

## Chapter 16

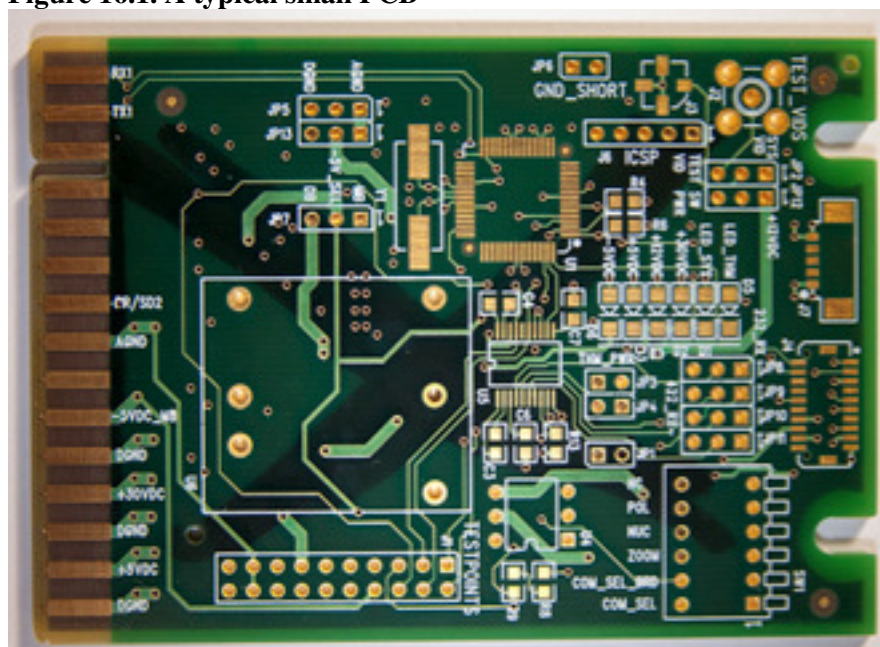
# Manufacturing of Printed Circuit Boards in Canada

*Ben Shepherd<sup>1</sup>*

### 16.1. Industry Overview

Printed circuit boards (PCBs) are used in a wide variety of electrical equipment and electronics goods, including consumer electronics such as computers. PCBs provide mechanical support for electronics components, and connect them using conductive tracks and other features. The essence of producing a PCB is to take a conductive material, typically copper (but see also the case of aluminum for quantum computing applications, below), and laminate it onto a non-conductive substrate. PCB features are then etched onto the copper using chemicals. Figure 16.1 shows a typical small PCB.

