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Global Value Chains in the Electronics Industry

Was the Crisis a Window of Opportunity for Developing Countries?

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Abstract

This paper presents evidence of the importance of electronics global value chains (GVCs) in the global economy, and discusses the effects of the recent economic crisis on the industry. The analysis focuses on how information is exchanged and introduces the concept of "value chain modularity." The authors identify three key firm level actors—lead firms, contract manufacturers, and platform leaders—and discuss their development, or "co-evolution" in the context of global integration. Company, cluster, and country case studies are then presented to illustrate how supplier capabilities in various places have developed in the context of electronics global value chains. The findings identify some of the persistent limits to upgrading experienced by even the most successful firms in the developing world. Four models used by developing country firms to overcome these limitations are presented: (1) global expansion though acquisition of declining brands (emerging multinationals); (2) separation of branded product divisions from contract manufacturing (original design manufacturing (ODM) spinoffs); (3) successful mixing of contract manufacturing and branded products (platform brands) for contractors with customers not in the electronic hardware business; and (4) the founding of factory-less product firms that rely on global value chains for a range of inputs, including production (emerging factory-less start-ups).

This paper—a product of the DFID supported Global Trade and Financial Architecture (GTFA) project—is part of a larger research effort to explore the impact of the crisis on global value chains and developing countries in particular. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at sturgeon@mit.edu and momoko@ide.go.jp.

Global Value Chains in the Electronics Industry: Was the Crisis a Window of Opportunity for Developing Countries?

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Introduction

The electronics hardware industry is the world's most important goods-producing sector. Not only does it employ more workers and generate greater revenue than any other sector, its products also enhance productivity in other activities and stimulate innovation across entire economies (Mann and Kirkegaard 2006). It is what Hirschman (1958) calls a "propulsive sector." Consider the case of the United States, where innovation in electronics hardware, which employed 1,105,900 in 2009, has helped spawn a host of downstream service industries, including the computer systems design services, telecommunications, as well as data processing, hosting, and related information services, which together employed 2,697,200.[1] The heavy use of computers and information technology in other sectors, including retail and wholesale trade, transportation, finance, real estate, education, professional services, and industrial production, make it clear how pervasive the changes made by electronic hardware have been.

The goal of this paper is to delineate the central characteristics of global value chains (GVCs) in the electronics hardware sector, describe how they have evolved to incorporate newly developed and developing countries, and discuss how they have been affected by the 2008–09 economic crisis. As is common GVC analysis, we focus on the key actors in the chain of value-added activities, where various activities are located geographically, and how information and knowledge flow within the chain.

This paper first presents evidence for the importance of electronics GVCs in the global economy, then discusses the effects of the recent economic crisis on the industry. The third section focuses on how information is exchanged in electronics GVCs, introducing the concept of "value chain modularity." The next section identifies three key firm-level actors: lead firms, contract manufacturers, and platform leaders, and discuss their development, or "co-evolution." A series of company, cluster, and country case studies are then presented to illustrate how supplier capabilities in various places have developed in the context of electronics GVCs. The sixth section identifies some of the persistent limits to upgrading experienced by even the most successful firms in the developing world. Four models used by developing country firms to overcome these limitations are then presented: (1) global expansion though acquisition of declining brands (Emerging Multinationals), (2) separation of branded product divisions from contract manufacturing (ODM Spinoffs), (3) successful mixing of contract manufacturing and branded products (platform brands) for contractors with customers not in the electronic hardware business, and (4) the founding of factory-less product firms that rely on GVCs for a range of inputs, including production.

Some of the cases presented here suggest that the 2008–09 economic crisis presented a window of opportunity, in particular, for firms based in Taiwan (China), which represent a key point of transformation in the industry and appear to be gaining more leverage in the industry in

[1] U.S. Bureau of Labor Statistics Current Employment Statistics program, http://www.bls.gov/data/#employment, accessed Janurary 15, 2010.

the wake of the crisis. The conclusion states the case that firms in the developing world will, in one or all of the ways described, soon come to play a more central role in driving the innovative trajectory of the industry by leveraging the full complement resources that have become available in GVCs.

The Electronics Industry's Role in Global Value Chain Formation

Each year, the electronics industry generates a mushrooming array of products and services increasingly used in nearly every human endeavor.[2] Now deeply entwined in our social fabric, electronics products and systems now support critical aspects of communication, education, finance, recreation, and government. Thousands of companies from dozens of countries contribute to the industry on a daily basis. Even a single product can contain work carried out by dozens of firms in multiple countries. Because there is less need for co-location of engineers than in other technology-intensive sectors, such as with the co-location of design with manufacturing, it is relatively easy for electronics firms to engage in the twin strategies of outsourcing and off-shoring. Global sourcing is common. Factories can be relocated with relative ease and produce a wide variety of end products. As a result, GVCs in the electronics industry are more geographically extensive and dynamic than in any other goods-producing sector.

Evidence of the importance of the electronics industry in GVC formation can be found in statistics on intermediate goods trade. Trade in intermediate goods is indicative of GVCs because fragmented production processes require that parts, components, and partially manufactured subassemblies cross borders—sometimes more than once—before finished goods are shipped to final markets (Feenstra 1998; Dean, Fung, and Wang 2007; Brülhart 2008). Table 1 shows the relative importance of various goods-producing industries in GVCs: intermediate electronics and automotive goods dominate total trade in the top-50 manufactured intermediate products (a combined 64.7 percent in 2006). Next important is a group of undifferentiated materials including metal stock (copper, aluminum, and steel), wood, and paper (8.4 percent in 2006), followed by chemicals and plastics, manufactured metal parts, gold and diamonds, aircraft parts, and so on. The share of electronics intermediates (including semiconductors, printed circuit boards, and so on) has grown dramatically since 1988, from 24.4 percent of the top 50 products to 43.3 percent in 2006. The share of automotive intermediates fell from the top spot in 1988 (25.1 percent) to the number two spot in 2006 (21.4 percent). As a result, the growth rate of electronics intermediates was the highest in the top-50 product groupings (13.8 percent per year).

[2] This section draws from Sturgeon and Memedovic (forthcoming).

Table 1 Industries in Manufactured Intermediate Goods in 1988 and 2006 Ranked According to 2006 Total Trade

Industries and product groups in top-50 MIG product list	MIG trade (US$, millions)	1988 Share of top-50 MIG (percent)	Share in total MIG trade (percent)	MIG trade (US$, millions)	2006 Share of top -50 MIG (percent)	Share in total MIG trade (percent)	1988–2006 Annual growth rate (percent)
Electronics	162,980	24.4	8.1	1,670,940	43.3	17.4	13.8
Automotive and motorcycle	167,506	25.1	8.3	824,392	21.4	8.6	9.3
Basic mat. (metal/wood/paper)	116,339	17.4	5.8	325,676	8.4	3.4	5.9
Chemicals and plastics	62,954	9.4	3.1	254,523	6.6	2.7	8.1
Manufactured metal parts	40,328	6.0	2.0	215,085	5.6	2.2	9.7
Gold and diamonds	47,596	7.1	2.4	203,064	5.3	2.1	8.4
Aircraft parts	37,131	5.6	1.8	184,575	4.8	1.9	9.3
Const equip & gen ind mach pts	20,166	3.0	1.0	78,688	2.0	0.8	7.9
Pharmaceuticals	0	0.0	0.0	66,503	1.7	0.7	NA
Propane	0	0.0	0.0	35,946	0.9	0.4	NA
Textiles (and hides)	12,657	1.9	0.6	0	0.0	0.0	NA
Total top-50 MIG	**667,657**	**100.0**	**33.1**	**3,859,393**	**100.0**	**40.3**	**10.2**
Total MIG for three industries							
Electronics MIG total	231,295		11.5	1,942,283		20.3	12.5
Automobiles and motorcycle	212,961		10.6	974,278		10.2	8.8
Apparel and footwear	73,610		3.6	239,866		2.5	6.8
Total MIG for three industries	517,866		25.7	3,156,427		32.9	10.6
Total MIG trade	**2,018,297**		**100.0**	**9,579,710**		**100.0**	9.0

Source: Sturgeon and Memedovic (forthcoming) from UN Comtrade Standard International Trade Classification (SITC) Rev. 1 data. To identify commodities as Consumption, Capital, and Intermediate goods, the conversion table Broad Economic Category (BEC) to SITC Rev. 1 from World Integrated Trade Solution (WITS) was used. In order to calculate constant price data, National Accounts data from United Nations Industrial Development Organization (UNIDO) Statistics Unit and a GDP deflator were applied.
Note: MIG - manufactured intermediate goods.

As the data show, the electronics industry accounts for a growing share of intermediate goods trade and, by extension, of GVC formation. Trade in automotive and motorcycle intermediates is also very important, but strong incentives for local content have undoubtedly dampened their growth. Somewhat surprisingly, given the attention paid to the industry in the GVC literature (for example, Gereffi and Korzeniewicz 1994; Gereffi 1999), intermediate inputs to the apparel industry appear to be far less important in terms of the value of total intermediate goods trade, than inputs to the electronics and passenger vehicle industries.[3] Of course, this probably reflects the low unit value of textiles and other inputs to apparel and footwear relative to inputs to electronics and motor vehicles, as well as the establishment of fiber and fabric production within the world's largest major apparel and footwear production centers, including

[3] In 1988, only two products likely to be inputs to apparel and footwear products appeared in the top 50, bovine hides and skins (SITC 46) and cotton yarn (SITC 48), comprising 1.9 percent of the value of the top 50 and 0.6 percent of total trade in all manufactured intermediates. By 2006 no apparel inputs ranked among the top 50. The four highest ranked apparel inputs in 2006 were knitted and crocheted fabrics (#94), non-woven fabrics (#109 out of 1,600), impregnated (waterproof) fabrics (#129), and parts of footwear (#175).

China, Mexico, and Bangladesh. In fact, the unit value of intermediate goods is likely to have a great effect on the composition of Table 1. For example, while GVCs in the aircraft industry are important drivers of global integration (see Kimura 2007), the high unit value of aircraft parts likely elevates their ranking in the Table 1 gold and diamonds also rank high in the table.

Turning to a comparison of *total* manufactured intermediates, rather than just the top 50, the increasing importance of the electronics industry in GVCs is evident in both absolute and relative terms. The lower portion of Table 1 shows that the share of total manufactured intermediate goods trade accounted for by the electronics industry increased from 11.5 percent in 1988 to 20.3 percent in 2006, and the average annual growth rate of electronics intermediates was the highest (12.5 percent per year) of the three industries most often discussed in the literature on GVCs. Inputs to apparel and footwear accounted for only 3.6 percent of manufactured intermediates in 1988, a share that fell to 2.5 percent in 2006 (see the lower portion of Table 1).

The Shift of Electronics Production to China

In the past 20 years, East Asia in general and China in particular have become increasingly important in electronics as well as other industries, both as production locations and final markets. This is reflected in the flow of intermediate goods. As Table 2 shows, “greater China” (mainland China, Hong Kong, and Taiwan) accounts for 33.1 percent of world imports of intermediate electronics goods and 29.4 percent of exports. Growth since 1988, especially on mainland China, has been extraordinarily high. The tendency for trade to be intra-industry, that is, for countries to specialize in imports and exports in the same industry, is also striking. All 15 countries in Table 2 appear on both the top importer and exporter lists, albeit in slightly different rank order after the top four: China, Hong Kong, the United States, and Singapore. While strong intra-industry trade can be a function of transshipment (for example, importing and exporting materials and parts via Hong Kong and perhaps Singapore), the tendency for specific countries to both import and export intermediate products in the same industry reveals the highly integrated nature of the global economy and, for developing countries, the rich opportunities for industrial upgrading, even when parts imports are high.

Table 2 Top-15 Intermediate Goods Importers and Exporters in the Electronics Industry, 2006

Electronics intermediate importers	US$, millions	% of total	Percentage change 1988–2006	Electronics intermediate exporters	US$, millions	% of total	Percentage change 1991–2006
China	186,294	18.9	15219.0	China	109,433	11.7	21649.1
Hong Kong, China	104,856	10.6	1452.2	Hong Kong, China	101,873	10.9	2580.0
United States	94,466	9.6	194.0	United States	101,807	10.9	179.4
Singapore	73,040	7.4	590.5	Singapore	97,278	10.4	942.2
Germany	51,569	5.2	236.3	Japan	88,994	9.5	160.8
Japan	45,639	4.6	422.5	Taiwan, China	63,824	6.8	834.0
Malaysia	44,695	4.5	466.8	Korea, Rep. of	55,028	5.9	543.2
Taiwan, China	35,899	3.6	405.6	Germany	52,685	5.7	235.5
Mexico	35,705	3.6	3048.9	Malaysia	43,966	4.7	512.9
Korea, Rep. of	35,486	3.6	365.8	Netherlands	30,637	3.3	520.2
Netherlands	26,868	2.7	392.9	United Kingdom	22,538	2.4	121.1
Philippines	23,685	2.4	1052.6	Philippines	22,024	2.4	1186.4
United Kingdom	23,130	2.3	79.5	France	19,148	2.1	131.3
France	19,577	2.0	118.8	Thailand	15,756	1.7	438.6
Thailand	18,607	1.9	423.3	Mexico	13,115	1.4	3594.1

Source: UN Comtrade Standard International Trade Classification (SITC) Rev. 1 data. To identify commodities as Consumption, Capital, and Intermediate goods, the conversion table Broad Economic Category (BEC) to SITC Rev. 1 from World Integrated Trade Solution (WITS) was used. In order to calculate constant price data, National Accounts data from United Nations Industrial Development Organization (UNIDO) Statistics Unit and a GDP deflator were applied.

While the importance of the electronics industry in GVC formation is undeniable, note that the trade statistics presented here contain no information about trade in services or the ownership of physical or intellectual assets. As a result, GVCs can exist without strong growth in intermediate goods trade.[4] Nevertheless, while current trade statistics cannot capture the more

[4] For example, in the automotive industry a pattern of regional production has been intensifying since the mid-1980s for both political and technical reasons. This has undoubtedly dampened trade in both final and intermediate goods. Nevertheless, global integration has proceeded at the level of buyer-supplier relationships, especially between automakers and their largest suppliers, which have plants in multiple regions. As a result, local, national, and regional value chains in the automotive industry are “nested” within the global organizational structures and business relationships of the largest firms (Sturgeon, Van Biesebroeck, and Gereffi 2008). These relationships structure not only the flow of physical goods, but also the flow of information, instructions, payments, and investment that characterize GVC development. The stable share of automotive parts in total manufactured intermediate goods trade, despite the establishment of dozens of final assembly plants in developing countries over the period (Sturgeon and Florida, 2004), probably reflects the strong drive for local content in this industry, both for regulatory and operations reasons (see Sturgeon, Van Biesebroeck, and Gereffi (2008) for an extended discussion). Similarly, apparel GVCs are highly dynamic, extensive, and robust, even though inputs (for example, fabric, fiber, and other footwear and apparel parts) make up a small fraction of total intermediate goods trade and none of the top 50. While the capacity to produce inputs and final products in developing countries has been growing strongly, orders are highly specific in terms of fabric and other accessories such as buttons and zippers.

"intangible" aspects of GVCs with any degree of specificity, the scale and rapid growth of intermediate goods trade in the electronics industry is certainly indicative of its importance and dynamism in GVC formation.

Effects of the Economic Crisis on Electronics Industry GVCs

As with almost all other sectors, the electronics industry was deeply affected by the economic crisis of 2008–09. The scale of the crisis in trade is reflected in figures on overall ocean transport traffic, which carried all but the most lightweight and expensive electronics shipped over long distances. The combined results of the 16 largest ocean container carriers publishing quarterly figures—including Maersk Line, Hapag-Lloyd, China Shipping, "K" Line, and NYK Line—showed revenue declines of 40 percent for the first nine months of 2009, $56 billion, in comparison to figures from a year earlier, $94 billion (Barnard 2009).

