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WEEE and ROHS: are they spurring innovation among small and medium sized electronics businesses in the U.S.?

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WEEE AND ROHS: ARE THEY SPURRING INNOVATION AMONG SMALL AND MEDIUM SIZED ELECTRONICS BUSINESSES IN THE U.S.?

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ACKNOWLEDGEMENTS

I remember the first assignment that John gave me as a fresh out of high school first year in his Principles of Environmental Management course. He was Professor Morelli to me at the time, and I had to give a presentation on the chapter in our text that dealt with pathogens in the environment. Little would I have imagined then that Professor Morelli would turn into my mentor John and would be guiding me in this final and most important assignment so far. John, thank you for your patience, your freedom, and your desire to make this thesis the best work that I could do.

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ABBREVIATIONS

	DEFINITION
CM	Contract Manufacturer
CEM	Contract Electronics Manufacturer
ENIG	Electroless Nickel Immersion Gold
EPR	Extended Producer Responsibility
EU	European Union
OECD	Organization for Economic Cooperation and Development
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Board
RoHS	Restriction of Hazardous Substances Directive
SMB	Small and Mid-Sized Businesses
SMT	Surface Mount Technology
WEEE	Waste Electrical and Electronic Equipment Directive

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ABSTRACT

Eight small businesses in the electronics industry from Rochester, NY were studied in order to determine whether the European Union's directives, *Waste Electrical and Electronic Equipment* (WEEE) and *Restriction of Hazardous Substances Directives* (RoHS) are spurring innovation in the US. Innovation was defined as any change in the design and manufacturing of the products, in the internal organizational structure and management of the business, or in the market strategies pursued by the small businesses that created a benefit beyond RoHS and WEEE compliance. Because WEEE and RoHS are based upon extended producer responsibility principles, this innovation would complement the findings of previous research completed on extended producer responsibility (EPR) legislation.

A case study with an in-depth interview was conducted for each of the eight companies to gather data on the changes the companies had taken in their operational, design, and management systems to comply with WEEE and RoHS. The collected data was analyzed to determine which of the changes were "spillover effects" that went beyond the requirements of WEEE and RoHS.

The analysis led to the finding that the directives were in fact leading to innovations within each of the companies. While some companies had more profound innovations than others, the directives had prompted the companies to take on initiatives that led to more efficient and environmentally friendly manufacturing and design processes

CHAPTER 1: INTRODUCTION

1.1 STATEMENT OF THE TOPIC

This research evaluated whether the European Union's (EU's) directives, Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substances Directives (RoHS), passed on January 27, 2003 are spurring innovation in U.S. small and medium size electronics businesses (SMBs) as they work to comply. WEEE and RoHS were developed around extended producer responsibility principles (EPR). Policy instruments that follow EPR ideology versus the common *command and control* perspective have been tied to innovation by manufacturers in the past. This research focused on (1) analyzing the projects or changes SMBs have undertaken in response to WEEE and RoHS compliance, which included determining the characteristics of the SMBs (managerial, operational, external influences) that have allowed for or led to the changes and assessing the attitudes of the SMBs towards these directives and their place in the business world's pursuit of environmental responsibility; (2) evaluating whether these projects and changes went beyond the explicit requirements of WEEE and RoHS; in order to (3) determine whether WEEE and RoHS are staying true to their EPR roots and spurring innovation within SMBs.

This research was conducted through the use of an expanded review of the literature and a series of case studies that include in-depth interviews. Eight small or medium size Rochester businesses were selected. An in-depth interview was conducted with each of the managers in charge of WEEE and RoHS compliance to gain a truly in depth assessment of how a small business has brought its products and operations into compliance.

1.2 SIGNIFICANCE OF THE TOPIC

Dow Chemical, McDonalds, Exxon-Mobil, and Johnson and Johnson are just a few of the multinationals whose environmental performance is heavily scrutinized, researched, and

criticized. This involvement from external stakeholders has spurred these large corporations to innovatively change business practices and models in order to lessen their impact on the environment.

However, an even more pervasive economic phenomenon resides in the United States that also has impacts on the environment: the small business. According to the 2007 small business report to the President, 99.9% of businesses in the United States are small, meaning under 500 employees.[1] In addition, these small businesses employ 50.9% of the workforce.[2] Unfortunately, due to the inherent qualities of small business – fewer employees, finances, and political clout – environmental protection has been seen by many as an inconvenient regulatory burden.[3]

The EU's WEEE and RoHS Directives, passed on January 27, 2003 by the EU, are two regulations that may be transcending the label of inconvenience for the over 1.5 million small businesses in the electronics industry in the U.S.[4] because, unlike traditional environmental regulations which govern emissions, effluents and waste, these directives affect the core business of these companies: their products. On the continuum of environmental regulatory motivators with voluntary initiatives on one end and command and control mandates on the other, WEEE and RoHS occupy a unique position. This position allows government to not explicitly mandate how an organization must comply with the regulations, like is the case with "end of pipe" regulations common in the U.S., but instead gets the intended end result of the regulations by affecting the market. Also unlike end-of-the-pipe regulations which focus on waste treatment, these directives focus on the product and manufacturing process. The government relies on the inventiveness and competitive strategies of organizations to comply. As the business world continues

[1] United States Government Printing Office. *The Small Business Economy: For Data Year 2006*. (2007). 10.
[2] *ibid*. p. 9.
[3] W. Mark Crain, "The Impact of Regulatory Costs on Small Firms" *Small Business Research Summary,* no. 264 (2005). From the Small Business Administration's Office of Advocacy: http://www.sba.gov/advo/research/rs264tot.pdf (accessed April 1, 2008).
[4] Office of Advocacy. "Employer Firms, & Employment by Employment Size of Firm by NAICS Codes, 2005." From the United States Small Business Administration: http://www.sba.gov/advo/research/us05_n6.pdf (accessed April 1, 2008). 9.

to progress in its willingness and ability for positive environmental performance, extended producer responsibility based regulation like WEEE and RoHS may prove to be a more efficient tool for government to affect change.

1.3 REASON FOR INTEREST IN THE TOPIC

SMBs are the new frontier of environmental management. Great progress has been made to make larger multinational corporations more conscious of the environment and corporations have responded by turning environmental issues into a business strategy. Unfortunately, the SMB has been left on the sidelines as if its environmental performance is not as important. However, unlike the nebulous concept of a large corporation with no geographic boundaries, esoteric business models, and thousands of employees, the small business is much more grounded to the average person. The small business usually is an integral part of the local economy, managed by a neighbor or employing a friend. It is this reduction in scale that makes the environmental performance of an SMB equally important. If we can successfully get SMBs to begin considering the environment in their business decisions, we would be so much closer to creating a society that values the environment as well.

Because of SMBs' placement in the electronics supply chain, the European directives, WEEE and RoHS, are acting as that driving force for U.S. SMBs in the electronics industry to begin addressing and integrating environmental issues into their business and products. However, unlike the multinational that has ample resources to mobilize its operations into compliance, the SMB has to be more creative and efficient with its limited resources. That innovation should be documented, analyzed, and shared.

CHAPTER 2: BACKGROUND

2.1 PRELIMINARY INTERVIEW

A preliminary interview had been conducted with Carl Dubois, the senior director of manufacturing, at Performance Technologies. Performance Technologies is a small company of a little over 200 employees based in Rochester, NY that manufactures communications networking equipment. This is exactly the type of business that would be heavily affected by these new regulations. From the interview it became clear that businesses like Performance Technologies are in a peculiar spot within the supply chain. They are the suppliers for the telecommunication business units of large manufacturing corporations like Hewlett-Packard, Motorola, and Sun Microsystems. However, they themselves are also the customers for the components they use in their circuit boards or networking equipment. Therefore, they not only feel the tug from their larger customers to comply, they must also pull their component vendors into compliance.

Dubois mentioned that since the regulation is foreign, any guidance or supplemental support from the EU or its member states has been slow to come. In addition, no business wants to be helping its competition in complying with the regulations, leaving the U.S. SMB on its own for WEEE and RoHS compliance. Compliance is a matter of business "life or death." If a company complies, it can do business; if it doesn't, it goes out of business.

Since at least half of their market is in Europe, Performance Technologies found it in its interest to stay proactive in converting product lines to comply with RoHS requirements. This allowed the company to educate its component vendors, while ensuring the continued business from its customers. The regulations have resulted in eliminating all product lines that used leaded solder paste, even for products that are not sold in the EU. The change led them to eliminate the circuit board cleaning process, develop an environmental management system as reassurance to customers of compliance, and to anticipate the impacts of regulations around the world. A newly recognized global

perspective on the environmental regulatory landscape has caused Performance Technologies to search for ways to increase the recycled content and recyclability of its packaging and begin creating the infrastructure for taking back disposed circuit boards from its customers. Except for converting product lines to comply with RoHS, all these actions are voluntary.

This interview confirmed some initial theories on the manner in which WEEE and RoHS were affecting SMBs in the area. WEEE and RoHS did in fact spur innovative circuit board design and manufacturing processes in addition to new environmentally positive projects that were not directly required by the directives. Some gaps that were identified that should be investigated were the impact of WEEE and RoHS on SMBs that weren't OEMs but instead did contract work for other manufacturers and on SMBs whose main clients were the military since they would most likely be covered through an exemption in the directives. Both these gaps were addressed in this thesis.

Because limited attention has been focused on SMBs and their environmental performance in the past, and because current efforts to adhere to these new directives has become a matter of product viability and therefore, any methods used for compliance are treated as valuable trade secrets, this research could provide useful guidance regarding best practices tailored for the small business environment.

2.2 HISTORY AND DEVELOPMENT OF THE EU ELECTRONICS DIRECTIVES

On January 27, 2003, the EU passed two directives that would change the way electronic manufacturers and distributors viewed their products: the WEEE and RoHS directives. These directives were revolutionary in that they turned extended producer responsibility principles (EPR) into law requiring producers to be responsible for all the life stages of their products, including their end of life.

2.2.1 WEEE DIRECTIVE OVERVIEW[5]

[5] European Union. Directive 2002/96/EC. From the European Commission's Environmental page:

In a resolution passed on November 14, 1996, the European Parliament named electronics as a priority waste stream and requested the Commission to begin drafting proposed directives that could work to reduce the volume of waste generated using extended producer responsibility principles. In 2003, it jointly declared with the European Council and Commission Directive 2002/96/EC on WEEE containing the following objective:

> The purpose of this Directive is, as a first priority, the prevention of waste electrical and electronic equipment (WEEE), and in addition, the reuse, recycling and other forms of recovery of such wastes so as to reduce the disposal of waste. It also seeks to improve the environmental performance of all operators involved in the life cycle of electrical and electronic equipment, e.g. producers, distributors and consumers and in particular those operators directly involved in the treatment of waste electrical and electronic equipment. (Article 1)

According to the Directive, starting on August 13, 2005, all products that enter the EU market must have their end of lives financed by the producer. All 25 Member states were required to transpose the directive into national law by August 13, 2004. It should be noted that many Member States required extensions in implementing WEEE with a notable example being the UK that didn't implement WEEE until January of 2007. In addition, a study done by the International Institute for Industrial Environmental Economics has found that Member States have interpreted (some correctly and most incorrectly) the directive and has lead to notable differences from country to country on how a company is supposed to pay for its products. [6]

2.2.1.1 SCOPE OF WEEE

The directive applies to ten categories of electrical and electronic equipment listed in Annex IA of the directive:

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[6] http://ec.europa.eu/environment/waste/weee/index_en.htm (accessed April 1, 2008).

Category	Targets		Category	Targets	
	Rate of Recovery	Rate of Reuse or Recycling		Rate of Recovery	Rate of Reuse or Recycling
1. Large household appliance	80%	75%	6. Electrical and electronic tools (with the exception of large-scale stationary industrial tools)	70%	50%
2. Small household appliances	70%	50%	7. Toys, leisure and sports equipment	70%	50%
3. IT and telecommunications equipment	75%	65%	8. Medical devices (with the exception of all implanted and infected products)	70%	50%
4. Consumer equipment	75%	65%	9. Monitoring and control instruments	70%	50%
5. Lighting equipment	70%	50%	10. Automatic dispensers	80%	75%

Table 1- WEEE Categories and Targets

The WEEE Directive's definition of electrical equipment goes beyond what is normally considered electronics in the United States which is usually limited to equipment that contains a circuit board and associated peripheral equipment. The directive, on the other hand, applies to everything from a computer to a hair dryer to a vending machine. It also applies to new and historic WEEE. Historic WEEE came on the market before the set August 13, 2005 date and could include waste from producers that no longer are in business. In addition, the directive makes the differentiation between private household waste an non private household waste concluding that the producer's financial obligations are only required for the managing of private household waste (i.e. the consumer market).

The directive is focused on producer responsibility and defines the “producer” to be anybody that manufactures and sells products under its own brand, resells products under its own brand, or imports EEE into an EU Member State. Because it includes importers, the definition of producer has extended the scope of the directive to the U.S. and beyond.

2.2.1.2 REQUIREMENTS OF WEEE

The WEEE Directive contains requirements for municipalities, distributors, treatment or recovery centers as well as for producers. This paper will focus on the financial obligations that the directive places on the producers.

According to Article 8, "Member States shall ensure that, by 13 August 2005, producers provide at least for the financing of the collection, treatment, recovery and environmentally sound disposal of WEEE from private households deposited at collection facilities." For historical WEEE put on the market before August 13, 2005, the producers are responsible for the waste generated through the replacement of a product by their product. Otherwise, the user or household are responsible for the disposal. This is an amendment to the original directive that didn't specify what type of historic waste the producer would have to finance.[7]

For new products being put on the market, the directive requires producers to provide an upfront monetary guarantee that the new product will have a way of being managed once it is disposed. The producer can opt to provide this guarantee individually or as part of a collective of producers. This part of the directive has been transposed in various ways. The collective has been interpreted to mean that a company can or must pay into a joint venture (sometimes a nationwide recycling organization) with a payment proportional to its market share the year before. This is in actuality a limited guarantee for all new products put on the market that year since it's using a metric associated with sales the year before. This puts the scheme into possible long term trouble when it comes time to actually manage those new products. In addition, this bypasses individual responsibility. The cost is no longer tied directly to the new product, and any design improvements meant to generate less WEEE in the future would not be directly felt by the company's

[7] European Union. Directive 2003/108/EC. From the European Commission's Environmental page: http://ec.europa.eu/environment/waste/weee/legis_en.htm (accessed April 1, 2008).

bottom line. However, there are some Member States that have transposed the directive as it is stated, and watch groups such as the European Environmental Bureau, Friends of the Earth and Greenpeace have been researching and discussing the issue.[8]

In addition, the European Recycling Platform (ERP) was founded by Sony, Electrolux, Braun/Gillette, and HP to provide a collective compliance scheme that could standardize collection, recovery, and data gathering infrastructure[9]. While they state they advocate for individual producer responsibility when guaranteeing future management of WEEE, they've actually been working to create competitive producer responsibility organizations (PRO) that still allow for some limited guarantee but have the potential to allow a company to benefit from individual design changes since the collected waste could be separated for different PROs instead of simply all grouped together, weighed, and proportioned off for producers for that year like is the case in the single nationwide recycling organizations.

2.2.2 OVERVIEW OF ROHS DIRECTIVE[10]

The RoHS directive had its origins since the late 1980s where the European Council passed a resolution to address and minimize cadmium pollution. Eight years after that in 1996, a Commission Communication was issued calling for a way to reduce the hazardous content of waste by possibly banning certain substances in products and operations. And in December 4, 2000, the Council passed a resolution cementing its endorsement of the precautionary principle. Therefore, by the time WEEE was passed and the need for controlling the hazardous content of waste electronics became urgent for the safety of disassembly workers, the foundation had already been laid within the European Council to develop and pass the RoHS directive 2002/95/EC.

[8] Rossem, Chris Van and Noako Tojo and Thomas Lindhqvist. Lost in Transpositon? A Study of the Implementation of Individual Producer Responsibility in the WEEE Directive. September 2006.
[9] Joint Statement by a group of Industry and NGOs on Producer Responsibility for Waste Electrical and Electronic Equipment. March 2007.
[10] European Union. Directive 2002/95/EC. From the European Commission's Environmental page: http://ec.europa.eu/environment/waste/weee/index_en.htm (accessed April 1, 2008).

The objective of the directive is to:

> Approximate the laws of the Member States on the restrictions of the use of hazardous substances in electrical and electronic equipment and to contribute to the protection of human health and the environmentally sound recovery and disposal of waste electrical and electronic equipment.

