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May 2011

Acknowledgements

The author would like to acknowledge Ronald Labonté, Ted Schrecker, Raphael Lencucha and Katia Mohindra for their valuable comments and feedback, and Michelle Payne for her diligent editing of this paper..

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ISSN 1925-5608

Abbreviations

ACD	allergic contact dermatitis
APEC	Asia-Pacific Economic Cooperation
AFTA	ASEAN Free Trade Agreement
ASEAN	Association for Southeast Asian Nations
BIT	Bilateral investment treaty
BOI	Board of Investment
CAFOD	Catholic Agency for Overseas Development
CEREAL	Center for Reflection and Action on Labour Issues
CM	contract manufacturer
CPU	central processing unit
CRT	cathode ray tube
CSR	corporate social responsibility
DALY	disability adjusted life years
EGME	ethylene glycol monomethyl ether
EIA	environmental impact assessment
EICC	Electronic Industry Citizenship Coalition
EPA	Environmental Protection Agency
EPZ	export processing zone
EU	European Union
E-waste	electronic waste
EWSR	European Waste Shipment Regulation
FAO	Food and Agricultural Organization
FDI	foreign direct investment
GeSI	Global e-Sustainability Initiative
GDP	gross domestic product
GPN	global production network
HSIP	Hsinchu Science based Industrial Park
IBM	International Business Machines Corporation
ICD	irritant contact dermatitis
ICT	information and communication technologies
ILO	International Labour Organization
ISO	International Organization for Standardization
LCA	life cycle assessment
LCD	liquid crystal display

MNC	multinational company
NAFTA	North American Free Trade Agreement
NGO	nongovernmental organization
OBM	original brand manufacturer
OECD	Organization of Economic Cooperation and Development
OEM	original equipment manufacturer
OHSAS	Occupational Health and Safety Assessment Series
OPT	outward processing tariff
PBDE	polybrominated diphenyl ether
PC	personal computer
PCB	printed circuit board
PDI	Plan for the Development of Informatic
PEL	permissible exposure level
ppm	parts per million
PPP	purchasing power parity
R&D	research and development
REACH	Regulation, Evaluation, and Authorization of Chemicals
RoHS	Restriction on Hazardous Substances
SDH	social determinants of health
TLV	threshold limit value
TRIPs	Trade Related Aspects of Intellectual Property Rights
US	United States
WEEE	Waste Electrical and Electronic Equipment
WHO	World Health Organization
WTO	World Trade Organization



1 Introduction

On August 12, 1981, the International Business Machines Corporation (IBM) introduced the first personal computer (PC) product into the household and small business market (Matthews & Matthews, 2003). Initially IBM held a vertically-integrated business strategy with all computer parts and components built in-house. However, to invest more of IBM's efforts in marketing the PC, the company transitioned to outsourcing the production of its microprocessors to contracted companies in the United States (US). The transition from vertical integration to horizontal specialization coincided with a global increase in market liberalization (Dedrick & Kraemer, 2002).

In the following years Taiwan, Singapore, Mexico, and more recently, China began to emerge as key players in the PC industry, increasing their global economic share of hardware production from 8.2% in 1990 to 23.9% in 2000 (Dedrick & Kraemer, 2002). During the 2000s, the PC sector took two significant hits, with the burst of the dot.com bubble in 2001, and the global economic recession in 2008. Yet, the structure of the PC industry continued to grow and outsource production outside the US, Japan, and Europe (OECD, 2010). Semiconductors¹, commonly used as an indicator for computer hardware production, had increased sales in 2010 after a 14% drop in 2009 (OECD, 2010). While spending in computer products decreased early on in the 2008 economic crisis, recent projections expect the annual growth in sales to be 5.3% (projection by Gartner) and 7.7% (projection by Forrester) after 2010 (OECD, 2010).

In less than two decades the computer industry expanded to become a global production network (GPN). The computer GPN is now one of the fastest growing and most profitable industries, with annual production growth rates reaching 16% for microchip fabrication (Williams, 2003b) and annual revenue growth rates exceeding 200% for semiconductors, as in the case of Taiwan in 1999 (Chang et al., 2001). The market value for PC shipments was expected to be USD 222.9 billion by the end of 2010 (Gartner, 2009).

The rapid growth of a global PC industry occurred with only a limited consideration or understanding of its social and health implications. As the demand for computer production expanded in the 1980s, occupational health and environmental concerns began to grow, centring around toxic metals and chemicals, such as lead, cadmium, and polybrominated diphenyl ether (PBDE), that are commonly used in computer production. While scientific research on the health impacts of such chemicals has greatly increased over the past 20 years, the rapid pace of technological turnover, characteristic of the PC industry, has created

¹ Semiconductors are commonly used in computer microprocessors. While the semiconductor industry supplies the majority of its products to PC companies, they are also utilized in cell phone companies. As a result, the semiconductor industry is not exclusive to PC supply chain activities.

challenges for researchers concerned with the exposure of workers to new compounds during production. Furthermore, exposure to toxic chemicals is not exclusive to computer industry workers, but also affects informal recycling workers [a job that has arisen because of the growth in electronic waste (e-waste)], and communities within range of the emissions and outputs from PC production sites. The generation of computer waste is not a domestic problem, but an international one with developed nations exporting large quantities of e-waste to developing and transitional nations such as China and India.

What remains to be better understood is how PC industries link to health through the globalized production supply chain and how the outsourcing of PC components manufacturing to the Asia-Pacific² region relates to health outcomes there. Relatedly, how has globalization – mainly through economic liberalization - influenced the global supply chains of PC production and what are the health consequences? The linkages to health are not just environmental and occupational health concerns, but also the indirect influence on health (positively and negatively) by both labour market changes and the socio-economic conditions of PC production workers (Ferus-Comelo, 2006). This paper will investigate how globalization of the computer industry has acted on: social determinants of health (SDH), especially employment and labour conditions; environmental health, from industrial production and e-waste; and occupational health.

1.1 Linking health and the personal computer industry: A conceptual framework

The following conceptual framework was created to illustrate the linkages of a globalized PC industry with health (Fig. 1). In a single PC there are over 1 500 components and parts (Dedrick, Kraemer & Linden, 2009; Williams, 2000). The activities of a global PC company include design, research and development (R&D), refining of raw materials, numerous manufacturing and assembly stages, and marketing. Consequently, the structure of a computer GPN is complex, involving the networking of numerous firms specializing in specific activities or components. While the framework created is a simplification of the PC industry structure, it highlights key aspects in a GPN relevant to health outcomes.

The scope of this paper is not to perform a life cycle assessment (LCA) of a personal computer, but to include economic, political, and social variables that underlie the globalization of the PC industry and its health linkages. Similarly, a case study approach is not taken, as there is insufficient information on the activities of a single PC supply chain. Global supply chains are highly interconnected between PC companies, with companies often sharing the same suppliers (Dedrick & Kraemer, 2002). Thus, defining the impact of a single supply chain is also less relevant to evaluating the globalized nature of the PC industry and its relationship to health. Analyzing a single GPN does not illustrate health linkages relating to the industry as a whole, such as national policies for high-tech industries and science industrial parks (industrial parks with a high concentration of high-tech and electronics industries).

The focus of this paper is primarily on GPNs investing and outsourcing to East Asia (mainly to Singapore, Thailand, Malaysia, Indonesia, the Philippines, Taiwan, and China) and Mexico. While there has been high growth in production in Eastern Europe, particularly Poland, the Czech Republic, Romania, and Hungary, this region represents a small share of global PC production. In contrast East Asia has seen a rapid growth in PC production since the 1980s. In Latin America, Mexico has become a major destination for outsourced PC industries due to its proximity to the US, one of the world's largest PC markets and the location of many PC company headquarters.

Issues relating to consumer activities and marketing are not considered. However, consumer trends will be indirectly noted through production trends, market access, and falling PC prices. Certain studies reviewed in this paper analyzed the information and communication technology (ICT) and electronics sectors, which include a wide range of industries other than PCs, such as cellular phones, white goods (domestic appliances such as refrigerators, laundry machines, etc), televisions, etc. Nevertheless, these studies remain relevant for an assessment of health issues related to science industrial parks, where electronics and ICT companies co-exist with PC industries. When information does derive from studies of the ICT or electronics industry, it will be explicitly referenced as such.

² Asia-Pacific will refer to East Asia and Mexico

This research paper is divided into distinct areas of the framework. It first reviews how economic liberalization has contributed to the global distribution and structure of computer production. Which multinational and state policies have influenced the distribution and structure of PC industries? How have the structures of PC industries influenced employment conditions, and what links are there to health? It then identifies and describes the important environmental and occupational health impacts of computer production. More specifically, how is PC production linked to occupational and environmental health at various stages of the supply chain? It next discusses the rise of e-waste: what health issues relate to e-waste and how is it distributed globally? Finally, it discusses the regulation of PC production and how it can be improved with respect to reducing health risks. In particular what international and national legislations have been created to manage PC industry production and e-waste, and what are their limitations?

2 Globalization of the computer industry

In 1985 the global share of hardware production remained largely within the US, Japan, and Europe, totaling 87.1% (with 49.2% for the US and 18.9% for Japan) (Dedrick & Kraemer, 2002). By the 1990s, the global distribution of PC supply chains changed drastically. A strong consumer demand arose and exceeded the capacity of existing PC supply chains. The strategic direction of numerous PC companies was foreign direct investment (FDI) and outsourcing certain activities to contract manufacturers (CMs) based in Asia-Pacific.

This period of PC expansion internationally corresponds with greater liberalization trends throughout the world (Athukorala, 2005; Dedrick et al., 2001; Ernst, 2005; Gaullier, Lemoine, & Unal-Kesenci, 2007). By the mid 1990s the majority of PC companies began outsourcing the production of key components to CMs (Dedrick & Kraemer, 2000; 2002). Emerging economies, such as Mexico, increased their stake in the industry, but the largest growth in total global share of hardware production occurred in East Asia (in particular in Singapore, Taiwan, China, Thailand, South Korea, and Malaysia) from 3% in 1985 to 28.9% in 2000 (Dedrick & Kraemer, 2002). Consequently, Japan experienced a sharp drop in the global share of the hardware industry from 29.2% in 1990 to 16.3% by 2000 (Dedrick & Kraemer, 2002).

This trend continued in the new millennium as the share of ICT³ trade in computer components and peripherals declined from 37% in 1996 to 25% in 2008 among the Organization of Economic Cooperation and Development (OECD) countries (OECD, 2010). Since the mid-1990s, China has grown to become the largest exporter of ICT goods, as a result of FDIs and outsourcing (Dedrick & Kraemer, 2001). From 1999 to 2008, the US trade deficit in agricultural and manufactured goods increased from USD 262.5 billion to USD 400 billion (Baily, 2011). Computers and electronics were the largest contributing factors to the increased US trade deficit, accounting for 48% of the deficit increase (Baily, 2011). Nevertheless, China's production remains closely linked to neighbouring countries such as Singapore, Malaysia, Korea, and Japan (OECD, 2010).

World trade grew rapidly following the internet bubble until the recession in 2008 (OECD, 2010). However, the distribution of trade continued to change. From 2006 to 2008 trade of computer and peripheral equipment by OECD countries declined significantly, falling even more rapidly during the economic crisis. This decline in trade among OECD countries corresponded with an increase in trade and a shift in production to non-OECD economies. China, Singapore, Malaysia and Thailand increased their trade in ICT goods. Share of imports from non-OECD countries to OECD countries increased from 32% to 48% from 1996 to 2008 (OECD, 2010). Growth in ICT manufacturing and related exports within OECD countries is mostly a result of Mexico, Korea, and eastern European members. From 1996 to 2008 the highest growth in ICT exports (particularly assembled ICT equipment) was in the Eastern European countries, Hungary (38% compound annual growth rate), the Czech Republic (32%), the Slovak Republic (36%), and Poland (28%) (OECD, 2010).

As PC companies proliferated in number, the increase in competition contributed to a drop in the costs of components (Dedrick & Kraemer, 2002). This rapid shift in the global supply chain has important links to health outcomes, both positive and negative. While the expansion and growth of PC industries provided increased job opportunities for both highly and low skilled labour in Asia-Pacific, poor and often unregulated working conditions placed the low skilled labour force at greater risk of environmental and occupational health risks (Leong & Pandita, 2006). While such issues appear to be localized there are important linkages to the forces of globalization. The national policies of emerging economies, in an environment of increasing free trade, have significantly influenced the patterns of global PC industries. The following sections discuss how such macro-scale factors link to more localized issues such as employment, wages, and working conditions.