Aggregate international trade statistics for 2008 and 2009 are still being finalized at this time, and preliminary estimates are unreliable. Nevertheless, past patterns are a reasonable indicator of recent and future patterns. Figure 1 shows world export growth from 1962 to 2006 in terms of intermediate, capital, and consumption goods, as well as capital and consumption goods combined into a "final goods" category. As the figure indicates, trade in intermediate goods appears to be much more volatile than trade in capital or consumption goods. This supports the notion of "bullwhip" effects of recessions and business cycles, where slowdowns and downturns affect part and component shipments more than final goods shipments because final goods producers tend to draw down parts inventories and delay reordering during periods of uncertainty (Escaith, Lindenberg, and Miroudot 2010). In addition, intermediate goods trade usually grows notably after recessions, especially U.S. recessions—U.S. company outsourcing has been one of the most important drivers of GVC expansion—but also following sectoral bubbles (for example, the 1985 PC bubble and the 2001 dot.com bubble), regional crises (the East Asian financial crisis), and worldwide slowdowns (the oil shocks of 1972 and 1979).

It is well documented that companies tend to be reluctant to hire new workers after the trough of recessions until demand improvements are sustained, making employment a lagging indicator of recovery. Related to this, however, and less well-documented, is a reluctance to invest in new production capacity and a carryover from efforts during recession to cut costs, leading to more aggressive implementation of outsourcing and off-shoring strategies. This pattern is in line with the findings of qualitative research (Sturgeon 2003) that lead firms in the electronics industry increase outsourcing and off-shoring following recessions because demand uncertainty makes investments in internal capacity seem more risky. Then, as the cycle continues,

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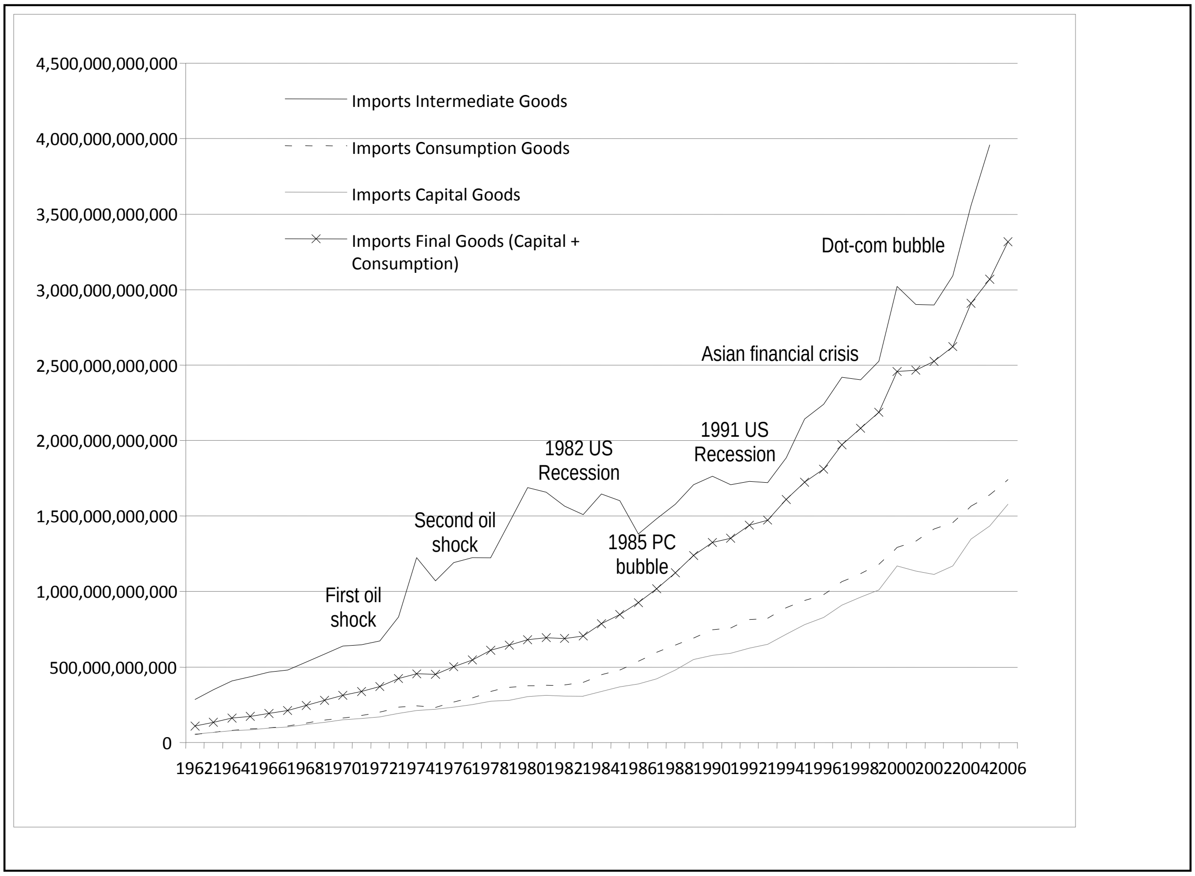
Design features are most often dictated by global buyers and change constantly as fashions and seasons vary, and deliveries are very timely, coordinated with the needs of retailers. In some cases, store pricing and barcode labels are attached to garments in the factory prior to direct delivery to retail stores. This type of explicit coordination is an important driver of industrial upgrading in developing countries, as suppliers expand their capabilities to meet the demands of global buyers, and is an important determinant for where value is captured in the industry: largely by the brand-carrying firms and large retailers based in industrialized countries.

firms report expanding outsourcing relationships that proved successful during the recession because there is insufficient time to install new capacity to meet rapidly growing demand.

Figure 1 World Imports of Intermediate, Capital, and Consumption Goods, 1962–2006



Source: Sturgeon and Memedovic (forthcoming) from UN Comtrade Standard International Trade Classification (SITC) Rev. 1 data. To identify commodities as Consumption, Capital, and Intermediate goods, the conversion table Broad Economic Category (BEC) to SITC Rev. 1 from World Integrated Trade Solution (WITS) was used. In order to calculate constant price data, National Accounts data from United Nations Industrial Development Organization (UNIDO) Statistics Unit and a GDP deflator were applied.

In the case of the United States, where up-to-date trade statistics are available (Table 3), the value of electronic component imports decreased at an average rate of 11 percent per year during the crisis period 2008–09 after being relatively stable during the period 1996–2007 at about $70 billion per year. Remarkably, imports of final products decreased much less. While these declines are significant, declines in imports of automobiles (–23.0 percent) and auto parts (–20.2 percent) were more dramatic. The value of electronic component exports also decreased during the crisis period, by 9 percent per year, which is even more remarkable since component exports increased at an average annual rate of nearly 6.7 percent per year during the 1996–2007 period, regaining in 2007 the peak of $50 billion reached in 2001, the height of the technology bubble (see Table 3).

Table 3 Average Annual Change in United States Imports and Exports, Final and Intermediate Goods in Three Industries, 1997–2009

	Average annual change (percent) — value of trade	
Imports	**1997–2007**	**2007–2009**
Electronics final goods	8.7	–3.8
Electronic components	–0.4	–11.0
Motor vehicles	5.8	–23.0
Motor vehicle parts	7.1	–20.2
Apparel	4.9	–7.4
Textiles and fiber	1.6	–15.8
Total non-petroleum Imports	**7.3**	**–10.1**
Exports		
Electronics final goods	8.0	–17.3
Electronic components	6.7	–8.9
Motor vehicles	0.5	–9.5
Motor vehicle parts	0.6	–14.7
Apparel	–8.7	–3.8
Textiles and fiber	4.2	–11.7
Total non-petroleum exports	**4.8**	**–6.2**

Source: U.S. International Trade Commission, http://dataweb.usitc.gov

Because electronic hardware and systems are rightly perceived as having a “propulsive” effect on other industries, and because deep expertise has tended to be concentrated in only a few places (for example, in Silicon Valley, California, and in large firms based in the United States, Europe, and Japan), politicians and policy makers have been loath to put too much pressure on firms to produce locally or to put up barriers to trade, even during economic crises. Intense competition, at first between American and Japanese producers, is what pushed early fragmentation of electronics GVCs, rather than trade barriers and local content rules. Producing electronic hardware in low-cost locations lowers prices, which speeds adoption of information technologies at home and leads to productivity spillovers (Mann and Kirkegaard 2006). Because trade barriers have been minimal in this industry worldwide, the main impact of the economic crisis has been to sharply reduce demand, driving the full absorption of operating inventories and accelerating existing trends toward consolidation and low-cost geographies discussed throughout this paper. However, the crisis may have hastened the longstanding trends of consolidation and supplier learning and GVC upgrading that will be discussed at length in subsequent sections of the paper.

Value Chain Modularity

Why is it that before and likely after the crisis, GVCs in the electronics industry are more extensive and dynamic than in any other goods-producing sector? One reason is that electronic parts and most final products have a high value-to-weight ratio that makes long-distance shipping relatively inexpensive. For the high-value components and some final products, such as notebook computers and mobile phone handsets, air shipment is common. Obviously, low transportation costs and the option for rapid delivery supports the movement of goods within GVCs and allows companies to engage in operating cost arbitrage based on geographic variations in operating costs. Moreover, the industry's propulsive nature has motivated a host of national policies to encourage its development, though not at the expense of liberal import policies to ensure access to advanced products, systems, and services. Given the fast pace of technological development in the industry, import substitution policies have rarely been implemented. More often, the industry has seen incentives for investment, including by multinational firms, and other industry supports.

Another reason for the global character of electronics production is the nature of the industry's product and value-chain architecture, which can be characterized as highly "modular." The industry's roots in large, highly complex military systems developed in the United States and Europe during the 1950s and 1960s (Principe, Davies, and Hobday 2003), and the myriad of commercial and consumer applications and product variations that followed during the 1970s and 1980s, led to the development of explicit de facto and de jure standards for describing components, system features, and production processes. Since then, the ability to codify electronic systems and system elements has been greatly enhanced by the advent of computer-aided design (CAD) technologies, and the shift away from hard-to-quantify analog systems toward digital systems that can by fully characterized in terms of unambiguous binary codes consisting of ones and zeros. Not only does digitization expand the scope of what can be achieved with electronics and information technology, but the codification and standardization it allows enhances interoperability and allows components and other system elements to be substituted without the need to redesign the entire product (Ulrich 1995). This "product modularity" has in turn enabled a high level of "value chain modularity," in which multiple firms can contribute to the realization of specific products and where component producers and other firms in the supply chain can be substituted without a need for thoroughgoing engineering changes (Langlois and Robertson 1995; Balconi 2002; Langlois 2003).

The key business processes in the electronics industry that have been formalized, codified, standardized, and computerized are product design (for example, computer-aided design), production planning and inventory and logistic control (for example, enterprise resource planning), as well as various aspects of the production process itself (for example, assembly, test and inspection, materials handling). Furthermore, because it is "platform independent," that is, not tied to any specific computing platform, the Internet has provided an ideal vehicle for sharing and monitoring the data generated and used by these systems. These technologies and practices are at the core of value chain modularity. It is the formalization of information and knowledge at the inter-firm link and the relative independence of the participating firms that gives value chain modularity its essential character: flexibility, resiliency, speed, and economies of scale that accrue at the level of the industry rather than the firm.

One of the most important implications of value chain modularity is that it makes it easier to accomplish work across great distances. This has created opportunities for developing countries, both as production locations for multinational firms and for local firms seeking to participate in the industry as suppliers and contract manufacturers. Once a local supplier has gained a role in a GVC, rapid product innovation and short product life cycles keep opportunities for learning and industrial upgrading coming. A handful of recent developers have taken particular advantage of these opportunities to compress their development experience (Whittaker et al. forthcoming). Singapore, Taiwan (China), the Republic of Korea, and, more recently, mainland China and the "ASEAN four" (Indonesia, Malaysia, the Philippines, and Thailand) stand out as examples.

Lead Firms, Contract Manufacturers, and Platform Leaders in Electronics GVCs

In the electronics industry's hardware "ecosystem" there are three principal actors: lead firms, contract manufacturers, and platform leaders. Of course, dozens of other entities play important roles in the broader industry, including software vendors, production equipment manufacturers, distributors, and producers of more generic components and subsystems. Nevertheless, an analysis of how these three firm-level actors interact in the industry's GVCs provides a useful if simplified portrait of the global electronics industry. The value captured by the most powerful firms in GVCs—lead firms with global brands and component suppliers with strong positions of "platform leadership"—can be extremely high.

Lead Firms

Lead firms in GVCs carry brands and sell branded products and systems in final markets to individual consumers, other businesses, or government agencies. These firms initiate, or "lead," the GVC's activities by placing orders with suppliers, giving them market power over suppliers. This "buyer power" is earned, if not by technological leadership and large investments in brand development, then by the financial risk taken on between placing orders and selling products.[5] Of course, the size of orders matters. Large orders in the supply base are driven by the expectation of large sales in end markets, and this connects lead firm power derived from market performance to their buyer power in GVCs.

Because the electronics industry has diversified as it has grown, lead firms compete in a widening array of end markets. Table 4, showing nine major end markets, reveals the remarkable breadth of the electronics industry. Each product example in the second column represents a significant and diverse market in its own right, with dozens of competitors. Examples of important firms are listed in the third column, but there are many more companies, large and small, competing in each of these markets and detailed product segments. Table 4 is necessarily incomplete and static. Applications for electronics technology have grown almost too numerous to list, with new companies formed and new products introduced almost daily. Moreover, many of these market segments contain companies that resell hardware products by integrating them into larger systems, adding software and offering after-sales services that tailor the systems for use in specific situations and settings.[6] The electronics and wider information technology "ecosystem," therefore, is vast.

[5] While this risk-taking is a source of lead firms' advantage over suppliers, lead firms often seek to pass on as much financial exposure to suppliers as possible. One such mechanism is "vendor managed inventory," where suppliers own the parts until the moment they pass onto the factory floor.
[6] Markets associated with specific industrial settings are sometimes referred to as "vertical markets," including banking, legal and accounting services, airline security, shipping, and so on.

As the nationalities of the well-known firms listed in Table 4 suggest, most important lead firms in the electronics industry are based in industrialized countries, especially the United States, Western Europe, and Japan. Of newly industrialized countries, Republic of Korea (hereafter, "Korea") stands out as a base of important lead firms, especially Samsung and LG. Because of their role as production platforms and contract manufacturing centers, only a handful of important lead firms have emerged from developing countries, including Acer, a PC company based in Taiwan; Huawei, a Chinese manufacturer of networking equipment; and Lenovo, a Chinese PC company that leapt onto the world stage with the acquisition of IBM's PC division in 2004. Later in the paper we discuss the possibility that lead firms from developing countries are finding new ways to compete successfully in global markets, and that the recent economic crisis has provided lead firms based in Taiwan with new opportunities to move into more important roles as lead firms in the electronics industry.