The directive uses the same definitions of EEE and producer as in the WEEE directive; therefore, again, extending its reach from simply the European Union to any company from any country that sells products within the EU. However, the directive does make two important exclusions from the scope of WEEE. Only eight of the ten categories of waste under WEEE are under the scope of RoHS. Categories 8 and 9, medical devices and monitoring and control equipment from Annex IA of WEEE fall outside the scope of RoHS.

All other electronic equipment in the eight remaining categories put on the European market from July 1, 2006 can not contain any of the six substances:

- Lead (0.1%)
- Mercury (0.1%)
- Cadmium (0.01%)
- Hexavalent chromium (0.1%)
- Polybrominated biphenyls (PBB) (0.1%)
- Polybrominated diphenyl ethers (PBDE) (0.1%)

Unfortunately, all of these substances are commonly used in electronic equipment. All six could easily be present in a single circuit board let alone in an entire piece of electronic equipment. Therefore, the European Council amended the directive with maximum allowable concentrations by weight.[11] These percentages are included in parentheses in the above list.

The European Council also recognized the criticality of some of these substances in electronic equipment and includes a provision that allows for exemptions in the cases

[11] European Union. Commission Decision 2005/618/EC. From the European Commission's Environmental page: http://ec.europa.eu/environment/waste/weee/legis_en.htm (accessed April 1, 2008).

where "their elimination or substitution via design changes or materials… is technically or scientifically impracticable, or where the negative environmental, health and/or consumer safety impacts caused by substitution are likely to outweigh the environmental, health and/or consumer safety benefits thereof."

The original list of exemptions included in Annex I of RoHS:

1. Mercury in compact fluorescent lamps not exceeding 5 mg per lamp.
2. Mercury in straight fluorescent lamps for general purposes not exceeding:
    a. halophosphate 10 mg
    b. triphosphate with normal lifetime 5 mg
    c. triphosphate with long lifetime 8 mg.
3. Mercury in straight fluorescent lamps for special purposes.
4. Mercury in other lamps not specifically mentioned in this Annex.
5. Lead in glass of cathode ray tubes, electronic components and fluorescent tubes.
6. Lead as an alloying element in steel containing up to 0,35 % lead by weight, aluminum containing up to 0,4 % lead by weight and as a copper alloy containing up to 4 % lead by weight.
7. Lead in high melting temperature type solders (i.e. tin-lead solder alloys containing more than 85 % lead),
    a. lead in solders for servers, storage and storage array systems (exemption granted until 2010),
    b. lead in solders for network infrastructure equipment for switching, signaling, transmission as well as network management for telecommunication,
    c. lead in electronic ceramic parts (e.g. piezoelectronic devices).
8. Cadmium plating except for applications banned under Directive 91/338/EEC (1) amending Directive 76/769/EEC (2) relating to restrictions on the marketing and use of certain dangerous substances and preparations.
9. Hexavalent chromium as an anti-corrosion of the carbon steel cooling system in absorption refrigerators.

Since the passing of the original directive, seven Commission Decisions have been passed expanding the list of exemption activities to 29.[12] As stated Article 5 section (c) of the directive, the European Commission met five years after the passage of RoHS on January 24, 2008 and passed 2008/385/EC which reviewed the exemptions and added three more to bring the total to 32.[13] No exemptions have been eliminated yet.

[12] European Union. Directive 2002/95/EC "Consolidated Version." From the European Commission's Environmental page: http://ec.europa.eu/environment/waste/weee/legis_en.htm (accessed July 10, 2008).
[13] European Union. Directive 2008/385/EC . From the European Commission's Environmental page:

2.3 OVERVIEW OF EXTENDED PRODUCER RESPONSIBILITY PRINCIPLES

Both WEEE and RoHS are founded upon EPR principles with WEEE explicitly mentioning producer responsibility in its preamble (paragraphs 5, 8, 12, 19). EPR principles had been around and advocated by the Organization for Economic Cooperation and Development (OECD) since the 1990s.[14] The OECD's definition of EPR is:

> An environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle. An EPR policy is characterized by: (1) the shifting of responsibility (physically and/or economically; fully or partially) upstream toward the producer and away from municipalities; and (2) the provision of incentives to producers to take into account environmental considerations when designing their products.[15]

The definition makes two important points. The first is that the responsibility is placed solely on the producer. The producer has the power over the product that no consumer or government could have. The producer has the power to redesign a product to eliminate hazards, substitute hazardous materials used, and according to EPR advocates, properly manage the end-of-life of the product. This leads to the second important point of the definition. The producer's responsibility no longer is thought to end after the product leaves facility doors; instead the responsibility extends to the ultimate recycling, treatment, or disposal of the product. Therefore, it appears that the main goal of EPR is simply to reduce post-consumer waste. However, by making the producer accountable through its product's end of life it inevitably puts the financial and physical responsible for that reduction on the producer since he will be paying for it. This will then drive improvements that go beyond waste reduction such as these listed in the OECD's Guidance Manual:

- reducing the number of landfills and incinerators
- reducing the burden on municipalities for the physical and/or financial

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http://ec.europa.eu/environment/waste/weee/legis_en.htm (accessed July 10, 2008).

14 Organization for Economic Cooperation and Development. *Extended Producer Responsibility: A Guidance Manual for Government (*OECD Publishing, 2001), 13.

15 Organization for Economic Cooperation and Development. "Extended Producer Responsibility." From http://www.oecd.org/document/19/0,3343,en_2649_34281_35158227_1_1_1_1,00.html (Accessed April 14, 2008).

requirements of waste management
- fostering recycling and reuse of products or parts thereof
- improving the ease and timeliness of dissembling products fro recycling or reuse
- reducing or eliminating potentially hazardous chemicals in products
- promoting cleaner production and products
- promoting more efficient use of natural resources
- improving relations between communities and firms
- encouraging more efficient and competitive manufacturing
- promoting more integrated management of the environment by placing an emphasis on the product's life cycle
- improving materials management[16]

Therefore, many EPR initiatives have also been tied to Design for Environment (DfE) initiatives. Swedish researcher Lindqvist and his team analyzed the effects of EPR legislation in Europe on packaging, batteries, vehicles, and electronic equipment and found that the legislation had "stimulated innovation" in design and manufacturing. For example, the EU Directive on End of Life Vehicles creates a mandatory target stating that 85% of a vehicle's materials by weight to be reused and recycled with that rate increasing to 95% in 2015. The car manufacturers are required to insure by setting money aside upfront that the last owner of the vehicle does not have to pay for disposal. This financial obligation and strict target has already spurred companies such as Nissan to begin replacing materials with easier to recycle plastics and designing components like the fuel to tank to be easily disassembled.[17]

Therefore, it has been shown that EPR-based regulations can spur innovation and while reducing landfill and other negative environmental impacts without heavy-handed command and control style legislation. Through the proper internalization of costs, especially disposal costs, by the responsible producers instead of by the consumers or municipalities, regulations based upon EPR principles have resulted in product redesigns, recycling infrastructure, and the other benefits. However, the effects of WEEE and

[16] Organization for Economic Cooperation and Development. *Extended Producer Responsibility: A Guidance Manual for Government (*OECD Publishing, 2001), 13.

[17] Tojo, Naoko, Thomas Lindqvist, and Gary Davis, "EPR Programme Implementation: Institutional and Structural Factors," *OECD Seminar on Extended Producer Responsibility, EPR: Programme Implementation and Assessment* (2001). From: http://www.p2pays.org/ref/19/18269.pdf (accessed April 14, 2008). 20.

RoHS have had a much further reach since they affect not only main manufacturers but their suppliers as well. As a result, U.S. companies that supply EU manufacturers have also had to comply with these directives in order to keep their EU customers expanding the potential for innovation up through the supply chain.[18]

18 Kenji Hall "Sony Likes the Yield From its Junk: In a Turning Point for Tech, it Finds a Way to Make Money From Used Electronics." *Business Week*, 40, (September 17, 2007). Proquest, via Wallace Library, http://library.rit.edu/electronic/electronic.html , (accessed September 25, 2007).

CHAPTER 3: LITERATURE REVIEW

3.1 CHALLENGES POSED BY EU ELECTRONICS DIRECTIVES

SMBs operating in the U.S. appear to have given RoHS a much greater role of importance and priority than WEEE. This can be seen through the amount of resources available relating to RoHS instead of WEEE. For example, the IPC Association Connecting Electronics Industry, arguably the most important global trade association for the industry, has participated in numerous conferences on RoHS amendments and in its "Environment, Health & Safety"[19] and "Knowledge"[20] webpages makes many references to RoHS and none to WEEE.

However, this preference can also be explained by the ramifications of the directives. Unless the SMB was directly selling its products under its brand to consumers in the EU, then WEEE does not have a large immediate impact on an SMB's operations. In addition, for businesses manufacturing telecommunications, monitoring, measurement, or large appliance equipment; their products are not the high volume, quick obsolescence style of products that create the waste the WEEE directive is truly focusing on reducing. Their products will not become waste until five, ten, or even twenty years in the future versus the yearly upgrade of personal computers, mp3 players, and cell phones. In the preliminary interview, Dubois indicated that Performance Tech is taking a proactive approach to WEEE by working to develop infrastructure to accommodate the chance that its customers like Sun Microsystems would begin collecting waste electronics and then divide the waste down through the suppliers. Nevertheless, throughout the interview, it became clear the electronics industry is preoccupied by RoHS.

[19] IPC. "Environment, Health & Safety." *Industry* (2008). From http://www.ipc.org/ContentPage.aspx?Pageid=3.4 (Accessed July 8, 2008).
[20] IPC. *Knowledge* (2008). From http://www.ipc.org/ContentPage.aspx?Pageid=4 (Accessed July 8, 2008).

3.1.1 ALTERNATIVES

The first issue at hand with a directive that is restricting the use of certain substances is to find alternatives. Unfortunately, manufacturers have found serious limitations with the alternatives. Premier Farnell PLC, a London based, global distributor of electronics, created the following table outlining the main problems[21]:

Material or component	Alternative	Limitations of Alternative
Tin/lead solder	Lead-free solders	All different to tin/lead…
Silver/cadmium oxide contacts	Silver/tin oxide	OK at low voltage, wears faster at high voltage.
Chromate passivation	Various	Most are less effective as corrosion inhibitors on bare metals.
Mercury switches	Gold contacts	Only mercury gives bounce free contact and life is significantly longer.
Tin lead electroplated terminations	Tin alloys	Risk of tin whiskers. Wetting characteristics different.
PBDE flame retardants	Other flame retardants	Characteristics may be different. Need to comply with fire regulations.

Table 2- Limitations of Alternative RoHS Materials

Out of all of these materials, the replacement of the tin/lead solder with a lead-free solder has been the most problematic because of (1) its ubiquitous nature on a circuit board and (2) the very different characteristics of its alternatives.

The tin/lead solder could not be replaced by a homogenous solder of tin. Tin, zinc, cadmium, antimony, and indium are metals where "whiskering" is known to occur. These whiskers "are electrically conductive, crystalline structures of tin that sometimes grow from surfaces where tin (especially electroplated tin) is used as a final finish," and can cause various degrees of short circuits in electronic equipment.[22] The photo below from NASA's Goddard Flight Center's research shows examples of tin whiskers on a

[21] Premier Farnell PLC. *Premier Farnell RoHS Legislation and Technical Manual: Step-by-step Guide (Version 2)* (2005), 13. From http://uk.farnell.com/jsp/bespoke/bespoke8.jsp?bespokepage=farnell/en/rohs/rohs/facts.jsp. (Accessed July 7, 2008).

[22] Michael Sampson and Dr. Henning Leidecker. NASA GSF. "Basic Information Regarding Tin Whiskers." *Basic Info/FAQ*. (2007). http://nepp.nasa.gov/WHISKER/background/index.htm. Accessed July 8, 2008.

capacitor. Unfortunately, experiments yield inconclusive and sometimes conflicting results as to why these whiskered are formed in the first place.[23]

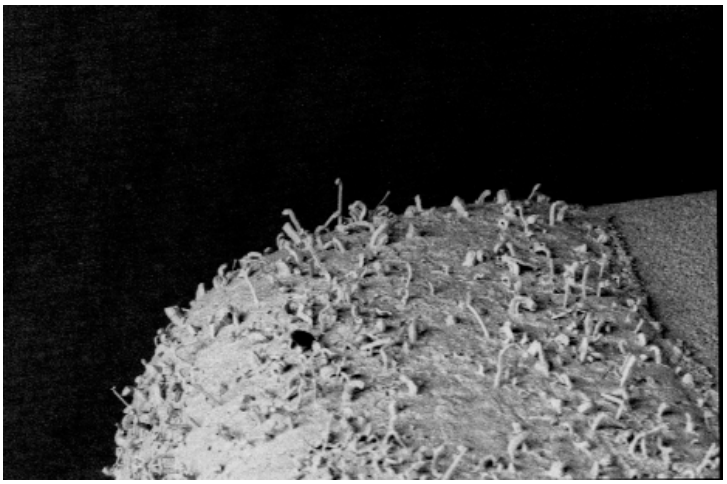

Figure 1- "Tin Whiskers on the Terminations of Pure Tin-Plated Ceramic Chip Capacitors" [24]

Therefore, a pure solder of tin can not be considered so that leaves different alloys as possibilities. Unfortunately, because the solder is a mixture of sometimes even three or four different compounds, the melting point of the solder is increased from that of a homogenous compound and that of the traditional lead/tin solder. This increase in melting point causes companies to increase the energy powering the reflow ovens in order to raise temperatures. These ovens are used to fuse the different components onto a circuit board during the surface mounting process.

The most commonly used alloy is a Tin/Silver/Copper alloy with respective percentages for silver and copper of about 3.0% and 0.5%. This alloy is abbreviated as SAC305 and has been deemed by IPC's Solder Products Value Council as the "alloy of choice for the electronics industry."[25] However, this alloy has a melting temperature of around 217 degrees Celsius versus the traditional tin/lead solder of 183 degrees Celsius.

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[23] Sampson, "Basic Information Regarding Tin Whiskers."

[24] Michael Sampson and Dr. Henning Leidecker. NASA Goddard Space Flight Center. "Tin Whiskers on the Terminations of Pure Tin-Plated Ceramic Chip Capacitors." *Photo of the Month Archives* (2005). From http://nepp.nasa.gov/WHISKER/photos/pom/2001august.htm. (Accessed July 8, 2008).

[25] IPC. "Solder." *IPC Compliance Web Site* (2005). From http://leadfree.ipc.org/RoHS_3-2-1.asp. (Accessed July 8, 2008).

Therefore, this 30 degree increase decreases the window of appropriate temperatures within the oven. Since it is not only the solder passing through the reflow oven but the entire board- laminate, wires, capacitors, etc.-, the reflow oven temperature must not surpass a temperature that damages the other circuit board components. Therefore, companies may not only have to replace their solder but also other circuit board components to more heat resistant varieties. Premier Farnell PLC created this table outlining the typical maximum temperatures that circuit board components could resist[26]:

Components	Typical Maximum Temperatures (^{o}C)
Aluminum electrolytic capacitor- max temp. depends on size	240-250
Tantalum capacitor- various types	220-260
Film capacitor	230-300
Surface mount relay	226-245
Crystal oscillator	235-245
Connector- depends on type of plastic used	220-245
LED- may function but light output affected	240-280
Ball Grid Array and Chip Scale Packaged devices	220-240
Other ICs	245-260

Table 3- Circuit Board Component Maximum Temperatures

In addition, all lead free alloys tend to lack a characteristic that is important when fusing the components onto a circuit board- wetting.[27] Wetting refers to the tendency of a fluid to spread across a surface. For example beads of mercury typically would have very little wetting while oil may be on the opposite side of the spectrum. Wetting allows the solder to fully spread across the area where the component will fit and properly fuse in the oven. Otherwise, gaps on the board may lead to defects. This further reinforces the need to keep temperatures high, which then exacerbates the issue of staying below the maximum temperatures for circuit board components.

[26] Premier Farnell PLC, 16.
[27] Premier Farnell PLC, 16.