3 In the OECD Information Technology Outlook 2010 report ICT goods consist of: computer and peripheral equipment; consumer electronic equipment, communications equipment, electronic components; measuring and precision equipment; and miscellaneous.

2.1 Trade agreements and relations

As early as the 1960s Asia-Pacific states manufactured basic computer components for US PC companies. These contracts, however, reflected a minority of PC industry production, as the political environment maintained protectionist policies and trade restrictions for East Asian nations. The Cold War prompted the US military to fund the development of advanced computer technologies within the US, and, for security reasons, limited US based companies from outsourcing computer technology for fear of advancing the military capacities of opposing states (Ó Riain, 2006). The late 1980s marked a significant stage in expanding PC production overseas. With a high level of competition between PC firms the computer industry received a strong push to look internationally to reduce costs (Dedrick & Kraemer, 2002).

By the 1980s, the new direction of liberal economic policies in Southeast Asia fostered greater trade, resulting in a significant increase in FDI towards China and countries of the Association for Southeast Asian Nations (ASEAN) (Felker, 2003). The global economic climate facilitated investments in the region, with Singapore being one of the first Southeast Asian nations to take advantage of liberalization in FDI flows (Athukorala, 2005). The loss of confidence of American investors in Mexico after that country's announcement to default on loans corresponds with a shift in US investments to East Asia. These policies attracted FDI in high-tech industries in East Asia through reduced costs for manufacturing firms and the elimination of trade barriers for intermediate goods (Athukorala, 2005; Ernst, 2005; Phelps & Wu, 2009).

Bilateral investment treaties (BITs) provide key measures to protect foreign investments in the host country, and determine entry conditions for foreign investments (Salacuse & Sullivan, 2005). During the 1990s the US attempted to create a preferential trade agreement through the Asia-Pacific Economic Cooperation (APEC) (Schott, 2006), which would have accelerated the investments of PC GPNs in the region. However, most East Asian countries had no BITs with the US during the 1980s and 1990s (UNCTAD, 2005).

No significant trade agreement arose until the 1990s, after the accession of East Asian states to the World Trade Organization (WTO), in 1994. Nevertheless, certain trade arrangements played, and continue to play, an important role in the structure of computer GPNs. First, the joining of ASEAN nations to the WTO has increased regional competition and the movement of PC assembly and manufacturing firms within the region, creating more international opportunities for PC GPNs. Parts and components of semiconductor devices accounted for 59% of ASEAN exports in 2003 to 2004 with the ASEAN Free Trade Agreement (AFTA) playing a significant role in enabling the intra-regional flow of components (Athukorala, 2005). The fastest growing product category traded within the ASEAN region was parts and components, with its portion of regional exports rising from 18% in 1993 to 24% in 2004 (Gaullier et al., 2007). A significant share of computer parts and components production comes from major CMs who directly supply major PC companies (Botelho et al., 1999; Ernst, 2005; Lüthje, 2006). Additionally, the North American Free Trade Agreement (NAFTA) made Mexico a key location for final assembly processes in the PC industry (Gaullier et al., 2007).

The reduction and elimination of trade barriers among ASEAN states has facilitated the horizontal specialization of PC supply chain activities with the distribution of firms based on the comparative advantages of a country. Consequently, the global pattern of trading in the PC industry shifted exporting and production to the Asia-Pacific region. In terms of worldwide trade, East Asia tripled its trade surplus in computer hardware during the 1990s to greater than USD 60 billion, while the US and European trade deficit in computer hardware grew to USD 27 billion and USD 37 billion, respectively (Dedrick & Kraemer, 2002). From 1999 to 2008 the US has increased its trade deficit in computer and related equipment from USD 44 billion to USD 107 billion (Baily, 2011). For OECD countries, the trade deficit in ICT goods increased from USD 14 billion in 1996 to USD 193 billion in 2008, mostly due to trade in computer and peripheral equipment (OECD, 2010).

Similar to the regional trade trend in ASEAN, much of the international trade is between firms for components and intermediate products within GPNs rather than final products between countries (Thorbecke & Yoshitomi, 2006). The outward processing tariff (OPT)⁴ implemented by the US eliminated tariffs on

4 The outward processing tariff was designed to increase the competitiveness of US firms against imported goods produced at lower cost and with lower real wages outside the US. The outsourcing of labour intensive activities was first initiated by US electronic companies (Athukorala, 2005).

intermediate goods exported by the US, and only imposed a tariff for the value added internationally (Athukorala, 2005). The OPT promoted the creation of specialized companies focusing on key components across the region (Athukorala, 2005).

Another significant trend arose in the new millennium with the accession of China into the WTO in 2001, which increased investor confidence. However, China started its movement to more liberalized policies in the 1990s, with significantly reduced tariffs for imported PCs, dropping from 82% to 35% between 1992 and 1993 (Dedrick & Kraemer, 2001). Due to lower costs and China's proximity to large and emerging markets, the industry began relocating the manufacturing and assembly of computer parts from ASEAN states and Mexico to China (Gauillier et al., 2007). Around 75% of the goods exported to China from ASEAN are considered high- or medium-tech goods (Thorbecke & Yoshitomi, 2006). China is the largest recipient of components and parts from Japan, ASEAN, and Korea (Felker, 2003; Thorbecke & Yoshitomi, 2006). While final assembly processes are still strongly concentrated in Mexico, the shift of activity to China has come at the cost of decreasing ASEAN's share in the manufacturing of parts and components, creating strong competition within the region. Along with the strong competition in manufacturing, ASEAN states have focused efforts in more profitable areas such as design, R&D, and the creation of regional headquarters for PC industries (Felker, 2003).

While the links to health may seem distant, the location of PC supply chain firms influences the distribution of more localized occupational and environmental health issues. In addition, the strong competition between supply firms has ramifications for working conditions and wages. The Trade Related Aspects of Intellectual Property Rights (TRIPs) of the WTO has played a pivotal role in the international expansion of GPNs with important links to health. In the PC industry, secrecy of intellectual property is a strong priority and the basis of a firm's competitive advantage. However, the protection of intellectual property information hinders the transparency of firm activity, limiting the understanding of the chemicals utilized, which could, negatively harm staff and the environment. Academic research faces a temporal mismatch by being limited to data from PC supply chains that is over three to five years old (Liu, Lin, & Lewis, 2010). The relevance of research is further reduced as the rapid pace of PC technological advancement can result in new chemicals being utilized during manufacturing after two to four years (Chang et al., 2001). Consequently, any effective regulations regarding health concerns during production consistently require change at the same rate as technological advancements within the PC industry. Recognizing key trade agreements only partially explains the distribution of PC industries and its relationship to health outcomes. National policies of Asia-Pacific states have played a significant part in promoting investments and trade in high-tech industries.

2.2 National policies in high-tech sectors

Within the context of international agreements, how have national policies contributed to the distribution of PC companies globally? Proponents of liberalization (Yamazawa, 1990; 1995; Petri, 1993) have shown how trade liberalization has promoted job creation and technology transfer to developing and transitional states in Latin America and Asia-Pacific (as cited in Felker, 2003). In contrast, others argue that the regulation of liberalization and protectionist measures by states, such as Korea, Taiwan, and China, played a greater role in developing their technological capacity (Dedrick & Kraemer, 2001; Saxenian, 2005). Ultimately, both have been important to the distribution of PC industries: while liberalization is unlikely to be a cause of the global redistribution of PC production, it did create more opportunities for FDI and hence for global supply chains (Dedrick et al., 2001).

Beginning in the 1970s, East Asian states promoted FDI through the creation of export processing zones (EPZs), as used in Singapore, China, and Malaysia; and joint ventures with local and foreign based companies, as commonly utilized by Taiwan and South Korea (Felker, 2003). By the 1980s, Southeast Asian states began to liberalize their FDI policy, lower taxes to electronics industries, offer tax holidays to new foreign companies, and reduce restrictions on foreign ownership (Dedrick & Kraemer, 2001; Felker, 2003). Singapore reinvested in infrastructure to encourage design and R&D, while the Port of Singapore Authority increased customs efficiency to facilitate supply chain movement of intermediate products (Felker, 2003). Following Singapore's path, Malaysia streamlined the foreign investment approval process, and created tax

incentives for design and R&D. Similar approaches were taken by Thailand, the Philippines, and in the late 1990s by China (Felker, 2003). Consequently, FDI in computer manufacturing increased significantly in the late 1990s (Dedrick & Kraemer, 2002).

With the influx of foreign companies, East Asian nations initiated a new policy direction in the 1990s to help develop local companies, diversify component production, and promote skill development. In Thailand, the Board of Investment (BOI) created a program in 1992 to form linkages between multinational companies (MNCs) and local companies (Felker, 2003). In addition, the BOI created incentives for projects affiliated with the National Science and Technology Development Agency to help develop Thailand's R&D capabilities. In 1993, Malaysia initiated the Vendor Development Program where local and multinational companies provide assistance to local vendors. In 1999, the Global Supplier Program was created to help transcend local subcontractors of MNCs to be part of the international supply market (Felker, 2003). By the mid 1990s, China began to prioritize development in the PC industry, with the formation of the Ninth Five-Year National Development Plan (Dedrick & Kraemer, 2001). This created greater opportunities for FDI, and joint ventures to developing domestic PC production.

The significance of government policy approaches to liberalization is also exemplified by the adoption of such policies in Latin America. Since the 1980s, Mexico and Brazil have been hubs for local and foreign computer industries, although Brazil generally had more local PC and ICT firms (Dedrick et al., 2001). While Mexico created a sudden transition to tariff reductions and restrictions, Brazil managed a more gradual transition.

To preserve domestic manufacturing and R&D in the computer and ICT sector, Brazil created various incentives for companies that ensured some level of local content, R&D, and production (Dedrick et al., 2001). The policy measures of Law 9284/91 have been successful in certain areas, such as increasing local R&D, with 67% of firms increasing R&D spending by at least 50% between 1994 and 1996 (Botelho et al., 1999). Brazil's ICT industry invested 4.8% of total sales in R&D in 1997, similar to other successful computer industry nations such as Korea (3.7%) and Taiwan (4.6%) (Botelho et al., 1999).

In general, the government of Mexico placed a heavy emphasis on a "laissez-faire" approach (Dedrick et al., 2001). While Mexico attempted a similar approach to Brazil's, with its Plan for the Development of Informatic (PDI) in 1994, the initiative was unsuccessful due to limited funds to pay for new projects and limited coordination among institutions involved in the PDI (Dedrick et al., 2001). The PDI is one of the few attempts by the Mexican government to promote the development of local industries. With a quick transition to free markets, Mexico experienced a rapid development in export industries, and a sudden rise in contract manufacturing (Dedrick et al., 2001). As a result, the PC industry landscape in Mexico remains heavily dominated by US companies (Dedrick et al., 2001).

While the efforts taken by the Brazilian government were successful in certain areas, the domestic computer industry still faced challenges to compete in a global market. Many domestic hardware and component firms were replaced by major foreign PC companies, such as IBM and Hewlett Packard (Botelho et al., 1999). Nonetheless, some domestic firms were able to transition to other ICT sectors, in particular banking automation (Dedrick et al., 2001).

In the case of East Asia, Felker (2003) questions the success of local ownership policies (except for Singapore) in their ability to enhance local companies' production and revenue through strong links to large foreign companies. Nevertheless, FDI had increased substantially in East Asia. Within less than two years, FDI in Southeast Asia increased from USD 938 million in 1999 to USD 6 billion in 2000 (Dedrick & Kraemer, 2002). The use of CMs by PC companies has grown substantially, increasing by more than fourfold during the 1990s (Dedrick & Kraemer, 2002). Despite failures to implement policies to increase local business capacity, the strong growth in FDI indicates important pull factors to Asia-Pacific. A survey conducted by McMillan, Pandolfi, and Salinger (1999) sampled 39 companies involved in PC production, primarily in manufacturing of electronics components, computer storage devices, semiconductors, peripheral equipment, and computers. The following factors were noted to be most important in location decisions: political stability, 17%; infrastructure, 18%; cost and availability of skilled labour, 17%; location relative to suppliers

and customers, 16%; and tax incentives, 10% (McMillan et al., 1999). A recent survey of electronics firms by Dedrick, Kraemer, and Dunkle (2010) also noted firms prioritizing increased revenue, and cost and availability of labour for outsourcing new product development. These factors are common to East Asia contributing to the growth in PC FDI in the region. Similarly, proximity to customers has played a significant role in the PC industry outsourcing activities to Mexico.