Table 4 Main Electronics Markets, Products, and Lead Firms

Main market segments	Product examples	Lead firm examples
1. Computers	Enterprise computing systems, PCs (desktop, notebook, netbook), embedded computers	IBM, Fujitsu, Siemens, Hewlett-Packard, Dell, Apple, Acer, Lenovo
2. Computer peripherals and other office equipment	Printers, fax machines, copiers, scanners	Hewlett-Packard, Xerox, Epson, Kodak, Cannon, Lexmark, Acer, Fujitsu, Sharp
3. Consumer electronics	Game consoles, television, home audio and video, portable audio and video, mobile phone handsets, musical equipment, toys	Toshiba, NEC, Vizio, Sony, Sharp Apple, Nintendo, Microsoft, Samsung, LG, NEC, Matsushita, Hitachi, Microsoft, HTC, Philips
4. Server and storage devices	Portable, internal, external, backup systems, storage services	Toshiba, Western Digital, EMC, NetApp, Hewlett-Packard, Hitachi, Seagate, Maxtor, LeCie, Quantum
5. Networking	Public telecommunications, private communications networks, Internet, mobile phone infrastructure	Alcatel, Nortel, Cisco, Motorola, Juniper, Huawei, Ericsson, Nokia, Tellabs
6. Automotive electronics	Entertainment, communication, vehicle control (braking, acceleration, traction, suspension), vehicle navigation	TomTom, Garmin, Clarion, Toyota, General Motors, Renault, Bosch, Siemens
7. Medical electronics	Consumer medical, diagnostics and testing, imaging, telemedicine, meters and monitoring, implants, fitness	General Electric, Philips, Medtronic, Varian
8. Industrial electronics	Security and surveillance, factory automation, building automation, military systems, aircraft, aerospace, banking and ATM, transportation	Diebold, Siemens, Rockwell, Philips, Omron, Dover
9. Military and aerospace electronics	Ground combat systems, aircraft, sea-based systems, eavesdropping and surveillance, satellites, missile guidance & intercept	L-3 Communications, Lockheed Martin, Boeing, BAE Systems, Northrop Grumman, General Dynamics, EADS, L-3 Communications, Finmeccanica, United Technologies

Source: Authors.

Contract Manufacturers

Contract manufacturers make products for lead firms and sometimes provide design services as well. The popularity of contract manufacturing in the electronics industry is a direct result of value chain modularity, which enables a clear technical division of labor between design and manufacturing at multiple points in the value chain, most notably between the design and assembly of final products and the design and fabrication of integrated circuits, or ICs. At the product level, some lead firms still assemble products in their own factories, but the use of contract manufacturers has been a strong trend since the late 1980s. Production services alone—comprising component purchasing, circuit board assembly, final assembly, and testing—are referred to in the industry as electronics manufacturing services (EMS), and also known as original equipment manufacturing" (OEM) firms in Taiwan. Historically, the largest EMS contract manufacturing firms have been based the United States and Canada (see Table 5.); for example, Celestica was spun off from IBM in 1997. These firms tend to have global operations and produce for lead firms in most of product segments listed in Table 4. In recent years, Foxconn (Hon Hai), based in Taiwan but with very large production facilities in China, Vietnam, and the Czech Republic, has emerged as the industry's largest player, in part on the basis of huge orders received from Apple for the production of the iPod and iPhone product lines. A number of firms based in Singapore have also risen in the EMS ranks, including Venture and Beyonics, ranked 7th and 12th in the world, respectively, in 2009.

Table 5 Top-Five Electronics Contract Manufacturers Different Regions, 2009

Top-five contract manufacturers	Primary service	2009 revenue (US$, millions)
Taiwan, China		
Foxconn/Hon Hai	EMS	44,065
Quanta Computer	ODM	23,265
Compal Electronics	ODM	19,424
Wistron	ODM	16,226
Inventec	ODM	12,349
North America		
Flextronics (U.S. & Singapore)	EMS	30,949
Jabil Circuit (U.S.	EMS	11,685
Celestica (Canada)	EMS	6,092
Sanmina-SCI (U.S.)	EMS	5,177
Benchmark Electronics (U.S.)	EMS	2,089
Other locations		
Venture (Singapore)	EMS	2.428
Elcoteq (Luxembourg)	EMS	2,090
SIIX (Japan)	EMS	1,360
Beyonics (Singapore)	EMS	1,120
Zollner Elektronik (Germany)	EMS	970

Source: Digitimes (Taiwan, China) and company annual reports.
Note: EMS = electronic manufacturing services; ODM = original design manufacturing (services).

Manufacturing plus product design services are known collectively as original design manufacturing (ODM) services. Nearly all large ODM contract manufacturers are based in

Taiwan, with manufacturing now concentrated in China. These firms (top of Table 5), have historically focused on producing for lead firms in the personal computer (PC) industry. Because manufacturing process technology, especially at the circuit board level, is quite generic, EMS contract manufacturers can aggregate business from lead firms in many electronics subsectors. Design expertise is far less generic, however, which explains why ODM contract manufacturers have historically been confined to the PC industry (Sturgeon and Lee 2005).

It has proven to be a powerful combination for U.S.-based "global" EMS contract manufacturers to have facilities both at home, to work out the manufacturing details of new product designs in collaboration with lead firm design groups, as well as abroad, to perform high-volume production in locations with lower costs and proximity to promising new markets. In some cases, the offshore affiliates of these large suppliers have challenged developing country contract manufacturers on their home turf. In other cases, a complementary pattern emerged where global suppliers rely on "second tier" developing country suppliers for components, services, and as subcontractors. A third pattern is for developed country suppliers to specialize in products and services that require the initial co-location described above.

Despite these differences, both the EMS and ODM contract manufacturing segments have been characterized by rapid growth and geographic expansion, making them key actors in electronics GVCs. Because of this rapid expansion, they now purchase the bulk of the world's electronic components, albeit on behalf of their lead firm customers. Even with large market shares in specific product segments (for example, Taiwanese ODM contract manufacturers produce more than 90 percent of the world's notebook computers), their market power (and profitability) has generally remained low because they are highly substitutable. Even though they purchase billions of dollars worth of components, the buyer power of contract manufacturers is limited because components are purchased specifically on behalf of their customers. Contracts for key components, such as high-value microprocessors and application specific integrated circuits (ASICs) are negotiated directly between lead firms and semiconductor companies; contract manufacturers are provided allocations at set prices. Markups on generic parts are also low or nonexistent, since the pricing for these inputs is well known to lead firms. As a result, the electronics contract manufacturing sector has long been characterized by intense competition, low profitability, and dramatic consolidation, even as it has experienced rapid growth.

Most recently, revenues of ODM contract manufacturers based in Taiwan have surged ahead of EMS contractors. Because of their expertise in small form factor (that is, portable) product design, ODMs have been able to capture the lion's share of new business for burgeoning product categories like portable computers, smart phones, and navigation devices.

Whatever the competitive battles and complementarities that have emerged among developed and developing country suppliers, the most important change is that increasing supplier capability is allowing lead firms to implement global production strategies in ways that were unimagined 20 years ago. Sustained efforts by the largest lead firms to expand and consolidate their sourcing networks have helped to create a new class of huge globally operating suppliers in the electronics industry, and supplier consolidation has meant that there are larger, more capable suppliers to choose from. Suppliers have collected bundles of capabilities and can now provide one-stop shopping for lead firms seeking regional and global supply solutions. This new class of global supplier has internalized many of the most difficult and costly aspects of cross-border integration such as logistics, inventory management, and the day-to-day management of factories (Sturgeon and Lester 2004).

Platform Leaders

In some industries, such as PCs, mobile phones, and a few industries unrelated to electronics such as bicycles, platform leaders play a crucial role (Galvin and Morkel 2001; Fixson and Park 2008). Platform leaders are companies that have been successful in implanting their technology (in the form of software, hardware, or combination) in the products of other companies. In extreme cases, platform leaders can capture the bulk of industry profits and retain tight control over the innovative trajectory of the industry. In the electronics industry, the notebook PC and mobile phone handset cases show why the term "lead firm" does not necessarily imply that branded product firms such as Dell and Motorola are the dominant and in many cases the most profitable actors in the chain.

Using the language of Baldwin and Clark (2000), it can be said that Intel, as the dominant platform leader in the PC industry, has the technological capability and market power to unilaterally change the location of key "pinch points" in the GVC. In other words, Intel can decide how to bundle tacit, proprietary activities and where to locate the points in the chain where codified handoffs can occur and open standards can begin. It is logical to think that PC producers, if they were able to develop a viable substitute for Intel chipsets, would seek to protect and enhance their profitability by abandoning Intel. In fact, many have tried in the past. IBM's late 1980s Microchannel PC architecture and the 1990s IBM/Motorola/Apple PowerPC CPU (central processing unit) alliance are examples of how branded PC companies have tried, and failed, to supplant Intel's platform leadership in the PC industry. In most industries, however, lead firms, not component suppliers, define system architecture. Personal computers and mobile phone handsets are important and well-known cases of industries where platform leaders dominate, but it is important to note that such cases are in fact quite unusual.

Apple is an interesting case of a lead firm that is also a platform leader. The system architecture of Apple products is proprietary, even though most parts and many subsystems are purchased from outside companies. Most notably, Apple has successfully created a vibrant "ecosystem" of third-party vendors to supply software applications and hardware add-ons by carefully limiting the scope of its products and publishing specification for the creation of Apple-compatible products. Note here that fully open systems, such as the Linux PC operating system, are a rarity, even in the electronics industry, where many firms claim to provide them.

Very few platform leaders have as yet emerged from the developing world. In the electronics industry a notable exception is MediaTEK, a "fabless" semiconductor design house founded in 1997 in Taiwan. The company has moved along with the market, providing chipsets for reading compact disks (CDs), digital video disks (DVDs), digital video recorders (DVRs), and high-definition televisions (HDTV). Most recently MediaTEK mastered the difficult art of combining fundamentally different technologies, such as analog and digital signal processing on the same chip, in what is known in the industry as "system-on-chip" (SOC) technology. Using SOC capabilities, the company began offering single-chip "platform solutions" with the advantages of lower cost, smaller size, and lower power consumption, while sacrificing, to some degree, the ability customize platforms in the interest of product variety. In the years 2004 and 2005, MediaTEK leveraged its experience in audio, imaging, and video to develop chipset solutions for mobile phones with functionality for audio capture (voice recording), music playback (MP3), image capture and playback (camera and video phones). MediaTEK chipsets have played a central role in supporting the development of low-cost phones suitable for the Chinese market, covered in detail later in this paper.

The Rise of Supplier Capabilities in Electronics GVCs

East Asia has contributed to the development of GVCs for a long time and in different ways. Japanese trading companies were some of the earliest sources of low-cost consumer goods for the West, such as footwear and apparel produced for large retailers in the United States and consumer electronics produced for branded lead firms such as RCA and Philips. When wages rose in Japan, Japanese trading companies became intermediaries in more complex "triangle manufacturing" arrangements that brought factories in Korea, Taiwan, and Hong Kong into a system that had previously consisted of Japanese factories exporting directly to countries in the west (Gereffi 1999). Eventually, global buyers in the West learned how to buy directly from factories in developing East Asia, or through local intermediaries in places like Hong Kong.

As firms in Korea and Taiwan began to supply more technology-intensive products like electronics with help from the state, their paths diverged. By and large, Korean firms followed in Japan's footsteps. During the 1980s Korean *chaebol* (business family) emerged as large, diversified enterprise groups with a vertically integrated stance toward product development, manufacturing, and marketing. Today, using their own brand names, Samsung, LG, and Hyundai Motors compete head to head with firms based in the United States, Japan, and Europe in global markets for technology-intensive products, such as mobile phone handsets, flat-panel television sets, and passenger vehicles.

In Taiwan, however, local manufacturers began by supplying components and subassemblies, rather than finished products, but sought—and indeed were asked and in some cases forced by de-verticalized "manufacturers" in the West—to move up the value chain. As a result, they began to assist in the design process and take full responsibility for component purchasing, final assembly, and the organization of multi-country value chains in East Asia. Taiwanese contract manufacturers had long hoped to leverage this learning process to become full-blown original brand manufacturers (OBMs), selling their own branded products on markets (Weiss and Hobson 1995). Few have been successful, however, in large part because OBM activity brought them into direct competition with their customers (small in number and very powerful), and put future orders at risk.[7] The fallback strategy for Taiwan-based suppliers was to

[7] Exceptions include Giant Bicycles, which began as a supplier of "private label" bicycles to U.S. retailers like Montgomery Ward and eventually developed its own line of high-quality branded products, and to some extent Acer, which recently surpassed Dell as the number 2 PC brand in the world after Hewlett-Packard, the first brand not based in

remain within the expanding set of value chain niches that had been made available, and to increase their range of competencies in contract manufacturing and design services, while expanding geographically into mainland China in an effort to respond to customer demands for ongoing cost reductions. As a result, a different business model and path to development, separates Taiwanese firms, such as TSMC, Quanta, and Hon Hai, from their Korean "national champion" counterparts, such as Samsung and LG.

The reasons for the different paths of Korea and Taiwan are complex. They include the more fragmented industrial structure of Taiwan noted by Feenstra and Hamilton (2006), the larger home market in Korea, different capabilities in the customer base (retailers versus de-verticalizing manufacturing companies), and different state policies (the Korean state actively promoted vertical and horizontal integration). Korea's earlier insertion into GVCs also played a role. From more arms-length relationships, GVC coordination and governance evolved. Taiwan's buyers were more circumspect about offloading full design and product conception responsibilities to suppliers, in part because they had observed how Japanese and Korean suppliers had overtaken their customers with their own brands in consumer electronics (televisions) and home appliances (microwave ovens). The differences between Korea and Taiwan, then, reflect differences in strategy, developed in a co-evolutionary manner with a set of de-verticalizing customers, and not just different starting points in industrial structure. As a result, we see Taiwan as transitioning toward the new "compressed development" model rather than simply a variant of "late development."

The success of the ODM contract manufacturing model eventually shifted Taiwan's industrial policy away from efforts to create full-blown, vertically integrated, globally competitive national industries through a process of sequential value chain upgrading. Eventually, most ODM contract manufacturers and other Taiwan-based suppliers in electronics GVCs realized that it was better to spin off their branded product divisions to compete in end markets and, as shall be seen, a few of these "ODM Spinoffs" have met with some success.

As mentioned previously, the prevalence of GVC modularity in the electronics industry has played a critical role in enabling the industry to spread geographically and, by extension, to include developing and newly developed countries in the industry's GVCs. Even though the specifications and information handed off between value chain functions in the electronics industry tend to be highly complex, the combination of information technology and well-known standards means that specifications can be codified and temporarily simplified, creating a pinch point in the flow of tacit information that allows data to be transmitted across vast distances and to other firms (Baldwin and Clark 2000).

Obviously, even with product modularity and value chain modularity, this sort of outsourcing would be impossible without suppliers with the capabilities to accept the work and efficiently meet the requirements of lead firms. Such firms exist today, but it was not always the case. Following are a few examples from Singapore, the United States, Mexico, and Taiwan of

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the United States or Japan to achieve this high market share (Vance 2009). Full success with this supplier-driven upgrading model, however, has been elusive (Sturgeon and Lester 2004).

how these capabilities emerged, including several firm-level examples, a cluster-level example from a regional production hub in Mexico, and a summary of the trajectory of contract manufacturers from the United States and Taiwan as they have developed and set up international operations. These cases show how supplier capabilities have co-evolved with lead firm outsourcing strategies in the electronics industry to help create the extensive GVCs seen today.

Singapore and Southeast Asia

In the early 1970s, American semiconductor firms located "back-end" (post-production) semiconductor assembly, which was very labor-intensive at the time, in East and Southeast Asia, and Japanese companies located low-cost transistor radio production in Taiwan and Hong Kong (Grunwald and Flamm 1985; Sayer 1986).[8] Over time, semiconductor assembly was automated, with the Philippines becoming a favored location; more labor-intensive processes, including circuit board and final product assembly, were shifted to developing East Asia as well. At first, most of these capabilities were contained within the affiliates of multinational firms, but local capabilities gradually developed. This was especially true for suppliers serving the affiliates of American multinationals, which have proven to be more willing to encourage local suppliers to take on additional responsibilities than their Japanese counterparts (Borrus, Ernst, and Haggard 2000). Singapore was a favored location for multinational firms in the disk-drive industry (McKendrik, Doner, and Haggard 2000), but production and subassembly work gradually spread to local firms that soon outgrew the small land and labor markets in Singapore and set up operations throughout Southeast Asia (Deitrick 1990; Vind and Fold 2007). Because rates of unionization were very low in the U.S. electronics industry, and because modularity allowed design and innovation functions to remain at home, these moves were not strongly resisted by politicians or the general public.

