East Asian Science, Technology and Society: An International Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/teas20

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To cite this article: Wen-Ling Tu (2021): “Invisible” Pollution? Knowledge Gridlock in Regulatory Science on Electronics Toxics, East Asian Science, Technology and Society: An International Journal, DOI: 10.1080/18752160.2021.1924950

To link to this article: https://doi.org/10.1080/18752160.2021.1924950

Published online: 06 Jul 2021.

East Asian Science, Technology and Society: An International Journal (2021) 0:1–27
DOI 10.1080/18752160.2021.1924950

"Invisible" Pollution?

Knowledge Gridlock in Regulatory Science on Electronics Toxics

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Received: 2 May 2019 / Accepted: 28 April 2021

Abstract "High-tech" provides a cachet of futuristic wonders to localities claiming cutting-edge technological research and industrial innovation. But the high-tech electronic manufacturing processes release hundreds of chemicals and are no doubt ridden with extremely high but hidden environmental health risks. This article aims to increase our understanding of "ignorance" about electronics hazards in the Asian context. It argues that the electronics industries have been under constant innovation, and novel uses of chemicals are introduced to the industrial operation at a much faster pace than the health and environmental assessment can work to comprehend the impacts of the chemicals. In such a context, regulatory science has often failed to effectively monitor and control toxic waste discharges in the high-tech electronics sector. Taking several high-tech pollution disputes in Taiwan as examples, and based on interviews with experts in pollution regulation, this paper discusses multiple constraints on scientific advance in studying toxics that are exacerbated by lagging regulations. These are further entangled with research resource limitations, privileging of high-tech industries in suppressing negative information about toxicity risks, and knowledge repression within the scientific community due to dependence on government and industry, all of which has crippled building knowledge for effective regulatory science–resulting in knowledge gridlock.

Keywords High-tech ▪ electronics toxics ▪ Taiwan ▪ undone science ▪ knowledge production ▪ regulatory science ▪ trade secret ▪ Moore's Law

1 Introduction

Over the past three decades, high-tech electronics product manufacturing and consumption rates have grown exponentially. The Information Technology (IT) industries have played a vital role in driving the world economy. Many developing regions, notably Taiwan, have supported IT industries with public resources to promote

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national economic development. An increasing amount of the assembly of electronic goods has been shifted to large scale integrated contract assembly firms, which have emerged as globalized production networks in the electronics industry (Lüthje 2006). The rapid growth in contract manufacturing, which takes place through a complicated web of subcontractors, is often centered in Asia.

Riding the wave of global IT development, Taiwan has expanded its electronics manufacturing capabilities, beginning from the 1960s, and by 2018 held a global business share in the semiconductor industry valued at 62 USD billion (*E.E. Times*, 15 August, 2018). According to the Industrial Technology Research Institute (ITIR), the output of Taiwan's chip manufacturing and packaging testing segments is foremost in the world, accounting for 70 percent and 50 percent of world market share, respectively (*Central News Agency*, 21 March, 2019). Taiwan's integrated circuit (IC) output value ranked third globally, only behind the US and South Korea, in 2018 (*News Lens*, 14 September, 2018). The electronics manufacturing industry is considered Taiwan's primary strength.

However, behind the economic prosperity, Asian people seldom notice that high-tech manufacturing is a chemical-intensive industry. Early studies in the United States indicated that chemicals used in semiconductor production included reproductive toxins, mutagens, and carcinogens (Mazurek 1999). The studies led to the phasing out of a family of toxic chemicals, which seemed to signal the end of health concerns. Nevertheless, when the electronics manufacturing industry shifted to countries with less costly production, most located in Asia, the knowledge concerning toxicity management and regulation did not make the same journey. According to an investigative report on Korean workers' health disputes carried out by Bloomberg Businessweek, the scientists noted an array of reproductive toxins and environmental hazards in the country's three largest microelectronics plants (Samsung, SK Hynix, LG), and the findings showed significantly elevated miscarriage rates, with a rate for those in their thirties as high as in the US studies decades ago (Simpson 2017).

The environmental and health studies of electronics production have not caught up with the rapid pace of global economic and technological development of the IT industry. Taiwan is an example of a country lacking systematic studies on the ever-changing use of chemicals in the electronics industry and their impacts on human and environmental health. Some research has identified environmental impacts associated with electronics production, including substantial land, water, and air pollution; massive clusters of land developments which have led to resource use conflict and forced the farmers off of their land; and substantial water demand that has exacerbated struggles over water in the high-tech development regions (Chang, Chiu, and Tu 2006; Tu 2007; Tu and Lee 2008, 2009). However, these social analysis studies have not been translated into strong support for regulatory control improvement.

It should be noted that Taiwan has long been characterized as a developmental state. Before lifting the martial law in 1987 and during the authoritarian regime, the central government played a dominant role in resource allocation and promoting industrial development. The people in Taiwan had accumulated dissatisfaction toward the government for its political oppressions and failure in dealing with industrial pollution. The rise of anti-pollution protests in the 1980s thus became a breakthrough point for the people to challenge the authoritarian state, forcing the government to actively respond to social requests for environmental improvement. (Li and Lin 2003: 62–70). The Environmental

Protection Agency (EPA) was then established in 1987 to tackle the environmental issues and set the divisions to deal with air, noise, water, and soil pollution problems with personnel mainly from environmental engineering related backgrounds.[1]

Some studies have argued that the growth of the environmental movement in Taiwan has run parallel to the nation's democratization process (Ho 2006). The lifting of martial law created new political opportunities in Taiwan that led to a dramatic increase of grassroots environmental resistance in the 1990s (Hsiao 1997). However, such an environmental drive did not lead to a significant organized force to challenge IT development for its environmentally negative impact. Tu (2007) argued that the power of conventional environmental mobilization has been lost in the IT development context because the imperative of IT growth has dramatically changed social, political and economic dynamics at the local level. Electronics workers, who are also community members, have been closely attached to the industry. Connections between electronics industries, high-tech job opportunities and high-profile economic development interests won immense public support and environmental campaigns against the electronics industry had less influence in driving change in the toxics regulations and industrial practices (Tu 2008). However, Chiu (2014) noticed that the environmental campaign against electronics pollutions has transformed into a pursuit of just distribution of environmental benefit and risk, and of the right to participate in the decision-making process and the right to recognition after the mid-2000s. Such a transformation has been a way to mobilize more social support to hold high-tech electronics accountable, and to challenge the developmental state to address the policy issues of environment and public health.

Beyond Taiwan, some studies have indicated that the global electronics industry has operated beyond the control of the national governments; and countries and communities, in the role of suitors for IT investment, have failed to demand improved workplace and environmental conditions (Smith et al. 2006). The international campaigns for sustainable electronics often shape the issue as corporate social responsibility (CSR) and call for electronics producers to proactively reduce and eliminate chemical and physical hazards.[2] But this does not seem to be sufficiently persuasive to stem polluting unless there are also consumer campaigns or local protests. However, given the fact that democracy and demands for improved standards of living have advanced in recent decades in much of Asia, even as the electronics industry has grown enormously, developing countries such as Taiwan and South Korea may have no excuse to continue ignoring the high-tech health and environmental impacts of the industry. The question has become critical: What has

[1] Taiwan EPA was established on 22 August 1987, as an agency that encompasses toxic substance management, environmental sanitation, environmental monitoring and inspection. Prior to its official establishment, it had been under the auspices of the Ministry of the Interior before 1971, part of the Department of Environmental Health from 1971 to 1982, and the Environmental Protection Bureau under the Department of Health between 1982 and 1987 (TEPA website). Some have argued that the formation of a cabinet-level EPA was influenced by the vibrant environmental movements aligned with the transition of Taiwan from authoritarian state to democratic state (Hsiao et al. 2015; Ho 2011). Today, TEPA has 920 staff working in seven departments with a total budget more than 4 billion New Taiwanese Dollar (EPA statistic website https://www.epa.gov.tw/Page/10FC53345F1EEB9E).