These efforts clearly demonstrate how Asia-Pacific countries proactively regulated economic activities to create more local ownership in the 1990s. Greater local ownership can contribute to health by increasing the socio-economic well-being of the population and indirectly through more taxable revenue for government offered health services. However, to attract FDI in high-tech industries East Asia has lowered taxes to electronics industries, eliminated tariffs to encourage trade, and provided tax holidays (Ernst, 2005; Felker, 2003). In 2004, Chinese electronic manufacturing activities were taxed at 3.2% compared to 15.3 to 26.7% for other sectors (Manhart, 2007). Thus the PC industry contributes relatively little in tax revenue towards government programs that could promote health, such as equitable access to public health services. In the case of China, insufficient local taxation has resulted in hospitals and health centres implementing for-profit (cost-recovery) models. Consequently, the rural poor in China (many of whom migrate to urban areas to find work, and thus constitute the labour force of PC firms) are pushed into extensive out-of-pocket expenditures, creating deeper poverty and inequity in access to health services (Liu, Rao & Hsiao, 2003). The expansion of science industrial parks has the potential of improving public health services as a spillover effect from economic growth. However, Phelps and Wu (2009) note that science industrial parks have limited influence on enhancing the public sector of host countries. As to how such health care policies link to economic policies of the PC industry requires further research.

2.2.1 Exploring the pollution haven hypothesis

The pollution haven hypothesis outlines concerns about the impact of liberalization on exporting dirty technologies or avoiding environmental regulations (Bommer, 1999). Williams (2000) notes that improvements in environmental performances in developed nations could be due to a shift in manufacturing to developing countries. However, there is little data to confirm the hypothesis (Williams, 2000). Based on a literature review, Letchumanan & Kodama (2000) concluded that liberalization, in terms of FDI, did not result in pollution havens, and in some cases reduced it. However, the study is limited in a few ways. First, the correlation between FDI and pollution content in developing countries takes a sector wide approach, while the pollution haven hypothesis is more relevant to individual firm decision making. Second, the assessment does not consider the impact of supply chains and subsidiaries of foreign companies.

Third, liberalization can indirectly contribute to pollution levels. Domestic firms of developing nations which are unable to compete with cheap imported goods may resort to environmentally unsafe methods of production. Additionally, the contribution of liberalization to poverty promotes informal economies such as metal smelting and informal recycling of e-waste which can be detrimental to health (Sepúlveda et al., 2010; Shinkuma & Huong, 2009).

2.3 Structure of GPNs

The combination of macro-scale factors has shaped the structure of PC GPNs with consequential links to health. Certain companies such as IBM, Compaq, Toshiba, and Apple maintained some in-house production of PCs. However, companies are following the example of Dell which has outsourced manufacturing and design to CMs (Dedrick & Kraemer, 2002). CMs based in emerging economies now account for a large share of production activities (Ernst, 2005; Lüthje, 2006). In 2007, numerous microchip manufacturing plants were being built in China and other parts of Asia, but not in the US (Baily, 2011). Similarly, Taiwan has emerged as the leading supplier for notebook PCs.

Segments of the PC industry supply chain are relocated to minimize costs and access key markets. The relevance of accessing markets is a growing priority for PC companies. In China the purchase of 5 million new PCs is expected to occur every year after 2003 (Hicks, Dietmar, & Eugster, 2005). In the early 1990s, 60% of PCS sold in China came from foreign PC companies, but by the late 1990s over 80% came from

domestic firms (Greeven, 2006). Intel, Hewlett Packard, and the Inter-American Development Bank have each committed USD 1 to 3 billion in programs to develop consumer markets in developing countries (Cherry & Gottesfeld, 2009).

The movement of companies globally has resulted in important trends in the structure of PC GPNs. First, since the early 1990s PC production has grown annually, while PC firms have experienced reduced revenues. In 2009, worldwide PC shipments were expected to grow 2.8%, but the market value of PCs was expected to decline 10.7% (Gartner, 2009). The drop in market value can be attributed to the decline in PC average selling prices (Gartner, 2009). The average price of a PC dropped from USD 2 000 in the early 1990s to USD 1 000 in 2000 (Dedrick & Kraemer, 2002). Up to 2009 the average selling price in the US continued to drop to USD 580 (Worthen, 2010).

The high competition among PC firms and the customer demand for cheaper products has increased pressure on lower tier firms in the supply chain to reduce costs. Samel (2010) notes how supplier firms that take a high volume, low product diversity model of production are vulnerable to volatile market demands. This structure creates problems in labour standards based around working hours and work shifts. Six of seven manufacturing firms assessed by Samel (2010) for printer and PC component parts in Malaysia, Singapore, and Thailand were noted to have the high volume, low diversity model of production. With limited legislation and enforcement of labour rights in Asia-Pacific countries, employment conditions are strongly dictated by economic forces, with wages determined by domestic market conditions. Consequently, working conditions remain poor with increased pressure to maintain lower labour costs.

Furthermore, the demand for reduced costs from PC firms has also increased competition between lower tier firms within the East Asia region. The recent arrival of China in high-tech manufacturing has resulted in a large shift in PC production from Southeast Asia to China (Gauillier et al., 2007). The strong competition of manufacturing firms in East Asia has resulted in suppressing wages and may create incentives for factory managers to violate employment contracts in order to provide competitive prices. Although more research is needed to better understand factory managers' decision making in CMs, the downward pressure of price competition is leading to more unhealthy conditions of work in the PC industry.

The result of the drop in prices has been significant with firms throughout the supply chain having reduced profit margins (Worthen, 2010; Yang, 2006). However, following the all time low in 2009, prices for PCs have been on the upswing with the average selling price in the US increasing to USD 615 in November 2010 (Worthen, 2010). Major PC companies are now focusing on selling higher end products and gaining higher profit margins. This recent shift in prices suggests that the push for reduced pricing has reached its limit for manufacturers (Worthen, 2010). Yet, at the present stage it is difficult to determine if this upswing in prices will be sustained, and whether increased profit margins will trickle down to improved working conditions.

Second, to attract FDI in the 1980s, East Asian countries created science industrial parks with the required infrastructure for manufacturing operations including reliable water supplies, electrical power, waste management, and worker housing complexes (Phelps & Wu, 2009). The result has been the clustering of competing PC GPNs in localized areas, attracted to the similar appeal of reduced costs and market access. The Pearl River Delta region of China is a key region, where many industrial parks are situated. In particular, Dongguan and Suzhou, China, are common sites for PC related firms, with computer production accounting for up to half of the gross production value of Dongguan's industries (Walcott, 2003). These industrial parks play a key role in the link between globalization and health outcomes of the population, with the capacity of some parks exceeding 100 000 workers.

The Hsinchu Science based Industrial Park (HSIP) in Taiwan has become a global centre for notebook PC supply chain operations. In 1989, Singapore opened a science park for foreign research units linked with the national university, and offered specialized equipment for prototype manufacturing. Following suit, the Philippines, Malaysia, Indonesia, and Thailand opened their own science industrial parks, some specializing in PC industry activities, such as wafer fabrication (Felker, 2003). The industrial areas in Mexico known as maquiladoras emerged for high-tech industries following the signing of the NAFTA, with many high-tech firms based in Guadalajara (Astill & Griffith, 2004).

The third trend of PC GPNs is the rapid turnover in technology, with estimates of depreciation in PC products reaching 1% per week (Dedrick & Kraemer, 2002). The rapid pace of technology turnover has involved the use of new chemicals during production, limiting the time for environmental and health impacts to be fully researched. Health and safety staff and production engineers in HSIP indicated that new production procedures may have been implemented without understanding potential toxic risks (Chang et al., 2001).

Fourth, the fragmentation of PC supply chains, with greater outsourcing, has resulted in each segment having only partial knowledge of chemical uses, resulting in a knowledge divide as to possible environmental and health risks. Last, intellectual property protection limits knowledge sharing on environmental and safety concerns between competing firms and within a supply chain (Chang et al., 2001).

Important questions arise as to how major PC companies in the US, Europe, and Japan are linked to early stages of resource extraction and primary commodity industries (these include materials such as copper, lead, silicon, and plastics). These activities are common to less industrialized developing nations and can have large impacts on environmental and occupational health. Presently, China dominates the extraction of rare earth metals, which are commonly used in a wide variety of products (Bradsher, 2009). Nongovernmental organizations (NGOs) have reported worker rights abuse and environmental impacts in coal mining in China, and in extractive activities of coltan (commonly used for cellular phones) in the Democratic Republic of the Congo (Bradsher, 2009; Montague, 2002). As these basic materials are involved in numerous industries, it is difficult to illustrate a clear link specifically to the PC industry. Furthermore, there is limited information on the practices of extractive firms and their linkages to health. More will be discussed on this issue in section three.

2.3.1 How has liberalization contributed to the distribution of PC wealth?

The Asia-Pacific PC industry has expanded rapidly due to reduced costs, tax incentives, and access to new emerging markets in the region (Dedrick & Kraemer, 2002; Felker, 2003; Ernst, 2005). With GPNs maintaining a concentration in East Asia, the region has developed into a hub for a wide range of PC supply chain activities ranging from basic assembly to R&D. However, has the global expansion of the PC sector altered the balance of wealth between countries, in particular, developed and emerging economies? The question is especially relevant to macro-scale health issues, such as the national capacity for health services and poverty reduction, where high-tech industries account for 7% of the gross domestic product (GDP) in China, and probably more in other East Asian states (Manhart & Griebhammer, 2006).

The answer depends on what economic variable is assessed. When considering the geographic location of final assembly, the answer is yes. The US share of final hard drive assembly was almost zero in 1998 (Gourevitch, Bohn, & McKendrick, 2000). In computer hardware production, China exceeded the US to be the world's largest producer in 2004 (Yang, 2006). In the case of portable notebooks, Taiwan is a dominant force, taking 70% of the global market share by volume in 2004 (Yang, 2006). However, by nationality of the parent firm (or flagship firm), the US dominates with 85% of global production, and 15% for Japan in 1998 (Gourevitch et al., 2000). Much of the wealth generated returns to the US, Japan, and the EU. Evaluating the Apple iPod and an HP notebook, Dedrick et al. (2009) found the lowest profit margins for firms based in Taiwan and Korea.

While a few original brand manufacturers (OBMs), such as Acer, have emerged from East Asia, almost 95% of manufacturers are original equipment manufacturers (OEMs), whose products have less value than OBM products (Yang, 2006). Around 90% of electronics exports in China are through OEMs and CMs (Leong & Pandita, 2006). The continued dominance of the US PC industry is maintained despite major PC companies outsourcing all, or most, manufacturing and design processes. Large computer companies generally focus on R&D, sales, distribution and customer relations, where a significant amount of value is added (price of final product value versus sum of intermediate inputs) (Dedrick et al., 2009). This global pattern, often described as Wintelism, is where flagship PC companies maintain greater control by setting the technology standards for the industry (Felker, 2003). Furthermore, major PC companies avoid responsibility for lower-tier supply chain processes and focus on building a larger market share. This control is not exclusive to OBMs, but to CMs existing in second and third tiers of the supply chain, such as memory and

processor design and manufacturing firms. Many of the outsourced activities in R&D and manufacturing in Southeast Asia are owned by US and Japanese companies. Intel, for example, has experienced one of the highest profit growth rates in the PC industry, partially by maintaining strong control over microchip standards since the 1980s (Dedrick, et al., 2009).

Emerging PC economies in Asia-Pacific have benefited from employment opportunities. However, to absorb the value of PC industries, domestic companies need to be able to receive technological knowledge from competitive foreign companies. The argument for technology transfer has been proposed by liberal theorists, but the evidence has been mixed. Irwin and Klenow (1994) suggest that in the semiconductor industry spillovers in learning are substantial (as cited in Saggi, 2002). The case of Taiwan has commonly been used as an example of successful technology transfer. The circular migration of Taiwanese engineers to Silicon Valley and back to Taiwan has facilitated the knowledge transfer needed for Taiwanese firms to remain competitive in a global market (Saxenian, 2005). However, the spillover effect of technology to domestic companies remains a problem. In many cases intellectual property remains a top concern for firms and can limit the technological transfer to local companies (Chang et al., 2001; Dedrick et al., 2010).