The important role of multinational affiliates in driving supplier upgrading in Southeast Asia is illustrated in the case of Beyonics, an EMS contract manufacturer based in Singapore. In 1981, two Singaporean engineers decided to start their own company after they were laid off from the Singaporean subsidiary of the German camera manufacturer Rollei. Seeing that the local tool-and-die business in Singapore was underdeveloped—because most foreign firms tended to bring in their own tooling—the two set up their own tool-and-die shop on a chicken farm owned by one of the founder's parents. From their experience at Rollei they knew that advanced lathes for precision metal cutting could be stopped quickly to make rapid set up changes. The two retrofitted some inexpensive lathes with motorcycle brakes to achieve the same effect. The company, which was initially called Uraco, generated $700,000 in revenues during its first year of operation, mostly by supplying precision metal parts to American disk drive producers, which were investing heavily in manufacturing in Singapore and Malaysia at the time (*Business Times* 1995).

As Uraco grew, it began to supply a wider range of products to the disk drive industry, including precision metal stampings and assembled electronic circuit boards. Most of the company's business was with Seagate, the leading American disk drive manufacturer at the time,

[8] This section draws from Sturgeon, Humphrey, and Gereffi (forthcoming).

but the company also exported precision parts to Hitachi's disk drive operations in the Philippines. Because of the extreme volatility in disk drive and PC markets, in 1987 management began the first of many efforts to diversify the company's customer base by distributing electronic components, eventually winning distributorships from Motorola, Harris Semiconductor, and Siemens.[9] In the mid-1990s the company took these efforts at diversification a step farther. The idea was to leverage experience with electronic components, contract manufacturing, and warehouse management to manufacture and sell products of its own design, including connectors, crystals, automated warehouse vehicles, electronic ballasts for fluorescent lamps, light bulbs, and telecommunications products. Ultimately, these attempts were not successful, and the bulk of Uraco's business remained in providing EMS contract manufacturing services and precision-engineered metal parts to foreign firms operating in the South East Asian region. As traditional distribution networks in the region matured, the need for the company's distribution services waned as well.

Nevertheless, in 1995 the company underwent a successful initial public offering on the Singapore stock exchange. In 1996, as annual revenues were approaching $53 million, Uraco won an important contract to manufacture flatbed scanners for Hewlett-Packard (Business Times 1996a). In 1997 the firm reorganized its business into three divisions: precision machining, contract manufacturing, and investment (Business Times 1996b; 1997). The company's troubles were not over, however, and flagging profitability led to a management reshuffling in 2000 and a name change to Beyonics in 2001. The company returned to profitability in 2001, when it generated nearly $300 million in revenues, with 62 percent coming from contract manufacturing services, 29 percent from precision engineering, and 9 percent from distribution (Geocities 2004).

The company's current product and service offerings are electronics manufacturing services (that is, contract manufacturing), medical and consumer plastic injection molding and assembly, precision engineering services, precision metal stampings, and precision tooling design and fabrication services. This is a highly focused and complementary product portfolio, covering many of the processes and a few of the basic products required to produce a wide variety of electronics and closely related goods. The company has followed the rest of the electronics contract manufacturing industry into the bundling of services to enable the production of complete products through its acquisitions of precision plastic moldings suppliers, Techplas (in 2000) and Pacific Plastics (in 2002). In 2003 the company merged with a similar Singaporean contract manufacturer, Flairis Technology Corporation, to achieve additional economies of scale and scope. The company's distribution activities and attempts at selling its own branded products have been dropped entirely.

With this tighter focus, the company has expanded dramatically. As shown in Table 5, the company now ranks twelfth on a list of world's largest EMS electronics contract manufacturers. Through a combination of internal expansion and acquisition, Beyonics has

[9] The opportunity for electronic component distribution in Singapore and Malaysia stemmed from the lack of an adequate conduit to connect local chip assembly and test operations with the growing subassembly and product-level manufacturing that foreign firms were doing in the region. Offshore affiliates of both semiconductor and product-level firms had increased their Asian operations, and Uraco's new distribution arm helped to connect the dots.

developed a solid regional manufacturing footprint, most notably by establishing "vertically integrated" electronics contract manufacturing campuses in Kulai, Malaysia in 2005; Suzhou, China in 2006; and Batam, Indonesia in 2007. In all, the company currently operates 16 facilities: 3 in Singapore, 6 in Malaysia, 3 in China, 2 in Thailand, and 2 in Indonesia.

While Beyonics may have grown much larger than most local firms in East Asia that started as suppliers to multinational corporations (MNCs), there are several lessons to be drawn. First, Beyonics' managers demonstrated the use of dynamic capabilities (Teece 2009) for sensing opportunities, seizing them, and transforming the company as needed. Second, they stumbled by trying to diversify and develop their own products, which required end-user marketing competences they had not yet developed, but recovered when they refocused on providing producer services to MNCs in the region. Third, like most large electronics contract manufacturers, Beyonics has struggled to remain profitable, even as the company has grown rapidly. Fourth, as the company expanded, it chose a variety of lower cost locations within Southeast and East Asia, balancing its investments in China with locations in Malaysia, Thailand, and Indonesia. What the Beyonics case illustrates most dramatically, however, is how, with enough time (a 28-year span in this case), local firms with extremely humble roots have been able to grow, master advanced technologies, and set up multiple locations in Asia, largely by serving American MNC affiliates in the region.

The United States

In the United States electronics industry, a combination of globalization, outsourcing, and vertical bundling at suppliers in the 1990s helped to push a small but elite set of supplier firms to quickly move beyond their traditional cluster- or national-scale footprint to become global in scope. Vertically integrated lead firms with global operations based in both the United States and Europe, including Lucent, Nortel, Alcatel, Ericsson, and Apple Computer, sold off most, if not all, of their in-house manufacturing capacity—both at home and abroad—to a cadre of large and highly capable U.S.-based contract manufacturers (Table 5), including Flextronics/Solectron, Jabil Circuit, Celestica, and Sanmina-SCI (Sturgeon 2002; Sturgeon and Lee 2005).

Solectron (acquired by Flextronics in 2007) provides an example of how U.S.-based EMS contract manufacturers over-expanded during the 1990s. The company was concentrated in a single campus in Silicon Valley (California) from its founding in 1979 through the 1980s. In 1991 Solectron's key customers in Silicon Valley including Sun Microsystems, Hewlett-Packard, and Cisco Systems, demanded that Solectron provide global manufacturing and process engineering support. The company went on an acquisition-fuelled binge of global expansion and revenue growth; by 2001 the company's footprint had expanded to more than 135 facilities worldwide (see annex) and annual revenues had increased from $265 million to $12 billion. In the process of this expansion, the company acquired competitors, customer facilities, and an array of specialized firms with capabilities that allowed the company to offer a much broader package of services.

An example of a global electronics contract manufacturer that emerged as a lead firm spinoff is Celestica, an in-house manufacturing division of IBM that was spun off as an independent company in 1996. At the outset, the firm had only two production locations, a large complex near Toronto, Canada, and a small facility in northern New York State, since closed. By 2001, after completing 29 acquisitions of customer and competitor facilities, Celestica had accumulated nearly 50 facilities in North America, South America, Western and Eastern Europe, and Asia, and annual revenues had soared to more than $10 billion (see map 1).

Map 1 Celestica's Global Operating Footprint, 2001

Source: Celestica

In the round of consolidation that followed the technology bubble bursting in 2001, Flextronics (listed in Singapore, but managed from San Jose, CA) emerged as the world's largest electronics EMS contract manufacturer, a position that was further solidified through its acquisition of number 2-ranked Solectron in 2007. Flextronics' 2009 revenues were slightly less than $31 billion. Aside from dozens of stand-alone factories and technology centers around the world, Flextronics, with its strategy of "vertical integration," operates nine huge "industrial parks," where it has "invited" many of its most immediate suppliers of product-specific components (bare printed circuit board and plastic enclosures) to co-locate with its final assembly plants for rapid response in regional markets. Flextronics has one industrial in Poland and two each in Brazil, China, Hungary, India, and Mexico. In a pattern typical of many goods-producing industries, facilities located in developing countries tend to be significantly more vertically integrated than those in industrialized countries, where existing local suppliers and component distributors can be relied on for inputs.

The sale and spinoff of in-house manufacturing and parts operations in the American and European electronics industries underlines the structural shift that has been occurring in the electronics industry from in-house production to global outsourcing. The accumulation of this offloaded capacity within a relatively small number of huge suppliers shows the dramatic consolidation and increasing integration of the global supply-base. However, outsourcing, as such, does not tell the entire story. In the electronics industry, fast-growing lead firms with little if any in-house production capacity, such as EMC, Sun Microsystems, Cisco, and Silicon Graphics, also demanded that suppliers provide global support. And, in some key locations, lead firms did not necessarily have plants to sell or spin off, especially in newer locations like China and Eastern Europe. As a result, a great deal of the global expansion of suppliers in the 1990s was either "organic" in character, involving the enlargement of existing facilities and the establishment of new "greenfield" plants,[10] or achieved through the acquisition of regional suppliers, in what some industry participants refer to as the "rolling up" of regional supply bases to create a global footprint.

Global coverage allows the largest EMS contract manufacturers to produce high-volume, price-sensitive products for global markets from plants in China, and higher value, medium-volume products in regional production facilities such as Mexico and Eastern Europe. It also enables them to produce a variety of products locally for regions containing large developing countries such as India, Brazil, and China, and to work closely on lowest volume, highest value products with customers in industrialized counties, in places like Silicon Valley.

However, expansion in the 1990s was so rapid that the largest EMS companies quickly became overextended. Integrating diverse plants acquired from customers and competitors left these firms with excess capacity, facilities with incompatible factory and information systems, and too many plants in high-wage locations. Efforts at consolidation are ongoing, but overexpansion and poor management left certain companies, especially Solectron and SCI, with too much inventory in the system and in very weak financial position, making them ripe for acquisition. After the 2001 technology bubble burst, contractors made a strong push to increase capacity in low-cost geographic areas, especially China, and, as shown in the next section, to transform regional production hubs in Mexico and Eastern Europe to produce higher value, lower volume products previously manufactured in the United States and Western Europe.

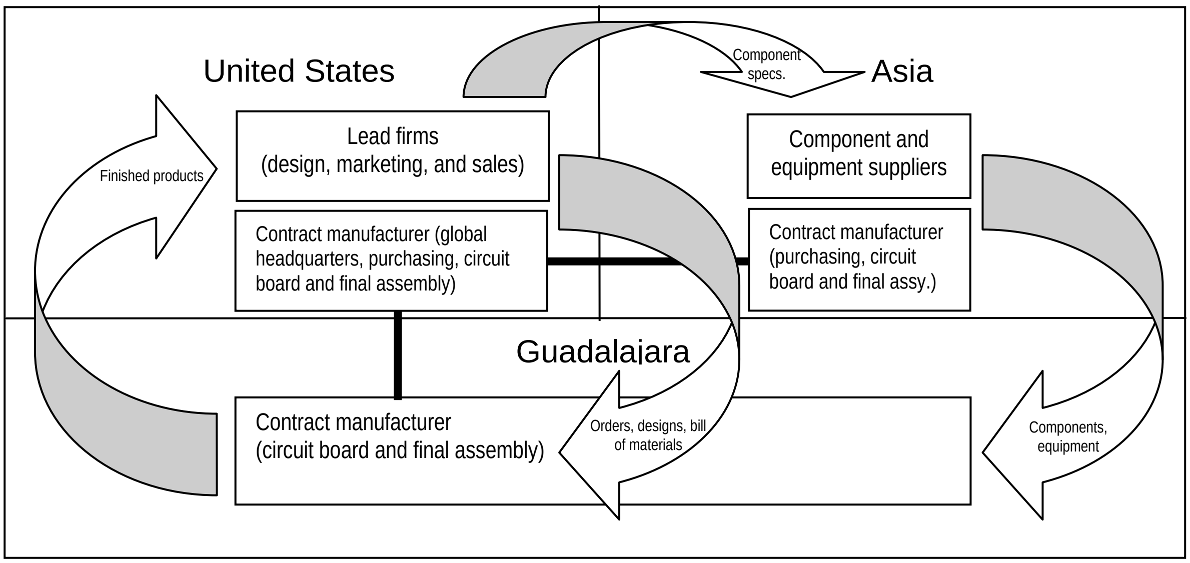
Guadalajara, Mexico

Economic downturns can have obvious negative effects on workers, companies, industrial clusters, industries, and entire national and regional economies.[11] But they can also provide an impetus for positive change, adaptation, better prospects for sustainable development for the long term, and an improved ability to weather future downturns. One example is the electronics cluster in Guadalajara, the capital of Jalisco State in southwest Mexico. The 2001 technology bubble bursting in 2001 was felt acutely across electronics GVCs, and the Guadalajara electronics cluster was no exception. Companies and facilities there went through a wrenching and rapid decline, but recovered through a remarkable process of industrial upgrading. This involved a move to new products and processes, as well as changes in work organization and training as high-volume production lines were transformed into high-mix production cells to accommodate a greater variety of higher value products.

[10] At Celestica, for example, 40 percent of global capacity expansion was "organic" in nature**.**
[11] This section draws from Sturgeon and Dussel-Peters (2006)

The Guadalajara electronics cluster is deeply embedded within electronics GVCs. With few exceptions, electronic goods produced in Guadalajara are designed and sold by U.S.-based lead firms. Most are produced by affiliates of U.S.-based global EMS contract manufacturers using imported components and equipment, especially from East Asia (see figure 2). Almost all output is exported, the vast majority going to the Unites States.