[2] The International Campaign for Responsible Technology (ICRT) and the Good Electronics Network, 2015. A Challenge to the Global Electronics Industry to Adopt Safer and More Sustainable Products and Practices, and Eliminate Hazardous Chemicals, Exposures and Discharges. https://goodelectronics.org/challenge-to-the-global-electronics-industry/.

impeded the countries with rapid IT development from developing regulatory capacities to control the hazardous substances discharged in the electronics industry?

This paper follows two high-tech environmental controversies in Taiwan, with the aim to explore the knowledge production problems in regulatory science: it has so far failed to properly understand and control the pollution problems surrounding Taiwan's high-tech clusters. Inspired by science, technology, and society (STS) studies, this article focuses on analyzing the obstacles in current scientific research for detecting the hazardous substances discharged by the electronics industry. Referring to IT manufacturing characteristics and the "undone science" discussions (Hess 2007), we have paid special attention to the conditions that restrain knowledge production and the social characteristics of regulatory science in the high-tech development context. The social implications of "problem invisibility" are further elaborated.

1.1 Research Method

This research tracks two environmental disputes associated with the high-tech manufacturing sites, Hsinchu Science Park (HSP) and Lungtan Aspire Technology Park (LATP), to illustrate the limitations of current scientific research in detecting the hazardous substances in the electronics industry. Both are located in northern Taiwan, about an hour's drive south of the capital city, Taipei. The data used in this paper are based on my two previous studies.[3] I followed the first confirmed high-tech pollution water discharge case (LATP at Siaoli River) between 2008 and 2015, and concurrently did a study of the environmental history of Hsinchu City, where the HSP was located, between 2011 and 2013.

This paper discusses environmental disputes around HSP and LATP for several reasons. First, Hsinchu Science Park was the first industrial park established in Taiwan for nurturing high-tech electronics industries, with its inauguration in 1980. With a long history of high-tech development and the highest density of IT manufacturing firms in Taiwan, HSP is a pivotal case for understanding high-tech pollution problems. Second, LATP's Siaoli River dispute provided the first clear evidence of high-tech hazards, in the form of waste water effluent that threatened drinking and irrigation water safety. Despite the clear causal relationship between the electronics manufacturing firms (polluters) and the pollution evidence, the case still underwent an inexplicably extended period of environmental review (2008–2013) within Taiwan's EPA. The episode finally ended in late 2015 when the firms sealed the pipe to stop the wastewater discharge into the river. Third, the pollution studies related to HSP and LATP presented both old and new hazard identification problems around the high-tech industry clusters. These problems, as understood over time, thus provide a more comprehensive insight into environmental knowledge production challenges in the electronics manufacturing and public sectors than would a one-time inspection.

In order to understand the knowledge production system in identifying the risks of electronics hazards and the social characteristics of regulatory science, my

[3] Some findings and analyses of these two studies were written into the book chapters (Tu 2015) and journal articles (Tu and Lee 2011; Tu and Ho 2015) in Chinese.

research team broadly collected and analyzed the data from the scientific reports that study and document the chemical pollutants associated with the HSP. A total of 64 scientific reports, most in the form of master theses, about air and water investigation in the HSP were reviewed. While master theses are considered unpublished research, I did not intend to do detailed analysis of the reports individually in terms of chemical findings. Instead, through reviewing these premature scientific studies, I identified several key experts who had conducted pollution studies in these two high-tech clusters and then developed more precise interview questions with the goal of acquiring their experience in researching high-tech toxics emission problems. Eight in-depth interviews with these experts were conducted in 2012. In this paper, I use accounts from five interviewees (see Table 1) who are from the fields of environmental engineering, water pollution, chemistry, environmental monitoring, and toxicology, and our central concern in reporting on these interviews in this article is the process of production of knowledge, as well as the impediments.

To collect the data of the Siaoli River dispute, my research team investigated the litigation and official documents, including the environmental impacts assessment (EIA) statements, to understand the major obstacles to identifying hazardous substances in the electronics sector. In 2009, I organized a group of students to conduct a broad survey of the communities along the Siaoli River to learn how people responded to the river pollution. Some of the students stayed in the community for a couple of months and have maintained friendships with local residents until today. From 2009 to 2012, my research team intensively attended the EIA meetings related to the dispute and the EPA official consulting meetings for setting standards for high-tech pollutant discharges, which were scheduled in response to the community dispute. Through the meeting observations, we were able to understand how pollutant issues were handled and the obstacles to making or raising environmental standards.

The Siaoli River dispute was basically set aside after the two companies agreed to zero-liquid-discharge for the EIA review in 2013. My research team continued to follow up the news reports and community meetings on river restoration issues until the pipes were finally sealed at the end of 2015. Three focus group discussions were conducted along with the disputes, with the discussion topics ranging from information transparency, decision making in the EIA, to citizen participation, etc. As few discussions referred to the knowledge-building problems in solving pollution disputes, in this paper I only encompass one focus group discussion, which focused on the finding of unusual hazards in the Siaoli river. Other sources for data collection

Table 1 List of interviewees

Interviewee	Position	Research focuses
L	Professor in Chemistry	Chemical analysis
R	Lecture in Environmental Engineering	Pollutant monitoring and analysis
K	Professor in Environmental Engineering	Environmental management
H	Professor in Statistics	Environmental monitoring for Hsinchu Science Park
W	Professor in Environmental Science	Environmental molecular science

include field observations, media reports via online news archives, and government documents on hearings, regulatory actions and environmental inspections.

2 Knowledge Production for Regulatory Science in High-tech Pollution

People have invested countless hours of R&D in the product manufacturing and applications of the electronics industry. Nevertheless, the scientific communities today still have limited knowledge of hazardous substances emission and risk exposure problems in this fast-changing electronics manufacturing sector. According to Joseph LaDou (2006), the founding editor of the International Journal of Occupational and Environmental Health, there is a dearth of studies of industrial hygiene, environmental safety, or occupational disease; and most of these studies are confined to the United States. Given that the manufacture and use of electronics products has rapidly grown and expanded to cover the globe, why do the current scientific studies fail to enhance regulatory capacity in high-tech manufacturing?

2.1 Undone Science and Toxics Ignorance: STS Perspectives

The science, technology, and society (STS) research that has emphasized scientific knowledge construction processes seemed to provide partial answers. This social constructivism approach is particularly concerned with the complex relationship between scientific knowledge production processes and social factors. Such studies indicated that scientific knowledge is often not as rational and objective as claimed by the technocrats during public decision-making processes. The hidden individual, professional, and institutional biases can affect knowledge dissemination and production (Ascher, Steelman, and Healy 2010). Some studies reminded us that society has tended to focus on productivity advantages, which may obscure our understanding of risks (Beck [1992] 2003). As Hess (2007) argued, under the fast pace of globalization, scientific autonomy is deeply influenced by the logic of capital funding, which often support the spending in R&D for commercial application while suppressing the science for regulatory actions that may impede the rapid industrial development. In the cases of toxic identification, some studies have indicated that the industrial sectors often use “manufacturing uncertainty” and “junk science” strategies to delay or eliminate regulatory actions. There are substantial lobbies from the industrial funders, who stress the impossibility of using science to confirm the relationships of causality between industrial hazards and health risks, resulting in the belated response to mounting incontrovertible evidence (Michaels and Monforton 2005; Michaels 2008).