**Figure 16.1.** A typical small PCB

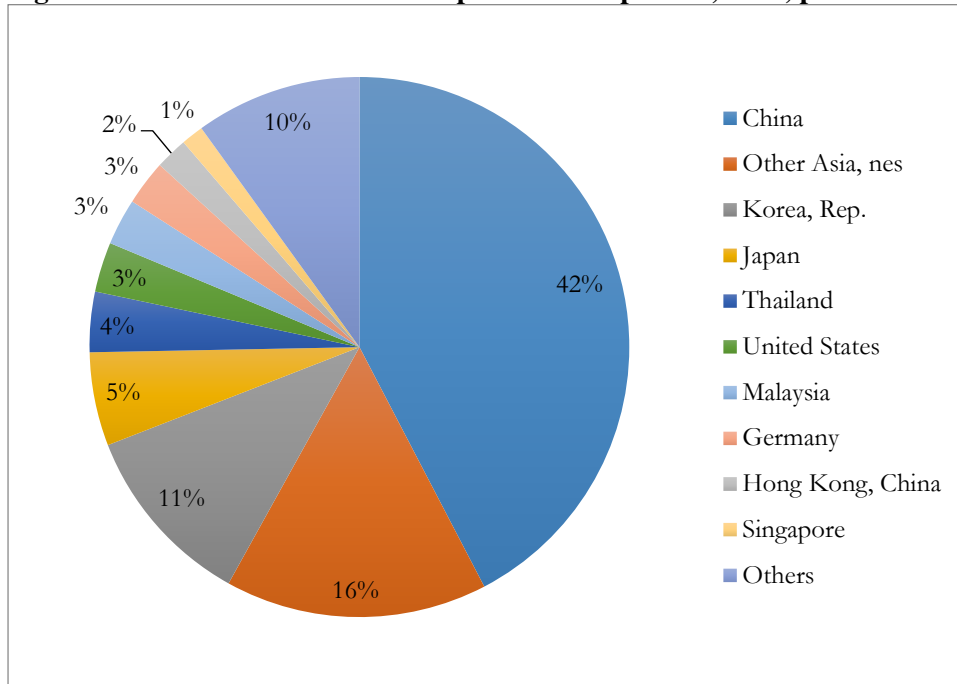


*Source: Case study firm*

World exports of PCBs amounted to \$39.5bn in 2014, with Asia the main center of export production, in particular China (Figure 16.2). Importing is more geographically dispersed, with Europe and North America figuring prominently, but Asia again dominant (Figure 16.3). Extensive two-way trade in similar products therefore characterizes the market.

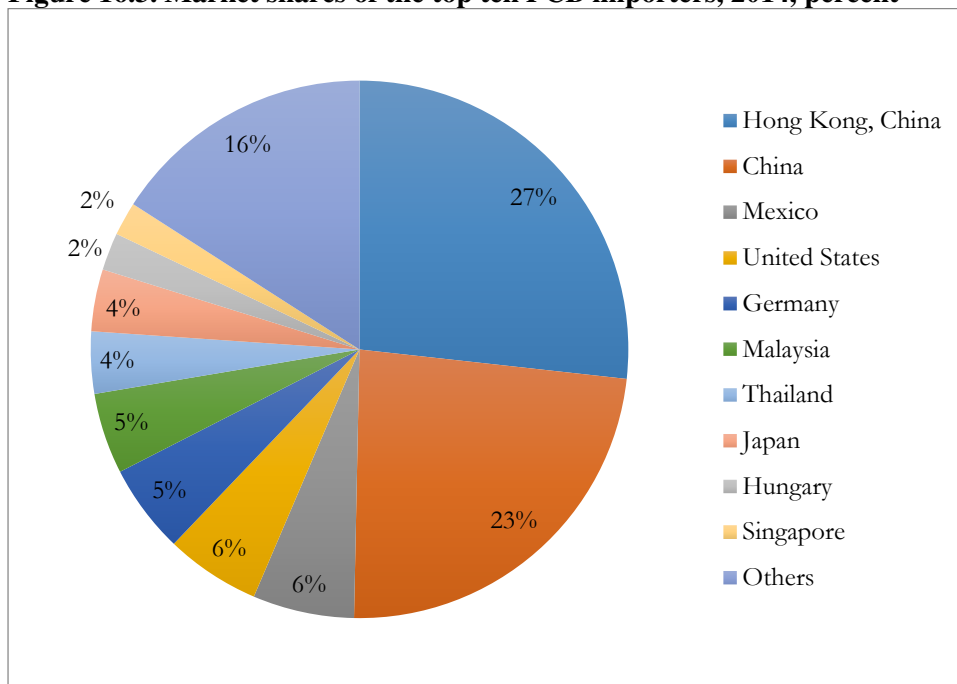
<sup>1</sup> Principal of Developing Trade Consultants