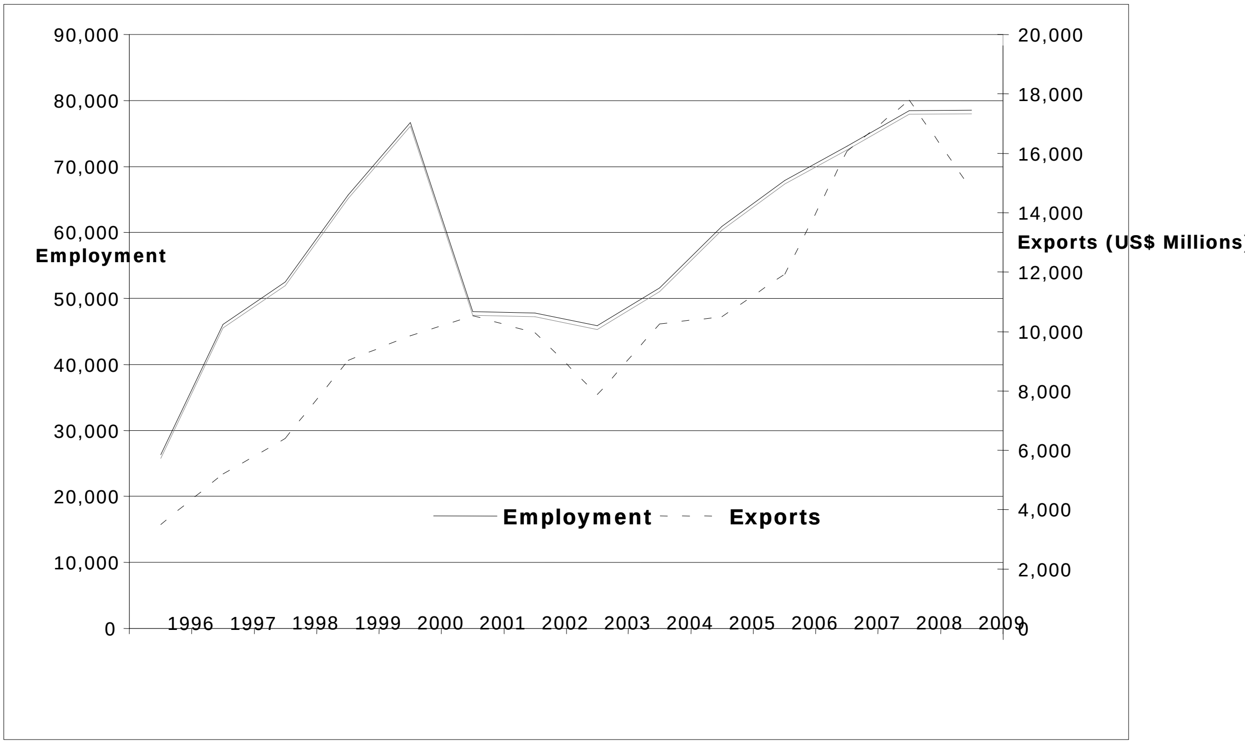
Figure 2 Position of the Guadalajara Electronics Cluster in Electronics GVCs



Source: Authors' drawing.
Note: Guadalajara, Mexico.

Until 2001 Guadalajara's factories competed directly with those in China in the production of high-volume, price-sensitive items such as mobile phone handsets and notebook computers. Because global suppliers dominate the landscape of electronics GVCs, competition between locations often occurs within the global footprint of contract manufacturers. Thus, decisions to shift work from one location to another are taken by the managers of contract manufacturing firms, carried out at the request of lead firm customers, or some combination. During 1994–2000, the value of electronics exports from Jalisco State, which contains the Guadalajara metropolitan area, on average, increased at a rate of 35.4 percent per year. During 2000–2005, the average annual export growth rate declined to only 1.3 percent per year, falling in absolute terms for several years (see Figure 3). While a few foreign electronics firms (for example, Hewlett-Packard and IBM) had been operating in Guadalajara since the 1970s, a new wave of foreign direct investment (FDI) peaked at US$611 million in 1998 as the affiliates of global EMS contract manufacturers expanded in the area as part of the worldwide expansion strategy described earlier. Flextronics, Jabil Circuit, Solectron, Sanmina-SCI, Benchmark, and Foxxcon (Hon Hai) all established facilities in Guadalajara, along with a handful of multinational component manufacturers and a few component distribution companies to manage the increased inbound flow of components. Because the decline in output after 2001 followed these huge investments, capacity utilization dropped precipitously and remained low for several years. As Figure 3 shows, the nadir for both employment and exports was 2003.

Figure 3 Guadalajara "High-Tech" Employment and Exports, 1996–2009



Source: CADELEC 2010

With new, large, state-of-the-art production facilities sitting idle, the stakes were very high in 2001–03. Employment had grown to about 10,000 workers each at several of the largest plants, and total high-tech employment in Jalisco State peaked at 76,666 in 2000. After the technology bubble burst in 2001, employment dropped by 40–60 percent at some plants, with total high-tech employment in Jalisco falling by 40 percent to 45,877. This downturn was more than a temporary drop in demand. In an effort to lower costs, global contract manufacturers were shifting high-volume work to their plants in China. There was no expectation that this work would come back to Mexico when the crisis abated. Failure to find new business would likely have meant further stagnation, decline, and possible plant closures. In an effort to utilize their state of the art investments in Guadalajara, the global firms provided the electronics cluster there a new role in the global industry: produce higher priced, lower volume products, often on a direct-ship, rapid replenishment basis to retail outlets in the United States.

This strategy led to a dramatic transformation and gradual recovery to pre-crisis levels of employment and exports. Very few of the products made in Guadalajara in 2000 are still made there. The assembly of high volume, price sensitive products has been shifted to other locations, mainly China. Products produced in Guadalajara after the 2001 crisis tend to have the following characteristics:

- **Products with high transport costs:** For example, 20 percent of the final costs of video game consoles are for transportation. Large and heavy products, obviously, are well suited for production in Mexico.

- **Products with complex logistics:** These products require last-minute configuration, very responsive logistics, and short transit times. Transportation costs also rise with low-volume, rapid-response shipments.

- **Products needing intensive development:** These are products with requirements for intense interaction between design, R&D, engineering, configuration, testing, and prototype development. Such products typically require close engineering collaboration and often call for multiple engineering changes during new product introduction. In some cases, lead firm engineers contact the production facility engineers every four hours and even every hour. U.S.-based engineers sometimes spend days or weeks onsite to solve problems. Long distances and vastly different time zones, as is the case with Asia, makes this type of manufacturing very difficult.

- **Very expensive products:** These include, for example, items for industrial or IT infrastructure applications in which labor is not a determinant cost.

- **Regulated products:** Regulations sometimes specify tariffs or come with other "rules of origin." For example, the 18 percent U.S. tariff on cellular phones produced outside of NAFTA has kept some higher value cellphone handset production in Mexico, even though they are produced in high volumes that would otherwise render them more suitable for production in China.

Prior to 2001 most production of products with the above characteristics had been done in the United States, where costs are high. Mexico offered a potential low-cost "near-shore" solution for more expensive products made in small batches, but first a series of challenges needed to be met. During the 2001–03 period contract manufacturers in Guadalajara undertook the following measures:

- Employment and new investment were dramatically cut.

- Remaining workers and managers went through an intensive period of re-training.

- New systems were developed to maintain product quality in the context of higher product complexity and diversity. These changes impacted procedures for product testing, inventory management, and work processes.

- New systems were developed to configure and customize products for small orders. This required an increase in engineering employment.

- "Hard tooling," that is, inflexible tooling dedicated to a single product, was replaced with "soft tooling." This transformation often meant less automation and greater labor intensity and worker skill, especially in final assembly.

At the level of circuit board assembly, where individual electronic components are mounted and affixed to bare circuit boards to create the major functional elements of electronics systems, highly automated robotic equipment can be reprogrammed with relative ease, making the work highly geographically mobile. In final assembly, however, automation is more difficult because of the radically different size and shape of finished products and poor flexibility of the equipment used. Assembly personnel, therefore, have had to adapt to a much more complex and challenging production environment. Instead of performing one or a few operations on the same product for months at a time, line workers must frequently perform new and different operations as a variety of products move down the line. Such work is much less geographically mobile.

Materials management, for both circuit board and final assembly, are also much more complex, and many plants are working to adopt the most advanced "lean production" methods for maintaining quality in the face of product variety. While circuit board assembly machines still feed final assembly stations in linear fashion, final assembly has been reorganized into "cells" that hold very little inventory and where workers perform several tasks rather than a single task. Finally, new logistics functions have been added to ship small lots, often by air, directly to retailers for distribution. Materials management, testing, and quality assurance systems have all been upgraded dramatically to accommodate the vast increases in product variety.[12]

The retraining and new process development specified here were implemented in 2001–02 for a small number of old and new products that fit the target profile of the plants. These new capabilities in turn provided a platform to win new low-volume, high-mix business in the period 2003–05. Since then, the Guadalajara electronics cluster has solidified its new role and employment has rebounded to pre-2001 levels, with a higher ratio of engineering and other skilled occupations. This is reflected in figures on exports per worker, which rose from 128,610 in 2000 to 226,723 in 2008. Due to the sudden drop in demand during the most recent economic crisis, this figure fell to 188,143 in 2009 (authors' calculations, CADELEC 2010). Because of the new product mix, high investment in worker training, and decreased portability of the work now performed in Guadalajara, contract manufacturing firms have apparently been more reluctant to engage in massive layoffs during the recent economic crisis than they were in 2001, at least so far (see year 2009 in Figure 3). While growth of high-tech employment in Jalisco State did decrease in 2009, employment remained stable at about 78,500 workers, 83 percent of whom were in manufacturing (CADELEC 2010).

The changes in Guadalajara's electronics industry since 2001 are a striking example of "industrial upgrading" (Humphrey and Schmitz 2002), in which the industry shifts to higher value products, more advanced processes, and adds a host of new functions and services. However, it is important to note that many of the techniques that support these changes were developed outside of Guadalajara. In this way, global contract manufacturers can provide a powerful mechanism with which to disseminate best practices. On the other hand, our field research also found that local officials, plant managers, and workers played a powerful role in the transformation of the region. Finally, while employment at foreign-owned contract manufacturing facilities is now back to 2001 levels, local suppliers have not made the transition to the new high-mix product profile of production in Guadalajara, and employment has not recovered at most of these firms.

[12] Increases in product variety vary by firm, but in general it has increased by several orders of magnitude, that is, from tens to thousands. As a result, the number of components in use have increased even more dramatically.

The case of the transformation of the Guadalajara electronics cluster provides some lessons for the concept of GVC upgrading and for the prospects for economic transformation in locations where modular GVCs touch down. First, any neat partition between product, process, and functional upgrading as specified by Humphrey and Schmitz (2002) seems problematic because of the powerful complementarities that flow from product upgrading. The shift to higher value, lower volume products, in this case, *required* firms to upgrade processes to accommodate rapid changeover and to add new functions to control a much more complex inventory basket and to develop new engineering inputs to support changes. Second, rapid upgrading was possible in part because the skills to do so had been developed within the larger global structure that the facilities in Guadalajara are part of. Finally, the authors' research found that local firms have not been able to adapt to the new requirements of the cluster, in part because the resources and knowledge to transform their plants is not available locally. Nevertheless, the upgrading achieved after the technology bubble burst in 2001 may have provided the Guadalajara electronics cluster with some protection during the current economic crisis.

Taiwan (China)

Taiwan-based ODM contract manufacturers have come to dominate world production of PCs, but have historically had difficulty selling their own branded products to consumers.[13] However, the recent economic crisis may have created new opportunities for Taiwan-based firms to overcome these barriers, as will be discussed in this section on the evolution of electronics hardware production in Taiwan.

While there are significant PC components, subsystems, and peripheral devices in which Taiwan-based firms are not active—namely software, printers, hard disk drives, and higher-value semiconductors such as microprocessors and memory—Taiwan has developed what is arguably the world's most capable and agile supply-base for the design, manufacture, and delivery of PCs and related products, especially notebook computers (Dedrick and Kraemer 1998). Initially working in close geographic proximity, mostly along the Taipei-Hsinchu corridor in Taiwan, this supply base grew to constitute an extremely efficient system that could respond rapidly to orders from lead firms. Notebook computers, which generally have a high enough value-to-weight ratio to make air shipment viable, can be shipped from Taiwan (or now from mainland China plants owned by Taiwan-based contractors) to end users in the United States and Europe within two to three days of incoming orders.

This powerful productive engine has developed, almost in its entirety, in response to orders from lead firms based in the United States, and more recently, Japan (Sturgeon 2007). At the same time, the development of contract manufacturing in Taiwan and elsewhere has provided lead firms with an increasing range of sourcing options. This process of co-evolution means that Taiwan's electronics industry has been able to develop without a significant cadre of local lead firms. From the late 1970s to the present day, sourcing from Taiwan has expanded from computer monitors, to various components and subsystems, to complete desktop and notebook PC systems.

[13] This section draws on Sturgeon and Lee (2005) and Kawakami (forthcoming).

Firms from the American PC industry have played an especially important role in the development of Taiwan's electronics contract manufacturing sector. In the early 1980s IBM began sourcing PC monitors from television producers in Taiwan, including Tatung, for its new line of PCs. As the demand expanded rapidly and the open architecture of the IBM-compatible PC became firmly established in 1984 with the IBM model AT, some entrepreneurial firms in Taiwan, including Acer and Mitac, recognized the opportunities and moved aggressively to develop the capability to design PCs and peripheral devices based on the emerging standard. IBM's modular PC system architecture relied on a central processing unit (CPU) supplied by Intel and on operating system from Microsoft, and because the contracts famously did not block Intel and Microsoft from selling to IBM's competitors, a bevy of new entrants, intense price competition, and a series of boom and bust cycles soon followed. These conditions caused contract manufacturing to become a popular strategy for lead firms in the United States seeking to cut costs and limit investments in fixed capital in the face of severe market uncertainty. The surging demand for contract manufacturing services encouraged existing Taiwan-based contract manufacturers producing consumer electronics and electronic component companies to develop capabilities to assemble PCs.

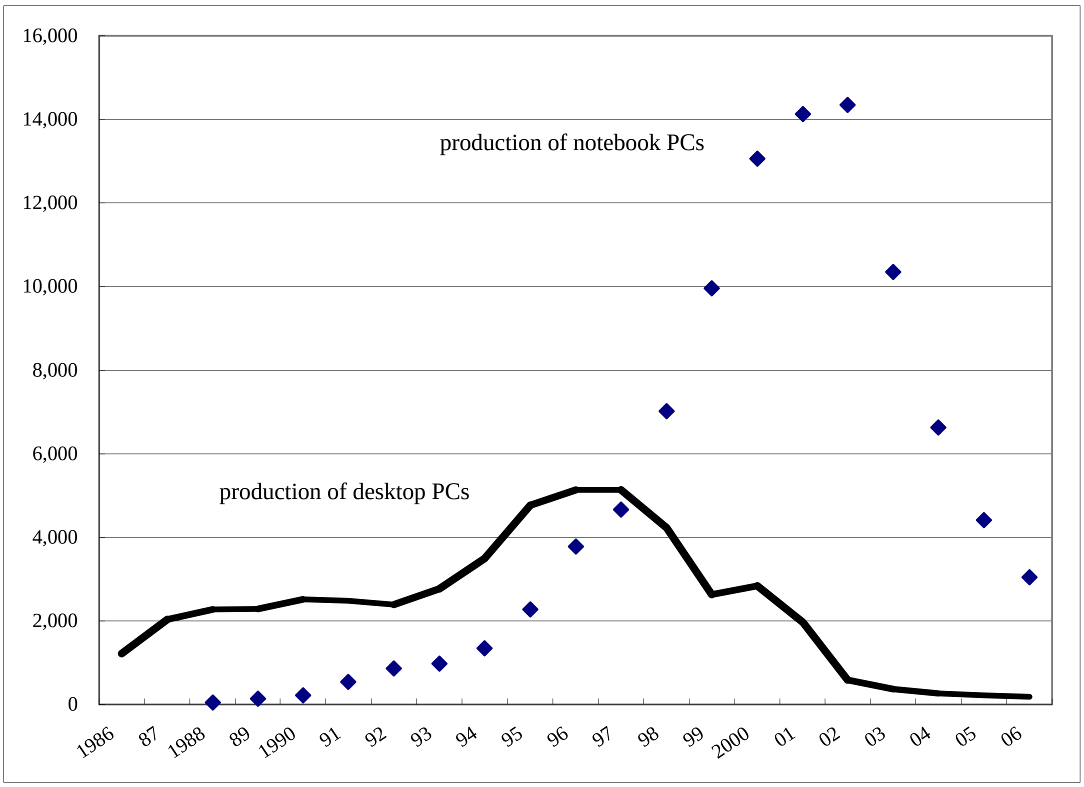
Then, in the late 1980s, a set of firms that had been focused on the design and manufacture of handheld calculators entered the field. These firms—including Quanta, Compal, and Inventec—eventually became the dominant notebook computer producers, in part because the design and assembly competencies that drove miniaturization in calculators were well suited to notebook computers, where small size, low weight, and efficient power consumption are key factors for success. In addition, calculators, while much simpler, are similar to PCs in that they are built around a CPU whose product architecture determines product functionality.