Hess (2007) subsequently developed the “undone science” concept, which discussed the subject of systematic knowledge *nonproduction* by the scientific and academic communities. He believed that the mainstream scientific agenda is deeply affected by the values of industrial innovation and competition. While studies related to environmental sustainability are critical for the long-term welfare of the planet, they have been allocated very limited resources. Frickel et al. (2010) define “undone science” as “areas of research identified by social movements or civil society organizations as having potentially broad social benefit, but are left unfunded, incomplete, or generally ignored" (445). Citing the "chlorine sunset" controversy as an example, they argue that undone science has hindered the country from controlling hazardous substances, as the regulatory agencies have never completed the systematic scientific study of the identification of unsafe chlorine compounds.

The controversies in identifying the scientific dangers of fluorinated compounds also shared similar stories to the chlorine case. By reviewing the sixty-year history of scientific controversy on the environmental and health impacts of the most widely studied per-and polyfluorinated alkyl substances (PFASs), Richter, Cordner, and Brown (2018) indicated that the case demonstrated how "undone science is better conceived as 'unseen science,' research conducted but never shared outside of institutional boundaries" (705). Although lay and regulatory knowledge production around the risks of PFASs is growing, the chemical companies intentionally sequestered data that was concerning to make the already-conducted research as invisible as possible, and thus unknowable. As a result, the regulatory action and public awareness about toxic chemicals control has still been limited.

In the PFASs case, the powerful corporation had great influence in the production of scientific ignorance. As the authors noticed, very limited independent or academic research on the health or environmental impacts of PFASs were conducted before the Tennants' litigation. "Corporate proprietary trade secrets on in-use chemicals, the legally unregulated status of PFOA, and a lack of institutionally mandated impact oriented science" (Richter, Cordner, and Brown 2018: 702–703) were all factors contributing to the knowledge desert of the exposure, health, and epidemiology related to a chemical like PFOA. Their research reminds us to pay attention to the hidden bias of institutional structures and regulatory frameworks, which "privileges industry incentives for rapid market entry and trade secret protection over substantive public health protection" (691).

Boudia et al. (2018) adopt a STS perspective to analyze the chemicals as residues and the limitations of current environmental science. They argue that the chemicals often interact with each other and the environment in complicated ways. Such interactions "pose problems for environmental protection laws, which regulate exposures substance-by-substance, task-by-task, and medium-by-medium" (169). This kind of "hyper-segmentation" presented in the law and scholarship cannot correspond to how chemicals behave and are transformed in the real environment. The systems of regulatory knowledge-making thus produce ignorance, which impedes people's capacity to perceive the chemical harms. In this sense, the identification of "undone science" and "ignorance" is in fact part of a broader knowledge politics, wherein various competing groups and interests constantly struggle over the construction and implementation of alternative research agendas.

McGoey (2019) further invited us to think about a complex web of ignorance practices in the processes of political and economic domination. She revealed how ignorance can be more than just an absence of knowledge, as the powerful actors may selectively engage with deliberately unknown as a political practice for economic gains and strategically minimize their responsibility to others. In her words, "non-disclosure is tactically deployed to avoid the repercussions of inconvenient evidence" (2). Emphasizing how knowledge and ignorance can be mobilized for political achievement, McGoey (2019) reminded us to consider "strategic ignorance" or "ignorance alibi" as "a tool of class domination and corporate power, rather simply as individual acts of ignoring divorced from wider economic contexts" (118). In her studies, the individuals were often driven by their fear of having a fight with corporations over leaking commercial secrets (284). Silencing people to reveal the concerns makes things much less perceptible or much less challengeable. Secrecy hides and strategic ignorance creates, as she stated, "constructing plausible rationales for why problems should not exist, and therefore do not require closer investigation or penalization" (293). Her insights help us to situate ignorance in the political and economic power dynamics where knowledge production, government regulations and corporate accountability are at play.

The above studies have deconstructed the myths of scientific neutrality, challenged the general concept that science must isolate the external factors in order to create reliable knowledge, and raised questions regarding the political roles of the experts in traditional decision-making processes. The analysis of undone science and limitations of environmental science further lead us to delve into the complications of knowledge production, application, and dissemination, which are embedded in a broader institutional arrangement and network. These perspectives have spurred us to more keenly observe the role of the institutional factors that interlock with political, legal and commercial considerations in the shaping of scientific research and knowledge applications. However, even such analysis appears incomplete in terms of understanding high-tech environmental knowledge-production. To comprehend the knowledge production of the environmental regulatory science in the electronics industry, we cannot ignore the characteristics of high-tech electronics development, which deeply influences production of chemical hazards in the industry.

2.2 The Electronics Pollution Characteristics and Hidden Environmental/ Health Impacts

The development of the electronics industry is different from other manufacturing in terms of its unprecedented speed of advance. Driven by so-called Moore's Law (proposed in 1965 by Intel's co-founder Gordon E. Moore),[4] which observed that smaller and faster chip capacity doubled every two years, electronics production processes are often characterized by continuous innovations, flexible global production networks, and sudden developments (Smith, Sonnenfeld, and Pellow 2006). Rapid technological innovation catalyzed by business competition and just-in-time manufacturing shorten the production cycle as well as the life spans of electronics products.

Unlike other major industries such as petrochemical and steel where stable output is often set as the top goal for any given production line, the high-tech electronics industry is under constant pressure to change existing manufacturing procedures to increase number of products manufactured, reduce costs of device manufacture, and make the products perform better.

[4] It is important to note that Moore's law was an empirical observation, and is not analogous to laws of motion in natural science. Gordon Moore made this observation in 1965, when the integrated circuit was still in its early development stage and had barely found its way out of the laboratory (Ceruzzi 2005). Thanks for the editor's comment, which reminds us that the "Law" in itself "is nothing but an observation by an IT executive of industrial trends before 1965 and his speculation that things will go on like this indefinitely."

It is then understandable that production engineers in the electronics industry are compelled to keep trying new formulas of chemicals for etching, cleaning, and other uses. Many new chemicals or new mixtures of chemicals that were hitherto never used in large quantity have been introduced to the production lines of the electronics manufacturing sectors. Some studies have already identified that IT production requires the use of numerous synthetic chemicals such as mercury, brominated flame retardants, trichlorethylene, toluene, and other toxic organic solvents (Williams, Ayres, and Heller 2002). The manufacturing processes release hundreds of chemicals and have often poisoned their workers (Byster and Smith 2006; Scipper and de Haan 2005). The well-known cases in Taiwan include the sudden deaths of young female electronic workers in Philco-Ford in the 1970s (Arrigo 1985) and the recent RCA workers' toxic tort class action against their employer and its parent companies (Jobin, Chen, and Lin 2018; Lin 2018). Some studies documented the water, air, and land pollution problems around high-tech clusters in Taiwan (Lin, Panchangam, and Lo 2009; Tu 2008).