**Figure 16.2. Market shares of the top ten PCB exporters, 2014, percent**



Source: UN Comtrade via WITS; author's calculations

**Figure 16.3. Market shares of the top ten PCB importers, 2014, percent**

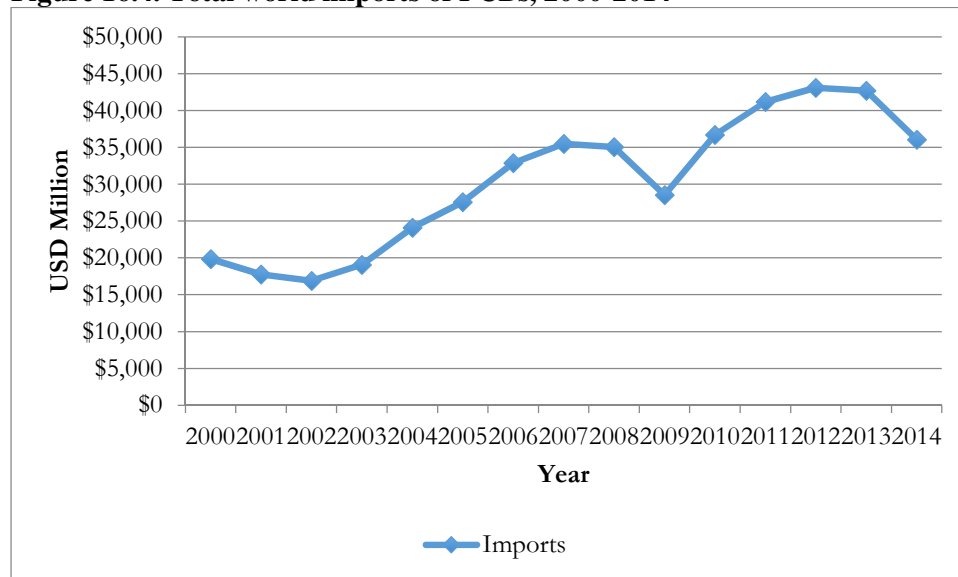


Source: UN Comtrade via WITS; author's calculations

PCBs are electronics components that serve as inputs into a large number of value chains, both local and global in scope. PCB manufacturers occupy a mid-range position in terms of typical electronics value chains. They are downstream from designers, who create the patterns of circuitry that manufacturers etch onto the PCBs. But they are upstream from final assemblers, who bring together PCBs with electronics components such as integrated circuits, resistors, and capacitors to create finished goods.

PCBs are widely used products, but although demand is increasing overall (Figure 16.4),<sup>2</sup> production has steadily been shifting from developed to developing economies, particularly China. In North America, for example, 257 out of a total of 567 PCB manufacturers have closed over the last ten years. The industry is widely regarded as being in the sunset stage in most segments, so production costs and lead times are important determinants of commercial success. There is also a perception in some quarters that more stringent environmental regulations<sup>3</sup> in developed economies are in part responsible for the migration of the industry towards locations where environmental rules are not enforced with the same rigor.

**Figure 16.4. Total world imports of PCBs, 2000-2014**



Source: UN Comtrade via WITS; author's calculations

## 16.2. Background Information on the Firm

Against this background, the case study firm, a Canadian company, has been doing business since 1985 in Richmond, British Columbia. Having started in supporting the graphic arts industry, it branched into PCB production during its first two years of operations. It now works out of a 7,000 sq. ft. facility near Vancouver International Airport. All production equipment is owned by the firm as a historical legacy, not leased.

The firm is a small business, currently employing ten staff. Market conditions are difficult, as noted above: over the last five years, sales have decreased at a rate of about 6%. However, the company's website is very effective in generating sales: orders increased by 57% year on year through this channel. The case study firm specializes in three lines of business. The first is production runs of proven PCB designs. The second is production of new designs, typically for equipment, based on information supplied by the customer. The third is production of aluminum based PCBs for cutting edge quantum computing applications. In the first two business lines, the case study firm's short lead times—three and five days respectively—help it compete with overseas producers, which need to factor in much longer transport times in addition to production times.

<sup>2</sup> The 2014 figure is likely understated due to reporting lags in WITS.

<sup>3</sup> PCB manufacturing uses strong chemicals for the etching process. Those chemicals have to be handled and disposed of in particular ways. Also, there is residue (waste) produced from etching. In this regard, stringent environmental regulations can become a factor for relocation decisions of PCB manufacturing firms.