The modular system architecture of PCs, and the dominant role of the CPU and operating system software in setting system architecture, along with intense competition and short product life cycles, created the conditions for the emergence of a set of firms to specialize in the iterative, post-architectural portions of product design, including the board-level operating system (BIOS), which determines how the machine handles the input and output from its main board to the other elements of the system, such as storage and displays. However, because most functionality resides in chipsets and software—system elements that computer producers do not design—control over the innovative trajectory of the industry has continued to reside in "platform leaders" such as Intel and Microsoft, which have traditionally worked closely with branded PC firms on future requirements. However, as the notebook format has come to dominate consumer PC sales, and branded PC firms have either left the business (IBM), changed their business focus to bundling services with PCs (Hewlett-Packard), or tried to move up-market to servers and storage systems (Dell), Intel has begun to work more closely with Taiwanese firms on the requirements for next generation CPU design for mobile computing (Kawakami, forthcoming).

The migration of Taiwan's electronics production to mainland China began to accelerate in the mid-1990s, following a sharp drop in desktop PC prices (some models fell below $500). The migration started with components and peripherals and then spread to assembly of desktop

PCs and motherboards, with the latest stage being notebook computers in the period 2001–06, when notebook PC ODMs moved nearly all of their manufacturing from Taiwan to mainland China. As sales of notebook PCs expanded rapidly, surpassing desktop units in the early 2000s, production in Taiwan soared from 2.3 million units in 1995 to a peak of 14.3 million in 2002. However, after 2002, notebook PC production in Taiwan dropped just as rapidly, even as Taiwanese firms produced a larger share of the world's output, reaching 92 percent in 2008 (see figure 4). This migration contributed to the dramatic expansion of two industry clusters for electronics manufacturing, one in the Pearl River Delta near Hong Kong focused on the assembly of desktop PCs, PC main boards, and peripheral products, and the second in the Yangze River Delta near Shanghai, focused on notebook PC assembly. Smaller Taiwanese contract manufacturers and component suppliers were not able to make this move, leading to a dramatic consolidation among firms specializing in notebook PC production: the number of Taiwanese notebook PC producers fell from 45 in 1993 to only 21 in 2006, with market share shifting dramatically in favor of the largest five producers (Kawakami forthcoming).

Figure 4 Taiwan, China, Production of Desktop and Notebook PCs, 1986–2006



Source: Kawakami (forthcoming) from the Internet Information Search System, Department of Statistics, Ministry of Economic Affairs, China.
Note: PCs = personal computers.

The co-evolution of lead firms, suppliers, and platform leaders outlined here reveals a recursive dynamic of outsourcing, upgrading, and further outsourcing; the enabling role of open standards and modular product architecture in the PC sector; the intense competition and rapid product life cycles that drove lead firms to seek to spread risk and lower costs through outsourcing; and the entrepreneurial agility displayed by Taiwanese firms to recognize and quickly seize new opportunities to specialize in narrow segments of the value chain.[14]

Upgrading: Pluses and Minuses for Developing Country Firms

The advantages of incumbent lead firms with deep technological expertise, in terms of value extraction in GVCs, as well as the limitations for firms based in developing countries, are illustrated by the well-known case of Apple Computer Inc. Linden, Kraemer, and Dedrick (2007) estimate that only $4 of the $299 retail price of an Apple 30 gigabyte video iPod MP3 player is captured in China, where they are assembled and tested by the Taiwan-based ODM contract manufacturer Inventec. The share captured by domestic Chinese companies is even less; probably limited to packaging and local services. This is, in part, because iPods are assembled from components made mostly in other countries, such as the United States, Japan, and Korea. But more importantly, it is because Apple—which conducts high-level design work and software development in-house and orchestrates the product's development, production, marketing and distribution—is estimated to capture $80 of the sale price. This study also estimates that $83 is captured in the United States by Apple's technology suppliers and by retailers. Clearly, assigning the $183 per unit wholesale price of exported iPods (as would be reported in trade statistics) to the Chinese economy misrepresents where value is created in the global economy. Similarly, a "teardown analysis" of the recently released iPad tablet computer by the consulting firm iSuppli estimated Apple's gross margin for the product (the $499 sale price less the component costs) to be $270, or 54 percent (Hesseldahl 2010). Assembly costs for the iPad may be higher than for the iPod, but it can still be assumed that very little of the product's value is captured in China, and even less by mainland Chinese companies.

For developing country lead firms involved in product innovation, the solution in technologically intensive product areas like electronics is to purchase highly modular design solutions from platform leaders. This allows quick market entry, but can also lead to several traps. First, as already mentioned and to be covered in more depth later, there are the high costs associated with acquiring highly functional components and subsystems, as well as the royalties that must be paid, directly or indirectly, to the platform leaders and other standard setters in the industry. Second, there is the "modularity trap," as identified by Chesbrough and Kusunoki (2001), where the highly integrated off-the-shelf components and subsystems provided by platform leaders reduce product distinctiveness. By and large, the world's major contract manufacturers have been trapped in low value-added segments of the electronics GVC: manufacturing and iterative, detailed design. In the PC industry, most of the industry's profits have been captured by branded lead firms such as Dell and Hewlett-Packard, and especially by platform leaders in software operating systems (Microsoft) and CPU chipsets (Intel).

[14] Another important factor that has not been discussed here is the role of Japanese technology partners, which provided critical technologies and components, such as disk drives, that came as "black boxes" or with licensing restrictions that inhibited Taiwanese firms from building up fully independent technological capabilities. Restrictive licensing agreements have continued to be important, for example in Taiwan's flat-panel display industry (see Akinwande, Douglas, and Sudini 2005).

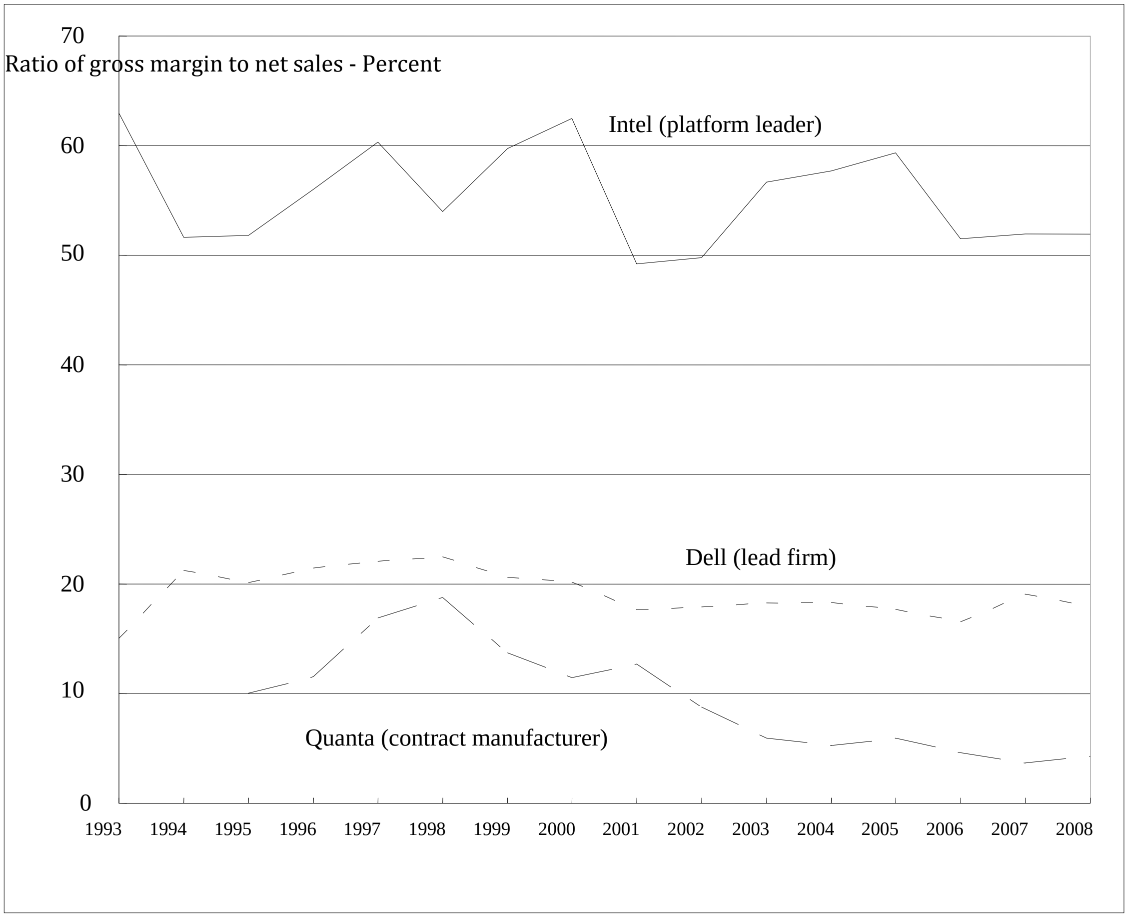
Intel's Platform Strategy for Taiwan's ODMs

In consumer electronics products like the iPod or video game consoles, lead firms can control product architecture and extract the lion's share of profits from GVCs; but in other industries, platform leaders dominate. For example, in her analysis of major players in the notebook PC value chain, Kawakami (forthcoming) shows the highest profit (more than 50 percent, measured by the ratio of gross margin to net sales) made by Intel—the platform leader that supplies most of the central processing chipsets to the notebook PC industry—while profits are much lower at Dell, one of the most important lead firms in the PC industry (less than 20 percent), and extremely low (below 5 percent after 2001 and dropping) at the Taiwan-based contract manufacturer Quanta, which assembles the largest share of Dell-branded notebook PCs in China (see Figure 5). This measure of profitability, which in fact does *not* take Intel's huge capital investments into account, clearly shows the dominance of Intel in terms of value capture, the relatively modest performance of Dell, as well as the declining profitability of Quanta, despite its apparent success in capturing a growing share of global notebook PC design and production.

Such disparities have led to a series of conflicts between Intel and branded-PC lead firms over the expropriation of value-added. In the early 1990s, lead firms, especially Japanese firms Toshiba and NEC that dominated the notebook PC market at the time, enjoyed high profits. The capability of Japanese lead firms to develop Intel CPU-inclusive chips sets in-house and to verify those developed by third-party vendors, constituted a core competitive advantage. However, in 1997, Intel, following a strategy it had employed to dominate the desktop PC industry (Gawer and Cusumano 2002; Tatsumoto, Ogawa, and Fujimoto 2010), began to offer highly integrated chipsets and launched "mobile modules" that integrated CPUs and chipsets for the notebook PC industry as well.[15] This provided a turn-key solution (integrated platform) for latecomer firms. Intel also exercised its market power by controlling the flow of information. The company stopped disclosing technological information necessary for developing chipsets, and kept the internal structure of its products as a proprietary black box. By doing so, Intel successfully negated the previously scarce and valuable engineering know-how of lead PC firms (Ogawa 2007). In addition, the emergence of 3D-CAD system for developing molds and the launch of thermal modules that could deal with problem of heat dissipation in small notebook PC enclosures negated the valuable know-how about product miniaturization and heat treatment that Japanese lead firms had accumulated earlier.

[15] The initial product offering coupled Pentium CPUs with second-level cache memory on a single circuit board module.

Figure 5 Value Capture in Notebook PC GVC in Three Competitors



Source: Kawakami (forthcoming), based on annual reports.

Lead firms were affected by Intel's platform strategy in different ways. American PC firms—Dell, Gateway, and Compaq—embraced the new platforms as a way to increase their market share in notebook PCs. Exploiting the increased modularity of the product, these firms stepped up their use of Taiwanese ODMs to reduce costs and speed product life cycles. The market for notebook computers expanded rapidly as a flood of relatively inexpensive machines hit the market. By contrast, Japanese firms, which had based high profitability on superior R&D and production capabilities, resisted the commoditization of the product. Toshiba, the world's leading notebook PC company in 1997, faced not only a sharp decrease in market share, but also mounting losses from its notebook PC unit. NEC, the world's second-largest notebook PC brand firm at the time, and other Japanese firms suffered similar fates. This led to a rapid increase in orders from Japanese lead firms to Taiwanese ODMs, but only for their lower cost models (see Sturgeon 2007). As time wore on, high-cost notebook PCs made in-house by Japanese lead firms were increasingly restricted to the Japanese market. In this way, lead firms across the notebook PC industry started to specialize in concept creation, brand marketing and the management of suppliers and to contract out mass production, product development, logistics, and after-service to Taiwanese firms.

In 2003, Intel again used its power as a platform leader to "encapsulate" another bundle of hard-to-integrate PC functions. This time their "Centrino" chipset added key power management features that made it suitable for mobile applications. Taiwanese ODMs provided the design expertise needed to generate a flow of new products based on the chipset, and soon dominated world production of notebook PCs.

To summarize, Intel has repeatedly used its platform leadership position in the PC GVC to capture a larger portion of the industry's profits. The emergence of readymade technological solutions with well-defined external interfaces encapsulated the most difficult electrical engineering problems, and the rewards for solving them, within Intel, and created a swarm of low-cost competitors to Japanese producers. Intel's platform strategies have repeatedly devalued the core competencies of lead firms in the notebook PC industry, especially Japanese lead firms, which have developed and relied on in-house system integration competencies more than U.S. firms have. A secondary effect, intended or not, was to create a larger role for Taiwanese ODMs in the industry, along with an ongoing set of opportunities for them to expand their competencies. Less system-level design work was required to create notebook PCs overall, but Taiwanese ODMs have taken on many new tasks, gained many new competencies, and grown rapidly—if not profitably.

China: Modularity and Competitive Outcomes in Mobile Phone Handset Industry

Despite China's attempts to nurture a group of former state-owned enterprises as national champions (or a "national team": cf. Nolan 2001; Sutherland 2003),[16] and recent announcements of a renewed focus on government purchases of "indigenous technology," little progress has been made. Rather, China's development in technologically intensive sectors such as electronics has been driven by close engagement in GVCs, with its export sector dominated by foreign financial, technological, and organizational resources. The success of this approach is underscored by the fact that nearly two-thirds of China's manufactured exports come from foreign-invested firms.[17] But what does this reliance on outside capabilities mean for development? On one hand, it has resulted in an unprecedented acceleration of industrialization. However, as was the case with Taiwan, once engaged, it can be difficult to move beyond low-value niches and to gain the autonomy and profits that can come with lead firm or platform leader status in GVCs. Song (2007) has shown how profits in China's electronics industries have become very thin, despite massive increases in labor productivity, in what he calls a "Chinese-style modularity trap."[18]

Imai and Shiu (forthcoming) provide an example of this from the domestic Chinese mobile phone handset industry. From 1999 to 2003, the market share of local firms soared from 5 to 55 percent, but subsequently—and very suddenly—local handset firms lost this ground to

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[16] This section is drawn from Imai and Shui (2006 and forthcoming).

[17] Four Asian economies—Japan; Republic of Korea; Taiwan, China; and Hong Kong, China— account for 70 percent of foreign direct investment in China (Hamilton and Gereffi 2009, 145). We should not forget that many mainland Chinese firms are small and localized. They produce a portfolio of highly commodified goods and services and engage in intense price competition with other local firms (Steinfeld 2004).

[18] Linden, Kraemer, and Dedrick (2007) estimate that China captures only a few dollars of the $300 retail price of every Apple video iPod exported to the United States.

multinational brands, notably Motorola and Nokia, as consumers began to expect products with color LCDs and increased functionality, such as MP3 music playback and cameras with both still and video capabilities. Local handset design houses did not have the competencies needed to bundle these new technologies in larger, more integrated design platforms, reopening the window for the multinational brands, whose deep internal design and system integration capabilities, built up over many decades, allowed them to rapidly retake market share.