Some researchers suggest that the current pattern of PC industries creates a greater dependency for developing countries on PC companies in the US, Japan, and Europe. The large growth in CMs and OEMs is highly dependent on contracts from large PC companies in developed countries. Lardy (1995) and Huang (2001) noted that East Asia's dependence on FDI for exports prevented the growth of the domestic private sector, with limited linkages of MNCs to local firms and low levels of exports by domestic companies (as cited in Greeven, 2006). Alternatively, the relationship is likely to be co-dependent, with developed states depending on CMs in Asia-Pacific, Eastern Europe, and Latin America. Presently, there is insufficient research to evaluate dependency theories within PC GPNs. Nonetheless, Asia-Pacific countries offering low taxes to firms and gaining low profit margins will provide limited resources for public health care services. Whether employment opportunities and higher wages gained from the PC industry can offset the need for free health services will be investigated in the following section.

2.4 Links to labour conditions and health

To generalize the overall impacts of globalization on social welfare remains a challenge. Presently, there are research gaps as to how the computer industry impacts poverty and population health. The incentives for high-tech industries and the flow of capital to urban areas have likely contributed to greater rural-urban inequality in income and employment in Asia-Pacific, especially China. However, how the PC industry itself has contributed to intra-state inequality has not been extensively researched. Dedrick and Kraemer (2002) argue that, while there has been a gain in employment in foreign based firms and a loss in domestic industry employment, there has still been an overall gain in employment due to the PC industry. Additionally, wages in the PC sector appear to be higher and include better benefits than other electronics industries, especially for highly skilled workers (Gourevitch et al., 2000; Schipper & Haan, 2007).

These trends are generally based on a quantitative analysis of employment wage statistics. In contrast, testimonial reports by NGOs and researchers have noted how wage conditions, especially for low skilled labour, do not appear to be improving in the PC sector. While minimum wages have increased in China, they are not reflective of the costs of living (Leong & Pandita, 2006). Whether minimum wages are enforced is another issue. A survey of 14 foreign invested electronics firms in Guangdong Province, found eight of these firms paid workers below the minimum wage (Leong & Pandita, 2006). These are likely to contribute to SDH via poor socio-economic conditions including poor diet and inappropriate housing. While the ability to generalize findings from interviews with workers remains difficult, the work of NGOs provides insight into existing problems in the industry.

Problematic to increasing wages to improve labour conditions, has been the high competition within the PC industry. Computer prices have been consistently falling since 1990, and the push for cheaper products moves down the supply chain. Intense price competition between PC component and parts manufacturers has dropped supplier profit margins to 1 to 5% in Taiwan, with similar margins in other countries (Dedrick et al., 2009; Yang, 2006). This suggests that liberalization has created opportunities to take advantage of

lower costs and tax incentives, rather than improving labour wages in sectors of comparative advantage. The following sections will discuss how labour issues in the PC industry in Asia-Pacific relate to health outcomes of especially low skilled workers. Issues relating to occupational health and safety will be discussed in more depth in section three.

Labour wages in the PC industry:

The importance of labour wages in determining the location of PC industries has been questioned, as labour costs represent a minor fraction of the total costs of production (2.5%) (Dedrick & Kraemer, 2002). However, labour costs remain a relevant and important issue. First, the value of low wage labour will depend on specific activities of the PC industry, especially assembly operations which require more manual labour. Last, as the average PC price dropped by more than 50% from the early 1990s to 2000, the profit margins of PC companies dropped as well; thus, making labour costs (greater than 5% of total costs) more substantial and more elastic to changes in the PC market relative to fixed costs such as technological capital. As a result certain aspects of PC production which are labour intensive are outsourced to areas in which labour is cheaper.

Work activities involved in PC production are complex, involving R&D; fabrication of various parts; manufacturing of microchips and semiconductors; and assembly. While the range of activities in the PC sector is vast, the literature notes that the distribution of wages⁵ tends to fall into three categories. Within the hard drive industry the lowest wages are found in China (USD 0.68/hour), and Malaysia (USD 1.88/hour), and are concentrated in the assembly of hard drives, amounting to over 100 000 staff. In Singapore, wages are close to USD 5.85/hour, with the majority of work directed to final assembly of disk drives (Gourevitch et al., 2000). The last group consists of Japan, Western Europe, and the US. In these countries, wages are the highest at USD 17 to 22/hour (Gourevitch et al., 2000).

With the movement of more complex fabrication and design processes to East Asia, a demand for highly skilled labour has grown. Emerging PC component industries in Brazil, Mexico, Taiwan, Malaysia, and Korea have actively invested in tertiary education in technology and engineering to increase the local labour supply of highly skilled workers (Dedrick et al., 2001). With liberalization of previously closed markets, developed countries have taken advantage of highly skilled labour, which is now available at a relatively lower cost. Costs of highly skilled labour in East Asia are 10 to 20% that of the US. In 2002, the annual cost of a chip designer in Silicon Valley was USD 300 000 per year in contrast to USD 60 000 in Taiwan and USD 24 000 in Suzhou, China⁶ (Ernst, 2005). The availability of skilled workers, particularly with lower wages, has been a pull factor in shifting some design and R&D activities to East Asia (Dedrick et al., 2010) and has indirectly increased the employment opportunities for low skilled labour.

Employment in the PC industry:

Qualitative assessments from NGOs provide some insight on the impact of the PC sector on the health of low skilled workers (CEREAL, 2007; Ferus-Comelo, 2006; Leong & Pandita, 2006; Lüthje, 2002; Manhart & Grieshammer, 2006; Schipper & Haan, 2007). In most cases the name brand PC companies do not employ low skilled workers directly. Rather workers are employed through local hiring agencies, CMs owned by local firms, or by subsidiary firms owned by second tier supply chain companies based in Japan and the US. It is in these manufacturing plants where the population health risks are greatest.

While research has been undertaken on the impact of globalization on PC labour wages, there remains limited information on its potential impact on social welfare and health. While job opportunities have increased in developing countries, the global share of wages in the hard drive industry remains mostly in the US (40% of global wages) and Japan (30% of global wages) (Gourevitch et al., 2000), which can be attributed to the higher wages paid to smaller workforces in these countries. Asia-Pacific has the highest quantity of labour staff with around 40% of global employment in the hard drive industry, but less than 15% of global wages (Gourevitch et al., 2000). The trend of labour positions moving to Asia-Pacific has continued in the new millennium, with employment in PC production in the US declining by more than 50% from 2000 to 2007

⁵ Wages are converted in terms of purchasing power parity (PPP) based on 1997 rates.

⁶ The annual costs of a chip designer are not converted in terms of PPP, but highlight costs to US chip designing firms.

(Linden, Dedrick, & Kraemer, 2009). Similarly, annual compound growth in employment in manufacturing has declined in OECD countries from 2001 to 2008 (OECD, 2010).⁷

Similar to EPZs, the demographic composition of low skilled labour in the PC industry tends to be women and minority groups, especially in assembly processes (Ferus-Comelo, 2006; Lüthje, 2002). In China, science industrial parks near major urban areas have resulted in intra-state migration from rural areas to employment opportunities within the parks. The coastal city of Suzhou, China, has become the largest laptop production centre in the world with annual outputs near 10 million units (Leong & Pandita, 2006). Similarly, HSIP in Taiwan was 632 hectares and home to 348 companies and 98 725 employees in 2003 (Chang et al., 2006).

Migrant workers comprise a significant portion of the low skilled labour workforce in East Asia. In ASEAN states, migration between countries is very common. Migrant workers are vulnerable to health issues, not only through work hazards, but due to their irregular citizenship status. A combination of limited time off, transportation limitations, and access to health services can create greater health risks for migrant workers. The issue is further compounded as many workers in science industrial parks are believed to be illegal immigrants (Walcott, 2003).

With the quick turnover in consumer products and the rapid pace of technological advancement, outsourcing of activities is required in order for production to be completed in short time frames. The result has been greater employment volatility in relation to PC market volatility. Following the drop in PC demand in early 2000 and the 2008 recession, numerous PC companies and CMs reduced their workforce, some by as much as 85% (Felker, 2003). Rapid and high volume production, in turn, has resulted in more flexible or non-standard employment arrangements (Patterson, 2010; Samel, 2010). However, in terms of employment security, most temporary contracts in Thailand lasted three to six months or even years. In certain cases the employees were taken as full-time staff (Schipper & Haan, 2007). In contrast, temporary contracts in the assembly operations in Mexico are fairly common ranging from month-to-month or fifteen days. The Center for Reflection and Action on Labour Issues (CEREAL) found temporary workers accounted for 60% of employees in electronics firms in Mexico in 2006 (CEREAL, 2007). Another rising trend is outsourcing labour from hiring agencies. In a few cases CEREAL has noted claims of inappropriate treatment of outsourced workers, such as being given less financial and social benefits, than non outsourced workers, even though the Mexican Labour Law applies equally to directly hired employees and those outsourced from hiring agencies (CEREAL, 2007).

Labour unions in the PC industry:

Most NGO groups note the need for labour unions as a mechanism to respond to the social and health concerns of employees (Ferus-Comelo, 2006; Liu, 2009; Manhart & Griebhammer, 2006; Schipper & Haan, 2007). One of the most common issues in East Asia has been the limited freedom of workers to organize unions and to collectively bargain (Manhart & Griebhammer, 2006). In many cases greater involvement of low skilled labourers facilitated greater compliance with codes of conduct issued by major PC companies. Chen et al. (2009) noted greater implementation success for the Occupational Health and Safety Assessment Series 18001 (OHSAS 18001)⁸ when all employees participated in firm decisions.

Unions have started to form in East Asia, but patriarchic norms and expectations of male leadership and membership in unions limits the participation and representation of a large female work force in the PC industry (Ferus-Comelo, 2006). In the beginning of 2009, on average there were 3.3 labour unions for every 100 companies in Taiwan. Although there are 519 000 labour union members, this represents a small portion of the 8.8 million labourers in Taiwan (Liu, 2009). Similarly, in China and Taiwan, there are limitations on the rights of labourers to organize and form unions (Adams & Mclaughin, 2009). As employment strategies have transitioned from majority full-time to temporary employment, the result has been a decrease in eligible unions, in number and size. While few free labour unions independent of government involvement exist

⁷ 1995 used as index for annual compound growth rate

⁸ OHSAS 18001 is the international assessment standard addressing health and safety risks in organizations. It is compatible to series 9001 and 14001 of the International Organization for Standardization (ISO) which address quality and environmental management by organizations and companies.

in East Asia, the pattern seems to be changing to some degree. In Malaysia, four regional unions were in the process of being registered by the Department of Trade Union Affairs in 2010 (Koshy, 2010). In addition, one of the world's largest CMs, the Taiwan Semiconductor Manufacturing Co., has received pressure from employees to form a labour union (Liu, 2009).

Labour conditions and health:

From an SDH perspective, labour factors have important linkages to health, especially in emerging economies. After 470 supplier audits made by one PC company during the 2004 to 2008 period, Chinese plants were found to have the most violations with 83% of audits in violation of labour standards (Samel, 2010). The PC company also noted working hour violations in 62.5% of firms in the Philippines, 45.8% in Thailand, and 36% in Singapore (Samel, 2010). In Apple Computer's 2010 Supplier Responsibility Progress Report, audits were conducted by Apple's supplier responsibility auditor along with local third party auditors (Apple, 2010).⁹ The audits found manufacturers were regularly violating environmental and social codes: 54% exceeded the 60 hour weekly work limit; 39% inadequately met requirements for occupational injury prevention; 35% violated wage and benefits requirements; and 17% did not meet chemical exposure standards (Branigan, 2010).

Similar trends in violations of social and environmental codes are noted in other PC companies by the Electronic Industry Citizenship Coalition (EICC)¹⁰ (Samel, 2010). In terms of worker safety conditions or availability of appropriate safety equipment there is considerable variance between firms. Generally, the key causes of accidents in semiconductor production are mostly fire (47%), followed by fluid leaks (22%) and explosions (5%) (Chao et al., 2008). Some hard drive manufacturing plants in Thailand did not have adequate safety equipment or appropriately inform their workers of the risks in hazardous chemical use (Schipper & Haan, 2007).