The case study firm's production runs for these two business lines are typically small. For larger orders, it uses offshore suppliers. Typically, the case study firm's customers are technology companies and start-ups. The case study firm accompanies them from the early stages of development, up to the point where they reach a level of sophistication and scale where they can deal with offshore producers directly.

For the production of standard circuit boards and new designs, the case study firm typically deals with Canadian firms. Most business comes through established relationships that have been in place for some time, or through the company's website, which allows potential customers to upload a design and receive an estimate. A common example of a device in which the case study firm's PCBs are used are testing equipment in the oil sector, which is an important industry for Canada. In many cases, these probes are destroyed during use, so there is consistent demand for production.

The most innovative part of the case study firm's business is its production of aluminum-based PCBs for quantum computing applications in commercial businesses. Whereas traditional computers function on the basis of bits—which can either take the value of one or zero—quantum computers use “qubits”, which can be one, zero, or any quantum superposition of those two states. In theory, quantum computing offers the potential for significant gains in computing power and speed over traditional computers, although the technology is still in the development stage. Major breakthroughs are likely in the coming years. The case study firm appears to have been the first company globally to manufacture aluminum PCBs for use in quantum computing applications. Aluminum PCBs have important properties relative to the traditional copper alternative, and they are exploited in applications such as quantum computing. For example, aluminum PCBs can be used in low temperature superconductive environments, as well as in applications where the radiation absorption properties of aluminum are important.

The case study firm's involvement in quantum computing through the production of aluminum PCBs is more international in focus than its core businesses, even though the market is very much a niche—it is partly for that reason that larger companies have not entered it. The case study firm deals with world-renowned commercial and research organizations. The value chain for production of quantum computer applications is more internationalized than, for example, the energy value chain referred to earlier. The case study firm deals with international clients and ships its products overseas: it is an SME that is actively involved in exporting in this part of its business. To the best of the company's knowledge, it is currently the only provider of aluminum circuit boards worldwide.

At various points in its history, the case study firm has received assistance from the Business Development Bank of Canada (BDC). For example, the Bank played a role in enabling the current team to acquire the business three years ago.

### **16.3. Description of the Value Chain**

Although the three main business lines at the case study firm are distinct in respect of some important characteristics, they also have important similarities that make it possible to analyze their operation from a value chain perspective in a unified way. That is the approach taken in this section—to discuss the case study firm's operations in a general way, entering into specifics in relation to the role of services in the value chain, and in particular the decision to source services in-house or through a third-party provider.

As a general proposition, services are important intermediate inputs at a variety of points in the value chain. Overall, the company estimates that services account for around 14% of total costs. Some services are provided in-house, while third parties supply others. As a small business, the case study firm constantly faces the trade-off of the cost involved in using outside suppliers versus the cost and difficulty of acquiring the necessary knowledge and practice in house.

The following sections describe the case study firm's production process, from customer conception through to delivery and after sales follow up, and also discusses the role of general support services and back office functions. Full details of the firm's use of services by Central Product Classification code are provided in the tables at the end of the case study. In total, the firm uses 40 different types of services according to that classification at all points during its production process. Seventeen of those services are supplied in house only, 13 are supplied by unrelated third parties, and ten are supplied through a combination of those two means. As these numbers indicate, services are obviously important to the firm's operations, and its ability to link with suppliers and customers. Services are therefore an integral part of the value chain in this case, even though there is relatively heavy reliance on in-house supply due to the company's small size.

### *Pre-Manufacturing: Design, Materials Sourcing, and Logistics*

In all cases, it is the customer who undertakes design of the PCB layout. The customer submits the design to the firm, which provides an estimate for manufacture. If the estimate is accepted, there is a purchase order for a given number of units, and an order certification. The firm only provides input on the design if there is a blatant error, or if there is some technical problem with the design that makes it impossible to manufacture.

The only exception to this approach, and it is a partial one, is for the aluminum-based PCBs. They were developed in-house, using the case study firm's expertise, including conducting experiments and tests. So in this one particular case, in-house research and development services were important. Although the technology is finding cutting edge applications, the case study firm has not been able to protect it by patents because NASA scientists originally developed the methods in the 1960s, and thus are in the public domain.