The chemical substances used in and released from the electronics manufacturing industry are voluminous and novel. Given Moore's Law, it is often futile to try to review the thousands of chemicals introduced within a short period. The high-tech hazards are apparently somehow regulated yet unruly. Given that global competitiveness increases and the pace of change quickens, adequate toxicological assessment of chemicals almost never proceeds in advance of their introduction into manufacturing settings, as former IBM medical director Dr. Myron Harrison commented (Byster and Smith 2006: 207). Earlier studies also indicated that potential risks of chemical compounds released by the manufacturing processes have been poorly understood (Mazurek 1999). The pollution facts cannot be scientifically approved in time and the problems are concealed.

The health and ecological footprints of the global electronics industry thus remain largely hidden from the public today. Some studies further argue that the dearth of the environmental and health research can be attributed to the powerful electronics industry's influence in downplaying the health impacts of chemical exposures in the industry (LaDou 2006). Tu (2008) reviewed the characteristics of IT development in Taiwan and argued that the challenges to environmental governance are rooted in the "IT-dominant structure according to which the state is in favor of IT promotions and the capacity to govern the environment is consequently weakened" (109). In such a context, the environmental legislation, regulation, and implementation have been set aside to shield the electronics sector from being environmentally responsible, and the governing entities have acted as defenders for the IT companies. The media coverage, in the fear of losing advertisement support from the IT sector, has often celebrated the clean and positive image of the electronics industry and diverted public attention away from its negative socio-environmental consequences (118).

The above studies provide us with some understandings of chemical use characteristics in the electronics industry and their environmental risk implication, as well as the powerful influence of the electronics sector in downplaying the toxic exposure impacts. However, these studies do not depict the obstacles that the scientific communities face in breaking through the knowledge barriers concerning the large number of "unknown" chemicals/hazards. In particular, how can we judge when the science is undone when the problems are unknown? How do scientists perceive limitations of regulatory science for environmental hazards of the high-tech? Are they lacking the prerequisites of knowing to obtain knowledge of hazards, because of high-tech constantly changing manufacturing processes? Or are they lacking willingness to know, because of social, economic, political and institutional constraints?

In this article, I contend that the scientific community in Taiwan has a very limited ability to provide scientific evidence of attribution related to high-tech manufacturing pollution. Below, I first discuss two high-tech pollution controversies in Taiwan, the Keya River pollution disputes, related to wastewater apparently discharged by the Hsinchu Scientific Park (HSP), and the Siaoli River pollution disputes, which were clearly linked to high-tech production pollution by the Lungtan Aspire Technology Park (LATP) but which met with no governmental regulatory actions to stop the pollution. These cases allow us to explore the ineffectiveness of regulatory science in identifying hazardous substances discharged by the industry. I will then examine environmental knowledge-making problems in the scientific community to understand the intertwining of institutional and electronics pollution characteristics that restrain knowledge production in the sector.

3 Research Limitations in Identifying High-tech Pollution Problems

3.1 Keya River Pollution and Hsiangshan Oyster Contamination: Is HSP the Major Pollution Contributor?

The Keya River, the second largest river in the City of Hsinchu, absorbs wastewaters discharged by the HSP's high-tech industry (185,000 cubic meters per day (CMD) compared to the river's own water flow of 106,000 CMD), households, and traditional industry, and eventually flows into the Hsiangshan coastal wetland. In 1997, a journalist revealed a case of suspected pollution-induced sex change in *Thais Clavigera* (a species of predatory sea snail) in the Hsinchu Hsiangshan coastal region (*China Times*, 31 May, 2011). Academic experts also issued a heavy metal contamination warning for the farmed oysters of Hsiangshan (Chiou 1999; Wang 2001). In a paper published by the British journal *Environmental Pollution*, Han et al. (2000) alleged that the oysters of the Hsiangshan region were contaminated with heavy metals. After the media broke the news, Hsinchu's oysters became unmarketable. The scholars publicly apologized for the report and some politicians swallowed raw oysters to show their support for the oyster farmers. The government took no further action to clarify pollution sources or the attribution of responsibility. In 2006, the Fisheries Department publicly confirmed that the 200 hectares of oyster farms along the Hsiangshan region were indeed contaminated with heavy metals and requested the oyster farmers to abandon their farms and change their professions (*China Times*, 10 May, 2006).

To clarify the links between the HSP and the oyster contamination, this study reviews some post-2002 studies related to heavy metal contamination in farmed oysters at several major river outlets along the Hsiangshan region. For example, Chen (2004: 30) indicated that "the concentration levels for arsenic, copper, nickel, zinc, tungsten, and indium have increased over three-fold after the HSP wastewater discharge into the Keya River began. Among them, copper and tungsten have increased over 10 times." The results showed that the Hsinchu Science Park has contributed most of the copper and tungsten pollution in the middle and lower streams of the Keya River. Chang's (2004: 6) research also found that, "the water and sediment samples collected by the testing station located downstream of the emission point indicated higher levels of heavy metals such as arsenic and nickel, which are the primary pollutants emitted by the semiconductor industry and have clearly come from the Hsinchu Science Park."

Hsu et al. (2011: 197) stated that tungsten concentrations observed in the Keya River "reached about 300 micrograms per liter (ug/L), up to nearly four orders of magnitude higher than the average world river concentration (0.03–0.1 ug/L)" (200). The annual discharge of the dissolved tungsten from this mere 24-kilometer-long river was estimated to be 300 mg/m^3 × (80 × 106) m^3/yr. The study highlights the fact that the Keya River can supply a considerable quantity of tungsten (i.e. 23.5 tons per year) into the adjacent ocean, as high as that by a large river, such as the Yangtze, if its dissolved tungsten concentration is similar to that of the global river average (200). They further investigated tungsten and 14 other heavy metals (such as cadmium, tin, and gallium) in a stream receiving treated effluents from HSP. By cross-referencing samples of metals such as tungsten, silver, and copper used by the semiconductor industry from different time periods (before 1992 when the Hsinchu Science Park had not been fully developed, and after 1992) and by studying spatial distribution of particulate concentrations of the heavy metals measured, this study concluded that the semiconductor industry has had a significant impact on the marine ecology of the Hsiangshan region, such as the pollution-induced sex change of snails and the drop in the reproductive rate of marine life.

However, scientific studies have not reached a consistent conclusion regarding the connection between the heavy metal contamination of oysters and the HSP wastewater. For example, Wu (2005) speculated that although oysters have been severely contaminated by copper and arsenic, the main source of the pollution did not come from the HSP because water samples collected from the HSP wastewater discharge point showed copper and arsenic concentration levels lower than those collected from the household effluent points downstream. Tsai (2007: 49) believed that "these heavy metals most likely came from the HSP and factories at the Hsiangshan industrial district." An expert in chemistry told us that farmed oyster experiments conducted at different river outlets showed that the Sansinggong River[5] that flows through the Hsiangshan Industrial Zone had contributed more pollution to the Hsiangshan coast than had the Keya River (Interview L, 17 July 2012, Taipei).

By summarizing only some of the studies, we already saw that these scientific studies have yielded contradictory views on "who" is the real contributor to the Hsiangshan oyster contamination. It should be noted that the environmental records for Keya River are all in compliance with regulatory standards, based on the Taiwan EPA's records of its "National Environmental Quality Monitoring Network." Under the "Soil and Groundwater Pollution Remediation Network," the record showed a few contaminated sites in the HSP, which are not considered severe compared to

[5] Sansinggong River is 7.5-kilometers-long, stemming from Zhudong Hill (east of Hsinchu) and flowing into Hsinchu Plain. Its downstream flows through Hsiangshan Industrial district and eventually merges into Keya River at the northern part of the Hsiangshan wetland.

that of the nearby Hsiangshan Industrial Zone, which is occupied by traditional industries. There was also no serious air pollution incident in the official records.