In science parks in Thailand, new employees are required to undergo preliminary medical exams consisting of blood tests, chest x-rays, urine tests, and eyesight exams (Schipper & Haan, 2007). For temporary workers, some of the required tests were paid for by the workers themselves (Schipper & Haan, 2007). In some cases workers believed their dismissal from employment was a result of being pregnant, or becoming pregnant during the probation period¹¹ (Ferus-Comelo, 2006; Schipper & Haan, 2007). However, insufficient information exists regarding reasons for discrimination against pregnant workers. In Thailand, many PC parts and components firms offer some form of health care services. However, depending on the firm, they range from regular medical check-ups to only one exam per year (Schipper & Haan, 2007). Workers have complained about the quality of medical check-ups offered, and their concerns for exposure to harmful chemicals involved with their work activities. Workers in Thailand found chemicals in their blood tests and lung infections through outside hospitals, but not through company provided check-ups (Schipper & Haan, 2007). While health centres are available in science parks, out-of-pocket medical expenses can significantly affect the affordability of health care for low wage labourers in emerging economies, and create a greater economic burden. In Thailand, temporary workers receive less medical benefits than permanent staff, with firms not providing medical check-ups (Schipper & Haan, 2007).

How medical services differ for migrants, whether documented or not, has not been evaluated, but testimonials have suggested firms discriminate against international employees in work contracts. In the case of the CMs for Apple Computers in Taiwan, Filipina migrant workers are asked for "placement fees" exceeding Taiwan regulations, and violating the code of conduct issued by Apple (Adams & McLaughlin, 2009). In China, migration is mostly intra-state due to a large supply of low skilled labourers from rural areas looking for work opportunities.

Wages for low skilled workers are not sufficient to cover living expenses and remittances to family members. The resulting trend has been for low skilled labourers to work overtime (Leong & Pandita, 2006;

⁹ Worker stress was not assessed in the audit.

¹⁰ More regarding the EICC is discussed in section 5.

¹¹ Firms have denied discrimination of workers based on pregnancy. Urine tests are not conducted for pregnancies, but for drug testing (Schipper & Haan, 2007).

Manhart & Griebhammer, 2006). The most commonly cited labour rights infraction in Malaysia, Thailand, and China is working beyond the legal limit (Samel, 2010). Consequently, there appears to be an emerging trend of stress related illnesses and health issues, with some firms employing psychologists to help address emerging staff issues related to stress (Schipper & Haan, 2007). Along with the rising trend in temporary employment, worker stress has become a significant issue within the PC industry. Numerous NGO reports have noted stressful working environments in the PC industry. In interviews with workers in a PC laptop components factory in China, the Catholic Agency for Overseas Development (CAFOD) noted stressful working conditions including no talking, no stretching, and no toilet or water breaks from the production line. In another factory, which manufactures monitors, a worker stated a requirement of wearing a red overcoat when a large mistake was made (Astill & Griffith, 2004). NGOs have suggested that such stressful conditions are likely responsible for the 12 attempts of suicide by employees from Foxconn, a PC component manufacturing firm, in Longhua, China (GoodElectronics, 2010).

3 The cradle of PCs: Health and PC production

The previous section investigated the impact of PC industry globalization on economic welfare as an SDH. However, there are important direct health outcomes as a result of the computer manufacturing process. More specifically how does the PC industry influence environmental and occupational health risks during computer production? With strong competition within the PC sector, the drive for lower prices has resulted in outsourcing to reduce production costs. Additionally, emerging economies are now becoming emerging markets for PC industries. In the process of PC production hundreds of compounds are used (Williams, 2003a). Most environmental health impacts range from the local factory level (worker exposure to chemicals) to the regional and national level (air and/or water pollution). The World Health Organization (WHO) notes that hazardous compounds that are produced and expelled from industries can directly harm staff, reduce air quality, and contaminate groundwater (WHO, 2010). On a larger scale the energy intensive activities of PC production have been shown to directly contribute to climate change through emitted greenhouse gases and indirectly through greater fossil fuel consumption for powering production plants (Williams, 2003a). In a life cycle assessment conducted for desktop PCs in China, human health impacts relating to exposure to toxic chemicals and reduced air quality were found to account for around half of the total impact of manufacturing PCs¹² (Duan et al., 2009).

For the purposes of this investigation the impact of hazardous compounds and waste disposal will be the focus. While global estimates of emissions and energy consumption can calculate the relative impact of the PC industry on climate change, the links to environmental health are more challenging to make. Present climate change impact studies are accurate at national and global levels, but less accurate at the local level. Furthermore, predicting the health impacts of climate change is not simply an environmental health study, but requires a multidisciplinary approach to investigate how political, economic, and social factors contribute to greenhouse gas emissions and fossil fuel demand. Nevertheless, there are studies which illustrate the extent of fossil fuel energy use in PC production. Williams (2003a; 2004) estimates 0.97-1.2 kg of fossil fuel is used to produce one microchip. This is likely to underestimate fossil fuel use, as Williams uses global estimates of percentage of energy use. The activities of PC industry manufacturing are highly concentrated in regions where fossil fuel energy use is more prevalent than the global average.

The complexity of GPNs also makes it difficult to determine the environmental and occupational health impacts at each level of the supply chain. Using a materials flow analysis, Williams (2003a) assesses the material, energy, and financial capital inputs and outputs of component parts. While other studies have reviewed environmental and health impacts of PC component manufacturing, Williams reviews multiple components common to PCs. Life cycle assessments using Eco-Indicator'99 include an estimate on health impacts relative to resource and ecosystem impacts, but do not provide information relating to prior cases, toxicity studies, or long-term health issues.¹³ As Williams focuses on the latter issues, the following sections will be based on Williams' review (2000, 2003a) of the environmental and occupational health impacts of producing key components: silicon supplies and intermediate silicon products; microchip processors; printed circuit boards (PCBs); and liquid crystal displays (LCDs).¹⁴

12 The studies used Eco-Indicator'99 which determines relative impact of a product through the course of its life cycle in three damage categories: resource use, ecosystem quality, and human health.

13 The damage modeling for ecosystem quality and human health is based on four variables: *fate* links emissions to a change in concentration; *exposure* links change in concentration to a dose; *effect* links dose to human effects such as incidence of a particular pathology; and *damage* which expresses effects as disability adjusted life years (DALY). The relative contribution of each damage category is calculated as a fraction of total damages. The weighting and ranking of each damage category is based on a panel decision to represent the relative value of each damage category.

14 The following discussion is not a comprehensive review of health impacts related to PC production, but is meant to illustrate how health issues exist throughout the supply chain of PC GPNs.

3.1 The beginning of the supply chain: Primary commodities and resource extraction

Much of the literature on PC production centres on later stage manufacturing and fabrication. What needs to be better understood is the link between resource extraction and the initial stages of manufacturing to PC production. The previous discussion illustrated that PC industries have concentrated in Mexico and East Asia. However, resource extraction and primary commodities are likely to involve more firms in the developed and developing world.

Determining a link proves challenging as primary commodities for PC manufacturing (e.g. aluminum, copper, silicon, and plastics) are sold to numerous other industries, with the PC sector constituting a small part of the global share. In addition, data on flows between different sectors and within supply chains remains limited (Williams, 2000). While hundreds of chemicals and materials are involved in PC production, the case of silicon will be used to illustrate global links of primary extracted resources and primary manufacturing.

3.1.1 The case of silicon in PC industries

Silicon is derived from a variety of sources including charcoal, coal, and quartz. While quartz is traded regionally and is extracted in developed states, charcoal is heavily exploited in developing states including Zambia, India, Kenya, Sudan, Brazil, and Nigeria (Williams, 2000). Charcoal is traded internationally with over 600 kilotons exported in 1998 (Williams, 2000). These early stages in the PC supply chain pose serious potential health risks to local populations. Emissions from charcoal production contain many organic compounds which can be detrimental to human health. Coal extraction is extensive in China and contributes to 2 500 deaths annually from “black lung disease” (Williams, 2000). Nevertheless, it is necessary to recognize that the PC industry consists of a small share of early stage production. The high-tech sector itself only represented 5.8% of the demand for total silicon production in 1998 (Williams, 2003b).

Intermediate products derived from silicon metal, such as chlorosilanes and polysilicon have a much larger stake in PC production. Around 60 to 65% of chlorosilanes, particularly trichlorosilanes, are utilized in semiconductor industries. While the precursor silicon metal is produced mostly in China, (followed by the US and Brazil), chlorosilanes are mostly produced in Germany and the US. The greatest risk from chlorosilanes is to workers involved in its production, as contact with hydrochloric acid or water can result in an explosive chemical reaction (Williams, 2000).

The remaining stages of the silicon supply chain in PC industries involve the building of polysilicon, followed by silicon wafers, and then semiconductor devices. The most notable change in these intermediate steps is a dramatic rise in value added. Per kilogram the value of trichlorosilane, polysilicon, and silicon wafers rises from USD 3 to USD 50 to USD 1 500 (Williams, 2003b). The US and Japan take a growing role in the later stages of silicon production, absorbing much of the value added in silicon supply chains. The wafer industry was valued at 5.6 billion in 1998, with Japan accounting for 38%, the US 27%, and other Asian states 20%. However, other Asian states are growing in the global share of wafer production (Williams, 2000).

The growth rate for the value of the semiconductor industry has been strong from the late 1980s to the 1990s at over 10% per annum. In contrast the charcoal, coal, and quartz sectors grew much more slowly at 2.5% per annum during the same period (Williams 2003b). The growth in the semiconductor industry has been significant, it has reached the scale of the coal industry, and is forecasted to be 10 to 20 times greater than coal by 2020 (Williams, 2003b). Thus the stake of PC industries in silica extraction and primary production will grow as the demand continues to increase.

The case of silicon illustrates the complexity and length of GPNs. The same case exists for numerous other chemicals and compounds involved in PC production. Presently, there is limited data on environmental and occupational health impacts in extraction and primary commodity production of silicon and other compounds. Most of the information has been suggestive of possible impacts, with limited empirical evidence. Part of the evidence problem arises from the complexity of global supply chains, and the limited government opportunities to regulate and monitor environmental and health impacts in developing countries.

3.2 Microprocessors

Microchips are the central component for computer function. This sector within the PC industry has shown significant growth rates with the average annual growth in economic value near 16% from 1970 to 1999 (Williams, 2003a). The estimated total value of the global industry is somewhere close to USD 139 billion. Production is almost evenly distributed between East Asia, the US, Europe, and Japan. However, control remains mostly within Japanese and US firms (Williams, 2003a).

The process of manufacturing involves five main stages of layering silicon wafers with specific patterns. A range of chemicals is utilized to selectively remove parts of the wafer to create patterns and to add additional elements. Many of these chemicals if inappropriately discharged can be detrimental to the health of staff and local populations. Many of the organic and inorganic compounds used are acutely toxic to humans at specific exposure levels. Arsenic, used for chemical vapour deposition, can increase the risk of lung cancer. In HSIP ambient levels were found to be ten times more than those found at coal power plants (Chein et al., 2006). Eleven of 20 sampled facilities in the industrial park were found to have ambient air levels of arsenic above the limited value (Chein et al., 2006).

Studies have shown negative impacts on reproductive health after waste from microchip production contaminated water supplies in the 1980s (Williams, 2003a). Long-term exposure to chemicals can contribute to increased birth defects and cancer rates among workers at semiconductor fabrication plants. Following a leakage of chemicals from storage drums in Silicon Valley, a noticeable rise in miscarriages and birth defects was observed in contaminated areas (Williams, 2003a). While no research has been able to prove a conclusive direct relationship, epidemiological studies have shown female fabrication workers have an elevated risk of miscarriages due to exposure to glycol ethers used as a photoresistant solvent (LaDou, 2006a; Williams, 2003a). Lin et al. assessed the national birth and death registry of Taiwan to assess the incidence of birth defects in newborns from female (2008a) and male (2008b) semiconductor workers from semiconductor plants. The study found no relationship between semiconductor female workers and the incidence of miscarriages or birth defects from 1984 to 2000 (Lin et al., 2008a). When male staff were assessed from 1980 to 1994 there was a significant increased risk of newborn death with heart anomalies (Lin et al., 2008b). Whether this potential risk underlies the observed cases of discrimination against pregnant women has not been researched. A lab study with rats determined that trichloroethane, a chemical commonly used in the production process, correlated with heart abnormalities (Williams, 2003a).