This case provides an example of how the three GVC governance variables of complexity, codifiability, and supplier competence can contribute to explanations of competitive outcomes (Gereffi, Humphrey, and Sturgeon 2005). The introduction of new features, such as color screens, cameras, and audio playback, raised the technological requirements for mobile phone design and drove rebundling in the value chain for the low-cost mobile phones popular in China. Technological change shifted the location of key pinch points in the value chain, which, in short order, created and eliminated opportunity for different firms. On the one hand, rising competency requirements favored multinational firms, with their deep in-house design competence, but also the Taiwan-based IC design house MediaTek, which provided highly integrated chipsets that encapsulated much of the new functionality demanded by Chinese consumers. Losers were local handset firms and the independent design houses they relied on for system design.

As table 6 shows, China has suddenly become the world's largest producer, exporter, and consumer of mobile phone handsets. In 1998, a negligible 2.2 million handsets were assembled in China, just over 2 percent of world output. By 2005, production surged to at least[19] 300 million units, more than 37 percent of world output. This increase in production reflected three trends: (1) a worldwide boom in mobile phone sales, (2) the rise of China as a primary location for mobile phone handset production, and (3) the emergence of China as the largest single national market for mobile phones. From 1998 to 2005, worldwide mobile phone sales increased 25 percent per year, from 174 to 816 million units. As China's share of world production increased, the share of handsets produced for export increased from 55 percent to more than 75 percent. But the domestic Chinese market was also booming. According the Chinese Ministry of Information Industry, the number of mobile phone subscribers in China soared from about 25 million in 1998 to about 400 million in 2005. As handset sales surpassed 100 million units in 2003 and 2004, increased domestic production, along with import restrictions, caused imported handsets to fall as a share of sales.

[19] Imai and Shiu (2007, 5) note that this number likely undercounts production in 2005. A significant number of handsets in China are produced illegally, which could be a contributing factor.

Table 6 China's Mobile Phone Handset Production, Export, and Consumption, 1998 and 2005

Indicator	1998	2005	*CAGR* (percent)
Production			
World handset production (millions of units)	174	816	25
China handset production (millions of units)	4	304	86
China share of world production (percent)	2.3	37.2	
Exports			
China mobile phone exports (millions of units)	2	228	94
Export share of production (percent)	55.0	75.2	
Consumption			
China mobile phone subscriptions (millions of units)	25	400	49
China handset sales[a] (millions of units)	3	88	59
China handset imports (millions of units)	2	13	35
Import share of sales (percent)	47.1	14.5	

Source: Imai and Shiu 2007.

Note: CAGR = compound annual growth rate.

a.. Sales figures for 2003 and 2004 were 109 million and 100 million, respectively. While annual sales may have leveled off or even declined since the 2003 peak, because of saturation in urban markets, the figures for handset sales in domestic consumption probably underestimate the real total due to undercounted sales of illegal and quasi-legal handsets.

Handset sales in China's domestic market rose from 3.4 million units in 1998 to an astonishing 109 million units in 2003. The most successful multinational brands in China—market leaders Nokia (Finland), Motorola (Unites States), and Samsung (Korea)—account for 95 percent of exports and quickly came to dominate domestic sales as well. Local Chinese brands held just 5 percent market share in 1999, while together Nokia and Motorola controlled 70 percent of the market. As the domestic market took off, however, dozens of local handset brands appeared and were able to capture 55 percent of the market by 2003.

As Imai and Shiu (forthcoming; 2007) argue, the success of local firms can be explained by a combination of market opportunity and government policy. Multinational handset producers could not simply divert a share of export production to the local market. The feature-rich phones produced for export were too expensive for Chinese consumers, and those produced for export to the United States are incompatible with China's dominant mobile phone standard (GSM) in any case. While even the older GSM phone models sold by multinational firms in China were too expensive for most of the Chinese market, the more fundamental problem for multinational firms was the lack of variety in their lower end product lines. High costs and low product variety created a market opportunity for local cell phone handset companies, and local brands did well by selling simpler, less expensive handsets with a wide variety of exterior designs and other technologically superficial features.

On the policy side, in 1999 the Chinese government, through its Ministry of Information Industry, placed limits on imports by creating a licensing system for the production and marketing of mobile phone handsets. The dominant multinational firms were able to secure licenses though their joint ventures with China's major state-owned telecommunications operating companies, Eastcom and Capital, but these came with strict minimum export ratios and high local content requirements. The dozens of small local companies that were granted licenses did not face these requirements, but did face a different challenge, a lack of mobile phone design expertise.

Technical barriers in fast-moving and technologically complex products like mobile phones are high, but not as high as they might be, were there not so many options for purchasing mobile phone handset technology. While system-level mobile phone design requires a high level of competence, there are a variety of market solutions in the industry, from semiconductor "chipsets" that encapsulate key features of the phone to fully designed (ODM) phones. Price pressure and the need for high product variety favor system-level designs that add features and appealing exterior design to standard chipsets that perform the basic functions of the phone, such as converting voice to digital signals and back again and sending and receiving signals. This demand for system-level design and integration created an opportunity for a new cadre of Chinese independent design houses (IDH).

The largest Chinese IDH is Techfaith, a Shanghai-based company founded in 2002 by Motorola China's former sales manager; 11 of 13 executive directors were previously employed by Motorola China. Other IDHs, such as CEWC, SIM, Longcheer, and Ginwave, were formed by engineers from state-owned ZTE, Konka, and Cellon, a silicon valley IDH. Estimates vary, but Imai and Shiu (2007) estimate that up to 50 percent of the handsets sold by local producers are designed by local IDHs. Customers of the top five Chinese IDH firms shipped 31 million phones in 2005, a year when total reported handset sales were 88 million.

The largest local Chinese handset brands—Bird, Amoi, Lenovo, TCL, Konka (together accounting for about 20 percent of the market in 2005)—have inhouse design groups, but the dozens of other smaller players use IDHs exclusively. The advantage of IDHs is that they can pool design elements across horizontal segments. The IDH SIM, in its 2005 annual report, claimed that it sold 152 models based on 12 main boards (Imai and Shiu 2007, 19). IDHs are also suppliers, either directly or indirectly, to "guerilla" handset makers (illegal or quasi-legal handset companies) that purchase complete motherboards to produce simple imitations of models sold by well-known brands. By 2005, the market share of legal local brands had fallen to 40 percent (Imai and Shiu 2007, 6) and the Chinese IDHs were in deep trouble. Techfaith, for example, has retreated from contract design services and now survives mainly on contract assembly services. Guerilla handset makers are the only domestic firms in the sector that have continued to thrive after 2005. Concentrated in Shenzhen and Guangdong, they accounted for approximately one-fourth of the total production of handsets in China in 2009. They are highly dependent on MediaTek chipsets platforms that encompass communication and multimedia functions and survive on extremely thin profit margins (Kawakami, forthcoming).

The GVC governance dynamics of the Chinese mobile phone handset case are quite clear: competitive outcomes in the Chinese industry shifted as the GVC governance variable of complexity went up (see Gereffi, Humphrey, and Sturgeon (2005) for a discussion of key GVC governance variables, complexity, codifiability, and supplier competence). Rising complexity altered where the codified links in the chain had to be positioned. Local firms were forced to bundle new technologies in larger, more integrated platforms, which raised the competence level required to deliver handset design services. This was something that local design houses could not do, and Mediatek stepped into the breach with their own integrated platform. The competitive problem this posed for local handset makers was that the larger, more integrated platforms could not be as easily customized to create the differentiation on which the local handset firms based their competitive positioning. The local Chinese handset industry has been caught in a classic modularity trap.

Overcoming the Limits to Industrial Upgrading in Electronics GVCs

Such examples as the Chinese mobile phone handset industry reveal the opportunities, but also the challenges and limits to industrial upgrading in electronics GVCs. On the other hand, there are a growing number of important exceptions that suggest that new models of learning through close engagement in GVCs could be emerging, with broader lessons for developing countries (see Yeung 2009). As mentioned at the start, there are four identifiable models electronics companies from the developing world are using to escape these limitations: (1) global expansion though acquisition of declining brands (Emerging Multinationals), (2) separation of branded product divisions from contract manufacturing (ODM Spin-offs), (3) successful mixing of contract manufacturing and branded products (Platform Brands) for contractors with customers not in the electronic hardware business, and (4) the founding of factory-less product firms that rely on GVCs for a range of inputs, including production (Emerging Factory-less Start-ups). The analysis in this final section is derived from the authors' ongoing research and secondary sources covering very recent events and nascent trends. As such, it is more speculative and forward-looking and less certain.

Emerging Multinationals: Exceptions or the New Rule?

The case of Lenovo, a partially state-owned Chinese PC company, shows one way in which lead firms from developing countries have been able to overcome traditional barriers to upgrading their positions in GVCs.[20] In the mid-1990s Lenovo, benefiting from a protected market, emerged as the largest domestic producer of PCs in China. As import restrictions were lifted, however, Lenovo struggled to remain competitive, as have most developing country national champions in technology-intensive sectors. After the technology bubble burst in 2001, persistent low profitability in the global PC industry, for the reasons described earlier, led some of the largest multinational producers to exit the industry, precipitating a wave of acquisitions, most notably Lenovo's purchase of IBM's huge PC division in 2004.

The IBM purchase gave Lenovo a new headquarters in the United States with a large R&D center in North Carolina; an advanced notebook computer development facility in Japan;

[20] This section draws from Whittaker et al. (forthcoming).

three final assembly plants in China and one in India; regional distribution facilities in the Netherlands, Dubai, Florida, Australia, and India; and an important corporate planning, finance and business process development group in Singapore. The deal also came with a dense set of ongoing supply relationships, mainly with Korean, Taiwanese, and American component producers and contract manufacturers, the largest with global operations, to provide main boards, microprocessors, memory, disk drives, monitors, LCD screens, keyboards, and contract manufacturing services.[21] Lenovo's new American CEO, based in Singapore, was a former Dell Computer executive. He led a management team with top executives from China, the United States, Europe, and India. While it would be wrong to portray Lenovo as something other than a China-based company, the structure, geography, ownership, leadership, supply base, and sources of innovation at the new Lenovo were vastly different from the national champions that emerged in Japan and later in Korea.[22]

Lenovo can be seen as an example of a small but dynamic set of "Emerging Multinationals" (Bonaglia, Goldstein, and Mathews 2007), also called "Dragon Multinationals" by Mathews (2002) in the context of Chinese East Asia. In many cases, such firms can fairly be characterized as updated, globalized manifestations of traditional national champions. Additional examples include other Chinese firms such as Huawei (communications infrastructure equipment) and Haier (home appliances and consumer electronics), as well as firms from countries as diverse as Mexico (Mabe, home appliances; Cemex, cement) and Turkey (Arçelik, home appliances). As Bonaglia, Goldstein, and Mathews (2007) put it, "These new [multinational enterprises] did not delay their internationalization until they were large, as did most of their predecessors, and often become global as a result of direct firm-to-firm contracting. Many *grow large as they internationalize*; conversely, *they internationalize in order to grow large*" (p. 3, emphasis in the original). These companies have sometimes become global by "rolling up" (purchasing) smaller regional producers with well-known but declining brands using funds generated not so much by selling products or services in their home markets but by acting as suppliers to existing multinationals, tapping into international capital markets, and producing and selling globally.

What remains to be seen is whether these examples are exceptions that prove the rule or the vanguard of a new wave of multinationals with roots in the developed world. It is notable that all of the emerging multinational mentioned here, with the exception of Huawei and perhaps Lenovo, work in relatively mature product areas. It also remains to be seen whether companies from the developing world can prosper in the lead firm position without building up deep internal expertise in market and product definition organically or whether such expertise will continue to develop once it has been captured through acquisition.

[21] The IBM PC Division was in many ways the vanguard of "de-verticalization" at IBM, and the focus on design and marketing and select critical technologies and capabilities (e.g., integrated mouse pointer technology and notebook design in its Japanese "Thinkpad" design facility) is a prime example of what leading U.S. "manufacturing" firms had become during the 1990s though the process of co-evolution with their global (mostly Asian) supply-base.
[22] In 2007 Lenovo had 27,000 employees worldwide: 18,400 in China; 2,780 in the USA; 2,040 in Europe, the Middle East, and Africa; and 3,800 elsewhere. In terms of ownership, 45 percent of the company's shares were publicly traded; 6 percent were held by IBM, 7 percent by investment banks, 42 percent by its parent company Legend Holdings. The Chinese Academy of Sciences maintained 27 percent ownership of Lenovo through its 65 percent share of Legend Holdings (Ling 2006).

ODM Spinoffs: Settling for Scraps or Setting the Agenda?

During the recent economic crisis, the authors identified a set of significant successes for a set of Taiwan-based ODM Spinoffs, branded factory-less lead firms that have become legally independent from their former ODM contract manufacturing arms. Acer pioneered this model when it separated its branded PC business from its ODM contract manufacturing (Wistron) and PC peripherals (BenQ) businesses in the early 2000s. By so doing, the company successfully avoided competing with their ODM customers in final markets and put Wistron into position to compete with pure-play (that is, contract manufacturing only) ODMs such as Quanta and Compal, which had been winning huge contracts at the expense of Acer. In order to create viable conditions for the contract manufacturing business, spun off lead firms typically make aggressive moves to use non-affiliated ODMs for contract manufacturing services. For example, today Acer uses Quanta and Compal for the bulk of its contract manufacturing services; Wistron now ranks a distant number three. ASUSTek, founded by former employees of Acer in 1990, followed suit when it spun off Pegatron in 2008.

One case is the successful launch of “netbook” computers, the ultra-low-cost portable PCs, by Taiwanese branded firms. AsusTek first developed the idea for simple-to-use and ultra-low-cost portable PCs in 2006 and launched its first product, the “EeePC” netbook computer, in 2007 (Shih et al. 2008). The quick success of the EeePC set new expectations for PC consumers regarding PC prices and disrupted Intel's product roadmap, as well as those of competitors in the notebook PC market. Intel had promoted the development of low-price PCs for educational purposes in developing countries, but it had not envisioned or encouraged the netbook product space in *developed* countries. Intel responded by quickly adapting a newer processor, the Atom, developed primarily for embedded products and mobile devices, for use in netbook computers and other low-cost mobile electronics. Traditional branded PC lead firms like Dell and HP were not developing ultra–low-cost machines, not least because price erosion was a perennial concern. In response to the success of EeePC, these firms decided to enter the netbook market as well. Among them, Acer is by far the most successful follower; and a sharp increase in netbook shipments helped them surpass Dell to become the world’s second largest selling PC brand by the third quarter of 2009.

Even while moving away from formerly affiliated contract manufacturers, ODM Spinoffs are well positioned to leverage ODMs’ deep expertise in product definition and design. Proximity, both spatial and cultural, allows them to effectively collaborate with ODMs. For example, Acer’s rising competitiveness may stem from its ability to bargain with ODMs over terms of trade and to leverage their extensive knowledge of current business conditions, especially component availability and costs. Acer has good intelligence about the current business conditions and cost structures of individual ODM firms, and ODMs have difficulty hiding profits from Acer, in part because of the dense labor market in Taiwan’s technology sector (for example, several ex-employees of Quanta and Compal now hold key positions at Acer). Proximity to ODMs and easy access to the flow of information within Taiwan’s electronics cluster may be enough to sustain and even expand Acer’s competitive advantage in the PC industry.