Materials are sourced from a variety of locations. One important input is copper, which comes mostly from the USA (80%) and Canada (20%). Aluminum is sourced from Europe. Chemicals used in the photolithography process are sourced from Asia.

Services are important at this stage in the value chain. For instance, a customs clearance agent is used to facilitate the flow of raw materials from overseas, with advantages in terms of compliance and risk management. Other services are provided in-house, such as quality assurance based on ISO standards, and storage and inventory management. The decision to store goods in-house is based largely on the company's scale of operations: there is a clear advantage to keeping operations under one roof, and not outsourcing this particular function. It is also part of the company's strategy of ensuring fast order turnaround—a matter of just a few days in most cases.

### *Manufacturing Process*

Production takes place in-house, at least until the customer reaches a level of scale and sophistication where outsourcing needs to be contemplated. In that case, offshore facilities in Chinese Taipei are used: the design, which has already been produced in small numbers by the case study firm and has proven itself, is sent to the offshore partner, the article is produced at scale, and it is sent back to the customer. In the production process, the case study firm brings together raw materials and the customer's design to make the final product, typically first as a prototype, and then in whatever number the customer orders.

Scale plays a key role in the provision of services during the manufacturing phase of the value chain. The production process needs to be controlled so that uncertainties as to quality and execution can be minimized. It is therefore important to have access to expertise, and the key determinant of the case study firm's sourcing decision is whether or not the relevant knowledge exists in-house. If it does, the

scale of the business means that there is a clear preference for leveraging internal capabilities. For instance, the case study firm has a chemist to assist with the production process itself, and this person is a member of staff, so the provision of production management services and engineering advisory services is in-house. Similarly, all repair and maintenance is done in-house, as is product testing and analysis.

Respecting environmental regulations in relation to chemicals used in the production of PCBs, as well as waste products, is a key issue for the case study firm. The company uses a combination of in-house expertise and third-party provision to ensure that waste materials are sent to the appropriate locations for disposal or processing. Some of the waste is used by a third party to reclaim copper, which is then of commercial value. Wastewater is evaluated as to composition by a third party laboratory, to ensure compliance with domestic laws and regulations.

In terms of administrative services, they are mostly provided in-house. The main exception to that approach is for payroll: a third party provider takes care of calculating wages, benefits, and tax and social security withholding amounts.

### *Post-Manufacturing*

This phase of the chain refers to activities such as delivery and sales. As in other stages, the case study firm's small size means that it relies on in-house expertise whenever possible, but uses third party providers whenever it is cost-effective and efficient to do so. This part of the process involves a number of services elements, which are discussed separately.

Packaging of PCBs takes place in house, and shipping documentation is also prepared within the firm. After that point, however, third party service providers intervene. Given the short lead times that are an important part of its competitive advantage, the case study firm uses courier services to ship goods to the customer. A third party also supplies customs clearance services.

### *Post-Sales Services*

The case study firm's PCB are intermediate goods for the production of other electrical goods and electronics products. Once received by the customer, they are combined with other inputs to make a more advanced product, or even a finished consumer good. Some of the case study firm's products find industrial applications, as already mentioned, for example in the energy industry in Canada.

Of course, post-manufacturing support is important for the case study firm's customers. The case study firm retains an image of each and every PCB that is produced. If a difficulty arises, the customer sends an image of the area of the PCB with a problem. The firm examines the issue, and takes responsibility if necessary. Alternatively, the company may repair or replace the units in question. All of this activity is undertaken in-house.

### *Back Office, Utilities, and General Services*

In addition to production-specific processes, the case study firm also requires services inputs to keep the business operating properly, and to ensure compliance with relevant reporting requirements and financial obligations. Again, it uses a mix of in-house provision wherever possible, and third party provision when the cost and efficiency benefits are significant.