3.1.2 MANUFACTURING PROCESSES

Because of the challenges and limitations posed by the alternatives to the restricted substances, companies have had to modify their manufacturing processes. *Lead-Free Magazine*, an online publication published through the collaboration of about a dozen large electronics companies, gives the following list of changes that may result from a lead-free switch in surface mount technology[28]:

- Determining process compatible lead-free board finishes
- Determining availability of lead-free components
- Determining thermal compatibility of both boards and components to new thermal profile
- Selecting solder paste chemistry to suit assembly process and the soldered assemblies reliability and operating conditions
- Process optimization and statistical process control development
- Training of operators and line managers to new lead-free process
- Material and logistical control for dual systems, if running both a leaded and a lead-free process
- Defining a proper rework process for lead-free assemblies
- Identifying the lead-free assembly for field service

The magazine addresses questions dealing from the use of "dummy components" to test new temperatures and processes resulting from the switch to lead-free to cleaning of old solder pots that used to house tin/lead solder.[29]

In addition, some companies are keeping two product lines open- one that is RoHS compliant and another that is not. Reasons for this include the fact that one product line is used for non EU customers or that one product line is used for customers that are exempt from RoHS such as the military and medical equipment manufacturers. However, this duplication can result in even more challenges and changes for a company. Even the National Weights and Measures Laboratory (NWML), the enforcing body for RoHS, has recognized the need to look beyond the product and to the manufacturing process for the product to ensure that not only the components are compliant but also the

[28] "Frequently Asked Questions." *Lead-Free Magazine* (2007). From http://www.leadfreemagazine.com/faq.htm. (Accessed July 8, 2008).
[29] Peter Biocca. "Solder Material." *Lead-Free Magazine* (2007). From http://www.leadfreemagazine.com/pages/vol006/solder_material_vol6_1.htm. (Accessed July 8, 2008).

materials used to assemble the components.[30] Therefore, a company must successfully segregate RoHS and non-RoHS compliant components and even processes. Procedures as rigorous as those used to ensure the purity of organic foods may be in order for businesses manufacturing two types of electronics where companies use separate machinery, inventory controls, and material processing standards for the two product lines and then acquire the certification of third party auditors to ensure RoHS compliance.[31]

3.1.3 MATERIAL DECLARATIONS

In November of 2007, the NWML published its first end of year report outlining the organization's work in enforcing RoHS during its first year of inception since July 1st, 2006. In one year, it had audited only about 180 companies and deemed 150 to need no further action (NFA). This means that the NWML found that a company had already fixed the problem that it had self declared or that the problem had minimal risk to the environment and market.[32] Therefore, the other 30 companies received improvement plans (10-20), compliance notices (5), EU notifications (3), and warning letters (1). Only one company received an offence brought to justice in the form of a simple caution.

Clearly 180 companies in a market filled with millions of electronics manufacturers is more like one molecule of H20 in the drop that falls in the bucket. In addition, none of the resolutions were as sensational as the 2001 seizure of 1.3 million Sony Playstations at the Dutch border for elevated cadmium levels. However, this is just the beginning of RoHS and one would expect the NWML to begin getting more and more stringent as more and more companies are brought aware of the directives. But for companies in the present, self enforcement and declaration has become a more serious threat and

[30] National Weights and Measures Laboratory. *Enforcement of the Restriction of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2006 (RoHS).* (2007), 9. From http://www.rohs.gov.uk (Accessed July 8, 2008).
[31] Ray Franklin. "Surprise Contamination, Part 2." *RoHSwell.com*. (2005). From http://www.rohswell.com/News/Genl009.php. (Accessed July 8, 2008).
[32] National Weights and Measures Laboratory, *Enforcement…*, 18.

protection against future liability than NWML enforcement. Even the NWML boldly states on its webpage: "Sitting back and doing nothing is unlikely to protect you."[33]

As a result, the IPC has issued two standards for material declaration management: IPC-1751 *Generic Requirements for Declaration Process Management* and IPC-1752 *Materials Declaration Management* that was tailored specifically for RoHS compliance. These standards include a PDF and XML management program to collect the information from suppliers that would protect a company through due diligence. The NWML states that for a regulation such as RoHS where offence can be proven without intent to do harm, a company's best protection is ensuring that all reasonable steps were taken to prevent noncompliance and the company exercised due diligence. The NWML writes:

> In terms of RoHS, this means that you have looked at the way in which you control your production and material supply and put in place a series of appropriate checks to prevent any problems occurring. Once you have done this you must ensure that the system of checks is being carried out. If you have a system that nobody knows about, or cares about, the system is useless and any defense is likely to fail.[34]

However, due diligence does not come without complexity. The IPC standard includes two different forms with six different classes of declaration from which a company could pick. One form would have to be completed for each "manufacturer listed item."[35] Therefore, if a company has ten electronic products that each contains 50 components, and then those components each contain ten smaller components; the amount of data that one would need to monitor expands exponentially. The IPC forms do make the declaration that "if the item is an assembly with lower level parts, the declaration encompasses all lower level materials for which the manufacturer has engineering responsibility."[36] This ensures a never ending paper trail of self declared RoHS compliance.

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[33] National Weights and Measures Laboratory. "Due Diligence." (2007). From http://www.rohs.gov.uk/content.aspx?id=7. (Accessed July 10, 2008).
[34] National Weights and Measures Laboratory. "Due Diligence."
[35] IPC. IPC-1752 *Materials Declaration Management*, Version 1.1 (2007), Form 1.1.
[36] IPC. IPC-1752, Form 1.1.

This leads to the last section of IPC-1752 standards: Verification Procedure. These procedures range from the simple validation that fields that require numerical answers have numerical answers to the more difficult confirmation of data through analytical documents and sampling to the most difficult process of auditing suppliers.[37]

3.1.4 COST

The cost of all these upgrades and changes ranges from estimates of $1 billion dollars for the consumer electronics industry[38] upwards to $32 billion dollars for the global electronics industry.[39]

A list of costs that companies have experienced was stated by the IPC as including:

- R&D
- Higher Materials Costs
- Supply Chain Management for in-scope and out-of-scope products
- Higher energy costs due to higher operating temperatures
- Training
- Need for tight inventory control and purchasing
- Excess and obsolete inventory
- Materials Declaration and compliance testing[40]

In addition to these initial costs, it is estimated that the industry will spend about $3 billion a year to maintain compliance. On average, an individual company spends $2,640,000 for the initial conversion and $482,000 for annual maintenance.[41]

3.2 IMPACTS OF THE EU ELECTRONICS DIRECTIVES ON SMBS

While large companies on both sides of the Atlantic have had to change their processes and materials to comply with WEEE and RoHS, the regulations also affect many SMBs.

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[37] IPC. IPC-1752, 18.
[38] IPC. "IPC 'ROHS Lessons' Presentation Given at the Asian-Pacific Economic Cooperation (APEC) Meeting in Australia." *IPC Compliance Web Site*. (2007). From http://leadfree.ipc.org/RoHS_2-6.asp (Accessed July 8, 2008).
[39] James Carbone. "RoHS Cost: $32 Billion and Counting." *Purchasing.com*. (2008). From http://www.purchasing.com/index.asp?layout=article&articleid=CA6565989&article_prefix=CA&article_id=6565989&industryid=48381 (Accessed July 8, 2008).
[40] IPC. "IPC 'ROHS Lessons.'"
[41] Carbone, "RoHS Cost."

It is estimated that in the EU, small and medium sized enterprises account for 99.8% of all companies, 66% of all employment, and 65% of all revenue.[42]

In the U.S., the statistics are similar. According to the 2007 small business report to the President, 99.9% of businesses in the U.S. are small, meaning under 500 employees.[43] In addition, these small businesses employ 50.9% of the workforce.[44] In 2005, over 1.5 million small businesses were in the 334 NAICS sector for Computer and Electronic Product Manufacturing and 335 for Electrical Equipment, Appliance, and Component Manufacturing.[45] In addition, in a 2005 follow up study, the findings remained consistent with 1995 and 2001 results that stated that U.S. small businesses have a disproportionate burden placed on them by regulations. The 2005 study found that for an environmental regulation, a small business pays around 46% more per employee to comply than a firm with over 500 employees and businesses with less than 20 employees pays 364% more.[46]

The apparent reaction among SMBs in the UK is one of overwhelmed anxiety. Small businesses are worried they don't have either the knowledge or the financial resources to switch over their processes and pay the new fees to stay in compliance with WEEE and RoHS.[47] In fact, in a 2007 survey of SMBS in the UK, only 59% of those businesses in the electrical equipment and machinery manufacturing industry were aware of the WEEE directive.[48]

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[42] M. Ilomkai and M. Melanen. Waste Minimization in Small and Medium-Sized Enterprises: Do Environmental Management Systems Help?. J. Clean. Prod., 2001, 9, 209-217.

[43] United States Government Printing Office. *The Small Business Economy: For Data Year 2006*. (2007). 10.

[44] *ibid*. p. 9.

[45] Office of Advocacy. "Employer Firms, & Employment by Employment Size of Firm by NAICS Codes, 2005." From the United States Small Business Administration: http://www.sba.gov/advo/research/us05_n6.pdf (accessed April 1, 2008). 9.

[46] Crain, 6.

47 Hendy Armstrong. "The UK Approach to the Implementation of the EC WEEE Directive: A Brief Analysis of the Disproportionate Burden Imposed on the Local Independent Computer Retailer," (2007) From Independent Trade Association of Computing Specialists: http://www.itacs.org.uk/downloads/weee_impacts.pdf (accessed January 9, 2007).

[48] NetRegs. "SME-nvironment 2007: UK Summary." (2007) From NetRegs: http://www.netregs.gov.uk/commondata/acrobat/smenvironment07uk_1856733.pdf (accessed April 7, 2008). 5.

3.3 NEGATIVE PERCEPTIONS OF ENVIRONMENTAL REGULATIONS AND SMBS

This reaction is consistent with previous studies within the UK. Since 2002, <www.netregs.gov.uk> has been conducting surveys with thousands of small and medium sized enterprises, ranging in size from 1 to 250 employees, in order to gauge SMB's attitudes and actions towards environmental issues. One question whose response has maintained relatively stable is: Does your business undertake activities that could cause harm to the environment? In 2005, NetRegs found that only 7% of those surveyed answered positively to that prompt.[49] This percentage rose slightly in 2007, with 15% of the surveyed SMBs agreeing[50]. However, when prompted to list the types of activities that could be potentially harmful to the environment such as:

- Storage of chemicals,
- Product or import packaging,
- Storage of waste,
- Emitting smoke to air,
- Causing a local nuisance,
- Discharging to sewers or waters, and
- Using water pumped from lakes, rivers, etc.;

almost half of the SMBs stated they did partake in at least one of those activities.[51] This indicates a disconnect between the actions and attitudes of SMBs that could be partially due to the question of whether pursuing environmental initiatives provides a cost benefit.[52] Since SMBs don't see their operations impacting the environment, SMBs have a more difficult time justifying any new initiatives that go beyond compliance if the initiatives don't provide tangible results. Despite the low levels of awareness shown by the NetRegs surveys, in another study of UK firms, almost 90% of the surveyed companies agreed with the statement: "we take sufficient environmental action to meet

[49] NetRegs. "SME-nvironment 2005: UK." (2005) From NetRegs: http://www.netregs.gov.uk/commondata/acrobat/2005_uk_summary_1197319.pdf (accessed April 7, 2008). 1.
[50] NetRegs (2005), 1.
[51] NetRegs (2008). 2.
[52] Andrea Revell and Robert Blackburn, "The Business Case for Sustainability? An Examination of Small Firms in the UK's Construction and Restaurant Sectors," *Business Strategy and the Environment*, 16 (2007). ABI/INFORM Dateline, via Wallace Library, http://library.rit.edu/electronic/electronic.html, (accessed April 14, 2007).

legislation."[53] This focus on environmental compliance was demonstrated in a survey of UK SMBs in the printing industry where the participants were satisfied meeting the regulations, but not willing to take the next step towards innovation which the authors defined as:

- Market development,
- Product differentiation, and
- Cost competitiveness.[54]

That regulatory motivation diminishes as the business gets smaller though. A study of Israeli micro-enterprises, defined by the study as smaller than SMBs and family-owned and run, found that the car mechanic shops it surveyed felt that environmental regulations were either too irrelevant or complicated to follow.[55] This observation was also made for UK SMBs in the annual NetRegs surveys, where businesses with at least 50 employees were more likely to state legislation as a reason for addressing environmental issues than those with less than nine employees.[56]

Some question has also been raised not only about the economic viability of pursuing environmental initiatives but the actual positive environmental effect they allegedly create. In a statistical analysis of waste minimization performance of Welsh SMBs that pursued or did not pursue environmental activities, the results surprisingly demonstrated that those SMBs that did pursue environmental activities had worse performance than those that did not. The authors concluded that this unexpected result could be due to the fact that SMBs pursuing environmental activities could be those whose historic environmental performance had been so low that either regulatory, consumer, or other

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[53] Michael Peters and R. Kerry Turner, "SME Environmental Attitudes and Participation in Local-scale Voluntary Initiatives: Some Practical Applications." *Journal of Environmental Planning and Management* 47, no. 3 (2004). ABI/INFORM Dateline, via Wallace Library, http://library.rit.edu/electronic/electronic.html, (accessed April 14, 2007). 461.

[54] Ian Worthington and Dean Patton, "Strategic Intent in the Management of the Green Environment within SMEs: An Analysis of the UK Screen-printing Sector." *Long Range Planning* 38, (20005). ABI/INFORM Dateline, via Wallace Library, http://library.rit.edu/electronic/electronic.html, (accessed April 3, 2007). 205.

55 Debby F. Mir and Eran Feitelson. "Factors Affecting Environmental Behavior in Micro-enterprises: Laundry and Motor Vehicle Repair Firms in Jerusalem." *International Small Business Journal*, 25 no. 4 (August 2007): 410. ABI/INFORM Dateline, via Wallace Library, http://library.rit.edu/electronic/electronic.html, (accessed December 16, 2007).

[56] NetRegs (2007). 4.

stakeholders had pressured them to become more progressive. Therefore, the apparent reactive nature of SMBs towards the environment and their impacts could have skewed the results.

The pessimistic outlook on SMBs and environmental performance is summed up in Ruth Hillary's preface of her book about the SMB condition. She described SMB's as:

> Largely ignorant of its environmental impacts and the legislation that governs it; oblivious of the importance of sustainability; cynical of the benefits of self-regulation and the management tools that could assist it in tackling its environmental performance; difficult to reach, mobilize or engage in any improvements to do with the environment.[57]

3.4 POSITIVE PERCEPTIONS TO ENVIRONMENTAL REGULATIONS AND SMBS

However, the outlook on the SMB environment isn't unanimously bleak. Recent studies outside of the UK have shown that small businesses have dealt with the challenges posed by environmental, health, and safety regulations through innovative process or management changes. A Chilean study found that cooperative government regulations led to incremental innovations, process changes, and the implementation of environmental management systems that went beyond the regulations' call for pollution control.[58] The author of the study states, "In spite of the fact that innovation was not an explicit target in any of the studied agreements, the facilities embraced it, as I have argued, as a way of overcoming the constraints posed by their regulatory environment"[59]

A large reason the SMBs studied were able to overcome those constraints was the nature of the regulatory environment in which they operated: Cleaner Production Agreements (CPAs). These CPAs were agreements between industry and government on action plans

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[57] Ruth Hillary. *Small and Medium-Sized Enterprises and the Environment: Business Imperatives* (Greenleaf: Sheffield, 2000), 18.

58 Orlando Jimenez. "Innovation-Oriented Environmental Regulations: Direct Versus Indirect Regulations; an Empirical Analysis of Small and Medium-Sized Enterprises in Chile." *Environment and Planning*, 37 (2005): 735. Ebsco, via Wallace Library, http://library.rit.edu/electronic/electronic.html, (accessed January 8, 2008).

59 Jimenez, 741.

meant to reduce environmental impacts such chemical effluent, packaging, air emissions, waste generation, and pesticide usage. Jimenez describes them as a form of "indirect" regulation indicating the flexibility businesses were given in their efforts to reach the agreed upon levels of environmental impacts.[60] Therefore, businesses had more freedom to use unique production or management techniques.