During the economic crisis of 2008–09, the arrival of new platform solutions for low-cost mobile devices—Intel's Atom chipset and Google's Android operating system discussed below—have created new opportunities for ODM Spinoffs to identify and fill underserved market niches, especially for low- to mid-range products that established multinationals previously deemed unattractive. In a dynamic similar to that in the China mobile phone handset case—where local firms used MediaTek platforms to fill underserved low-cost and rural mobile phone handset market niches in China—Taiwan-based ODM Spinoffs are having success in low-end markets in both developed and developing countries. But instead of being easily pushed aside when consumers demand more sophisticated products, they appear to have the technological capabilities, and the close working relationships with ODMs, to move up-market into more lucrative segments for existing "mainstream" products.

The case of low-cost PCs recently developed by local companies from mainland China provides a useful contrast. Inspired by the success of MediaTek, an IC design house based in Taiwan called Via Technologies entered the netbook market with their own platform and by marketing their own low-cost PC chip-set platform to a set of small "guerrilla" PC makers in China. As with the China mobile phone handset case discussed previously, the problem for these firms is an inability to respond when consumers begin to ask for more sophisticated products. The guerrilla PC makers cannot add new features fast enough; preliminary analysis suggests that consumers in China are moving to products from HP, Acer, and Lenovo when they upgrade.

Platform Brands: Leveraging Modularity to Define New (Low-end) Product Categories

As shown earlier, competing with customers has proven to be a poor strategy for ODM contract manufacturers. Most ODMs have either given up their brand aspirations or legally separated their branded product business from their contract manufacturing business. A few, however, have been successful in selling branded products, based on highly integrated platforms, in markets that are of little interest to their main contract manufacturing customers. One such company is ASUSTEK, which a long successful business selling branded PC motherboards to "value-added resellers" that assemble custom desktop PCs for individual end users and small companies, an especially popular sales channel in Europe. Overall, this sales channel has remained small and is of little interest to dominant PC brands.

A more current example is HTC, a Taiwan-based mobile phone handset ODM founded in 1997. At first, HTC developed handsets branded with the logos of carriers such as Orange, 02, T-Mobile, Vodafone, Cingular, Verizon, Sprint and NTT DoCoMo (company website). More recently, HTC won the ODM contract for the G1 Smartphone, based on Google's Android software operating system. Shortly after the G1 hit the market, HTC began selling its own Android-based phone using the HTC brand. In this case, mixing ODM contract manufacturing with the selling of branded products has not created a conflict because Google is not interested in generating profits from selling phones under its own brand. In fact, the opposite is true. The G1 was launched with the intention of gaining platform leadership in smartphones and other Internet-enabled portable electronic devices. Even Android licensing is of little interest to Google as a revenue-generating business. Their main goal is to provide more mobile users with easy access to the Internet, where Google's search engine and other online Google services expose them to Web advertising, Google's main source of revenue. In the context of Google's business model, HTC branded phones are welcome. If Android takes hold in mobile electronics, opportunities for HTC and other firms with the design capabilities to become "Platform Brands" could expand rapidly.

Emerging Factory-less Start-ups: Moving into the Driver's Seat?

Recently, a few firms from developing countries have been able to engage in pure systems integration, assembling system elements purchased through the global supply base. In this sense, they resemble factory-less start-up firms typically seen in advanced technology regions such as Silicon Valley, California. Such firms may or may not have a strong technology kernel, but they inevitably have a clear product roadmap and marketing strategy, and rely on a host of technology and (if needed) manufacturing partners to realize their finished products or services. An example from the automobile sector is Chery, a small state-controlled Chinese automobile company based in Wuhu, some 200 km west of Shanghai. The company has been able to develop and market a line of Chery-badged vehicles within a remarkably short time by making use of the supply base, both within China and in the West, for a full range of inputs, from parts to process technology to design expertise.[23] These sourcing arrangements, which have only recently become readily available for fledgling companies like Chery to piece together, show that Chery is nothing like a typical car company, and that it is far removed from the most recent entrants to the mass market for cars, the vertically integrated and horizontally diversified national champions from Korea: Hyundai, Kia, and Daewoo.

Similar cases from the electronics industry can be found in the area of portable global positioning (GPS) and portable navigation devices (PNDs). Until the early 2000s, the mobile navigation market was dominated by Japanese manufacturers such as Pioneer, Panasonic, and Clarion. These firms supplied automakers with very sophisticated systems with rich functions. Because U.S. government policy limited the accuracy of global positioning system (GPS) signals prior to 2000, the systems developed by Japanese electronics firms relied on comparisons of measured distance and direction traveled to on-board map databases. While some of these systems were sold as aftermarket products, many were supplied directly to automakers for inclusion as optional in-dash original equipment on new cars. These firms worked closely with auto makers to customize products and meet strict quality standards. Their products had integral system architectures based on proprietary technologies developed in-house and were extremely expensive, as much as one-tenth of a car's sale price.

In the early 2000s, the availability of more accurate GPS signals allowed a set of start-up PND makers to enter the market with ultra-low-cost aftermarket products that quickly began to erode the profits and market share of traditional car navigation makers. Among the market share leaders today are Netherlands-based TomTom, U.S.- and Taiwan-based Garmin, and Mitac, based

[23] For styling and engineering, Chery works with Italdesign, Pininfarina and Torino in Italy. Additional engineering and development work is outsourced to Lotus Engineering and MIRA in the UK and to Porsche Engineering in Germany and Austria. It works with AVL in Austria on gasoline and diesel engines, and with Ricardo in the UK on hybrid powertrains. Heuliez in France supplies a retractable hardtop for the Chery A3 coupe cabriolet, a car designed by Pininfarina. For critical parts and subsystems, Chery sources from global suppliers such as Bosch, ZF, Johnson Controls, Luk, Valeo, TRW and Siemens VDO (Whittaker et al. forthcoming).

in Taiwan. These Emerging Factory-less Start-ups are able to produce affordable products by making heavy use of Taiwanese ODMs' capabilities in designing and manufacturing portable electronics. In contrast to the integral architecture of in-dash car navigation systems, PNDs have highly modular architecture, which lowers development costs. PNDs initially cost only $500–1000, but today TomTom's lowest cost model sells for less than $100. This affordability opened up new markets, such as handheld GPS, and world shipment of PNDs grew from less than 1 million units in 2004 to more than 10 million units in 2006 (Nikkei Electronics 2007). While not all of these companies are fully based in Taiwan, they are all making heavy use of Taiwan-centered supply-base capabilities. Tom Tom outsources to Inventec and Quanta. Garmin was founded in the United States by a Taiwanese immigrant entrepreneur; R&D and production are both located in Taiwan. Mitac itself is a Taiwanese IT hardware company.

Again, companies that jump to the head of GVCs in this way are quite common in the industrialized world. Many are started in Silicon Valley each year, for example. But without the backdrop of a technology cluster with the capital and intellectual resources of Silicon Valley, Emerging Factory-less Start-ups may be unable to develop the deep design, system integration, and market-defining expertise that would allow them to compete at the vanguard of fast-moving markets. On the other hand, with close relationships with the world's most dynamic set of EMS and ODM contract manufacturers, it seems inevitable that an increasing number these firms will meet with success over the long term.

Crisis and Convergence

The recent economic downturn has created a seemingly conducive climate for the implementation of these new models, as shown by the following scenarios. First, traditional Intel customers, the branded PC lead firms, were displeased with the sudden arrival of small, portable netbook computers selling for less than $300, but Intel's quest for business during the crisis may have allowed it to overlook the objections of its traditional customer base. Even without Intel's cooperation, the appearance of excess Celeron stock in distribution channels provided the first opportunity for ASUSTek's EeePC. Second, the economic downturn introduced a new cost-consciousness among consumers in developed countries that made netbooks and PNDs attractive options. The downturn also heightened the search for new markets, and those with the greatest potential for growth are in developing countries, where netbook computers and PNDs may serve as ideal entry-level machines.

In the past, PC standard platforms were largely used in PC-related products, and ODMs were mostly confined to that market. Very recently, the arrival of highly functional but low-cost platforms like the Intel Atom chipset and Google's Android operating system is driving product convergence in netbooks, smartphones, and PNDs. Intel's Atom chipset, for example, is being used in netbooks, PNDs, embedded systems, and the new Google TV platform. This may be disrupting the status quo and improving the competitive position of ODMs. The introduction of new software-based platforms from companies with no direct prior involvement in the PC industry, such as Google, may be opening up new strategic space for ODMs. By combining new platforms with the capabilities of ODMs, lead firms appear to be able to quickly launch products that cross traditional product boundaries. In this way, convergence is creating a broader market for both ODM contract manufacturing services and new opportunities for Platform Brands and ODM Spinoffs. These trends may finally steer the Taiwan's electronics industry out of the (albeit very large and expanding) cul-de-sac of PC design and manufacturing and into the larger innovation system of the electronics industry.

Conclusions

This paper has summarized the evolution of GVCs in the electronics industry and highlighted some recent developments that have come into focus during the 2008–09 economic crisis. It shows the increasingly important role the electronics industry has played in GVC formation since 1988. One enabler of this is value chain modularity, which allows firms and work groups to collaborate on relatively complex projects from a distance. As companies have learned how to instigate, sustain, and expand these cross-border collaborations, electronics GVCs have expanded rapidly. The result is an industry that is both spatially dispersed and tightly integrated. Three key actors were identified in electronics hardware GVCs: lead firms, contract manufacturers, and platform leaders. Modularity, in the realm of both product architecture and industrial organization, has opened strategic space for all three of these GVCs actors. In particular, modularity has allowed the industry's most successful platform leaders to continually stake out and hold key territory in the industry's technological landscape. The strategic moves of platform leaders such as Intel, therefore, can trigger changes across large swaths of the industry.

A key to GVC development, as argued here, is the emergence of deep supplier capabilities, most recently in contract manufacturers based in Taiwan, the United States, and Singapore. Consolidation, both organizational and geographical, has cemented the position of these firms as critical actors in electronics GVCs. Since the largest contract manufacturers have established facilities throughout the world and are purchasing huge volumes of electronic components on behalf of their customers, their investment and purchasing decisions influence industry trends in less developed countries like Malaysia, the Philippines, Thailand, Vietnam, and Mexico. Clearly, the crisis is causing GVCs in the electronics industry to undergo further consolidation, both organizationally and geographically. It may be that the firms in the Taiwan/China nexus are joining firms based in places like the United States, Japan, and Europe as key players in the global innovation system of electronics industry—not just the production system.

The experiences of electronics contract manufacturers provide examples of both the limits and opportunities for suppliers in electronics GVCs, and thus serve as important lessons for latecomer firms from developing countries. However, given the integrated nature of the global electronics industry, latecomer firms have to consider global suppliers not only as examples but as potential dominant competitors as well. While the barriers created by recent developers are substantial, there are few zero-sum games in an industry as dynamic as electronic hardware. As this paper argues, new models for GVC participants may be emerging that will allow latecomer firms to leverage, rather than seek to supplant, the deep capabilities that have built up in the global electronics supply base over the past 20 years.

If we are to draw any lessons from the long history of GVC development discussed, it is a lesson against stasis and for continuous change and opportunity. Assumptions about industry life cycles, where product segments stabilize as the industry matures, do not seem to apply to the electronics industry. At the same time, long exposure to the industry's rapid but volatile growth and the sudden emergence of immense new market opportunities (for example, the PC, the mobile phone, and the Internet), has allowed electronics companies in the developing world to build up extraordinary capabilities. We need to ask, not how emerging economies can repeat the experiences of successful recent developers like Taiwan and Singapore, but what roles might be available in electronics GVCs in the future. Newcomers should seek to avoid the pitfalls and limits of GVC engagement and supplier-led upgrading outlined here, certainly; however, in an integrated global industry, this has proven to be exceedingly difficult, even for firms with established roles in the industry and deep expertise in their GVC niche.

Looking forward must instead consider the possibilities of using the same palette of globally distributed capabilities that firms in the industry see, as well as acknowledging the expanding potential for new combinations. The combination of value chain modularity and deep capabilities in multiple locations will continue to create huge opportunities for both suppliers and lead firms in electronics GVCs. Lead firms have options to assemble and reassemble GVC elements in new ways for new markets and products that did not exist even a few years ago. Dynamic change is nothing new in the electronics industry (see Brown and Linden 2009). However, going forward, new industries and value chain combinations will inevitably include more firms—lead firms, contract manufacturers, component suppliers, and even platform leaders—based in newly developed and developing countries. We can anticipate, if nothing else, a spate of new lead firms born in developing countries without the expectation that they will need to move up the contract manufacturing ladder in their efforts to become branded companies. Today, more GVC elements are available than ever before, either for sale or for hire, and it is only a matter of time before one, and then several new, world-beating electronics companies arise from the developing world to dominate some as-yet-unknown product area in the ever-expanding electronics industry. We may look back on the crisis of 2008–09 as an inflection point where firms from the developing world began to lead, rather than follow, the development of the global electronics industry.

Annex: Solectron's Operations at the Height of Global Expansion

Table A.1 Solectron's Operations, 2001

Region	Regional head-quarters	Manufact-uring	Materials manageme nt	New product introductio n	After-sales service	Tecnology developme nt
Asia Pacific						
Taipei, Taiwan	X					
Singapore		X	X	X		
Johor, Malaysia		X	X	X		
Penang, Malaysia		X	X	X		X
Suzhou, China		X	X			
Penang, Malaysia		X	X			
Wangaratta, Australia		X				
Singapore			X			
Liverpool, Australia				X		
Bangalore, India						X
Tokyo, Japan	X					X
Kanagawa, Japan			X	X	X	
Europe and Middle East						
	HQ	Mfg	Mat	NPI	Serv	Tech
Reading, U.K.	X					
Bordeaux, France		X	X	X		X
Herrenberg, Germany		X	X	X		
Munich, Germany		X	X	X		X
Östersund, Sweden		X	X	X		X
Istanbul, Turkey		X	X	X	X	
Dublin, Ireland		X	X			
Carrickfergus, N. Ireland		X	X			
Dunfermline, Scotland		X	X			
East Kilbride, Scotland		X	X			
Timisoara, Romania		X	X			
Longuenesse, France		X		X		X
Pont de Buis, France		X			X	
Cwmcarn, Wales		X				
Norrköping, Sweden			X	X		
Tel Aviv. Israel			X			
Port Glasgow, Scotland				X		
Irvine, Scotland						X
Stockholm, Sweden						X
Americas						
Milpitas, CA, U.S.	X	X	X	X	X	
Fremont, CA, U.S.		X	X	X		
Austin, TX, U.S		X	X	X		X
Charlotte, NC, U.S.		X	X	X		X
Columbia, SC, U.S.		X	X	X		

Region	Regional head-quarters	Manufact-uring	Materials manageme nt	New product introductio n	After-sales service	Tecnology developme nt
San Jose, CA, U.S.		X	X	X		
Atlanta, GA, U.S.		X	X	X	X	
Westborough, MA, U.S.		X	X	X		
Suwanee, GA , U.S.		X	X	X	X	
Fremont, CA, U.S.		X	X			X
Everett, WA, U.S.		X	X			
Raleigh, NC, U.S.		X		X		
Aguadilla, Puerto Rico, U.S.		X				
Aguada, Puerto Rico, U.S.		X				
Los Angeles, CA, U.S.					X	
Austin, Texas, U.S.					X	
Memphis, TN, U.S.					X	
Louisville, KY, U.S.					X	
San Jose, CA, U.S.						X
Vaughn, Canada					X	
Calgary, Canada		X				
Guadalajara, Mexico		X	X			
Monterrey, Mexico		X	X	X		
São José dos Campos, Brazil		X	X	X	X	
Hortolândia, Brazil		X			X	

Source: Solectron company website

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