An example of the ways in which these two strategies work together is in relation to accounting. Day to day accounting work and monthly summaries are produced in-house. However, year-end work—

including tax compliance—is outsourced to a third party provider. Similarly, a mix of in-house and third party provision is used for insurance: medical insurance for employees is organized in-house, and a broker is retained for general insurance purposes to ensure that optimal insurance values and premiums are obtained. Insurance is waived on incoming shipments and instead the most reliable couriers are used—a factor that reduces shipment costs by as much as 30%.

It was noted above that BDC played a role—including the provision of financing—in enabling the current team to acquire the case study firm. In addition, it also provides business-consulting services. BDC goes over the company's financials and provides feedback, which is then incorporated into operations as appropriate by management.

Marketing is important for the case study firm, given the competitive nature of its industry. As previously noted, its website is an important channel for generating business, including in the cutting edge area of aluminum PCBs. Development and maintenance of the site are outsourced to a Canadian firm. More generally, IT services are both provided in house—the case study firm employees developed the company's network, for example—and outsourced, such as website development and email.

Even though the case study firm is a small business, research and development plays an important role. As previously noted, it appears to be the first manufacturer globally of aluminum PCBs used in quantum computing applications, for example. It has engaged with third party service providers as part of its research and development efforts, including the University of British Columbia, and the National Research Council of Canada. The Canadian government directly supports research and development activities through cash payments, but the case study firm's customers have also been active supporters in this area.

## **16.4. Looking Forward: Challenges and Opportunities for the Value Chain**

As noted at the outset, the PCB industry in North America has been shrinking in terms of the number of operators, in the face of increasingly strong competition from overseas, particularly Asia. The case study firm's sales have been declining, although should quantum computing take off as a technology, the company is well positioned to take advantage of new market opportunities, as it has already established links with key organizations in the sector.

The case study firm deals with international suppliers and customers in all aspects of its business, and in some cases offshores production to Chinese Taipei once a certain volume is reached. However, its value chain is perhaps more Canada-focused than others considered in this project. Nonetheless, the company very much fits the standard view of a value chain participant, namely a specialist in performing a particular task that is combined with others in complex ways to produce a final product. It is important to highlight that the case study firm deals with global companies, including Canada-based companies that are foreign invested, as well as multinationals like UPS and FedEx for courier and delivery services. The world market for PCBs is growing, and although there is a structural shift in production to low cost economies in Asia—perhaps also due to more general movement of the electronics cluster to that part of the world—there is still room for niche operators like the case study firm to enjoy considerable success.

In terms of the challenges faced by the business, a key one relates to environmental compliance. This area is believed to be—along with cost differentials—a major advantage for some Asian producers, where regulations are not as stringent as they are in Canada. As a small business, the case study firm needs to invest considerable resources in staying abreast of constantly changing environmental regulations. It uses chemicals that have environmental impacts and need to be disposed of appropriately. Environment Canada issues rules for individual chemicals, so companies like the case study firm constantly need to go back through their production processes to see if they use each one, and then comply with the relevant regulation. The case study firm is involved in an industry task force that is

working to streamline the process as it applies to PCB manufacture. Limiting compliance costs is a key concern going forward.

Another issue the case study firm faces is in dealing with large, lead companies. Given their scale, approaches can sometimes appear bureaucratic to a much smaller and more nimble operator. Although the case study firm deals directly with some international clients, its most obvious path to internationalization as a small business is through developing linkages with lead firms that export. To do that, it will need to address the issue of how best to interface with them, given differences in business practices and outlooks. Related to this issue is the development of new sectors of activity, like quantum computing. The technology offers real potential, and the case study firm has developed a competitive advantage. However, if it is to move to scale, it will be important to develop strong links with key operators, including service companies that are potentially important players in this emerging value chain.



