase greatly.

From these frameworks, I conclude that some form of external intervention will be necessary to address lead pollution in Guiyu. The legal and economic structures within Guiyu greatly restrict opportunities for internal change. Addressing these structures to allow for internal change is not within the best interests of China. Because the economic forces behind the e-waste trade have already overpowered legal structures, it is likely that a command-and-control approach will not work as well as an economic incentive within China. Outside of China, command-and-control approaches such as the Basel Convention have decreased e-waste exports, but face similar problems.

4.3. Potential Policy Directions

Currently, the United States is behind the rest of the world in terms of its e-waste handling policies. As the largest producer of e-waste in the world, the U.S. can set a strong global precedent for responsible e-waste handling by ratifying the Basel Convention. Lack of U.S. participation may be encouraging half-hearted participation among other large e-waste producers. With consistent regulations among all possible e-waste exporters to China, the amount of e-waste entering the country should decrease. Unfortunately, this may do little to change the reality of the e-waste problem. It is possible to justify the continued export of e-waste if it is claimed to be for re-use or refurbishment, even if the U.S. closes loop holes in the RCRA. This is how other developed nations continue to export large volumes of e-waste to China. Within the EU, only one-third of produced e-waste is accounted for in the WEEE system; the remainder is either in domestic landfills or has been exported.[34] One problem may be that the relevant port authorities are often unable to determine which shipments are permissible under the relevant regulations due to the inherent uncertainty of what defines *waste*. Though China has outlawed the import of all used electronic and electrical equipment regardless of its status, smuggling remains a common practice.

Anther strategy the United States could pursue is to force electronics manufacturers to internalize the costs of the externalities of their products. Different implementations of this strategy have been attempted on the state level, such as in Maine and Washington, and the international level, such as with the WEEE directive in the EU. As the original source of all e-waste, manufacturers are the primary beneficiaries of the eventual resulting externalities. Currently, safe, efficient processing of e-waste is made difficult by designs which do not consider recycling and disposal costs. Through design for disassembly and the reduction or replacement of hazardous materials, environmental impacts will be reduced and recycling will be made more profitable. With similar policies of EPR in the U.S., China, and the European Union, manufacturers will need to find ways to reduce the costs of responsible end-of-life treatment in order to stay competitive. As recycling becomes easier and more profitable, the economic advantages of informal recyclers will decrease. While that shift is occurring, the e-waste which does end up in the informal sector will be easier to manage and less hazardous. This strategy should also be accompanied by the U.S. closing loop holes in the RCRA, requiring consumers to dispose of e-waste properly rather than in a landfill.

The Chinese government should also take steps to address its problem with domestically generated e-waste. In a communist system, the implementation and enforcement of a command-and-control regulation can occur quickly with little backlash from industry or the public. In attempts to alleviate its e-waste handling problems, the Chinese government has passed many regulations over the past decade to make informal e-waste processing illegal and build standards for a formal processing system. Such intent has

[34]European Commission Environment. (2011, January 12). *Recast of the WEEE directive.* Retrieved from `http://ec.europa.eu/environment/waste/weee/index_en.htm` on December 12, 2011.

attracted foreign investment in e-waste processing plants in China. Given abundant cheap labor, it may be possible to profit from e-waste recycling even with improved environmental standards. Currently, the superior collection abilities of the informal e-waste sector undermine the ability of such plants to operate profitably. Even if the formal sector could organize an efficient collection system, formal systems are simply unable to offer the same level of economic incentive to owners of e-waste as the profitable informal system. To solve this problem, China could increase its enforcement of current regulations. In the past, the government has attempted to shut down individual operations in Guiyu. But because the work requires very little equipment or skilled labor to perform, the workshops can be moved and resumed almost as quickly as they are taken down. A more effective approach would be to target the collection centers, which are much less flexible. But without addressing the underlying economic incentives, the informal processing sector will require continued enforcement. Action against the informal sector would damage secondary markets by removing an important source used and refurbished devices and components. It would also require the state to implement its own collection system.

A better approach would be to integrate the effective elements of the informal processing sector into the state processing system. The informal processing sector is already extremely efficient at collection and interacting with the secondary markets. The state should intervene at the step in the process where remaining waste is sent to downstream processors for material recovery, as this is where the majority of human health problems and environment damage occur. Unfortunately, the remaining waste has a net negative value with externalities considered. The formal industry will only be able to divert the waste to its facilities if it can outbid the downstream processors for the waste. To provide the necessary finances to purchase e-waste, China could use funds collected from its recently implemented extended producer responsibility (EPR) policies. In this system, industries are economically incentivized to reduce recycling costs and the use of hazardous materials; the organizational efficiencies of the informal economy can be used to collect goods and repair and resell them whenever possible; and environmental and human health costs of the externalities of final disposal or material and component recovery will be drastically reduced by processing in state run facilities rather than informal sites like Guiyu. Though this system potentially suffers from a free-rider problem if countries continue to export waste to China, this would encourage Chinese authorities to enforce already existing import bans on e-waste.

5. Conclusion

The e-waste processing chain which moves e-waste to hazardous processing centers in Guiyu, China, is quite robust despite command-and-control regulations against the system. Unless the economic forces behind the system are addressed, it is unlikely that levels of lead pollution in Guiyu will improve. Though manufacturers should be encouraged to reduce the use of hazardous materials in devices and to design for

easier recycling, the effect on the e-waste processing industry will be delayed. To create a more immediate improvement—before the environment surrounding Guiyu is irreparably damaged—China should integrate its informal processing system into a more formal system which safely recovers recyclable material. This can be done by requiring manufacturers to pay for the recycling of their devices, financing the purchase of e-waste from informal collection centers otherwise destined for downstream e-waste processors. The United States should also amend the RCRA to prevent the disposal of e-waste into its landfills and implement its own EPR policies, creating a competitive market for its struggling e-waste recycling industry. Even if the United States continues to export e-waste to China, the growth of the formal processing sector in China will result in an economically efficient and environmentally-acceptable system for both parties.

Word count: 5,965