The absence of reported cases, during the 1990s in the US, corresponds to the movement of such industries to CMs in East Asia and Mexico. Since most of these companies are invested by foreign companies, it can be hypothesized that the standards of practice are transferred as well. Yet, the increase in activity in Asia-Pacific still raises concerns regarding the environmental impact of production. During the 1990s cases of contaminated water supplies and illegal dumping operations were noted in Taiwan (Chang, Chiu & Tu, 2006). Presently, there is limited information regarding the environmental health impact of companies in this region.

What remains unclear is how production will impact health issues on a larger or regional scale. A recent study by Liu et al. (2010) evaluated Taiwanese microchip production. The study conducted a life cycle assessment by applying the IMPACT 2002+ which measures specific indicators related to the environment and health (Fig. 2). Overall the study found gaseous emissions to be one of the most significant factors to summer smog and airborne inorganic compounds.

While Williams has reviewed a number of studies on the environmental and health impacts of PC production, there are significant gaps in the available literature. Much more research needs to be done to evaluate the toxicity of chemical compounds used, and for epidemiological studies on the population impacts. With the high turnover of PC technologies, changing production processes every few years, more recent data is needed to evaluate current issues of PC production.

3.3 Printed circuit boards (PCBs)

PCBs are the next stage where microchips are attached through specific electrical routes. Essentially PCBs are a maze of copper conducting paths stacked between insulated layers. In 2000 the global PCB production value amounted to USD 42.7 billion in 2000, with an average growth rate of 9.5% from 1996 to 2000 (Williams, 2003a). In 2003, the Taiwan Northern District Inspection Institute evaluated 75 PCB companies, and found the PCB industry to have the highest number of occupational accidents compared to other manufacturing industries (Chen et al., 2009).

Similar to microchips, PCB fabrication involves numerous chemicals to repeatedly etch wiring patterns onto the boards. This process involves alkaline and acidic compounds during the etching processes, and tin-iron solder in mounting components. Generally, there has been a lack of research by American PCB firms and few studies from Europe and Asia (LaDou, 2006b). China leads global manufacturing of PCBs, but there is limited published data regarding chemical use in manufacturing plants (LaDou, 2006b). The greatest health concern is in the large quantity of formaldehyde and metals, such as copper, silver, tin, lead, and chromium, used in production (Williams, 2003a). These can be hazardous through a variety of ways, such as unsafe working conditions for staff, contaminating groundwater supplies, or impacting public waste water treatment.

During production, chemicals heated in the copper bath can form formaldehyde vapours, which are harmful to human health (LaDou, 2006b). The requirement of “clean rooms” in PCB production creates an additional problem of re-circulating air and increasing exposure to formaldehyde vapour. An Environmental Protection Agency (EPA) study recommended that the PCB industry stop the copper process and remove formaldehyde from the process. Presently, there is no evidence suggesting this has been implemented by PCB industries (LaDou, 2006b).

Other major chemicals used in PCB production are glycol ethers (LaDou, 2006b). Taiwan uses 90% of the world’s supply of ethylene glycol monomethyl ether (EGME). During operations the average airborne EGME concentration for the workers was 8.13 ppm, exceeding the permissible exposure limit in Taiwan of 5 ppm (LaDou, 2006b).

3.4 Liquid crystal displays

While older monitors of cathode ray tubes (CRTs) have significant environmental health issues, they are rarely manufactured in the PC industry today. Nevertheless, the issue of CRTs is very relevant to the export and informal recycling of e-waste. Since the beginning of the millennium LCDs have dominated the PC market, with the global industry valued at USD 9 billion in 2001 (Williams, 2003a). Japan dominated LCD production in the 1990s. By 2001, Korea had the largest market share at 40% while Taiwan was rapidly growing its production share (Williams, 2003a).

Similar to microchips and PCBs, the greatest concern for health impacts are the long-term health effects due to chemical exposure. Of the 588 compounds in liquid crystals, 26 have acute toxicity potential (Williams, 2003a). In general, complaints of occupational dermatitis are frequently reported among workers in LCD factories and other PC component manufacturing firms. In a self administered questionnaire of 3 300 workers in the manufacturing of microchips, PCBs, LCDs, and communication devices in northern Taiwan, Shiao et al. (2004) found that 9.8% of workers complained of hand dermatitis symptoms. Of those reporting symptoms, 3.8% were diagnosed with allergic contact dermatitis (ACD) and 35.5% with irritant contact dermatitis (ICD) (Shiao et al., 2004). Phenylenediamine, nickel, and cobalt used during production were the most significant allergens for ACD. For ICD the major causal factors included exposure to fibreglass (52% of workers complaining of skin problems were exposed to fibreglass), cuts, friction, thermal burns, and solvents (Shiao et al., 2004).

Brominated flame retardants used in plastics are a rising concern due to their effects on human health. Specific compounds such as PBDEs are commonly produced from brominated flame retardant compounds. There is evidence such compounds are linked to neuro-developmental problems, cancer, and interference

with thyroid hormones (Williams, 2003a). Food consumption is the most likely source of contaminants within organisms. These compounds are bio-accumulative, stored in fatty tissues, and magnify in quantity higher up in the food chain. In Sweden, PBDE levels were shown to be rising in breast milk (Williams, 2003a). A similar trend is occurring in North America, with levels in breast milk increasing two fold every five years. Nevertheless, the minimum concentration that impacts health is poorly understood (Williams, 2003a).

In a contract factory for Apple Computers, n-hexane was utilized for cleaning display screens. The compound is a cleaning agent that can cause damage to the peripheral nervous system and spinal cord, leading to muscular weakness, or, in severe cases, paralysis (Branigan, 2010).

4 The grave of PCs: PC waste generation, movement, and the forces of globalization

Recent press attention was raised by NGOs investigating conditions in Guiyu, China, a major site for e-waste. After the appearance of e-waste and informal recycling activities, Guiyu's drinking water from groundwater sources had become significantly polluted, requiring water to be delivered from another township (Hicks et al., 2005). At times over 100 000 people, including children, are involved in the informal recycling process (Hicks et al., 2005). The problems associated with e-waste recycling in Guiyu contributed to e-waste being classified as hazardous waste under the Basel Convention (Davis, 2006).¹⁵

The rapid rate of technological advancement has contributed to e-waste problems and has outpaced the government's ability to accurately monitor and address health issues. In 2004, more than 180 million PCs were sold globally. Since the 1980s PC production has increased each year, and with that, so has PC waste. In 1994, 20 million PCs were obsolete compared to approximately 100 million obsolete PCs in 2004 (Widmer et al., 2005). With the rapid advancement in PC technology and strong competition reducing prices, there has been an increase in the quantity and frequency of PC sales, and in turn PC waste. In 2003, the quantity of obsolete PCs in the US was estimated to be 200 million cubic feet (Matthews & Matthews, 2003). For computer central processing units (CPUs), the lifespan fell from approximately five years to two years between 1997 and 2005 (Babu et al., 2007). The trend is similar in India, where the issue of e-waste is greatest (Dwivedy & Mittal, 2010).

E-waste has become a global issue, illustrating how environmental health issues extend beyond PC production. The issue is not specific to developed nations with the largest PC consumer base, but is growing in developing and emerging nations. China and India had the second and fourth highest PC growth rate per capita between 1993 and 2000 (Widmer et al., 2005). While the consumer market grows in emerging economies, there still remains a strong demand for used PCs. This demand, for cheaper used PCs, has created trade routes of PC waste to developing and emerging economies. Extraction of metals and other materials from PC waste can result in environmental and health risks, which is why developed nations have avoided such methods. However, in developing states such materials represent an economic opportunity for those living in poverty (Widmer et al., 2005). The focus of this section will be to assess the key linkages of global factors (including e-waste generation and its global exports) and health.

4.1 Environmental health impact of informal recycling

To evaluate the impact of PC waste on global environmental health trends is challenging, as most studies assess e-waste in general. The contribution of a product to e-waste is determined not solely by its number of items, but also by the mass per unit and by its lifespan (Robinson, 2009). Based on the low lifespan and relatively large mass of computers, PC waste is believed to contribute to the majority of overall e-waste¹⁶ (Robinson, 2009). In general, plastics and metals are the most common elements in PC composition (Widmer, 2005). In terms of hazardous chemicals the ones that are most concerning are: mercury, cadmium, lead, arsenic, hexavalent chromium, and compounds originating from plastic flame retardants (Babu et al., 2007).

Metals are commonly extracted in informal recycling processes due to their market value. In Delhi, India, the material extraction from recycling is mainly driven by the precious metal content of PCs. Precious metal recovery constitutes the majority of informal recycling efforts as over 80% of PC materials' market value can come from precious metals (Streicher-Porte et al., 2005). More than 315 million computer units were disposed of in 2004, contributing to around 1.2 billion pounds of lead, 4 billion of plastics, and 2 million of cadmium (Babu et al., 2007). As mercury is minimally represented in PC materials, the other 4 compounds will be reviewed for their environmental health impacts.

¹⁵ The Basel Convention on the Control of Transboundary Movements for Hazardous Waste and their Disposal was put in force in 1992 to restrict the flow of hazardous wastes. E-waste is regulated in the Basel Convention under List A of Annex VIII.

¹⁶ Average PC mass in the study was 25kg. This is likely to be representative of desktop PC mass rather than laptops.

Well managed waste sites pose limited environmental health risks from leaching metals and compounds (Williams et al., 2008). However, the process of informal recycling in developing and emerging countries places workers and the local population at great risk of exposure from toxic compounds, and its consequent impacts on health (Williams et al., 2008). Sepúlveda et al. (2010) reviewed environmental assessments of the concentration of lead and the byproducts of brominated flame retardants in e-waste sites in China and India. Overall, most studies found concentrations near waste sites were above average in terms of air particle levels, dust and soil levels, and levels in water supplies. Studies of blood lead levels have found higher concentrations in children in Guiyu (Williams et al., 2008). After surveying hospitals in the area, Hicks et al. (2005) found many Guiyu workers experienced cases of kidney stones and respiratory tract infections, with migrant labourers having the highest incidence.

The main applications of lead in computers are glass panels and gaskets in CRT computer monitors (3 to 8 pounds per monitor), and solder in printed circuit boards and other components (Babu et al., 2007). The negative health effects of lead can be serious, causing damage to the blood system, reproductive system, central and peripheral nervous systems, and kidneys (Babu et al., 2007). Cadmium, present in semiconductor chips, is a toxic metal which bio-accumulates in the human body and can cause severe respiratory problems (Babu et al., 2007). Chromium VI, used to prevent corrosion in steel plates, is a toxic compound permeable to cells, and can lead to lung cancer (Babu et al., 2007). In Guiyi province, Li et al. (2008) found neonatal levels of chromium from exposure to e-waste recycling were linked to higher levels of DNA damage.

Burning e-waste can release toxins into the air, with heavy metals and PBDEs entering into the atmosphere in ashes and fumes (Sepúlveda et al., 2010). High temperatures or insufficient metallurgical treatment of e-waste can result in the creation of polyhalogenated dioxins and furans, both with a high potential for acute toxicity and probable long-term carcinogenic effects. Emitted particles can have wide geographic impacts with re-deposition occurring close to the original source or traveling thousands of kilometres (Sepúlveda et al., 2010). Additionally, dust in wastewater can infiltrate water and soil and contaminate groundwater.

Dioxins, furans, and PBDEs are some of the most dangerous compounds to human health, which are mostly formed through the burning of flame retardant plastic compounds. As copper is a valuable metal commonly extracted from PC waste and a catalyst to dioxin formation (Williams et al., 2008), burning of copper wiring with plastic coating results in the formation of dioxins. Xing et al. (2009) determined that the level of atmospheric polychlorinated biphenyl compounds¹⁷ near an open burning site was significantly greater than residential areas. Exposure of polychlorinated biphenyl from inhalation was responsible for 93% of the total body loadings¹⁸ for e-waste recyclers in contrast to 27% for local residents (Xing et al., 2009).

Aside from atmospheric impacts, the released compounds can leach into groundwater and soils, and enter the food chain. In Taizhou, Zhejiang Province, the activities of e-waste recycling have contaminated neighbouring agricultural rice fields. The cadmium and lead content of rice near the recycling plant was found to be significantly higher than commercial rice samples, with lead intake exceeding the Food and Agriculture Organization (FAO)/ WHO tolerable daily intake level (Fu et al., 2008).