## Appendix A

**Table A.1. Establishment phase**

<i>Stage/ Category</i>	<i>Service</i>	<i>Central Product Classification (CPC) Ver.2 Code</i>	<i>Please mark (X) if the service is used in your supply/value chain</i>	<i>Supplied in-house</i>	<i>Supplied by another company in the group</i>	<i>Outsourced to third-parties</i>
<b>1. Government services (licensing etc.)</b>	Business liaison services (for example, services from trade development centres or SME centres)	Class of 9113 - Public administrative services related to the more efficient operation of business	X			X
	Company registration and licensing services	91138 - Public administrative services related to general economic, commercial and labor affairs	X	X		
	Information and statistical services	Class of 9113 - Public administrative services related to the more efficient operation of business	X	X		
<b>2. Other services (professional etc.)</b>	Banking and finance services	71121 - Deposit services to corporate and	X			X

		institutional depositors				
		71135 - Non-mortgage loan services for business purposes				
	Legal services	82130 - Legal documentation and certification services	X	X		X

**Table A.2. Raw materials/inputs pre-production phase**

Stage/ Category	Service	Central Product Classification (CPC) Ver.2 Code	Please mark (X) if the service is used in your supply/value chain	Supplied in-house	Supplied by another company in the group	Outsourced to third-parties
1. Procurement of raw materials	Procurement agent for raw material sourcing	85999 - Other support services n.e.c.	X	X		
	Customs-related services for raw materials imported	85999 - Other support services n.e.c.	X			X
	Quality assurance services (of raw materials)	83441 - Composition and purity testing and analysis services	X	X		
2. Logistics	Freight transportation services (of raw materials) by road, rail, sea or air	Division: 65 - Freight transport services	X			X
3. Storage	Storage of raw materials – general storage	67290 - Other storage and warehousing services	X	X		
4. Product Design	Conception and design of product	83920 Design originals	X	X		
	Industrial design	83912 Industrial design services	X	X		

**Table A.3. Manufacturing phase**

<i>Stage/ Category</i>	<i>Service</i>	<i>Central Product Classification (CPC) Ver.2 Code</i>	<i>Please mark (X) if the service is used in your supply/value chain</i>	<i>Supplied in-house</i>	<i>Supplied by another company in the group</i>	<i>Outsourced to third-parties</i>
<b>1. Production administration</b>	Production Administration - Production management	83115 - Operations management consulting services	X	X		
	Production Administration - Repair and maintenance of factory equipment	87156 - Maintenance and repair services of commercial and industrial machinery	X	X		
	Production Administration - Quality assurance and compliance with ISO	83441 - Composition and purity testing and analysis services	X	X		
<b>2. Services supporting factory daily operations</b>	Cleaning services of factory	85330 - General cleaning services	X	X		
	Engineering Services	83310 - Engineering advisory services  Class: 8332 - Engineering services for specific projects	X	X		X

*Services in Global Value Chains: Manufacturing-Related Services*

	Security guards for factory and warehouses	85250 - Guard services	X			X
	Sewage water treatment services	94110 - Sewerage and sewage treatment services	X	X		
	Repair and maintenance services of machines and equipment	87156 - Maintenance and repair services of commercial and industrial machinery	X	X		
	Waste collection and recycling services	Class: 9421 - Collection services of hazardous waste  94229 - Collection services of non-hazardous recyclable materials, other  94239 - General waste collection services, other	X	X		X
<b>3. Services from government regulation requirements</b>	Government inspections on fire prevention, health hazards,	91133 - Public administrative services related to mining and mineral resources,	X	X		

	environmental protection and other aspects.	manufacturing and construction  91290 - Public administrative services related to other public order and safety affairs				
<b>4. Worker- related services</b>	Personnel search and referral services - Recruitment of factory workers	85112 - Permanent placement services, other than executive search services	X	X		
	Social insurance for factory workers	91320 -Administrative services related to government employee pension schemes; old-age disability or survivors' benefit schemes, other than for government employees  91330 - Administrative services related to unemployment compensation benefit schemes	X	X		X