3.2 Siaoli River Disputes: Known Pollution Sources, Unavailable Risk Information

In contrast to the Hsiangshan oyster incident, it is crystal clear who is accountable for the Siaoli River pollution incident in the Hsinpu Township of Hsinchu County. Siaoli River is 16 kilometers long and flows from Longtan Township of Taoyuan County. Its midstream flows into Hsinchu County, where it eventually merges into the Fongshan River. At the downstream point where the Siaoli River intersects with the Fongshan River, a tap water intake point has been constructed to provide drinking water for thirty thousand people of the Hsinpu Township. However, two flat panel/TFT-LCD Manufacturers, AU Optronics (AUO) and Chunghwa Picture Tubes (CPT), established large-scale facilities and started to operate their businesses in the LATP, in upstream Siaoli River, in 2001. Beginning at that time, these two firms discharged over thirty thousand tons of wastewater directly into the Siaoli River per day and significantly affected the drinking and irrigation water quality for the local residents. The local residents filed numerous administrative complaints to the local environmental protection bureau regarding the wastewater pollution problems. However, the pollution problems did not officially surface until media exposure in 2008 (Tu and Lee 2010).

Unlike the Keya River's multi-source wastewater pollution problems, Siaoli River had long been classified by the government as one of the very few rivers having "A" grade water quality. Although the local environmental protection bureau alleged that Siaoli's water quality complied with effluent standards, reports issued by the Hsinchu Irrigation Association indicated that conductivity, chloride, sulfate, ammonia, and sodium adsorption rates all violated the irrigation water quality standards (Hsinchu Irrigation Association 2008). The scientific survey conducted by Tsinghua University in 2007 also specified that fluoride and phosphate ions (byproducts from the wafer cleaning, photoresist, and etching processes) as well as indium and tungsten ions (from the LCD display transparent electrode grinding and single-wafer cleaning procedures) were detected in the soil at a site downstream from the discharge point.[6] The local resident who initiated the anti-wastewater discharge campaign stated that in the EPA's health assessment meeting on the groundwater usage along the Siaoli River, the EPA officer admitted that "the evidence suggests that the water quality of streams nearby areas of industrial discharge is dangerously poor, despite its transparent or clean appearance" (fieldnote, 27 March 2009, Taipei).

The chemical expert who disagreed that the oyster contamination of Hsiangshan should be attributed to the Hsinchu Science Park has conceded that the high-tech optoelectronics industry is the main cause of pollution in the Siaoli River. He said: "The Siaoli River case is clear. Nothing else goes in and out of that water. Our survey

[6] This unpublished survey (the Longtan Sanhe Village Farmland Effluent Path Soil Sediment Sampling Survey Report, 2007) was conducted at the local group's request to understand the relationship between soil pollution along the Siaoli River and high-tech wastewater discharge (fieldnote, 26 February 2008, Taipei).

results show that the farther the downstream, the less the organisms” (Interview L, 17 July 2012). In October of 2012, a project report issued by the Environmental Protection Administration (EPA) in response to the Legislative Yuan showed that the water and farmland sediment samples collected in the Siaoli River region in 2011 were showing signs of salinization and that the trace element of molybdenum found in underground water was approaching limits set by the 2010 drinking water quality standards.

Although evidence of the wastewater pollution in Siaoli River by the optoelectronics industry is clear, questions such as what are the specific pollutants, what are the impacts of hazards to the environment and health, and whether the current environmental science can fully comprehend all substances used and released by the two firms remains quite controversial. After the EPA detected levels of rare heavy metals in the wells along the Siaoli River, it revised the drinking water and optoelectronics wastewater control standards by adding indium, gallium, and molybdenum to the list of controlled substances and enforcing restrictions on levels of total toxic organics (TTO) and the degree of acute organism toxicity (TUa) for the optoelectronics industry. However, the added standards were not set high or comprehensive enough to demand significant change in the industries.

If the local residents had not made this pollution a public issue by filing a lawsuit against the manufacturers for violation of public safety and appealing to the Taiwanese Control Yuan, which finally proposed corrective measures to the Executive Yuan for improvement, the pollution problems would still be unknown to the public today. The official monitoring records simply showed no violation of the national effluent standards. The citizens had persisted since 2007 in their uphill battle to demand that AUO and CPT stop their wastewater discharge into the Siaoli River. In the entire course of the disputes, the citizens’ efforts to acquire information on chemical contaminants found in the river as well as the drinking and irrigation water quality were frustrated. They simply could not get any meaningful data to understand what hazards were found in the river, despite the fact that the firms were required to do the soil and groundwater monitoring around the river and submit the data to the EPA.

The campaign against the Siaoli River pollution lasted over six years because both the public agencies and the high-tech firms claimed there was no scientific evidence to prove violation of environmental regulations. However, with significant pressure from the citizen groups, the AUO finally announced its “zero liquid discharge solution” in 2013 as a voluntary corporate proposal to resolve the wastewater discharge disputes (Tu 2017). On 30 December 2015, AUO and CPT finally held a pipe sealing ceremony to fulfill their zero-liquid-discharge promise.

For both cases, we observed the difficulty in making the link between the pollutants detected and environmental violations by high-tech electronics firms. The identification and impacts of hazards still remains at the debate phase, which makes high-tech pollution oversight by civil groups even more difficult. Moreover, the information disclosure seemed to be problematic both for scientific communities and for public officials under public scrutiny.

4 Multiple Constraints in Making High-tech Hazards Visible

In this section, I provide more detailed analysis of knowledge gridlock in revealing environmental hazards in the electronics manufacturing industry. Inspired by the STS "undone science" research concept and high-tech environmental studies, I pay special attention to institutional factors, such as the lagging regulations, which are also entangled with resource allocation problems. The distinct features of the electronics industry that lead to continual introduction of large numbers of new mixtures of chemicals and that seemingly intend to conceal pollution information are further examined. Moreover, I explore the appearance of "unknowns"[7] in the scientific community to understand challenges in identifying high-tech hazards.

(1) Entangled Regulations, Funding, and Knowledge Generation: Institutional Constraints

Cranor (2005) noted that the scientific and regulatory communities start way behind in the race to understand and control toxic substances. Today, scientists appear to know little about the effects on health and environmental safety for the hundred thousand substances or their derivatives that are in common use. Long-term effects of environmental or human exposure to a substance are less well known than short-term adverse effects; and there are asymmetries in what is known about the benefits (more is known) and risks (less) of products. Asymmetries in scientific methodologies also tend to prevent false positives results in studies rather than to prevent false negatives, which reinforces lax post-market statutes, because the threshold for a positive result in testing toxicity is very high (Cranor 2005: 32–33). It is then understandable that the advances of regulations are often far behind the rapid transformation of industrial production.

As a latecomer in high-tech industrial development, Taiwan has paid even less attention to upgrading its legal infrastructure to manage high-tech electronics hazards. An environmental scientist said that to conduct regulatory science for the emerging pollutants effectively, i.e. in order to decide whether to invest limited resources into the research, we need to know what substances are used by the industry before determining what risks these substances pose. But Taiwan's government has invested little in high-tech pollution research (compared to what the government has invested in IT product manufacturing and applications) and does not produce or integrate this kind of information. As a result, such risk information as can be acted on is mostly based on international research or regulatory data. The water pollution expert said,

> I do not have a team to constantly assess health risks of emerging chemicals. No one is doing related research domestically and we are dependent on foreign

[7] Here, I borrow the "unknowns" concept from Gross (2007: 751), who distinguished four categories of knowledge: (1) Ignorance: all fields of knowledge inevitably face knowledge limitations in a certain area, and this increases with every state of new knowledge; (2) non-knowledge: knowledge about what is not known but taken into account for future planning; (3) negative knowledge: considered as unimportant or even dangerous, such unknowns are caused by the suppression of knowledge production despite knowing that the knowledge does exist; and (4) extended knowledge: a method/plan to research non-knowledge and enter the process of gaining knowledge.