The role voluntary initiatives have with SMBs in fostering a more conducive environment for innovation was also examined in a UK study of two SMB industrial parks. The authors sent out consultants to deliver waste minimization workshops to the two sets of SMBs and then evaluated the outcomes both in activities and attitudes of the prompts to see if they spurred collaboration, improved environmental performance and changes in attitudes. By the end of the study, one company had redesigned a process to minimize paper usage and several companies collaborated on improving their facilities to minimize energy usage. In the spirit of industrial ecology, several waste exchange relationships were also formed within the SMBs in the park.[61]

Some researchers believe those examples of voluntary local business collaboration could carry over to the implementation of the WEEE directive. The directive is dependant on product recovery firms which have historically been small. However, the small size might lend SMBs to fulfilling a competitive niche within product recovery networks. A German study calls for the "preservation of very high flexibility typical for SMEs" in order to address the fickle collection rates, lack of homogeneity of collected materials, and need for specialized disassembly technology created by the directive.[62]

These studies demonstrated that while SMBs do have inherent characteristics that could hinder them in improving their environmental performance such as lack of human and

[60] Jimenez, 728.
[61] Peters and Turner, 463-466.
[62] Grit Walther and Thomas Spengler. "Empirical Analysis of Collaboration Potential of SMEs in Product Recovery Networks in Germany," *Progress in Industrial Ecology- An International Journal* 1, no. 4 (2004). 369. Ebsco, via Wallace Library, http://library.rit.edu/electronic/electronic.html, (accessed April 8, 2008).

financial resources. They do have characteristics that place SMBs in a position to use the external pushes from regulation as a vehicle for innovation.

A statistical analysis conducted on over 200 Spanish small to medium-sized automotive garages supported three hypothesis based on characteristics usually present in SMBs:

1. A capability of shared vision will be positively associated with the development of proactive environmental strategies by SMEs.
2. A capability of stakeholder management will be positively associated with development of proactive environmental strategies by SMEs.
3. A capability of strategic proactivity will be positively associated with the development of proactive environmental strategies by SMEs.[63]

In addition, unlike the previously discussed study, this analysis did support a fourth hypothesis relating proactive environmental strategies with improved financial performance.[64] The authors concluded that size should not be the only measure used in determining the resources available to a business. Organizational capabilities such as those listed above can determine the ability of an SME to pursue proactive environmental initiatives.[65]

3.5 MARKET FACTORS AND ENVIRONMENTAL REGULATIONS

These inherent internal qualities of SMBs may be put best to used in a situation where SMBs are searching for a competitive edge while responding to market forces that are pressuring change. Various cited market forces as a common or more effective motivation for SMBs to pursue environmental initiatives. Even the Chilean study argued that many regulatory initiatives fail to contain market factors. This omission prevented SMBs from making further "radical multimedia innovations" because it prevented environmental issues from becoming a part of the company's "strategic agenda."[66]

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[63] J. Alberto Arragon-Correa, et al. "Environmental Strategy and Performance in Small Firms: A Resource-Based Perspective," *Journal of Environmental Management* 86 (2008). 91-92. ABI/INFORM Dateline, via Wallace Library, http://library.rit.edu/electronic/electronic.html, (accessed December 16, 2007).
[64] Arragon-Correa, 98.
[65] Arragon-Correa, 98.
66 Jimenez, 740.

A Canadian study was able to correlate an SMB's innovativeness with respect to environmental initiatives to its competitiveness in terms of: cost containment, revenue generation, and liability management and corporate image.[67] The study analyzed four SMBs from the wood products, printing, metal products, and electric/electronic product industries. Out of the four, the electronics industry had the highest correlations between innovativeness and competitiveness. SMBs from that industry were more likely to cite as a driver of change market opportunities and had responded to market forces by designing the product to be easy to manufacture, increasing the product's useful, designing the product to accommodate multiple future users, among others.[68] The study was published in 2003, right at the beginning of the WEEE and RoHS passage.

WEEE and RoHS will therefore provide even further market incentive to not only comply with their provisions but to do so in a competitively strategic manner. All around the world the potential influence these directives will have on SMBs part of a global supply chain is being recognized. In a Hong Kong survey, the most commonly cited driver for environmental change was the supply chain-focused WEEE and RoHS directives.[69]

In the supermarket industry, the role of supply chain pressure had been studied intensively. Food retailers are viewed as "ecological gatekeepers" who through their initiatives can force a ripple effect throughout their suppliers and thereby also elevate the environmental performance of the suppliers.[70] A modern example of a large chain acting as an ecological gatekeeper is Wal-Mart. Through its Sustainability Score Card, Wal-Mart is setting minimum requirements for its suppliers. Since the suppliers do not want

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[67] Elisabeth Lefebvre, Louis A. Lefebvre and Stephane Talbot, "Determinants and Impacts of Environmental Performance in SMEs." *R&D Management* 33, no. 3 (2003). 277. Ebsco, via Wallace Library, http://library.rit.edu/electronic/electronic.html, (accessed April 8, 2008).

[68] Lefebvre, 272 & 274.

[69] Sonja Studer, et al, "SMEs and Voluntary Environmental Initiatives: A Study of Stakeholders' Perspectives in Hong Kong." *Journal of Environmental Planning and Management* 51, no. 2 (2008). 293. Ebsco, via Wallace Library, http://library.rit.edu/electronic/electronic.html, (accessed April 8, 2008).

[70] F. Belz. "Food Retailers as Ecological Gatekeepers." Paper presented at the 5th International Greening of Industry Newtwork Conference, Heidelberg (1996).

to lose such a large customer, they will conform improving their environmental performance and that of Wal-Mart.

In the case of WEEE and RoHS, the EU has taken the role of ecological gatekeeper within the electronics industry. Like in the Wal-Mart example, the SMBs along the supply chain doing business with large corporations such as Hewlett-Packard and Dell can't afford to lose such large customers. The effect of the regulations is further magnified by the "multiplier effect."[71] In the electronics industry, Dell may have a supplier of circuit boards who then has its own suppliers of components who then may even have their own suppliers of vendors. Therefore, the number of companies affected by the directives is exponentially greater than just the large corporations that sell directly to EU customers.

Unlike the previous EPR directives that deal with packaging, batteries, and vehicles, it is this multiplier effect that makes WEEE and RoHS unique and provides an even greater potential for spurring innovation among the SMBs along the supply chain. While the OECD has been able to find that EPR regulations successfully spur innovation in large European companies as discussed in the previous sections, not much research has been conducted on whether the same spur of innovation can occur in SMBs through WEEE and RoHS especially SMBs operating in the United States.

[71] Bjarne E Ytterhus, Petter Arnestad, and Solveig Lothe, "Environmental Initiatives in the Retailing Sector: An Analysis of Supply Chain Pressures and Partnerships." *Eco-Management and Auditing* 6, no. 4 (1999) 182. Ebsco, via Wallace Library, http://library.rit.edu/electronic/electronic.html, (accessed April 8, 2008).

CHAPTER 4: METHODOLOGY

Because of the "how" and "why" nature of these research questions, an appropriate methodology to use was a case study. Innovation and attitude changes are not the result of a linear cause and effect system. Therefore, a case study allowed for investigating the ways that a company and its complex managerial and operational processes as a whole were being affected by global regulatory and non-regulatory requirements.

4.1 CASE STUDY PROTOCOL- OVERVIEW

This case study was a multiple-case study with embedded units of analysis. Each small or medium sized business will be a case. Possible units of analysis could be:

- Supply chain management
- Product redesigns
- Manufacturing process changes
- Data accumulation challenges and methods
- Competitive strategies
- Management or personnel changes
- Global regulatory perspectives and management methods

For each case, an in-depth interview was conducted with the person responsible for WEEE and RoHS compliance. After the interview, a follow up interview or visit was possibly arranged to delve deeper into a specific unit of analysis depending on the information collected in the initial interview.

The objective of these multiple case studies is to answer the following questions:

- How are WEEE and RoHS impacting your business?
  - Operational, management, product design, market strategies
- Why have WEEE and RoHS impacted your business the way that it has?
  - Management, employees, operational characteristics, external stakeholders
- How have WEEE and RoHS affected your attitudes towards the role SMBs have

in the pursuit of sustainability?

Answering those questions will allow for the corroboration or dismissal of the initial hypothesis: WEEE and RoHS are spurring innovation among small and medium sized businesses in the U.S.

The following boundaries were imposed on this case study:

1. Only businesses with less than 500 employees were considered. Less the 500 employees is the generic definition of a small business according to U.S. Small Business Act.
2. Only businesses within the electronics industry were considered. These businesses include those under the NAICS code 334 (Computer and Electronic Product Manufacturing) and code 335 (Electrical Equipment, Appliance, and Component Manufacturing).
3. Only businesses located in Rochester, NY were considered. While this geographic boundary appears small, because of the global supply chain, small businesses across the nation will be facing similar challenges and opportunities. In addition, Rochester businesses are in a unique situation compared to other manufacturing areas of the country due to the amount of high technology products manufactured here that are exported out of the country.
4. Most of the evidence collected was in the form of coded interviews with managers and employees. However, it was not be limited to just interviews and can include the other five sources of data (documentation, archival records, direct observation, participant observation, and physical artifacts) if deemed necessary.

4.1.2 CASE STUDY PROTOCOL- VALIDITY

A high-quality case study design must satisfy three tests: construct validity, internal validity, and external validity. To establish appropriate construct validity, the investigator must:

1. Select the specific types of changes that are to be studied (and related them to the original objectives of the study) and

2. Demonstrate that the selected measures for these changes do indeed reflect the specific types of changes that have been selected.[72]

Innovation was defined as any change in the design and manufacturing of the products, in the internal organizational structure and management of the business, or in the market strategies pursued by the SMBs that created a benefit beyond RoHS and WEEE compliance.

Therefore, to maintain construct validity of this study the case study questions and field procedures directly addressed and requested descriptions of those changes. Those descriptions then tied directly back to whether the SMB is pursuing innovation as defined. Not only was evidence gathered describing those physical changes in product, process, management, and strategy, evidence also was gathered on the attitudes of the SMBs towards sustainability. This provided further construct validity since those descriptions were then used to determine the extent that innovation had penetrated the SMB's operations: Is innovation driven simply by market motivations or by a deeper or higher calling for responsible design, production, and disposal of products?

Because this case study was a causal case study that attempts to determine whether the EU regulations are causing innovative changes among SMBs, it had to pass the internal validity test. Therefore, it was important that the interview questions asked did not inadvertently lead to spurious connections or correlations. The questions, as a result, were open ended, thereby neutralizing any preemptive biases coming into the study. The rival theory that maybe these directives are not spurring innovation or are doing more environmental harm than good also was considered throughout the research process.

In addition, to satisfy the internal validity test, the interview guide included questions that gauge the SMBs awareness and understanding of the WEEE and RoHS directives. Examples of these questions were:

- How do you determine if you are WEEE or RoHS compliant?

[72] Robert K. Yin. *Case Study Research: Design and Methods* (Thousand Oaks, California: Sage Publications, Inc, 2003), 35.

- Do you believe you are now WEEE or RoHS compliant?
- What are your biggest concerns with ongoing WEEE or RoHS compliance?
- Are there other emerging international and domestic environmental regulations that you are monitoring? If so, what are they?

Answers to these questions lead to a judgment of whether this SMB is actively identifying compliance gaps and the degree it monitors and manages compliance within the supply chain. This information validated the data collected from interviews to ensure their credibility.

Member checks are another strategy used to satisfy the internal validity test for a case study.[73] This strategy involves presenting a hypothesis or explanation to a "member" of the culture that is being studied in order to test it or prompt a response. This case study used member checks through its follow up visits that are explained in the next section. These follow up visits provided an opportunity to expand on and clarify the ideas gathered in the initial in depth interview.

The multiple case studies themselves acted as the multiple sources of information needed to triangulate and further validate the data collected from the case study.[74] Triangulation "compares multiple sources of information about an object of inquiry" providing "both a credible means of verifying data and of developing concepts."[75] This strategy further ensured the internal validity of this case study.

Ultimately, the project did not end until the point of data saturation was reached. This point occurs when "new data are consistent with the hypothesis or explanation, require no modification, and provide no new surprises."[76] The researcher will "quit the field" once theoretical saturation is reached.

The final validity test that this study had to pass was external validity. The findings had to be able to be generalized for all U.S. SMBs in the electronics industry conducting

[73] John Morelli, *Research Methods for EHS Management* (unpublished, 2006), 85.
[74] Morelli, 85.
[75] Morelli, 85.
[76] Morelli, 86.

business with Europe. The characteristics of the companies were also be analyzed to determine which characteristics were helping or hindering the companies move towards compliance. Therefore, the extent of the domain was discovered as the study was conducted.

For a research map illustrating these validity concepts, see the appendix.

4.1.2 CASE STUDY PROTOCOL- FIELD PROCEDURES

Through work with RIT's Center for Electronics Manufacturing and Assembly and New York State's Environmental Management System Assistance Program, a list of potential companies that could be used as cases for the study was identified. If through this list, an insufficient number of cases was found, an alternative plan was to contact large manufacturers in the area such as Kodak and Xerox in order to determine whether they are using local, SMB electronics suppliers. This, however, was not found to be necessary.

The following protocol was used when approaching prospective companies:

1. Call contact person at the company. State the following: **I am a graduate student in the Environmental, Health, and Safety Management program at the Rochester Institute of Technology. The topic of my master's thesis focuses on the EU directives, WEEE and RoHS and whether they are spurring innovation among small and medium size electronics businesses in the U.S. I am conducting case studies on local small businesses as part of my research and [*insert name of person who recommended the company*] suggested this company as a possible case. Could I speak with your environmental manager or person responsible for compliance with these directives?**
2. Speak with the environmental manager or equivalent and verify the following:
    a. The company has less than 500 employees
    b. The company is in the electronics industry

   c. The company conducts business with Europe or is affected by WEEE and RoHS

3. Explain the topic more thoroughly.
4. Explain the case study and interview process (~ 1 hour interview).
   a. Briefly state protocols will be in place to protect any participants in this study.
5. Ask: **Will you be willing to participate in my study?**
6. Schedule interview time.

The following protocol was followed when conducting the in-depth interview:

1. Send the following five main questions to the interviewee ahead of time:
   a. How has your company prepared to comply with WEEE and RoHS?
   b. Have your company pursued any projects as a result of WEEE and RoHS?
   c. Do you believe SMBs have a role in the pursuit of environmental sustainability?
   d. Could you provide an estimate of the costs incurred from WEEE and RoHS due to:
      i. Engineering of alternative products and processes?
      ii. Yields of defective products or scrap?
      iii. Surplus non WEEE and RoHS compliant inventory?
   e. Are these costs different than those associated with typical product design and production?
2. Once on site, review subject protection protocols in more detail.
   a. Review level of anonymity.
3. Conduct interview based on interview guide.
4. Record the interview.
5. Ask whether other employees or managers are affected by the directives and whether they would be willing to be interviewed.
6. Ask whether he/she knows of any other SMBs in the area that may be appropriate for this study.
7. Ask if he/she would be available for a follow up interview.

A follow up visit may have been used to expand on the previously listed embedded units of analysis:

- Supply chain management
- Product redesigns
- Manufacturing process changes
- Data accumulation challenges and methods
- Competitive strategies
- Management or personnel changes
- Global regulatory perspectives and management methods

Therefore a follow up visit may have included:

- Tour of new processes changed to comply with RoHS and WEEE.
- Interview with design engineers who have changed design criteria to comply with RoHS and WEEE.
- Interview with CEO or president of the SMB for a high level perspective on the SMB's competitive strategies.
- Direct observation of products to see the difference between RoHS and WEEE compliant products and non compliant products.
- Review of environmental management system documentation.
- Direct observation of data accumulation software and interview with person responsible.
- Interview with employees who now have to address WEEE and RoHS compliance in their work.

Specific questions and procedures conducting and collecting data for these follow up visits were developed on an *as-needed* basis.

Other points in this protocol are:

- After the interviews and follow up visits, thank you letters were sent to the environmental manager.

- At no time were the interviewees able to read drafts of the research or notes unless to verify concrete facts.

4.1.3 CASE STUDY PROTOCOL- CASE STUDY QUESTIONS

The following guide has been developed for this case study. The questions on the guide will be asked during the in-depth interview portion of the study and the answers to the questions further expanded in a possible follow up visit.

The guide was used in a preliminary in-depth interview conducted February 21, 2008 with Carl Dubois. Dubois, as discussed in a previous section, is the senior director of manufacturing at Performance Technologies, a small, Rochester OEM that manufactures electronic equipment for telecommunication networks. After discussing the results of the interview with him and the other members of the graduate committee for this work, the following sections were added:

- An initial section that gauged the awareness and understanding of the interviewee on the WEEE and RoHS directives.
- A section that collected cost data in three areas: engineering of new products and processes, yield scrap, and surplus inventory. This cost data was supplemental information to the interview and was used to add further substantiation to findings and conclusions. The three areas were selected after discussion with Dubois. He stated that SMBs may not have all of this quantitative data available; however, from his experience and observation, the three areas identified were the major cost centers in the move to WEEE and RoHS compliance. By providing three different areas, the chances are increased that the interviewee will have a strong estimate on at least one of these cost centers.