**Table A.4. Delivery and sales/post-manufacturing phase**

<i>Stage/ Category</i>	<i>Service</i>	<i>Central Product Classification (CPC) Ver.2 Code</i>	<i>Please mark (X) if the service is used in your supply/value chain</i>	<i>Supplied in-house</i>	<i>Supplied by another company in the group</i>	<i>Outsourced to third-parties</i>
<b>1. Packaging and labeling</b>	Packaging Services	85400 - Packaging services	X	X		
<b>2. Delivery to wholesaler/retailer</b>	Customs-related services	85999 - Other support services n.e.c.	X			X
<b>3. Sales services</b>	Retail trade services - By internet or mail-order	Group of 623 - Mail order or Internet retail trade services	X	X		

**Table A.5. Back office, utilities, and general services**

<i>Stage/ Category</i>	<i>Service</i>	<i>Central Product Classification (CPC) Ver.2 Code</i>	<i>Please mark (X) if the service is used in your supply/value chain</i>	<i>Supplied in-house</i>	<i>Supplied by another company in the group</i>	<i>Outsourced to third-parties</i>
<b>1. Finance</b>	Auditing on financial accounts	Group of 822 - Accounting, auditing and bookkeeping services	X	X		X
	Financial services	71121 - Deposit services to corporate and institutional depositors  71313 - Group pension services  71701 - Services of holding equity of subsidiary companies	X			X
	Internal auditing (including audits of financial accounts and corporate governance)	Group of 822 - Accounting, auditing and bookkeeping services  83118 - Head office services	X	X		X
	Insurance services for machinery	71332 - Marine, aviation, and other transport insurance services	X	X		X



<b>2. General Management</b>	Business and management consultancy services	Class of 8311 - Management consulting and management services	X			X
	Company secretary services	83990 - All other professional, technical and business services, n.e.c.		X		
	Corporate communications, marketing and public relationship	83114 - Marketing management consulting services 83121 - Public relations services	X			X
	Courier, postal and local delivery services	Group of 681 - Postal and courier services	X			X
	Estate management	72112 - Rental or leasing services involving own or leased non-residential property	X			X
	Human resources management	83113 - Human resources management consulting services	X	X		
	Human resources management - - Personnel search and referral services for	Class of 8511 - Personnel search and referral services	X	X		

	back-office staff					
	I.T. and information system management, consulting and support, with webpage development	Class of 8313 - Information technology (IT) consulting and support services  Class of 8314 - Information technology (IT) design and development services  Class of 8316 - IT infrastructure and network management services	X	X		X
	Safety and security services	85230 - Security systems services  85250 - Guard services	X			X
	Telecommunication services	Group: 841 - Telephony and other telecommunications services  84210 - Internet backbone services 84221 - Narrowband Internet access services	X			X

		84222 - Broadband Internet access services				
	Uniform - Laundry	97130 - Other textile cleaning services	X			X
<b>3. Legal</b>	Legal services	82120 - Legal advisory and representation services concerning other fields of law  82130 - Legal documentation and certification services	X			X
<b>4. Research and Development</b>	Product development/ R&D	81129 - Research and experimental development services in other engineering and technology  81400 - Research and development originals	X	X		X
<b>5. Utilities</b>	Electricity supply	Class of 8631 - Support services to electricity transmission and distribution	X			X
	Gas supply	86320 - Gas distribution services through mains (on a fee or contract basis)	X			X
	Water supply	86330 - Water distribution services through mains (on a fee or contract basis)	X			X

**Table A.6: Post-sales services**

<i>Stage/ Category</i>	<i>Service</i>	<i>Central Product Classification (CPC) Ver.2 Code</i>	<i>Please mark (X) if the service is used in your supply/value chain</i>	<i>Supplied in-house</i>	<i>Supplied by another company in the group</i>	<i>Outsourced to third-parties</i>
<b>1. Sales/After-sales Customer services</b>	Customer services – complains and compliments handling	85931 - Telephone call centre services	X	X		
	Customer services – Technical support	85931 - Telephone call centre services	X	X		
	Customer services – warranty and repair services	Group of 872 - Repair services of other goods	X	X		