> data. Taiwan would only take notice after foreign studies have conducted research for five or ten years and published the results or even found problems and controlled the substance through international regulations. We are very passive domestically. . .. (Interview R, 13 September 2012)

However, due to the division of labor in the global electronics industry, the products and chemical use in the manufacturing processes are more different than similar in different high-tech regions of the world. It is then hard to directly apply foreign data in making regulations. Domestically, chemical hazards in the electronics industry often meet with the dilemma of being unrecognized under the current regulations or national standards.

The lagging regulations have more policy implications, as they indirectly draw the boundary of regulatory science and limit academia's willingness to investigate high-tech pollution. A professor of environmental engineering said that unregulated matters would be generally ignored by the regulatory agency and by academia:

> Because Taiwan is a country ruled by law, if there is no regulation, there is no violation. As long as there is no legal requirement, no officials would take the matter seriously. . . . Therefore, no regulation equates no action. . . . This is also a drawback for academia. Of course, someone will still do the research, but people would focus on the official concerns. (Interview K, 26 April 2012)

The regulations provide legitimacy for the regulatory agencies to set the policy research agenda and allocate research funding. The scholars are more motivated to study the legally regulated items because of the accessibility of funding. In Taiwan, the electronics toxics studies are often contracted by the government or high-tech firms for legal compliance purposes. But due to lagging regulations, studies conducted according to the laws in current operation are often unable to respond to the full range of health or environmental risk concerns. For example, inorganic suspended particles can provide more indicators to track high-tech pollution. But there are far more studies investigating volatile organic compounds (VOCs) than those studying inorganic suspended particles because of the regulatory stipulations. A professor researching toxics substances in the HSP said:

> Domestically, relatively more laboratories can analyze VOCs (than those that can analyze inorganic suspended particles). . . . Most of the EPA projects focused on VOCs. The professors' research agendas would of course follow the EPA projects. I would only conduct a research project if there is a contracted project. Few people would conduct research without funded projects. It would be easier for a new professor to establish a laboratory by going 'organic.' Everybody is doing it, so more data is piled up. In contrast, there are very few 'inorganic' related research projects being conducted. (Interview K, 26 April 2012)

An environmental scientist who analyzed pollutants in wastewater from high-tech parks further addressed the issue that legal compliance cannot ensure risk-free wastewater discharge:

> All of the plants would tell you that their wastewater discharge complies with the effluent standards. This is the official statement. Then everything would be okay and their statement would not be challenged. Why? Because they have done everything required by the regulations . . . (However) just because everything conforms with regulations at the time does not mean their discharges contain no harmful substances. (Interview R, 13 September 2012)

Because the regulations provide the legitimacy that is needed both for gaining a budget for environmental studies and for acquiring information that is often unavailable outside of the industry, the regulations create a narrow path of dependency for most pollution studies in high-tech manufacturing areas. However, inadequate environmental regulations have paradoxically rendered pollution studies almost useless in hazard exposure concerns. Such as in the case of the Siaoli River disputes, the environmental agency claimed that most records of the two high-tech firms met effluent standards, with only few disconformities (Tu and Lee 2009).

(2) Pollution Information Concealment Strategies in the Electronics Industry

My research echoes Cranor's finding that the regulatory and scientific communities are slow to respond to the adverse effects of chemical exposure, as they are handicapped by lack of resources, the slow pace of scientific data generation, and conventions of scientific epistemology. But my fieldwork further highlights that the slow generation of scientific epistemology is highly related to the pollution information concealment tendency in the electronics industry.

4.1 Gaining Funding in Exchange for Research Data Confidentiality

As discussed, funding sources are often in a close relationship with the legal authority, and the regulatory agency as well as the electronics manufacturers are the major sources of funding for environmental research of the industry, mainly for legal compliance purposes. For the environmental scientists, gaining the contracts for the research projects, whether from manufacturers or governments, is a matter of not only funding but also of insider information. However, even if there is an opportunity to gain insider information through the research projects, the funders often try to restrict the scientists from disclosing the research outcomes. If the funding comes from manufacturers, they would explicitly demand of researchers that "no research results can be published domestically or internationally" (Interview R, 13 September 2012). The manufacturers often request signed confidentiality contracts to ensure that the researcher "cannot mention the company's name and some details . . . the researchers may be allowed to mention how high is the quantity of certain substances being found, but cannot mention the concentration levels" (Interview R, 13 September 2012). This water pollution expert indicated that the manufacturers generally request the results of the commissioned projects be concealed because "it would just be asking for trouble" (Interview R, 13 September 2012).

What if the funding came from a public agency? The environmental engineer stated that:

> It takes money to conduct this type of research. It is quite impossible to get this kind of research fund from a science park. If the funding came from the EPA or the EPD, then you may disclose research findings upon their approval. If they forbid it, then you simply cannot disclose the findings. (Interview K, 26 April 2012)

In other words, the price of the “trade-off” to obtain the research budgets is often to let the research remain “undisclosed.” This forces the various high-tech environmental improvement efforts and discussions to remain within a closed community. The conditions of knowledge production for regulatory science force a researcher to choose between whether to extend his/her own knowledge by accepting the “undisclosed” trade-off or to stay in a “knowing there is a problem but cannot confirm it (non-knowledge)” state by rejecting the confidentiality requirements.

4.2 Trade Secrets

The incompleteness of knowledge on chemicals and their adverse effects on health and the environment in the rapidly changing electronics industry is further crippled by the issue of “trade secrets” claimed by the industrial sector.[8] The environmental scientist, who conducted “emerging contaminates” research, said that he found numerous new and previously unknown pollutants in the rivers, which all receive high-tech wastewater discharge in the Hsinchu area. Suspecting that pollutants are from the photo lithography processing of electronics production, he tried to search the substances used in the electronics manufacturing process. But citing trade secrets and patent constraints, the manufacturers can refuse to admit that they used the substances even if he found them in the emission data.

> The high-tech manufacturers would not tell you what substances they use. Even if they do tell you, the information would be considered a trade secret. This is an often-encountered problem. (Interview R, 13 September 2012)

The manufacturers’ refusal to disclose the chemical substance and emission data on the ground of “trade secrets” indirectly increases the difficulty in learning about problems. An environmental monitoring expert discussed a similar information concealment trick he had experienced during several years of the HSP environmental oversight process:

> Trade secrets means that they generally would not publicly disclose the type of rare metal they used for the production process. The problem arises when the environment is being polluted by this rare metal, yet you cannot know what

[8] Although there is the Freedom of Government Information Law that aims to protect people’s right to know, some environmental information has been restricted from being made available to the public if it is involved in trade secret concerns. In Article 18, it states that “Making available to the public or provision of the information about trade secrets or business operations of a person, legal person or group will hamper the right, competitive position or just interests of such person, legal person or group, except where it is necessary for public interest, protects people’s life, body, health, or is consented by the person concerned.” (EPA law website: https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=I0020026). As “public interest” is hard to define, there are disputes about confidentiality for scientific research it commissions as demonstrated in this case study.