Interview Guide

WEEE AND ROHS: ARE THEY SPURRING INNOVATION AMONG SMALL AND MEDIUM SIZE ELECTRONICS BUSINESSES IN THE U.S.

This research will determine whether the EU directives, WEEE and RoHS, are spurring innovation in U.S. SMBs in the electronics industry as they work to be in compliance. This research will focus on (1) analyzing the projects or changes SMBs have undertaken in response to WEEE and RoHS, (2) determining the characteristics of the SMB's (managerial, operational, external influences) that have allowed for or led to the changes, and (3) assessing the attitudes SMBs have towards these directives and their place in environmental responsibility.

1. Do you believe you are now WEEE and RoHS compliant?

[*This set of questions will gauge the interviewee's awareness and understanding of the WEEE and RoHS in order to validate their subsequent responses.]*

1.1. What are your biggest concerns with ongoing WEEE and RoHS compliance?

1.2. Are there other emerging international and domestic environmental regulations you are monitoring. If so what are they?

2. How has your company prepared to comply with WEEE and RoHS?

[This set of questions would introduce the topic and provide some understanding on how the SMB runs and how its culture and operations affect its preparation for WEEE and RoHS.]

2.1. Did any characteristics of your company or how it operates aid it in complying with WEEE and RoHS?

a) Management?
b) Employees?
c) Operational characteristics?
d) External stakeholders?

2.2. Did any characteristics of your company or how it operates hinder it in complying with WEEE and RoHS? Management?

a) Employees?
b) Operational characteristics?
c) External stakeholders?

2.3. What has been your company's biggest challenge?

2.4. What would happen if the U.S. would come out with similar legislation as WEEE and RoHS? How would that affect your business?

3. Have your company pursued any projects as a result of WEEE and RoHS?

[This set of questions delves deeper into the specific projects or changes that the SMB has done and why they have or have not done them.]

3.1. What operational or process changes have happened?

a) Why?

3.2. What product design changes?

a) Why?

3.3. What management changes?
   a) Why?

3.4. What would happen if your company opted to not comply with WEEE and RoHS?
   a) What other market opportunities could you pursue?
   b) What other market opportunities would you lose?

3.5. How have you addressed product lines that do not fall under the scope of WEEE and RoHS?

4. Do you believe SMBs have a role in the pursuit of environmental responsibility?

[This set of questions extends the issue of WEEE and RoHS compliance towards sustainability. They will provide information about SMB attitudes towards environmental protection and sustainability and whether WEEE and RoHS have affected those attitudes.]

4.1. WEEE and RoHS were written with extended producer responsibility principles (EPR) included explicitly in the text. As a producer, how do you feel about the responsibilities that these types of legislation are putting upon you?

4.2. How have these regulations affected your company's views on environmental protection?

5. What has been the cost of complying with WEEE and RoHS?

[*This set of questions will collect some quantitative data on the effect of WEEE and RoHS on SMBs.]*

5.1. What have been the engineering costs of redesigning compliant alternatives of your products?

5.2. What have been your scrap costs from defective yields (i.e. associated with RoHS compliant lead free solder)?

5.3. What has been your surplus inventory cost of non compliant WEEE and RoHS parts and products?

5.4. What percentage of your consumer base is requiring compliance with WEEE and RoHS?

5.5. Considering the unique costs associated with WEEE and RoHS compliance, how much of your business at a minimum would you say would have to be applicable for it to make economic sense to switch over to compliance with these EU directives?

6. Are there any other comments you'd like to make? Other areas that should be addressed?

[*This set of questions will be using the "snowballing" sampling strategy to acquire more data points.]*

6.1. Are there any other people within the company that should and could be interviewed?

6.2. Are there any other people outside the company that should and could be interviewed?

4.1.4 CASE STUDY PROTOCOL- RESEARCH SUBJECT PROTECTION PROTOCOL

As the researcher (ER), I did the following to protect participants in this study:

- In advance of the interview, provided each interviewee (EE) with a written statement introducing and providing the rationale for the research project, and describing the semi-structured interview procedure to be used by the ER;
- In advance of the interview, provided each EE with background information on the ER;
- Before beginning the interview, requested permission to record the interview on audio tape for sole purpose of enhancing the ER's note-taking ability;
- Explained that the EE may request that any part of the EE's response be kept confidential or off the record;
- Explained that the EE may turn off the tape recorder at any time during the interview;
- Showed the EE how to shut off the tape recorder and place the recorder within the EE's reach;
- Kept the audio tapes secure and inaccessible to others;
- Destroyed the audio tapes after the ER is through transcribing and analyzing their contents.[77]

At the start of the case study, the level of anonymity that the environmental manager and the company would feel comfortable applying was discussed. The following means were done:

- Not use specific names, but instead use titles.
- Not use the company's name.

4.1.5 CASE STUDY PROTOCOL- REPORT

After eight cases, enough information had been collected to complete the report. The first part of the report introduced each of the cases and gives a brief description of the organizational structure and manufacturing processes.

[77] Morelli, 79.

Next, the report focused on the three types of change that were described above:

- changes in the design and manufacturing of the product
- changes in the internal organizational structure and management of the business
- changes in market strategies pursued by the SMBs

It also had a section for patterns or differences in characteristics of the SMBs studied that either helped or hindered compliance to the directives. Ultimately, the report should become a guidebook for SMBs affected by the EU directives to use for compliance strategies.

4.2 DATA COLLECTION PROTOCOL

To ensure the reliability of the data collected the following strategies were used:

- Systemized note-taking conventions
- Consistent interview guide

These strategies ensured that the interviews were conducted in the same way at each company in order to minimize bias.

All interviews were taped. In *Interpreting Qualitative Data*, David Silverman states that audio recordings of interviews are satisfactory for "ensuring transcript reliability and documenting data collection procedures."[78] Therefore, after each interview, the recording was transcribed and any field notes taken were expanded within 48 hours. Each transcription followed common conventions. The questions asked by the interviewer were italicized and the words from the interviewee were left in plain text. Any comments or notes added by the interviewer about the interview or the interviewee were put in square brackets.

For each interview, the same interview guide presented in the previous section was used. This interview guide had been tested and modified based on the discussions with the interviewee and committee. If additional questions or areas of inquiry came up during

[78] Morelli, 83.

the interviewing process, they were added, "to the extent possible and reasonable, be positioned in the question sequence so as to minimize the disruption of the information flow in the original set of questions and probes."[79]

4.3 DATA ANALYSIS PROTOCOL

All interviews were transcribed and the information coded using the following categories:

- Supply chain management (SCM)
- Product redesigns (DES)
- Manufacturing process changes (PROC)
- Data accumulation challenges and methods (DATA)
- Competitive strategies (COMP)
- Management or personnel changes (MGMT)
- Global regulatory perspectives and management methods (GLO)
- Characteristics that helped compliance (POS)
- Characteristics that hindered compliance (NEG)
- Texts that refer to costs associated with compliance ($$$)

Coding the data was the first step in analyzing the data because "it provides a means of tagging data elements so that they can be pulled back together to provide a researcher a theoretical building block, to substantiate a theory, to refute one, etc."[80]

The general analytic strategy of the data collected in this study was one of explanation-building. The first part of the analysis, however, was one of description. The first question to be answered was how SMBs are complying with these directives. After looking at the data collected on those changes, one had to determine whether or not the changes matched the previously discussed definition of innovation. Then the data collected on the characteristics of the SMBs was used to attempt to explain why or why not the SMB pursued innovative changes. This explanation was based on patterns in the

[79] Morelli, 84.
[80] Morelli, 81.

data and literature review on EPR policy. Similarities in characteristics across the cases were studied to determine whether they led to similarities in changes pursued.

Once all these facets of the collected data were analyzed, the final conclusions would assess the effectiveness that WEEE and RoHS were as EPR policy instruments in spurring innovation.

4.4. DEVIATIONS FROM PLANNED METHODOLOGY

During the first interview, it became apparent that the interview guide needed some additional questions in order to guide the interviewees toward the research aspect. These questions naturally seemed to arise during that first interview and for consistency, these changes were then included in the interview guide for each the subsequent interviews.

Follow up questions:

- Please elaborate on your plans for addressing WEEE.
    - Objective: If not guided, the interviewees tended to focus exclusively on RoHS leaving a gap in the research.
- What other substances of concern is the company focusing on other than lead?
    - Objective: If not guided, the interviewees tended to focus exclusively on lead-free projects, again leaving a gap in the research.

New questions:

- Where did you get information on or assistance for WEEE and RoHS compliance? Did you find much sharing of information between companies or was it too competitive?
    - Objective: This question was used to gauge the competitive environment that the company was operating within to determine whether this environment affected the response to WEEE and RoHS.
- What spillover effects, if any, did you find resulted from the company's compliance efforts?
    - Objective: This question went straight to the core of this research and was asked towards the end of each interview.

Other than these small changes to the interview guide, the only deviation to the proposed methodology was in terms of the follow up visits. No follow up visits were needed. Two companies provided a tour of their production processes immediately following the interview. For some interviewees where some clarification was needed, the member checks were accomplished via emails. For instances where the interviewee felt that another person within the company would be helpful in this research, the two people were interviewed at the same time, eliminating the need for a follow up visit.

After eight cases, the point of data saturation was reached. A clear distinction could already be seen between the interviewees from contract manufacturers and original equipment manufacturers. By the third contract manufacturer and fifth original equipment manufacturer interviewed, no new major changes or impacts from WEEE and RoHS were identified. This point became reinforced when the snowball sampling strategy began leading to the same companies. By the last interviews the companies were suggesting contract manufacturers and competitors that I had already interviewed.

CHAPTER 5: FINDINGS

Nine managers representing eight companies were interviewed in this study and tours of the production processes at two companies were conducted for this study. Three of the represented companies were contract manufacturers (CM1, CM2, CM3), contracted to assemble or "stuff" the boards per the requirements of their customers or to manufacture bare circuit boards. Five of the represented companies were original equipment manufacturers (OEM1, OEM2, OEM3, OEM4, and OEM5). Their lines of business included network equipment, audio equipment, and monitoring equipment. Three of the OEMs (OEM3, OEM4, and OEM5) had in-house SMT lines and *through-hole soldering* processes, while the other two contracted the "stuffing" of the boards to CMs. As a result, three distinct categories of operation were observed within these eight companies:

- CMs
- OEMs that use CMs to assemble their circuit boards
- OEMs that had in house SMT and *through-hole soldering* processes to assemble their own boards.

WEEE and RoHS affected each of these three types of electronics manufacturers in different ways.

Company	In House Soldering Lines	Line of Business	Employee Size[81]
CM1	Yes	Contract electronics manufacturer	23
CM2	Yes	Contract electronics manufacturer	140
CM3	N/A	Contract circuit board manufacturer	40
OEM1	No	Wireless communication and time synchronization equipment manufacturer	50
OEM2	No	Process control equipment manufacturer	35
OEM3	Yes	Telecommunications equipment manufacturer	210

[81] Estimated from Hoover's Database via the Wallace Library. Accessed October 7, 2008.

Company	In House Soldering Lines	Line of Business	Employee Size[81]
OEM4	Yes	Audio equipment manufacturer	47
OEM5	Yes	Telecommunications equipment manufacturer	175

Table 4- Summary of Participating Companies

5.1 AWARENESS OF DIRECTIVES

The first line of questions in the in-depth interviews was intended to gauge the interviewees' awareness and understanding of RoHS and WEEE and other similar global regulatory developments. Two main findings were noted. The first was that all eight companies participating in this case study were aware and being affected by RoHS. However, for two companies, CM2 and OEM2, the only substance of concern was lead. For these two companies, when asked about their RoHS compliance efforts, the interviewees admitted to only focusing on eliminating lead solder and leaded parts from their products. When pushed to describe their efforts with the other substances covered by RoHS, they said the company is not actively pursuing those efforts. These statements are inconsistent with the fact that the CM issues Certificates of Compliance to its OEM clients where a box is checked stating:

> A mark in this box indicates that Part number(s) listed above is (are) in compliance with Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directives). If exemptions are taken, they are noted as follows: ...

Therefore, by checking this box, the CM is certifying that the identified parts do not contain any of the restricted substances, not just lead, and by accepting this certification, the OEM is acknowledging that the parts in the products, and by extension its products, lack all, emphasis on *all*, the banned hazardous substances. Only if the CM or OEM detailed known uses of the other five banned substances that are permitted under certain use exceptions within their products would it still be in RoHS compliance.

In comparison, the other six companies were involved in efforts to keep cadmium out of their metal powder coats, brominated compounds from their housing or chassis components, or chromium out of their metal plating.

The second finding was that there was a lack of understanding of the requirements of WEEE among the companies. The CMs were doing nothing in regards to WEEE which is understandable since the CMs would not be considered "producers" by the definitions in the directives. The only conceivable way they may be affected would be if the customers for which they manufactured boards sold their pieces in the EU, took back the products, and consequently transferred the responsibility of disposing of the circuit board to the CM. Nevertheless, the CMs had not considered such a possibility.

One OEM mentioned that when the company was learning about these new directives, it became clear that WEEE was still a long way from being implemented because of inconsistency among the EU countries on how to manage the *take back* (OEM4). This OEM, OEM3, and OEM5, have decided to adhere with the labeling requirements of WEEE by placing the "do not dispose in the garbage" or "wheelie bin" (as it is called in the UK) label on their products. In addition to the label, they include instructions with each of their products that when ready to be disposed, the products can be sent back free of charge. Nevertheless, these OEMs expressed concern that these efforts may not be sufficient once WEEE becomes stronger. It might become necessary to pursue the expensive registration process with each EU country and pay into an approved EU collection agency in order to officially comply with WEEE (OEM4).

One OEM stood apart from the rest by stating that it is not pursuing WEEE compliance because WEEE is based in China, and they don't sell to China (OEM2). The OEM was most likely thinking of the Chinese National Development and Reform Commission's version of WEEE made effective March of 2007. If they sell original equipment to Europe, which they do, they then fall under EU WEEE requirements. In sharp contrast, the OEM that seemed to be most comfortable with the WEEE requirements was one that

recently joined a French holding company and was allowing the French company to handle their WEEE (OEM1).

In summary, the awareness of RoHS was present in all eight companies but only six acknowledged the full substance bans under RoHS. With WEEE, no company seemed very comfortable with their efforts. The CMs did not address it, and the OEMs adhered only to the labeling requirements. Only one OEM had the possibility of a registered take back facility for their WEEE.

5.2 PROCESS CHANGES

The conversion to lead-free solder led to the most profound process changes for the companies in their RoHS transition. Therefore, companies with soldering lines were the most affected by the directive while the OEMs with no soldering lines were least affected. The CM manufacturing bare circuit boards had a different set of process issues it had to address in order to produce RoHS compliant circuit boards.

5.2.1 OEMS AND CMS WITH SOLDERING LINES

To comply with the lead bans under RoHS, all the companies running SMT and *through-hole* lines had to pursue some process changes to handle the higher temperatures of the lead free solder. The main distinction among these five companies with regards to process changes was whether the company decided to create a duplicate non-leaded line to run in parallel with the leaded line or instead switch its existing leaded line to a fully non-leaded line. Three companies opened up a new line (CM1, CM2, OEM5), and two companies switched over an existing line (OEM3 and OEM4). The OEM that opened up a new line, rather than switch its existing lines to non lead, did so due to the need to continue to serve legacy product already in the field that contained lead and lack of customer demand for a non-leaded product (OEM5). They did not envision ever switching to 100% lead free production.

Four of the five companies had to purchase new wave solder machines to handle their *through hole* soldering needs (CM1, CM2, OEM3, and OEM4). The other company

instead will purchase a selective soldering machine with a lead free pot (OEM5). According to the OEM, the purchase will be justified since the selective soldering machine will reduce the amount of manual soldering being done at the facility since a leaded pot can be switched into it, thereby increasing quality and decreasing employee exposure. Because the company has an exemption from the EU until 2010, it has yet to purchase this capital equipment.

For the companies running dual lines, separate hand soldering stations were also established ensuring the needed segregation of lead from RoHS product.

As for the non-leaded solder, silver/tin alloy being used, three companies specifically mentioned SACx as the solder of choice coinciding with industry norms (CM1, OEM4, and OEM5). Two companies described their challenge of the new solder in the desoldering process (OEM3, OEM5). Because the silver/tin alloy has a higher melting temperature, it also solidifies at a higher temperature leading to clogs in the usual vacuum desoldering machines for OEM5. The barrels of the vacuum were too long, allowing for the solder to solidify by the time it hit the screen in the back of the gun, clogging the machine. The OEM's solution was to use old technology in the form of spring loaded plungers with wide collection chambers where the solidified pieces of solder can remain once pulled by the plunger without affecting the efficiency of the machine.