4.2 Flow of e-waste

The issue of e-waste has been an active topic for over a decade, with the movement of e-waste being a globalized business. Much like the supply chain of PC production, the structure of the e-waste supply chain is determined by economic and legal differences among countries. Consequently, e-waste trading has concentrated strongly in Asia with major trading routes spurring from Hong Kong and Indonesia (Fig. 3), with the majority of e-waste ending up in Guangdong, China (Fig.3). The US's recycling sector states that around 80% of e-waste received is exported to Asia, of which 90% goes to China (Hicks et al., 2005). The US is believed to be producing the largest amount of e-waste exports. Accurate quantities of country exports are limited, but in 2002 it was estimated that 10.2 million units of used computers were exported from the US annually (Puckett et al., 2002).

¹⁷ Polychlorinated biphenyl compounds are noted to have similar toxicological effects to PBDEs, furans, and dioxins.

¹⁸ Total body loadings is the sum of exposure from inhalation and diet.

Arguments have been made that the reuse and refurbishment of used PCs are bridging the “digital divide” in developing states (Williams et al., 2008). Nevertheless, much of the e-waste ends up in landfills with informal recycling activities (Robinson, 2009). To create greater demand for domestic products and to address the e-waste problem, China has banned imports of all second hand electronics equipment and PCBs since April 2000 (Shinkuma & Huong, 2009). Similar policies exist in other countries, such as Vietnam and Cambodia, which have banned second hand PC imports. Yet, the issue of e-waste trading continues to persist. The challenge of curtailing e-waste exports is well exemplified in the case of China and the US.

The differing economic conditions of the US and China have created push and pull factors for e-waste. With e-waste trading legal in the US and the high costs of managing e-waste domestically, policies have supported the export of used electronics equipment. The underlying pull factor has been rural poverty in China and the lower socio-economic status of Asia-Pacific countries. With limited work opportunities, rural migrants are motivated by work opportunities in e-waste landfills involving informal recycling. Generally e-waste is utilized in three ways: the reselling of operational used electronics; refurbishing and repairing of items; and broken units disassembled and recycled to extract valuable parts. The highest value items in e-waste are reusable electronics (GAO, 2008).

The demand for cheaper electronics products has created a market where extracted compounds and used parts are purchased for refurbishing used items. However, with an increase in original brand electronics produced in China, national legislation is targeting an increase in domestic product sales, rather than second hand sales (Shinkuma & Huong, 2009).

Although the import of second hand electronics for re-exporting has been banned by many countries, imports of electronics are allowed unofficially (Shinkuma & Huong, 2009). The second hand economy is a growing sector in developing regions, with a strong demand for cheaper electronics and materials becoming a major economic “pull” factor that challenges import/export regulations. Many of these second hand products in e-waste trade are resold to developing states in Asia, such as Vietnam and Cambodia (Shinkuma & Huong, 2009). Additionally, China continues to grow in its demand for raw materials, which in turn encourages the import of used electronic goods (GAO, 2008). The US Government Accountability Office (GAO) also notes how foreign exporters and Chinese importers are able to escape China’s import regulations (GAO, 2008).

Regulation of e-waste in the region of Asia-Pacific remains limited. In Indonesia, electronics recycling activities in east Java occur in an industrial estate and on Batam Island (near Singapore, a major trade route in the Asia-Pacific region). This area is a “special bounded zone” exempt from government regulation and is significantly cheaper than creating formal recycling arrangements (GAO, 2008). Recyclers are at risk of exposure to toxic compounds and metals from crude methods of recycling. The following section will discuss how the growing issues of e-waste as well as occupational hazards are addressed by regulatory efforts.

5 Catching up to PC industry growth: What present legislations address the problems of e-waste and PC production, and are they sufficient?

Computer production and e-waste movement have become globalized industries with transnational supply chains. With the expansion of the electronics industry, there has been a rise in public concern from civil society organizations and NGOs. In the PC sector, numerous NGOs initially emerged out of Silicon Valley, and are now spreading their focus in Asia-Pacific. In addition, the EU and the US have been active in passing legislation to regulate PC production and e-waste. Existing regulatory initiatives involve industries incorporating environmental, health, and safety considerations, and govern the management of hazardous materials. The International Organization for Standardization (ISO) addresses quality and environmental management among the 163 member states through ISO 14001 and 9001 standards (Chen et al., 2009). In East Asia, PC manufacturing and assembly firms are generally certified by ISO standards (Chen et al., 2009; Manhart & Griebhammer, 2006; Schipper & Haan, 2007). In accordance with ISO 14001 and 9001, OHSAS 18001 was created to ensure safe working conditions and protect the health of employees (Chen et al., 2009). As a result of pressure from top tier PC companies, partly to enhance the company image and comply with customer requirements, there has been a trend of greater OHSAS 18001 compliance (Chen et al., 2009).

However, the question remains whether these efforts are able to effectively target the globalized pattern of PC production and e-waste. Some firms in East Asia certified to follow ISO 14001, were found to have forged certificates (Manhart & Griebhammer, 2006). A corporate social responsibility (CSR) approach, through self regulation by industries, has the benefit of being a transnational initiative, which targets specific segments of the PC production supply chain. In the private sector, the EICC has created an initiative to address environmental and social issues in PC manufacturing. Established in 2004, the purpose of the EICC is to develop a code of conduct throughout the industry pertaining to the social and environmental performance of firms (Manhart & Griebhammer, 2006; Samel, 2010). While the EICC has become a significant organization, environmental and labour rights abuses remain a large problem. A survey conducted in 2008 by the EICC found the environmental and social performance of firms to still be a troublesome issue (Samel, 2010).

The EICC, with its 45 members consisting of 3.4 million workers, is an important step in addressing health issues throughout the PC industry (Samel, 2010). However, compliance to the EICC code of conduct for lower tier CMs of PC companies remains a major issue. Through the EICC code of conduct, created in 2004, International Labour Organization (ILO) core standards are incorporated (Manhart & Griebhammer, 2006).

The Global e-Sustainability Initiative (GeSI) has partnered with EICC to tackle social, health, and environmental issues existing throughout the supply chain. However, whether a CSR approach is sufficient for addressing these issues will remain to be seen, since PC companies create two opposing strategies. As illustrated, PC companies conduct audits and require contracted firms to comply with the EICC code of conduct. At the same time, the drive for reduced PC prices has pushed suppliers to reduce costs from PC companies, consequently promoting poorer working conditions. Furthermore, not being a multi-stakeholder initiative, the EICC does not regulate production activities through an independent agency, but employs the use of corporate social responsibility. NGOs have noted there is limited transparency of EICC audits, which monitor labour rights performance of firms, and can reduce the effectiveness of improving labour and health conditions (Schipper & Haan, 2007).

Two other examples highlight the fact that the use of CSR through the EICC by itself may be insufficient to address labour and health issues. First, the Philippine Workers' Assistance Center noted that labour conditions did not improve from 2006 to 2008 despite PC company actions and suppliers upgrading their policies and efforts (GoodElectronics, 2009). Second, the recent case of n-hexane use by Apple Computers

contract firms, exemplifies the need for an independent regulatory body. In Suzhou, China, the supply firm Wintek, required Chinese workers to use n-hexane, even though the toxicity and health effects are known in the industry (Branigan, 2010).

Addressing the issue of health within the PC industry will require some form of independent regulatory system. Four significant initiatives have been created by the EU and involve regulating the use of chemicals in the industry: Regulation, Evaluation, and Authorization of Chemicals (REACH); the Restriction on Hazardous Substances (RoHS) Directive; the Waste Electrical and Electronic Equipment (WEEE) Directive; and the European Waste Shipment Regulation (EWSR).

5.1 Present legislations

On June 1st 2007 the European Parliament and the European Council put the legislation of REACH into force. The legislation requires industry to bear the burden of proof and to illustrate the safety of chemicals produced and sold within the EU (LaDou, 2006b). All substances made or imported into the EU must be registered, with information required being proportional to the health risks and quantity of production. For especially problematic chemicals (carcinogens, mutagens, and compounds which bio-accumulate, etc), companies will require authorization before being able to use them in production (LaDou, 2006b).

The initiative is significant in incorporating the principle of extended producer responsibility and the precautionary principle. This is especially pertinent to industries extending into Eastern Europe for a reduction in production costs. While the initiative is a significant step in addressing PC industry impacts, it is limited in addressing global PC production at a multinational level. While the scope of REACH includes imported goods, the legislation does not fully address outsourced production and the risk of such chemicals in Asia-Pacific. Furthermore, the initiative may in fact direct efforts away from Eastern Europe to CMs and OEMs in Asia-Pacific, supporting the pollution haven hypothesis. However, not enough information is presently available to evaluate how PC companies in the EU have adapted to REACH. Drawing causation of movement from REACH will need to account for other European legislation and for the general worldwide trend of moving to Asia-Pacific.

In contrast, the RoHS initiative of the EU addresses the globalization of PC industries by creating product requirements. By 2006, the RoHS banned the use of the following compounds and elements in the majority of EU electronics products: mercury, lead, cadmium, certain brominated flame retardants, and hexavalent chromium (LaDou, 2006b). To maintain PC component exports to Europe, China enacted the Administrative Measures on the Control of Pollution Caused by Electronic Information Products, which bans the same chemicals noted in RoHS for products marketed in China (LaDou, 2006b).

The Basel Convention involves the regulation of hazardous materials traded internationally, with the issue of e-waste recently being addressed by the Convention. However, concern remains whether the Basel Convention has sufficient financial resources and a comprehensive mandate to address the issue of e-waste (Davis, 2006). To address the growing quantity of e-waste the EU enacted the WEEE directive in August 2005. The legislation requires manufacturers and electronics companies to be actively involved in the recycling and dismantling of electronics products. The directive also promotes the production and R&D of PCs to facilitate reuse and recycling, and use of materials which protect human health and the environment. Similar to RoHS, the WEEE directive targets the final products, but extends responsibility to producers. Companies in the US, such as IBM, have incorporated similar policies to facilitate their activities in the EU (Williams, 2003a).

Along with WEEE the EWSR tackles the issue of e-waste through regulating and licensing of agents involved in exporting and importing. However, the effectiveness of the regulation has been questioned. As a result of differences in the level of enforcement among EU countries, several “escape routes” exist. While EWSR has focused more on improving the detection of illegal waste, sanctioning mechanisms seem to remain weak (van Erp & Huisman, 2010).

Strong challenges of managing e-waste movement remain from regulation efforts at the export side. While the US has not ratified the Basel Convention, it has banned the export of CRTs common to old PC monitors

and televisions since 2006. Yet, regulatory controls are easily evaded (GAO, 2008). Posing as buyers from Pakistan, Vietnam, Hong Kong, India, and Singapore, GAO (2008) found 43 out of 53 US electronics recycling companies willing to export broken CRTs. Of waste shipments inspected in the EU, 7% had violations considered illegal shipments, most being e-waste (van Erp & Huisman, 2010).

For e-waste there are numerous challenges for effective regulation: low prioritization of the issue by national authorities; uncoordinated enforcement of laws between and within countries; and not taking into account the influence of informal recycling (van Erp & Huisman, 2010). However, one major issue is the determination of legal versus illegal exports. This distinction depends on existing markets for second hand electronics in receiving countries (van Erp & Huisman, 2010). Banning the export of e-waste will require distinguishing products that have no market in the importing country, and whether receiving countries can process waste appropriately with their environmental regulations (van Erp & Huisman, 2010).

Williams (2003a) notes that the regulation of chemicals can be a complex process involving international trade, environmental regulation, and needed scientific information. Computer waste in landfills can result in the leaching of lead, which can contaminate water supplies. As a result the EU passed a legislation banning the use of lead in electronics products starting in 2006 (Williams, 2003a). However, the ban was highly contested by the US. The US argued that in 146 US landfill sites investigated, lead contamination in groundwater had only occurred in two sites, due to lead intensive industries creating larger quantities of lead waste (Williams et al., 2008). Furthermore, the use of alternatives to lead, such as silver, is problematic as previous cases of landfill sites failing to meet minimal standards have shown (Williams, 2003a). Nevertheless, the EU decided to keep its ban on lead based on the precautionary principle. How these legislations are implemented and how these legislations are open to trade dispute needs to be further researched.