> this rare metal is . . .. Even if you can detect this rare metal (in water or air), you may not know where it came from. (Interview H, 21 June 2012)

Without a more comprehensive understanding of chemical use in the industry, it becomes extremely difficult to determine what types of pollutants to test for. An environmental engineering scientist stated:

> You will have to guess what to detect. This is annoying because there is nothing to compare the findings with. Many studies are doing fingerprinting, but they do not even know where or how to fingerprint . . .. Only few known problems are being detected. If a problem is unknown, we would not even know what to test for . . .. (Interview K, 26 April 2012)

In the case of the Siaoli River disputes, we see such a tendency to leave information undisclosed presented by both the regulatory agency and the high-tech manufacturers. The EPA was reluctant to disclose the information concerning the pollutants from the firms and chemical contaminants found in the targeted river. In the entire course of the dispute, the EPA disingenuously declined the local residents' request for pollution information by responding that the water discharged by the two manufacturers had fully complied with the effluent standards. The two firms, claiming no environmental violations, did not make their soil and groundwater monitoring data available to the public even though the local residents won the administrative appeal for the right to information. The case demonstrates how hard the citizens must work to uncover and obtain high-tech pollution information. Moreover, such information concealment has hindered our ability to gain a comprehensive understanding of the full range of high-tech pollution problems. These obstructions have also often made it difficult for related studies to figure out the pollution hot spots (Interview R, 13 September 2012).

(3) Knowledge Generation Issues in the Scientific Community

4.3 Stymied Knowledge/information Flow across Sectors

The ineffectiveness of regulatory science can also be attributed to an obstructed flow of knowledge about the different parts of the manufacturing processes in the electronics industry. As discussed, the manufacturer's commissioning of a project is often the critical opportunity for scientists to understand the substance use of various manufacturing processes; this can help to clarify the causal link between the back-end sampling and the front-end production process. A professor doing HSP pollution research stated that understanding the chemical substances in the manufacturing process is the first step to tracing the pollution sources:

> Different manufacturers use different processes. For example, if you are a semiconductor plant, you will use stuff such as arsenic, boron, or the rare earth elements . . . different processes use different materials. So if we can prove that the material came from a certain plant, we can further conduct calculations using this model. We can then speculate which plant contributed to the pollution and how much pollution went into the air. (Interview W, 26 June 2012)

However, in reality, to acquire information of substance use in different manufacturing processes is very challenging. Very few scientists can master the source of chemicals and their application procedures. The scientist took the example of toxic substance perfluorooctane sulfonate (PFOS), which is a persistent organic pollutant restricted under the European Union and Stockholm Convention. It was detected in both the Keya and Siaoli Rivers. PFOS has one or two hundred precursors, so it is not necessarily effective to regulate the substance using the raw materials list (which is regulated by the Toxic Substance Control Act). Many precursors may also be hidden under patent rights and would not show up in the Material Safety Data Sheet (MSDS). The manufacturers can thus simply declare that the production process does not involve this substance. As a result, researchers can detect PFOS in the water, but cannot discern where the pollutant came from.

This scientist explained how a lack of cross-cutting information/knowledge interactions between chemical applications in production lines and environmental investigation may directly create a knowledge barrier in the regulatory science:

> Unless you know the production personnel well, know what substances they use, and have a strong chemical background, you would not be able to know what the chemical reactions and derivatives of the substances would create. The production personnel only know that the interactions of substances "A" and "B" would create a desirable product. They neither know nor care to find out what derivative pollutants may be generated in the production process. They have backgrounds in electronics, what would you expect them to know about chemical reactions? (Interview R, 13 September 2012)

4.4 Fragmented Research Agenda-setting and Limited Research Capacity

The individual professional experts probably need an overall comprehension of chemical applications, reactions, and releases in the entire manufacturing process in order to understand the high-tech pollution problems. However, the reality is filled with restrictions as most scientific studies/practices focus only on quality control of products and pay less attention to the byproduct from the production process.

> These personnel may know what quantity of certain substances would yield what effects for the product. They would record the outcome for the production purpose, but not the other chemical reaction processes. They know that mixing substances "A" with "B" would create the product "C." However, what will be created is not only product "C," there are also byproducts "D," "E," and "F." They do not know what "D," "E," and "F" are and do not care. Their stance is that they would do what they are regulated to do, and nothing more. (Interview R, 13 September 2012)

The current pollution studies focusing on individual hazardous substances have limitations to providing comprehensive understanding of the ever-changing, increasingly more complex, and more difficult high-tech pollution problems. When the scientists encountered multiple water pollution problems, like those we witnessed in the HSP case, the general public often get fuzzy conclusions from the scientific community. Without a more holistic research strategy, the scientists admitted that they had to depend on luck to investigate the problems. The professor of chemistry shared his experiences in working on "biological testing methods for acute toxicity," which was listed in 2012 as one of the official methods in detecting high-tech hazards:

> We all know that ammonia is toxic to aquatic organisms such as daphnia . . .. We find a lot of ammonia in wastewater. The same ammonia, or ammonium, would be ten times as toxic if its (ammonia) pH level is increased. So as long as pH increases, each toxicity unit amplifies as well. The results are quite substantial. We never knew this before . . .. When we trace back to see which parts of the factories used ammonia the most, the answer may be shocking to everyone . . .. Ammonia water is used during the photo lithography process for etching. The process used and released the so-called TMAH (Tetramethyl Ammonium Hydroxide) that was never detected or regulated . . .. (Interview L, 17 July 2012)

In this case, TMAH that was often used in the production process was deemed acceptable by the regulatory standard in the past. The scientist applied a new method (the biological acute toxicity test) and got new evidence of a linkage between the high-tech production process and the toxicity problems that were unknown in the past. While the fact that such knowledge generation led to reevaluation and regulation of the TMAH is appreciated, it demonstrates that there are still many problems unexplored and therefore unknown in assessing the impact of the emerging chemicals in the electronics industry. Regulatory science needs to be more open to new ways of data collection and research design in order to be more capable of identifying the hazardous substances and understanding how they react in the environment.

Moreover, to make regulatory science effective, it is insufficient to depend on only one or two science labs to work on the problems. One environmental scientist told us that for regulatory science to work smoothly, it would be inadequate for only one or two labs to have the detection and analysis capacities. The research capacity of the overall community must be considered. He addressed that it is necessary to extend the research capacity from a few labs to a whole scientific community.

> The technology must be pervasive. By pervasive, I mean that the government must have this laboratory capacity . . .. Then, the manufacturers must be required to have this capacity . . .. In addition, the independent third-parties must also have this capacity as well. (Interviewee W, 26 June 2012)

In other words, even if the elites inside the scientific community have the capacity to turn the "unknowns" into "known" facts for addressing pollution problems, the scientific community needs to be able to cooperate internally in order for the regulatory science to practically exert its regulatory and protective functions. The environmental engineer presented a comprehensive view:

> (Regulatory science) requires teamwork . . .. First, sample analyses are needed . . .. Monitoring pollution problems in the high-tech park requires more advanced

> professions. Regardless of whether it is arsenic or other contaminants, the amounts are mostly minute. It requires laboratories with adequate capacities to detect trace elements of pollutants. This is the first problem that must be resolved . . .. The second step is data analyses . . .. Then another group of people is needed to conduct risk assessments. In fact, all these three fields are difficult, and are considered quite difficult by academia as well. (Interview K, 26 April 2012)

4.5 Closed and Passive Knowledge Making

As discussed, institutional constraints posed by lagging regulations and resource allocation problems as well as the industry's information concealment have obscured and restricted high-tech electronics pollution studies. However, if these restrictions can be lifted, can we expect that more scientific knowledge generation provides better understandings about the electronics manufacturing pollution and risk problems? The answer is probably not an optimistic one. My study shows that knowledge-making inside the scientific community faces several challenges, including the restricted flow of knowledge concerning different parts of the manufacturing processes and fragmented research agenda-setting that makes full research capacity development and holistic understanding of pollution problems almost impossible. In addition, the environmental scientists in general have tried to avoid getting involved in pollution controversies.