OEM3 eliminated the cleaning process of its boards by using *no clean* flux. While customers at first were concerned with the different appearance of the board, the OEM succeeded in explaining that the lead-free solder now being used comes packaged with *no clean* flux. Therefore, the only reason the company would be cleaning the boards would be for customer perception and not out of necessity. The OEM decided to eliminate the cleaning process altogether saving on water usage and discharge.

5.2.1 OEMS WITH NO SOLDERING LINES

The two OEMs with no soldering lines in general did not have many process changes since those processes were contracted out to CMs; they opted to purchase components for

both leaded and non-leaded products. One of the OEMs did state that a new rework bench had to be established for the lead free lines (OEM2).

5.2.2 CM CIRCUIT BOARD MANUFACTURER

The remaining CM was a printed circuit board assembler that opted to produce different boards for RoHS and non-RoHS customers (CM3). This CM was currently developing its capability to produce RoHS compliant boards in house. For the past two years, it had contracted out electroless nickel immersion gold (ENIG) work. The company already had an immersion tin line in house that created a one micron thick white tin layer. However the tin layer experienced similar issues as lead-free solder containing high concentrations of tin. The pure tin can result in whiskering and bring the associated reliability issues to the board. Therefore, companies have been shifting increasingly to ENIG finishes.[82] After two years of losing money to contractors, this CM opted to purchase the equipment and materials to start up its own ENIG line:

> ENIG has been around for awhile, so assemblers are used to dealing with it. Another thing is that since it's a chemical process, the coating is flat. So as pitch gets finer on the surface mount component, people are leaning towards ENIG or silver or tin anyways because of the surface flatness. So I think it was just a logical choice for us to migrate to that. (CM3)

In addition with the new line, they purchased new water rinse for the lead free boards in order to prevent contamination of leaded boards and ensure compliance with RoHS.

5.3 DESIGN CHANGES

The biggest design concern for all the companies studied was ensuring that the components in their design did not contain any of the banned substances. For the OEMs that contracted out the circuit assembly board component this meant either providing to CMs approved vendor lists (AVLs) that had been screened for RoHS compliance or giving the task to CMs through the purchase order requirements to ensure that any components purchased for their work were RoHS compliant.

[82] Partee, Blaine. "Lead-free conversion: Surface finishes." *EMPfasis*. (2006) From: http://www.empf.org/empfasis/2006/mar06/lfconversion.html . Accessed on September 20, 2008.

For the OEMs with soldering lines and CMs who had to witness the effect of these new components in the assembly process, this concern meant not only ensuring that the components did not have hazardous substances but could also withstand the elevated operating temperatures. Four companies stated that they have had issues with RoHS compliant components warping under the heat of the new soldering processes, especially with the plastic casings of components (CM1, OEM2, OEM3, and OEM4).

The material and surface selection of the circuit board, as briefly discussed in the previous section, also had to be changed for the new RoHS processes. One CM had issues of board delamination due to the excess temperatures (CM2). Because of these concerns, one OEM requests specific copper laminate layers to ensure "a construction that would have a similar mechanical integrity for lead free" (OEM3). For both the CM board manufacturer and OEM3 and OEM4, the board material of choice is now the FR4 or Flame Retardant 4 board due to its heat resistance. While the CM is now offering ENIG finishes, OEM4 requests lead free HAL or Hot Air Leveling finishes for its boards which have been shown to have similar wetting characteristics and reliability as the traditional lead HAL finishes.[83]

For the companies offering RoHS and non-RoHS products, the decision to offer RoHS versions was determined by "drawing a line in the sand" and saying that new products starting from a certain point will be RoHS compliant and the old products will not be. All of the six companies offering RoHS and non-RoHS products stated that in order to control inventory, many non-RoHS products were being designed to contain the RoHS compatible components. This allowed the companies to "weed out" leaded inventory and add in the increasingly more pervasive RoHS compliant parts provided by vendors gradually without heavy inventory waste[84]. One OEM found that it had to redesign non-

[83] Liyange, Nimal. "Hot Air Leveling in the Lead-Free Environment." *Circuittree.com*. (2006). From: http://www.metallicresources.com/pdf/LFHALArticle.pdf . Accessed September 20, 2008.

[84] Gurnett, Keith and Tom Adams. "RoHS one year later: supplies of leaded solder drying up." *Military and Aerospace Electronics.* (2007). From: http://mae.pennnet.com/display_article/298415/32/ARTCL/none/none/RoHS-one-year-later:-supplies-of-leaded-solder-drying-up/ . Accessed September 21, 2008.

RoHS products not because it had intended to do so, but instead was forced to do so by its supply chain:

> One issue we found is that it's getting increasingly difficult to find parts that have lead for the old products. So this is an ongoing thing now because in some cases we can't get the part we used to buy so we have to make the conversion even though we don't need it. (OEM2)

For all the companies, RoHS compliance became a factor in the design process to ensure that RoHS was managed from the beginning of a product's life. For one OEM, this additional design criterion led to the addition of other criteria dealing with global recycling initiatives (OEM3). This spillover effect will be discussed in more detail in the next chapter.

5.4 DATA MANAGEMENT AND SUPPLY CHAIN

Consistently, the two biggest concerns given by the participating companies were either the chemistry issues previously described or the due diligence required to ensure that every component within their final products complied with RoHS specifications. This second concern became the enormous data management task associated with a simple circuit board containing hundreds of components, each containing many smaller components parts and materials.

One of the OEMs described the problem as such:

> We had to identify the RoHS compliant status of every component used on every building material. Our products are fairly complex and a typical bill of material for a typical product would have hundreds of part numbers, parts used on multiples on an assembly so thousands of components. We needed to develop enough component data to understand the RoHS compliant status of each and every part and to follow up with the component manufacturers about their own RoHS compliant plans… (OEM3)

The OEMs were not the only companies dealing with the exponential number of materials and components falling under RoHS. Even the circuit board manufacturer had a complex inventory to manage:

> We probably deal with ten or twelve different materials anyway other than standard fiber glass circuit board material. So it's just adding one more [circuit board material]… [but] it's not just inventorying one piece of material; it's inventorying sixty RoHS materials because of all the different material thicknesses and copper weights. And the first material out there is not necessarily the best choice. So we are now migrating to a second material. That kind of triples the inventory [until] you use up the middle inventory. (CM3)

As a result, half of the companies studied explicitly stated that their biggest concern in the transition to RoHS dealt with data management and supply chain issues. One OEM without soldering lines stated that their major capital investment was the establishment of a new database and schematic capture tool solely for RoHS compliant parts. An engineer designing a new RoHS product could look through this database and select components without the risk of selecting a non-RoHS compliant piece.

Three other companies opted to use the existing inventory systems and segregate the RoHS parts by assigning different part numbers to them (CM1, CM2, OEM2). For two companies this took the simple form of adding an "R" to the beginning (CM2) or an "LF" to the end (CM1) of the existing leaded components numbers to indicate RoHS compliant pieces. For OEM2, the process involved a complicated series of codes that told the company everything from whether: the RoHS status of an existing component is unknown; purchasing has investigated the component; the stock is mixed with RoHS and non-RoHS components; or the entire stock of components is RoHS compliant.

One OEM stands out from the other companies in deciding not to "re-part number" its components:

> We also chose, based on our high mix/low volume, not to re-part number our lead free and our normal product. What we decided to do, which was right for us, was to start ordering lead free parts…we then use the [lead free] parts in our regular leaded process…We're going to deplete all our leaded inventory. So in the last five years we have just about done that." (OEM5)

As stated in the previous section, using up excess non-RoHS inventory was a strategy pursued by all companies offering RoHS and non-RoHS product. One OEM

manufacturing only RoHS products included some potentially non-RoHS components in their RoHS products in the beginning of the transition:

> I was thinking to myself, the entire industry has to flush out all these parts. It's just going to take time. I can't *not* ship to somebody because I [may] have one fraction of lead in a penny resistor that I've got 9,000 of the old one and none of the new [RoHS] one. The old one may be compliant anyway, but nobody knew they had to put a [RoHS] sticker on it… (OEM4)

5.4.1 SUPPLY CHAIN ISSUES

The surplus inventory and data management problems were exacerbated by inconsistencies within the supply chain according to each of the companies studied. The OEM quoted above may have been correct in its assumption that the old part may have been compliant without the manufacturer been aware. Three companies explicitly stated their concern with the transition process of their component vendors:

> The biggest concern that we have is it seems like the semiconductor manufacturers have this mish mash of ways that they have transitioned their products. And it seems like it changes. A lot of times we don't know whether the product we are buying…is compliant or not… (OEM1)

> Our first step was going back to our existing inventory because that was one of the issues that we had from the very beginning, a lot of the manufacturers actually took the lead and transformed some of their product into lead free and just shipped it under the same part number. (CM1)

> The supply chain [is our biggest challenge]. There's no question about it because to some extent you're at their mercy for what they supply you. There's no consistency [between] manufacturer and manufacturer on how they label their materials. (OEM5)

In addition to confusion upstream of the supply chain, OEMs that contracted their assembly processes had the additional confusion of ensuring that the processes the CMs used were in compliance with RoHS. This meant clearly telling their CMs their RoHS needs; otherwise the CM could assume non-RoHS construction. However, the place where this requirement needs to be addressed (i.e. the drawings, bills of materials, purchase orders) is not consistent. One OEM recounted a horror story it had experienced

where it stated the RoHS requirement in drawings and bills of materials (OEM1). Because it had not stated it in the purchase order though, the CM had manufactured the assemblies with non-RoHS processes leading to the OEM to lose product and increase the wait time for its customers.

None of the companies were currently using X-ray fluorescence analyzer equipment to test the material compositions of the components purchased from vendors. Instead, they relied heavily on the certificates of compliance received from vendors and CMs. Therefore the information received from them is crucial since it is all that the companies are relying upon for due diligence.

Unfortunately, many of the companies studied agreed that WEEE and RoHS awareness and understanding seemed to decrease as one would go down the supply chain to the smaller component vendors. In addition, as discussed in the previous sections, some of the companies studied did not themselves have complete understanding of the full meaning of these directives. Nevertheless, the SMBs studied saw themselves as educators, and one as a kind of "evangelist," spreading the word to the smaller component and service vendors and to their large customers of what WEEE and RoHS will mean to their business:

> Manufacturers like [us] didn't have the luxury of time to let all of that [confusion] settle and really had to leverage our relationships and our spending capabilities as much as possible to prod certain component manufacturers forward. If they couldn't show us a product road map of releasing and replacing RoHS compliant components, then to identify different component manufacturers who would. (OEM3)

5.5 PERSONNEL CHANGES

Through the course of this study people in the following positions were interviewed:

- President of Company (CM1)
- Senior Director of Manufacturing (OEM3 &5)
- Director of Engineering (OEM1)
- Quality Engineer (CM2)
- Vice President of Operations (OEM4)

- Director of Operations (CM1)
- Senior Purchasing Agent (OEM2)
- General Manager (CM3)

These people were interviewed because they had the most knowledge of WEEE and RoHS within their respective companies. From simply looking at the list, it is clear that while these directives are environmental directives, the personnel in charge of compliance are not environmental staff, in fact none of the companies studied had environmental departments, but instead personnel working at the heart of the company: in manufacturing, engineering, and operations.

Two of the OEMs had one individual with responsibility for RoHS compliance. However, these individuals worked in different departments within their respective companies. One was in research and development (OEM2) and the other in design (OEM1). Another OEM opted to create a cross functional team consisting of engineering, manufacturing, and quality personnel to take the lead on RoHS compliance issues instead of giving the responsibility to one person (OEM5).

One CM and another OEM had the responsibilities dispersed throughout an entire department. The CM used the engineering group and the OEM, the design group:

> We don't have a person named "Mr. RoHS" or anything. Howe we conform here is dictated by our engineering group. It's their responsibility to maintain our qualifications here. It's their responsibility to educate the rest of us so that we don't fall behind. (CM1)

> "Design for Compliance" is part of the design engineering development's responsibilities now. We had to have some training and we made them aware of it and developed some tools to track this component data. But now that is standard operating procedure. There were no special jobs created for environmental regulatory compliance. (OEM3)

Ultimately, however, the companies studied gave the impression that responsibilities for RoHS compliance were integrated throughout the organization. Once the employees were trained and the information integrated into standard operating procedures, all the companies indicated that everybody in the company had a role to play in RoHS

conversion and compliance. One OEM gave a list of the types of people that had been affected: inventory, purchasing, automation managers, soldering managers, finance (OEM4). As one CM bluntly stated, "It's all everyone's responsibility. Everyone has been trained, so it's just part of business" (CM2).

5.6 MARKET STRATEGIES

While the companies studied provided many strategies and techniques to address the issue of WEEE and RoHS, for the majority of them the money they spent on creating these strategies and techniques was the issue they most wanted to discuss during the interview. This was especially true for the CMs and the OEMs with in-house soldering lines. The only exception to the OEMs was the OEM with in-house soldering lines that hadn't done the complete switch to RoHS only products (OEM5). The costs are summarized as follows:

Company	RoHS Transition Cost Estimate	% Market Share Requesting RoHS	% of RoHS Product
CM1	$100,000 capital investments $50,000 scrap inventory	10-20%	10-20%
CM2	$225,000 capital investments	20-25%	20-25%
CM3	$100,000 capital investments	50%	50%
OEM1	$3,000-$4,000 capital investments	<10%	60%
OEM2	$50,000 R&D $15,000-$25,00 purchasing $5,000-$10,000 defective products	10%	10%
OEM3	$3,000,000 capital investments	<50%	100%
OEM4	$250,000 capital investments and R&D	EU is smallest market	100%
OEM5	2% of annual sales	One customer	100% comply with RoHS5; 0% comply with lead ban

Table 5- Cost and Market Summary of Participating Companies

The costs in the table reflect the one-time costs that the companies accrued in order to make the conversion. It does not reflect the cost in labor needed to research and implement the changes. One OEM estimated that 7-8% of their total labor was being shifted to focus on RoHS (OEM1). For the OEMs with in-house soldering lines, as much as 100% of the effort of certain personnel was switched over to RoHS at the expense of other projects. In addition, these other projects carry their own opportunity costs since they would have developed new products that could have been more lucrative than RoHS compliance. Those opportunity costs alone could be estimated in the hundreds of thousands or millions of dollars. One interviewee from an OEM described the frustration of the product development group who had to completely shift its focus to RoHS for a year (OEM3). For a couple years after the initial transition, the company felt behind from its competitors in terms of new product innovation because of the year lapse.

In addition, the companies mentioned the energy costs associated with the higher temperatures required for the soldering of the lead-free flux. However, the initial concern of the rising cost of the precious metal silver giving companies a high "maintenance" cost for their RoHS conversion is diminishing. Ever since the peak in early 2008, the price of silver has been steadily decreasing from around $20 to $10 an ounce.[85]

The cost of RoHS compliant components had been an issue; however, the laws of supply and demand have leveled those out:

> Once we got going [on the RoHS conversion], we realized that there was a point where lead free components cost a little higher, and now the lead free components are less costly than the leaded components because the demand is there. In the supply chain, manufacturers are saying, "I'm not building any more lead; I'm building only lead free." (OEM5)

Another cost that those that opted to run both RoHS and non-RoHS lines have realized is the "cost" of floor space.

[85] Monex Precious Metals. "Silver Bullion Price Charts: 5-Year Close." http://monex.com/prods/silver_chart.html. Accessed on November 11, 2008.

> Although it may not be an issue right this second, floor space is money. So we probably could use that area to do something else, [e.g.] increase manufacturing. Whereas now, we are only doing 20% of our products lead free; that means that the area effectively is only being utilized at 20% capacity. The other 80% of the time it is sitting there collecting dust. (CM1)

However, for one CM, the switch to manufacturing RoHS products may be saving them money (CM3). For the past two years, they had been contracting out the final RoHS compliant finishing to subcontractors. Factoring in the set up, shipping, and lost time, the CM estimated that cost of using a subcontractor versus doing it in house to be near $50,000.