Certain problems may still arise in achieving the objectives of the legislation. First, strong competition between contract firms along with policies to attract FDI, illustrate a prioritization of economic growth amongst Asia-Pacific countries. Second, the rapid turnover of PCs creates the use of new chemicals that are poorly understood and that place a large burden on regulatory bodies. Regulatory bodies must be able to quickly respond to the rapid pace of change in PC production. While adopting the precautionary principle and extended producer responsibility in legislation helps to overcome these issues, there remains a large “grey area” on what is considered precautionary.

While areas of the developed world, such as the EU represent a large share of the PC market, it is difficult to predict the impact of emerging markets in Asia. The demand for cheaper computer products is more likely to grow in emerging economies with large populations, such as China and India. As to whether PC production will be uniform, based on standards of the developed world, or if a two tier production network (one targeting developed countries with stricter environmental standards, and the other targeting developing states with lower standards) will emerge is unknown. Furthermore, competition for second hand products derived from e-waste can promote competition for cheaper products. The varying possibilities highlight the need for international legislation targeting PC industries and to address multiple issues of PC production. Whether this is possible is partly a matter of political willingness and political ability.

5.2 Political willingness and political (in)ability

Market liberalization has fostered an economic climate where countries compete for foreign investments. In a liberalized global economy, governments face a paradox. To encourage investment, governments can create policies with less regulation and incentives to avoid taxes. In contrast, to better manage environmental and social issues, governments must adopt a regulatory system that favours public interests over PC sector interests. In general, there has been a consistent trend for governments to encourage FDI. The creation of industrial zones with different regulatory standards from domestic standards has moved government regulation away from environmental and health issues.

Do the economic gains from less regulated PC industries outweigh the environmental and social costs? The question of political willingness to regulate PC industries illustrates the contradictory activities of greater environmental and health regulation versus tax incentives and reduced regulation to encourage investment.

The issue of willingness partly depends on the economic share of PC industries. In Taiwan, the PC industry represents a major share of the national GDP. While there have been violations of the environmental impact assessments (EIA) law, this has not raised public concerns as the perceived economic benefits of the industries are highly prioritized (Chang et al., 2006). Government authorities have been involved in town planning projects and relaxing land use control to facilitate investment of firms. The water shortages in 1999 created serious problems for industrial firms, which require large quantities of water in semiconductor fabrication. As a result, the Ministry of Economic Affairs shifted water from farms to HSIP, leaving 15 000 hectares of farm land to fallow. In 2002, 3 000 hectares were ordered to be left uncultivated to provide water supplies to industries (Chang et al., 2006).

With limited government monitoring and privatization of waste management services, the burden of environmental and health monitoring stays within the PC industry. The prioritization of economic growth and the rapid turnover in technology has made the risk of environmental health issues more probable. In HSIP Taiwan, one of the largest disasters in the country involved improper dumping of toxic waste, which contaminated two major water systems used for Taiwan's second largest city (Chang et al., 2001). In the Cabinet report, it was stated that Taiwan's waste treatment capacity was insufficient to manage the quantity of hazardous waste produced (Chang et al., 2001). In the case of Nankan Creek, where 3 000 tons of waste water was discharged per day, the EIA committee was discouraged by the central government from determining the environmental carrying capacity (Chang et al., 2006).

While willingness for better regulation may remain a national issue, the international directives of RoHS and WEEE can create pressure on PC industries in emerging and developing countries. The legislations do not solely target companies within the EU, but also the access of PC products to EU markets. Around 70% of China's electronics exports to the EU are within the scope of the RoHS directive. If China is unable to meet the requirements of the directives, there is a risk exports will drop by 30–50% (Hicks et al., 2005). This indicates how better practices can extend across a supply chain, if, legislation targets market factors for the final PC product. Consequently, sections of the PC supply chain will depend on abiding by regulations in order to access markets in the EU. Such legislation has contributed to the development of domestic legislation in Asia-Pacific. Numerous countries in Asia have domestic legislations for better occupational health and to transition informal recycling efforts to formal recycling centres.

Even if political willingness to regulate production does exist, the ability of governments to do so is another issue. India has legislated directives to prevent workers' exposure to hazards, but its implementation remains ineffective. Industrial policies, such as the Factories Act in India, require employees to be informed in their local language of the chemicals being used. Yet, material safety data sheets are unavailable, and workers are unaware of their risks (Pandita, 2006).

A pilot program introduced by the National Development and Reform Commission of China hopes to determine the most appropriate method for managing e-waste (Hicks et al., 2005). However, such recycling projects have failed to compete with informal recycling, when more money can be earned by selling old and broken PC goods. Without addressing the economic disparity and the lack of local awareness of the health implications of recycling methods, the incentive for informal recycling will likely remain and challenge efforts for safer, formal recycling centres.

A similar case exists in Taiwan's efforts to recycle laptops where manufacturers are required to pay a recycling fee for each domestically sold laptop (Lu et al., 2006). The accumulated payments are then used to pay consumers as an incentive for appropriate disposal, and third party recycling agents. However, these funds are not sufficient to meet operating costs or to invest in new recycling technologies. Furthermore, as there is a strong demand in the second hand electronics market, consumers tend to sell used notebooks rather than recycle (Lu et al., 2006). In their assessment, Lu et al. (2006) found that certain disposal and recycling options at high recycling rates can have greater negative environmental impacts.

6. Conclusion

The issue of health arises at numerous levels and stages of PC production, and requires more extensive research to better develop a globalization and health framework. This paper provides an initial understanding as to how the globalization of industries, in this case the PC industry, relates to health by identifying key linkages. From the location selection of supply chain activities to the waste centres of disposed PCs, the activities of PC industries demonstrate important international linkages to health. With the rapid rate of technological advancement and evolving production processes, the linkages to occupational and environmental health evolve rapidly as well. The global expansion of the supply chain and the protection of intellectual property have limited independent assessments and contributed to ineffective regulation of PC industry activities throughout the supply chain.

Prior sections have indicated where significant gaps exist in research, and what is required to better understand the linkages to health of the global industrial activities of the PC industry. In the field of environmental and occupational health, numerous chemicals used in the PC industry still require research on toxicity and human health impacts. Such research is essential to tie health with industrial activities, and to better direct mandates and efforts at regulatory activities. Additionally, other important questions relevant to SDH remain avenues for future research. How have low wage employment opportunities improved healthcare access or the health status of the local population? How have capital gains from PC industries benefited revenues for the public health system and other social protection investments in developing countries? How have PC global networks affected the distribution of economic benefits within and between countries? Nonetheless, with the rapid evolution of PC technology and production, the adoption of the precautionary principle is relevant, and it is important for the PC industry to take a leading role.

One limitation of this investigation was not assessing the relationship between production outputs to consumption and marketing of PCs. The issue of consumer trends clearly plays an important role in health outcomes in GPNs and especially e-waste generation, with the consumer demand for cheaper PCs driving down profit margins throughout the supply chain and limiting or even decreasing employment wages below the cost of living. Consumption was indicated indirectly through production trends, e-waste rates, and market access. Yet, how consumer trends and the perception of PC companies influence health and working conditions is an important question that needs more research. Undoubtedly, a better understanding of PC consumer trends will require research on the role of marketing by major PC companies, a pivotal link between major brand name PC companies and consumers. While rapid technological advancement and strong competition amongst PC companies have contributed to short PC lifecycles, how marketing by PC companies has contributed to the built-in obsolescence remains to be better understood.

While this report focused on evaluating PC industries, the framework and patterns are likely to occur with other globalized industries. Industries in the electronics sector are most likely to share similar features to the PC sector. The cellular phone industry shares a similar pace of technological advancement, and may have similar health linkages to the PC industry. However, not all electronic products share the same rapid pace of technological advancement. More research on such industries will be needed to determine similarities.

With increased liberalization of global markets comes the opportunity to target new markets. With the reduction in computer costs and emergence of new populous economies, such as India and China, PC companies are directing efforts to penetrate new markets, to reach “the next billion.” The emerging markets provide a new opportunity for Asia-Pacific OBMs to target a market in which they are already operating. Market access is a complex process involving government regulation, foreign companies, and the consumer population. How competition in new markets will enhance domestic wealth in emerging economies is presently unknown. How this can contribute to the distribution of PC wealth is also yet to be determined and will depend a great deal on the redistributive tax and social protection policies of these countries.

The literature suggests that the expansion of PC industries has brought economic benefits to developing and newly industrialized countries. However, the benefits achieved by Mexico, Brazil, Taiwan, and Korea

do not conclusively suggest that increased liberalization (investment and trade with foreign companies) was responsible for those benefits. It is important to note that one of the benefits of liberalization consists of access to economic opportunities. How these economic opportunities are manifested will likely depend on a variety of variables, including location, property costs, domestic capacity, and market access. Many of these variables will depend on national differences, which in part can be regulated and influenced by state activities. Nevertheless, the trend has shown that capital wealth still remains within the initial dominant companies of the US, Europe, and Japan.

The last point raises the issue of where government regulation becomes valuable for economic development. Prior cases have failed to regulate liberalization to develop domestic sectors. Mexico with its national infrastructure plan is an example of an unsuccessful initiative in developing and maintaining domestic PC companies. Part of China's industrial policy has faced challenges through a shortage in trained and skilled labour to facilitate high-tech industrialization. In contrast, Singapore and Taiwan have developed national policies that facilitated the growth of local industries capable of competing in the global free market. The national policies invested to develop education and domestic industries have been a major factor in the selection of Asia-Pacific countries for outsourcing PC production. If effective, the role of national governments can be important in determining how trade liberalization will contribute to domestic economic opportunities and, ultimately, health outcomes.

Nevertheless, government regulations are not the magic bullet to facilitate the benefits of liberalization. With any government policy there will be some losers. In the case of the industrialization policies, incentives for electronics industries and the flow of FDI to urban areas, we see greater rural-urban inequality in income and employment. Furthermore, national policy support for large industries has been detrimental to small medium enterprises. Thus, national policies should not only consider facilitating economic growth, but question how economic growth can facilitate the distribution of wealth. While it is necessary to account for the economic benefits gained from liberalized market access, regulations must find a balancing point where environmental, social, health, and economic gains are optimized.

Determining whether the globalization of PC industries has been beneficial or detrimental for health is a challenging task. The reality of globalization is that health outcomes will be distributed differently based on how economic liberalization interacts with the pre-existing conditions and endowments of a country. Efforts to answer this question should not overshadow the specific health issues of: the working conditions in PC manufacturing in Asia-Pacific; the informal recycling of e-waste; and the exposure to harmful chemicals both during work and from release into the environment. There is significant research detailing such health issues, indicating the need for intervention. With the rapid evolution of PC industries, regulatory systems can be easily overburdened without the greater involvement of PC industries. The most significant strides in international regulations have been undertaken to incorporate extended producer responsibility and the precautionary principle. Nevertheless, targets relevant to PC industries remain heavily skewed towards environmental targets without explicit references to health. While legislation for e-waste and chemical utilization addresses important linkages to occupational and environmental health, explicit references and targets to health would address other important issues such as access to health services for workers and monitoring of exposure in working environments. This objective is unlikely to be reached by legislation targeting final products as with WEEE and RoHS. Rather, regulations would target the production activities of companies directly to ensure labour and health conditions are monitored throughout the international production network, including contracted firms and subsidiaries.

It is apparent that health outcomes are not the sole consequence of local conditions, but of global activities. Through trade and financial liberalization agreements, the increased movement of capital, outsourcing of PC production components, and provision of government incentives to attract investments have contributed significantly to the global distribution of PC industries, and, ultimately, to health outcomes. The impact of global PC industries on health is complex, impacting populations through their occupational health, environmental health, and socio-economic well-being. Additionally, the health issues of PC production should not be limited to the production process itself, but to factors contributing to the distribution of industrial activities (national tax incentives, capital and investment flow) as well as indirect impacts (generation of e-waste).

While gaps in research exist, this study shows a need for a health agenda to extend from a national to an international level, and not to target isolated companies but supply chains as a whole. Present efforts for regulation of PC industries need to connect health with present concerns for the environment and labour conditions, and recognize that health is not an independent local issue but rather a global issue with important links to globalized industries today.

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Appendix

Figure 1: Framework of linkages of PC industry to health outcomes