In the HSP oyster contamination dispute mentioned above, the news reports focused on how the research article published in the British journal (Han et al. 2000) caused huge losses to oyster farmers. While the politicians publicly ate raw oysters to demonstrate their trust in the safety of the product, the research itself was discredited as exaggerating the health hazards associated with the high-tech wastewater. The scholars were silenced after making a public apology in a press conference. In the public statement, one of the authors of the article alleged that the media quoted the data out of context and drew the conclusions from the parts (*Environmental Information Center*, 2002). The scholars were further mired in the legal disputes and were called in for questioning by prosecutors (*Commonwealth*, 30 May, 2011). Similar concerns that scientific findings may be exaggerated or misinterpreted were also raised by an interviewee:

> People are afraid that the data would be referenced or abused by someone else. This is what the manufacturers are afraid of the most. We also feel the same way. Out of 100 statistics, one may contain some uncertainties, and such uncertainties may be amplified by others . . .. (Interview L, 17 July 2012)

With the concerns of public scrutiny and "high-tech" reputation protection, the scientists and their research sponsors–either from the government or high-tech firms–are reluctant to, or even in fear of, making their pollution studies public. In other words, the experts, manufacturers, and the government at the core of the regulatory science who conduct or sponsor the research lack a sense of obligation to extend knowledge to a broader research community, and thus they in effect create knowledge repression, or negative knowledge. Furthermore, this hampers the collaborative opportunities for cooperation between the pollution scientists and other stakeholders to innovatively design the research and address the problems.

In the case of the Siaoli River dispute, the local citizen groups invited ichthyologists to set up survey stations along the Siaoli River to search for the cause of ecological damage and pollution. The results of this study indicated that the areas downstream of the CPT and AUO wastewater discharge points were devoid of fish life (*Liberty Times*, 4 November, 2009). The fish population surveys, a low-budget form of environmental monitoring, are not officially recognized as regulatory science. This example demonstrates how those outside the research community, with limited resources, may still strive for changing "known problem but unverifiable knowledge (non-knowledge)" into "extended knowledge." Although such a method does not produce full information about the polluting substances, it can serve as guidelines for official regulatory science to identify pollution hotspots and monitor the environment with a more holistic view, if the bureaucratic and institutional hurdles can be overcome.

5 Conclusion

The results of this study have indicated that environmental and health research in the high-tech electronics field has lagged far behind the rapid course of product development and application. While many high-tech regulatory studies have emerged in the advanced industrial societies, the Asian society with the fastest expansion of high-tech manufacturing has paid little attention to the toxic emission problems of the industry. This paper, taking Taiwan, the "silicon island," as an example, tries to fill in the gap to understand the knowledge gridlock in regulatory science on high-tech pollutants in the Asian context. Through the lens of STS studies and electronics pollution characteristics analysis, this paper identifies the institutional constraints posed by lagging regulations entangled with funding concerns that have impeded knowledge production to effectively address high-tech pollution. Monitoring or research conducted narrowly according to current regulations cannot truly respond to the environmental risks of the industry.

However, the ineffectiveness of regulatory science is not completely shaped by the institutional conditions. Knowledge generation concerning electronics industry hazards is also unable to keep up with the unprecedented speed of production changeover in high-tech electronics. It suffers as well from suppression of negative information. The electronics industry has been under constant innovation. Novel uses of chemicals are introduced to industrial operation at a much faster pace than the health and environmental studies can work to understand the risks. The trade secrets doctrine and tendency toward information concealment has limited access to the risk information to only a few academic labs, the government authorities, and the manufacturers. As a result, only a small number of core researchers can take a glimpse at the essence of high-tech risk problems, and it is not in their personal interests to make these public.

In addition to the institutional constraints and industrial characteristics, I have further examined the knowledge generation issues within the scientific community. While some individual scientists have made breakthroughs in learning about more high-tech toxics, the efforts to advance science do not equate to an effective regulatory control system. I have argued that knowledge making for the regulatory control of high-tech hazards has been set into closed and passive states. The scientists have been concerned about getting mired in political and social disputes that might cost their academic reputations and funding support. Many studies thus are locked in libraries or some encrypted bureaucratic databases rather than made accessible to the public. The nature of such knowledge-making impedes the progress of regulatory science, which needs to develop further knowledge to innovatively and effectively deal with the fast-growing high-tech hazards. The communities that cannot avoid the pollution and risks are often marginalized and traditional-livelihood communities, such as fishermen and farmers. They tend to be short on technical knowledge and are anyway subject to a considerable degree of exclusion, and may still remain ignorant of high-tech pollution and health risks.

We have no reason to be hopeful of finding an easy solution to overcome the multiple constraints on high-tech regulatory science, as discussed in this paper. However, the Siaoli River dispute seems to demonstrate that relentless citizen actions, through finding new ways of data collection (fish population survey and community water usage survey), legal battles, and policy advocacies, have somehow opened new lenses for the regulatory agency or scientific communities to look at and reassess the risks and policies (Tu 2017).[9] The controversies suggest that the improvement of regulatory science won't automatically take place without persistent environmental activism. But we must realize that the current citizen actions are insufficient to overcome the institutional constraints and knowledge generation dilemmas discussed in this paper. The woeful knowledge gap in the face of the high-tech sector it is supposed to regulate remains the threshold for citizens to participate in the relevant decision-making process. If we cannot construct a policy infrastructure to support new citizen initiatives, improvements can only stay at the individual-case level, and cannot significantly enhance the quality and accountability of regulatory science to redress high-tech hazardous pollution problems.

For the infrastructure building, we can further refer to the recommendations of the "Challenge to the Global Electronics Industry" report,[10] which identifies six key areas for change and actions for the electronics sector, including full information disclosure associated with the chemicals used and discharged, substitution of hazardous chemicals, worker, communities and the environment protection, insuring meaningful participation, and compensation and remediation for harm to people and the environment. These changes won't take place with corporate voluntary actions alone. In Asia, such changes would require the government to upgrade the regulatory policies and institutional infrastructures that can support full information transparency and community's right-to-know. The changes would also require the scientific communities to adopt more open and pluralistic approaches to break through the knowledge barriers and extend their knowledge to the outside world to further overcome knowledge gridlock problems. After all, to make such changes

[9] EPA listed gallium, indium and molybdenum as control substances in the "wastewater control requirements for the optoelectronics industry." According to the EPA, Taiwan is the first nation to enforce restrictions on these three substances in wastewater, as well as on levels of total toxic organics (TTO) and the degree of acute organism toxicity (TUa) permissible.

[10] For further information about the report, please refer to the website: https://goodelectronics.org/challenge-to-the-global-electronics-industry/.

requires not only change on the technical level of policy or regulatory support, but also our imagination in pursuing a better quality of democracy in an unavoidably rapid changing electronics world.

Funding

This work was supported by the Ministry of Science and Technology, Taiwan [107-2511-H-004 −005 -MY4].

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