5.6.1 OEMs

The OEMs had the largest discrepancy between the percentage of their market share requesting RoHS products and the actual amount of product being manufactured to comply with RoHS. Essentially, they were producing more RoHS compliant products than the market demanded. The reasoning behind the large switch despite current customer disinterest in the issue was best articulated by this OEM:

> We used to kid that well we just won't sell [in the EU], but that's not…we're trying to grow the company. We talked about running dual [lines]. But that was ridiculous too. Yeah it's nice to talk about, but just try and do it. You're going to monitor all this inventory constantly, label product and make it two different ways. Someone could have said, well you only have to comply in Europe, but in reality no. There was no practical way not to just be one hundred percent compliant. It would have cost way more money and probably the possibility of an accident, of a noncompliance incident would have been much higher. (OEM4)

Making the switch was viewed by these OEMs as necessary to compete in the global market and save costs. While the companies admitted that breaking into the EU market takes more than RoHS compliance, the OEMs did not want to be excluded because of that reason. When asked what would have happened if the company had opted to not comply with RoHS, all of them said that was simply not an option.

5.6.2 CMs

The CMs do not have the same level of control over their products as the OEMs since their customer base is much more diverse and may include OEMs that are not as globally oriented as were the OEMs studied in this research. Therefore, the CMs needed to have the flexibility to offer both options.

> So regardless of how our customer comes in to us, we have a channel or avenue that we can put them through that meets their requirements… So we are not recreating the wheel, we are just adding to it, providing more services or options. In this case it happens to be lead free. (CM1)

This CM stated that 70%-80% of its customer base would have to request RoHS products before the company would make a complete transition to lead free operations. The other CMs made the point that many of the component parts of their assemblies could work for either product making a complete transition unnecessary. However, that put the CMs in an interesting position since OEMs use their CMs as counselors in manufacturing best practices. The CMs described customers who leave the decision of lead or lead free up to them stating that it did not matter. While CM1 stated that it was not the company's role to advise their customers on the most "environmentally friendly" option if it did not suit their reliability or ultimate use needs, the CM1 said that in many cases the decision was already made due to component availability.

5.7 BUSINESS CHARACTERISTICS

Echoing the previous research done on small businesses[86,87], the companies studied stated various times that their size was both a help and a burden in their transition to WEEE and RoHS compliance.

One OEM stated that the smallness of its company gave them favorable odds when enforcement time came:

[86] Peters and Turner, 463-466.
[87] Arragon-Correa, 91-92.

> The upside…to a company our size…is the size of our dot on the world's radar system. I mean…we're a $6 million company. Our market share is 0.00000001% in any one product line. I'm going to do the best I can without bankrupting this company, and if it's not good enough then, there is nothing we can do. Maybe some of our competitors didn't have the luxury of being so cavalier about it, but I did. (OEM4)

However, this benefit was tempered when a company's customers were larger, more global, or better known since all those characteristics would attract the attention of enforcing authorities and lead to more vigilance. The OEM stated that they knew of other competitors in the area whose customer list did not allow them to be so "cavalier."

Two companies found that top management was flexible enough to be proactive and careful with the transition process (OEM3, OEM5). This again reflects the research done on the ability of SMBs to more easily gain a shared strategic proactivity towards environmental hurdles.[88] By having senior management involved and understanding the implications of the directives, these companies felt that were not rushing to comply with the directives and were better able to develop solutions that were tailored to their business needs, such as not renumbering the part numbers or switching all soldering lines to lead free.

One CM gave a different characteristic. They said that their size had always allowed the company to function as more of an "engineering shop" willing and able to tinker at new problems and ideas. They said, "I don't think [RoHS conversion] was anything more difficult than normal. We're kind of used to trying new things and dealing with a lot of engineering projects" (CM3).

One a much less positive note, one OEM though stated that no characteristic made the transition easier. The time and money spent on designing and implementing the changes were greater than any positive characteristic (OEM2).

[88] Arragon-Correa, 91-92.

Lack of time and money were consistently given as the characteristics that hindered the transition at each of these companies. One OEM gave a variation on this response (OEM4). They stated that unlike the larger companies, they aren't able to spread the cost of conversion throughout its various products. Instead of selling millions of products, an SMB most likely sells in the hundreds. Therefore, any cost in operation, if transferred into the cost of the product, would most likely increase the cost of the one product by more than what the consumer is willing to pay. So the company is expected to bear the entire cost in order to maintain customers. Otherwise, they would be at a competitive disadvantage to their larger competitors.

5.7.1 LOCATION IN SUPPLY CHAIN

One set of characteristics that was never explicitly stated throughout the interviews but was observed throughout the study was the location of the companies in the supply chain. The study included companies that were designing the products (OEM1-5), companies that were just assembling or "stuffing' circuit boards (CM1, 2), and a company that was manufacturing the actual bare board (CM3).

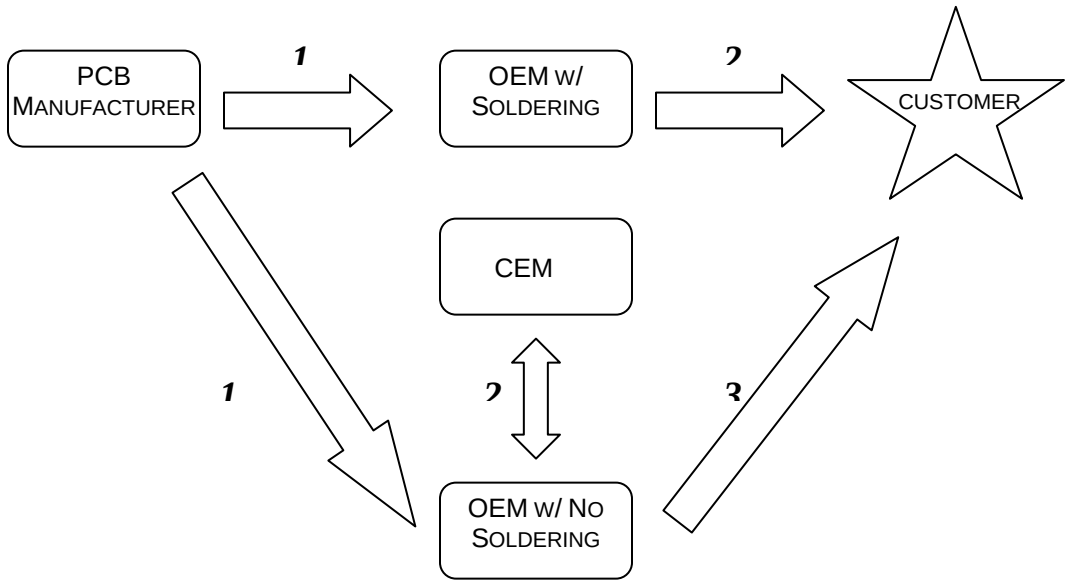


Figure 2- Supply Chain Relationships

By looking at the diagram one can see that the CMs, both printed circuit board manufacturers (PCB) and electronics assemblers (CEM) are more removed from the customer than the OEM. This gives the CMs two advantages. First, they only need to concentrate on specific areas of the RoHS problem. It is up to the OEM to take the holistic view and ensure all the different components and services were in fact in compliance. Second, the CM can view RoHS as an optional service that costs a premium for their customers, the OEMs. The OEMs pay that premium, but as discussed previously, are not able to bring that cost down to their consumers.

A difference also exists between the OEMs that have soldering lines and those that do not. For the OEMs with soldering lines, products go directly to the customer unlike the OEMs who contract pieces of their products to assemblers before sending the products to customers. Therefore, the CM assemblers have had to handle the chemistry and soldering process changes needed for RoHS compliance. The OEMs with their own lines have had to handle the chemistry and soldering process changes in addition to the data management and purchasing challenges that the other OEMs face. Therefore, the dimensions of the problem were different depending where on the supply chain the company worked.

5.8 ATTITUDES TOWARDS ENVIRONMENT AND DIRECTIVES

The last section of the interview guide was intended to gather information on the attitudes the companies had towards their roles as small businesses with respect to environmental sustainability. Throughout the study, this line of questions expanded past the environment and very specifically towards their perceived intentions of the RoHS and WEEE directives.

Acknowledging the caveat that studies have shown that people have a tendency to be overly positive when discussing environmental issues[89], the companies studied all had

[89] Jieqiong Yu, Peter Hills, and Richard Welford. "Extended Producer Responsibility and Eco-Design Changes: Perspectives from China." *Corporate Social Responsibility and Environmental Management* 15 (October 2007): 120

affirmative responses to the question: Do you believe small businesses have a role to play in environmental responsibility? Once company stated:

> …In general we are pretty environmentally conscious here. Most of the decisions we make, we try to pick the safest product possible for both the employees and the environment almost regardless of cost. (CM3)

All of the companies proudly described their recycling and metal reclamation projects. Some described their "green teams" of personnel who met regularly to find opportunities for conservation (OEM1, OEM5). Others described their energy efficiency projects. It was clear that the environment was a point of pride and respect for the communities they operate despite, or maybe because of, their size. This company specifically addressed the issue of size and failed to dismiss their smallness as not important in the pursuit of environmental sustainability:

> I believe that small businesses are driving [environmental responsibility]. I believe that small businesses are in tune to respond a lot quicker and are more able to adapt to changes like [RoHS and WEEE] than big companies. I talked with some colleagues in companies like Lockheed Martin…and they don't have a clue what their policy is going to be; they have no clue. Some of them don't even have a clue what RoHS is, and these are major corporations. To try to get a major corporation to adjust isn't going to be overnight. (OEM5)

Others were not as accepting:

> Sure, everybody [has a role to play in environmental responsibility]. But I think the big players have a larger responsibility to keep it reasonable because small business can be very nimble and change but they still don't have the resources to do something that is unnecessary. (CM3)

However, most affirmations tapered once the specific issue of WEEE and RoHS and the pursuit of environmental responsibility arose. Some companies were more receptive to the idea that WEEE and RoHS were helping the environment. The CMs agreed that it did make their employees more aware of the issue of putting electronic equipment in landfills (CM1, CM2). One OEM stated that the reason they were pursuing RoHS conversion despite the lack of customer demand was because "it was the right thing to do" (OEM5).

On the other hand, the remaining five companies expressed serious concerns about the intentions of the directives. Two companies stated that they felt that the electronics industry had been unfairly pinpointed as scapegoats to the issue of heavy metals in landfills (CM1, OEM4). They recounted statistics stating that ammunition and even automobile maintenance equipment use more lead worldwide than electronics.

Other companies felt that since they were not manufacturing high volume consumer electronics, the directives seemed unnecessary (OEM1, OEM3, and OEM4). According to one OEM, the recycling and proper disposal of electronics is an idea that businesses had always held:

> From my perspective, [RoHS and WEEE] make more sense for consumer products. We're more B2B (business to business). It makes less sense there. Businesses normally are set up for consuming and then disposing of these products. There's more of an infrastructure there. So to push that sort of concept down to that level is really no use. If we buy something here and we overbuy or if we buy something and it is out of its useful life, it should be our responsibility to dispose it properly. (OEM1)

One OEM even stated that instead of RoHS, they would have suggested a government sponsored recycling scheme:

> My idea was to get the government to pitch in and prop up a recycling industry, give them tax credits, zero interest loans, because they're not going to make money for a long time. But help them at least survive. That's how industries start and once people start working on things, I think they could figure out how to recycle that stuff effectively and eventually profitably. (OEM4)

Overall, the companies viewed these directives as less of an environmental directive and more of a political, competitive move by the EU.

CHAPTER 6: RESULTS AND ANALYSIS

The question that these findings were intended to answer was whether the RoHS and WEEE directives spurred innovation in companies. Because the directives are based upon EPR principles, as discussed in Chapter 2 and 3, this innovation would be in line with previous research done on EPR.[90,91] These innovations as discussed include any changes in processes or strategies that had not been explicitly required by the directives. These changes had instead "spilled over" as either obvious expansions of the RoHS or WEEE technical requirements or of the new competitive environment these directives created within the electronics industry.

6.1 SPILLOVER EFFECTS

As discussed in Chapter 5, despite the negative perceptions expressed by some of the participating companies towards the directives, the directives clearly led to changes that went beyond the explicit requirements of the directives. These spillover effects, each which will be elaborated on in this section, included:

- Product redesigns
- Increased efficiency in production and procurement processes
- Accessibility to global markets
- Establishment of recycling infrastructure
- Increased environmental awareness for employees and management.

6.1.1 PRODUCT REDESIGNS

Product redesigns were the most prevalent and obvious extensions of the directives observed. As shown in the previous section, the percentage of products being

[90] Organization for Economic Cooperation and Development. "Extended Producer Responsibility." From http://www.oecd.org/document/19/0,3343,en_2649_34281_35158227_1_1_1_1,00.html (Accessed April 14, 2008).

[91] Tojo, Naoko, Thomas Lindqvist, and Gary Davis, "EPR Programme Implementation: Institutional and Structural Factors," *OECD Seminar on Extended Producer Responsibility, EPR: Programme Implementation and Assessment* (2001). From: http://www.p2pays.org/ref/19/18269.pdf (accessed April 14, 2008). 20.

manufactured to comply with RoHS greatly exceeded the percentage of consumer base requesting RoHS compliance. OEMs have found that either because of supply chain component availability, capital investment costs, shop space, or logistics that to limit the product changes to simply those sold to the EU would be inefficient. As a result, many more customers are getting the benefit of lead, cadmium, chromium, mercury, and polybrominated flame retardant free products.

Unfortunately many of the companies do not see the change in such a positive light. Many focus on the reliability issues posed by the change to tin/silver solder versus lead. One OEM flat out stated that he believed they are now giving customers an inferior product and while they had not changed the warranty of the company's products, as he alleged many of his competitors did, he is worried that warranty issues may arise ten years from now. (OEM4)

One company took a different reliability issue and converted it into a competitive advantage (OEM5). One of the RoHS substances that does not get the amount of attention that lead receives is chromium. By eliminating hexavalent chromium from platings, companies found that the plating would peel off the metal or the paint would not adhere well enough to the plating leading to chipping. Both of these cases could lead to interferences in the circuitry of the electronics and thereby faulty products.

The purpose of adding chromium to platings is to prevent the corrosion of metal parts. Therefore, in addition to the issue of coating or paint chipping into the circuitry, a company has to ensure that the replacement plating has the same anti-corrosive properties as the original hexavalent chromium coating. The anti-corrosivity of plating can be tested through a salt spray method. According to OEM5, the company found that many plating companies inaccurately claimed the durability of their coatings; "a majority would say we can do a 12-hour salt spray, but that's not good enough for the environments that we put our equipment in (OEM5)." This OEM needed a metal coating that withstood a 96-hour salt spray:

> We worked with a couple houses specifically and [this one house] came up with a proprietary plating process that was RoHS compliant. They are the only one today that uses that. It's good for them. It's definitely good for them. (OEM5)

Here is a clear example of the directives causing technological innovation that benefits the environment and workplace through the elimination of hexavalent chromium and gives the company a strong competitive advantage. The opportunity that now remains is a reexamination of the negative perceptions of lead free reliability shared by companies such as OEM4 in order to develop a competitive advantage of a lead free soldered product with the same guaranteed reliability of a leaded solder product.

6.1.2 EFFICIENT PRODUCTION AND PROCUREMENT PROCESSES

Two companies explicitly described the ways that RoHS had caused them to make changes to their production and procurement processes that will result in efficiency gains. As stated in the previous section, OEM5 will purchase a selective soldering machine to handle the lead-free *through-hole* soldering processes. This will not only allow them to produce RoHS compliant product once their exemption expires, but will also allow them to produce better quality tin/lead solders on their products because it will reduce the amount of hand work needed.

As mentioned before OEM3 eliminated its flux cleaning process altogether. By eliminating this now unnecessary step in their manufacturing process, the company substantially reduced its water usage and discharge.

Another company discussed changes to its purchase orders and the electronic filing of the Certificates of Compliance that streamlined the procurement and contract process (OEM4). Supply chain management became much more crucial both downstream and upstream from the companies. One company compared RoHS compliance to the time when quality management systems were becoming popular and all the customers were sending questionnaires requesting information about their ISO 9001 systems (OEM3). Another agreed with that sentiment that a new person, environmental or more general, may need to be hired to handle the supply chain since their customers are not only

screening them but also asking to screen down the chain to ensure not only RoHS compliance but also environmentally friendly practices and other regulatory compliance issues (OEM5).

6.1.3 ACCESSIBILITY TO GLOBAL MARKETS

This leads into the next spillover effect which is an increased awareness of global regulations and markets. For both OEM3 and OEM5, the people interviewed were directors of manufacturing, and for both of those individuals, their job positions have broadened:

> There were no special jobs created for environmental regulatory compliance. My job changed. I'm chiefly responsible for monitoring developing legislation worldwide and assessing how they affect not just the manufacturing operations but the design of our products. It's my job to periodically update management and development staff to changes in regulations. (OEM3)

As a result, these OEMs are making themselves even more competitive within international markets by adjusting their focus to regulations that if not followed could have barred their entrance. At the end of the interview, OEM5 reemphasized this importance on export compliance issues:

> Even though WEEE and RoHS initiatives are strictly EU, export compliance is becoming very, very visible especially on [Department of Defense] applications… The US has UL [Underwriters Laboratories], Canada has CSA [Canadian Standards Association], and the EU has [the] CE [mark], and in order to get any of those you have to be compliant...What do we need to comply with? That is RoHS; that is WEEE; that is REACH. So it's all buried in that. It's just a matter of time before everybody grasps onto it. (OEM5)

6.1.4 RECYCLING INFRASTRUCTURE

One of the export requirements that some of the participating companies had had to comply with is of course WEEE. As stated in the previous chapter, four out of the five OEMs studied had some type of recycling infrastructure. These companies now have a system in place, some more developed than others, that will be able to properly handle the end of life waste of their products. These four companies did not wait for WEEE and

the corresponding EU recycling collection agencies to better organize themselves or to make sure that they in fact would be considered "producers" under the law. Instead they opted to take the initiative and assume the responsibility. Now their customers regardless of location have the opportunity to safely dispose and recycle their products.

One OEM took this recycling step further. After having to label all packaging materials in order to be compliant with the Chinese regulations, the company saw an opportunity for further improvement:

> So we complied with the labeling requirement which was to simply identify the packaging materials. But then that put us into a design cycle to eliminate urethane foam-to utilize materials that were highly recyclable. So at this point we're working on the completion of a corrugated-only packaging container that provides adequate protection of the product in case it drops and falls. But the point is that the materials used are recyclable. Not that that was required, but we can see perhaps incremental legislation in the future that would make it a requirement and an opportunity to possibly avoid a cost- not just be an environmentally-green citizen but also to manage our processes. We did in fact achieve cost reductions with the prototypes. (OEM3)

Because RoHS drove the companies to include an environmentally conscious criteria right in the beginning of a product's life cycle, companies like OEM3 and OEM1 were more open to including additional criteria dealing with, in this case, recyclable packaging material. OEM1 was also assessing the viability of cardboard-only packaging inserts.

6.1.5 ENVIRONMENTAL AWARENESS

In addition to these recycling initiatives and the removal of heavy metals from their products, the companies have used WEEE and RoHS to pursue additional environmental initiatives. While not all of the initiatives and attitudes described last chapter are the result of the new directives, some of the companies did agree that these regulations did increase the environmental awareness among employees and management. The two CM assemblers agreed that while they may disagree with the scope of the directives, they did see that now employees who may have originally thought that disposing of electronics in the regular trash was acceptable, may think otherwise (CM1, CM2).

For two OEMs, however, the directives went further. Coming back to OEM3, this company as a result of these new directives and the similar global legislation decided not only to include more environmental conscious criteria in the design process but also developed an environmental management system. While OEM5 has yet to make the complete shift, the company has seen not only pursued product adjustments but also improved their metal reclamation processes and began energy conservation methods:

> I think that [WEEE and RoHS] kind of pushed it a little bit more. Because I had to take it to the top level to get executive approval on it, the buzzwords were going around- "RoHS and WEEE." "What's RoHS and WEEE?" Oh they're environmental efforts to eliminate lead and recycling. "Oh that's good stuff. That's something we want to get into our marketing program." So that kind of steamrolled it. And then once you start doing that then- you know maybe we really need that recycle, reclaim program; we really need to change what we're doing there…It's that thinking- what can we do differently, not just on our products, but in our day to day stuff that we're doing. (OEM5)

The company began recycling their scrap metals and shifted to a four-day week with the entire company, and its machines, shutting down every Friday. The interviewee gave the impression that these initiatives would not have had the management buy-in and employee enthusiasm if it had not been for the directives.

6.2 EFFECTIVENESS OF WEEE AND ROHS AS EPR REGULATIONS

After analyzing the findings in the previous chapter and distilling from all those process, design, and management changes the spillover effects that were not explicitly required by the directives but that still provided a benefit for the company and/or the environment, it is clear that these directives are realizing their EPR potential and are in fact spurring innovation even within SMBs.

More interestingly, they are spurring this innovation in ways that are often overlooked from previous research done on EPR. Most research done on the effects of EPR regulations simply look at whether the regulation is causing design changes within

companies.[92] This research indicates that in addition to the design changes, companies can also change their manufacturing processes, facility operations, and customer services in response to these types of regulations.

Another issue that seems to be left out of existing research is the effect that a company's location within the supply chain affects the intensity of EPR potential. This research showed that the potential for spillover effects and innovation was diluted as an SMB moved away from its customer. It should be pointed out that in this chapter almost all of the examples were for the OEMs and not the CMs. The electronics industry is unique in that SMBs can find a niche and be OEMs. Otherwise, the SMBs would be subcontractors and as shown by the research not as affected by the EPR legislation. Therefore, if a government were crafting a new piece of EPR styled legislation with the attempt of reaping the spillover benefits, the government would have a large potential of skipping over the small business world if the legislation deals with an industry where SMBs are not OEMs.

A third point to be made about these results is that the companies' attitudes towards the regulations seemed to affect the extent to which they pursued additional projects. The companies that were not mentioned in this chapter such as OEM4 and CM3 were convinced that these directives had been unfairly developed and that their companies and type of business should not have been targeted:

> If you are going to be environmental conscious, do it right; don't waste your time and effort on things that don't work because there are so many things that do and so many places that needed it. I think that my pet peeve is just [wasting] time, money, and manpower on ridiculous environmental concerns. [In response to the WEEE and RoHS directives] (CM3)

However, this CM did have reason to question the intent of the law since the new ENIG process it assembled to construct RoHS compliant circuit boards has introduced cyanide

[92] Jiequiong Yu, Peter Hills, and Richard Welford. "Extended Producer Responsibility and Eco-Design Changes: Perspectives from China." *Corporate Social Responsibility and Environmental Management* 15. (2007). Accessed via ProQuest. September 25, 2008.

into the shop. This is a toxic compound that before now had been purposely phased out of the company.

For OEM4, the concern with the reliability of the new RoHS products and the potential for increased end-of-life waste product in the future caused the company to view the spirit of the law as simply the elimination of the toxic substances in their products instead of seeing the spirit of the inherent EPR principles within the legislation. As a result, the company did not see these directives as an opportunity to make any additional changes to their operations. Instead, the EPR regulation was viewed as more of a hassle.

Throughout the research, all the companies, to varying degrees, raised doubts about the true environmental effectiveness of these directives. The increased energy usage for the melting of the lead free solder, the now increased mining for silver, and the perceived hidden market agenda the EU was leveraging on the world, are just some of the concerns raised by the participating companies. Research has shown that SMBs respond best to regulations that provide agency cooperation and be flexible to their needs.[93] Unfortunately, these doubts about WEEE and RoHS make it difficult for an SMB to trust that the governmental authority is in fact attempting to reduce environmental harm, and instead they feel like victims or unfair targets. Already SMBs feel the regulatory burden harder than large companies.[94] Therefore, the doubts on the directives' intentions may have reduced the opportunity for spillover effects from the EPR principles simply because of SMBs' attitudes.

[93] Jimenez, 723.
[94] Crain, 1.

CHAPTER 7: CONCLUSIONS

Clearly since their inception, the WEEE and RoHS directives have been spurring small businesses across the Atlantic in Rochester, New York to not only innovatively handle the complex process, design, and cost challenges posed by the new requirements but also to use these challenges as opportunities to pursue additional projects that result in more efficient and in many cases, more environmentally conscious, manufacturing systems. The companies expanded the traditional design innovations usually attributed to EPR-based regulations to cover all areas of their operations.

The most widespread innovation found among the eight case studies, not including the CMs, was the increased and sometimes exclusive production of products that did not contain any of the banned substances despite lack of U.S. customer demand. This eliminates both customer exposure and employee exposure to hazardous substances.

Some "best practices" have emerged among small businesses experiencing the transition to RoHS and WEEE compliant production. The first is that proactive thinking was crucial to successfully transitioning in the most cost effective way. Companies that felt confident about their RoHS work consistently stated that management had agreed to begin working on the directives much in advance of the July 1, 2006 implementation date. This allowed them to decide whether to open a new RoHS line, re-part RoHS inventory, or evaluate the related capability of their suppliers. This forethought will continue to remain crucial as more governments around the world began passing similar RoHS legislation (e.g. China's Management Methods for Controlling Pollution Caused by Electronic Information Products Regulation made effective March 2007, Korea's Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles made effective January 2008, California's amended Electronic Waste Recycling Act made effective January 2007, etc.). For the companies that have not made the complete switch to RoHS compliant products, the time may be running out for leaded goods.

The second best practice is more of a set of best practices dealing with the technological and chemistry changes common among the set of companies. While Chapter 5 details each of these changes in detail, a summary is included here:

- SACx was the solder of choice among the companies.
- If the SMT lines were long enough to account for the increased soldering temperatures, the RoHS transition was not too difficult. The real cost was in purchasing a new, quality wave solder machine for the lead-free, *through-hole* soldering. One company opted to purchase a selective soldering machine.
- Simply removing the banned substances from the products was not sufficient since the components without the hazardous substances would melt, warp, or delaminate due to the higher soldering temperatures.
- Because none of the companies studied had X-ray fluorescence analyzer equipment to empirically test the composition of their component materials, separate inventory databases, separate inventory storage locations, and increased monitoring of the supply chain became crucial. Some of this concern was lessened for the companies that opted to make the full transition.

The third best practice was the most promising in regards to promoting environmentally responsible business. Companies coupled their work with WEEE and RoHS with additional environmental initiatives of their own. The OEMs that felt most comfortable with their transition (e.g. OEM1, OEM3, and OEM5) had also implemented environmental initiatives that went beyond the directives' requirements. Companies should be viewing these directives as opportunities to bring new environmental initiatives to the business. As the interviewee from OEM5 stated, now that the buzzwords "RoHS" and "environmental" are swirling in the spheres of top management is the time to implement environmental projects that ultimately will make the product more attractive. Customers, commercial or industrial, will benefit from high quality products free of lead, chromium, mercury, cadmium, and various types of polybrominated flame retardants; take back services for the end of life; recyclability or possible take back service for packaging materials; and the knowledge that they are doing business with a company

who is actively managing their environmental aspects. Because many of the eight companies studied are to be found toward the beginning of the supply chain, they have the potential of benefiting many types of customers all the way down to the end consumer with these environmental initiatives.

However, not all companies saw these directives in this optimistic light. The negative attitudes that many of the companies had towards the intentions of the directives may have limited the opportunity the directives had in spurring innovation. Almost all the companies expressed reservations about whether the removal of the banned substances was truly the most environmentally friendly option and the EU's political intentions.

Nevertheless, these eight companies were able to successfully address the EPR styled requirements of the WEEE and RoHS directives. The companies not only met the requirements of the directives, but as shown in this study, exceeded them.

7.1 FUTURE RESEARCH OPPORTUNITIES

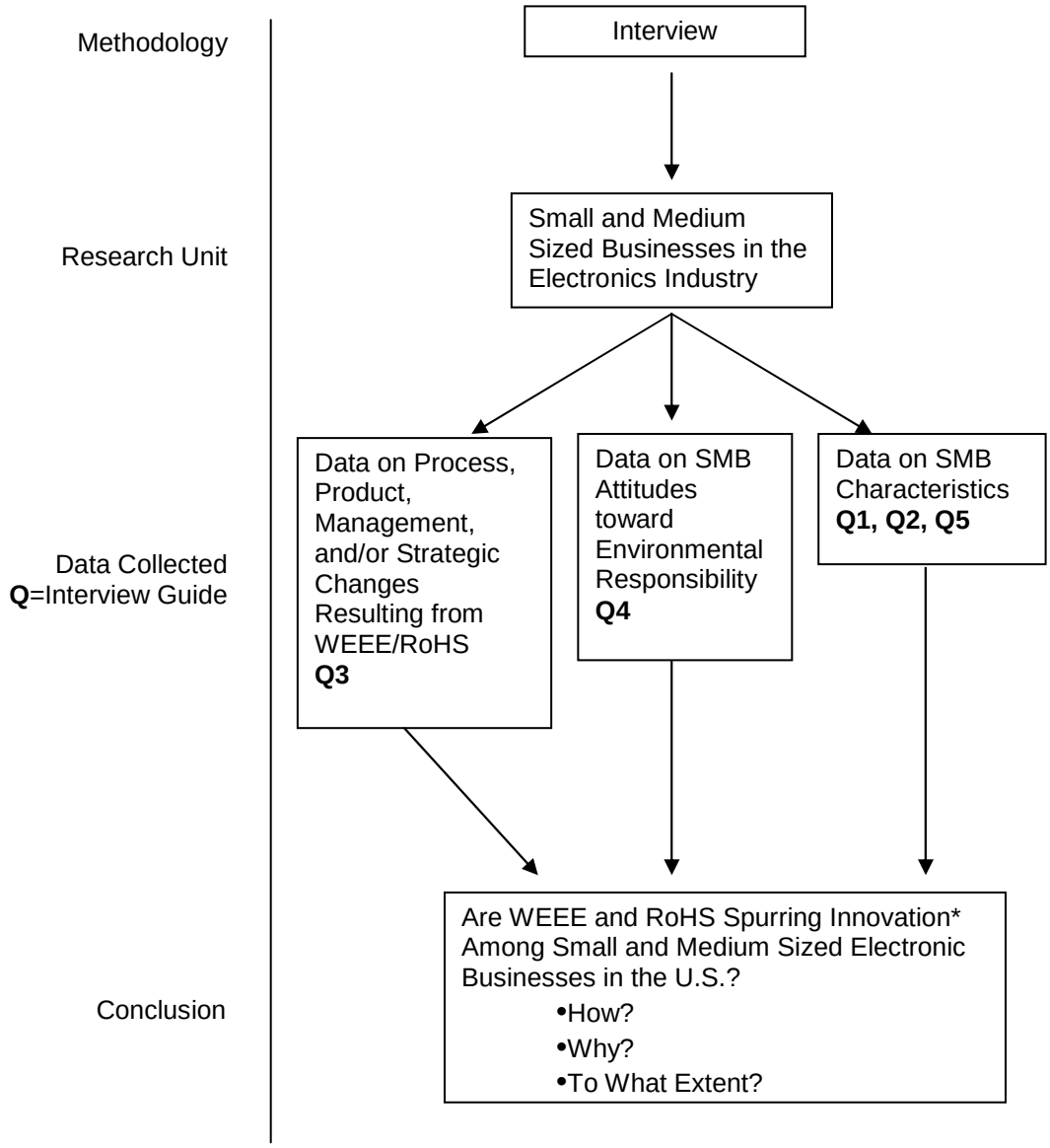
After studying the small business perspective of the directives it would be interesting to study the perspectives of their large business customers. Innovation may not be so easily spurred within the large businesses since in many cases they may not be as close to the complex manufacturing changes required to comply with RoHS as their small business contractors and suppliers. In this research the placement of a business within a supply chain was shown to influence the EPR effort. Size may be another factor that influences the effort.

Because the companies studied were not EU based companies, they understandably felt slightly removed from the pressure, but also from the support, a company in the EU would have. The interviewees of many of the companies remarked that while they were feverishly preparing for the RoHS implementation date on July 1, 2006, when the date finally came it was somewhat anticlimactic. The world had not changed, and they were conducting business as usual. They commented that if the U.S. had implemented similar legislation, the pace of full implementation would have been much quicker. It would be

interesting to conduct this research on eight small businesses within a country in the EU to determine whether they did in fact feel this pressure from their EU governments and whether the pressure helped or hindered the spur of innovation. Maybe if the U.S. had come out with similar legislation first, the companies would not have felt as open to additional "spillover" projects as they did to these foreign directives.

Another avenue for further research could be in policy analysis. If EPR legislation has the potential to not only accomplish the legislation's explicit requirements but give the companies the freedom to pursue additional initiatives since they decide the best way to address the issues in the regulations, where else can this style of legislation be used in the U.S. to engage in other environmental issues

APPENDIX: RESEARCH MAP



*Innovation will be defined as any change in the design and manufacturing of the products, in the internal organizational structure and management of the business, or in the market strategies pursued by the SMBs that creates a benefit beyond RoHS and WEEE compliance.

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