

Global Production Networks and Dynamic Cores in the World's Main Nodes: The Technological-Productive Transition of the Automotive Industry

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Abstract: The global production networks (GPNs) perspective, to account for key aspects of the new global space, takes on its full dimension from a theoretical-methodological approach to capitalism in terms of historical-spatial phases of development, implying the existence of industrial cycles differentiated by their dynamic core. The global automotive industry is undergoing a profound transformation due to the transition to electric and autonomous vehicles. Under its preceding technological-productive base, it had become part of the automotive-mechanical-metal-petrochemical complex that constituted the dynamic core of the Fordist-Keynesian development phase. Underlying this transition is a process of technological-productive revolutionization in the industry by the electronic-informatics and telecommunications sector, which constitutes the dynamic core of a new industrial cycle typical of the current phase of development. This implies a changing technological-productive base and a spatial and hierarchical reconfiguration of the automotive industry, with macro-regions and new leading countries, old leading macro-regions and countries that have become second-tier players, and new competing countries; with the deployment of new GPNs involving the dynamic cores of global nodes within macro-regions. This article concludes that the actual further regionalization of GPNs between the dynamic cores is in contradiction to the necessary global sourcing of key elements of the industry.

Key words: industrial cycle; dynamic cores; global production networks; technological-productive revolutionization

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1. Introduction

The global automotive industry is currently undergoing a profound transformation as a result of the transition to the production of electric and autonomous vehicles. Under its preceding mechanical-electrical technological-productive base, the industry had become part of the automotive-mechanical-metal-petrochemical industrial complex that constituted the dynamic core of the industrial cycle of the Fordist-Keynesian development phase.

Underlying this transition is a process of technological-productive revolutionization in the industry by the electronic-informatics and telecommunications sector, which constitutes the dynamic core of a new industrial cycle typical of the current phase of development, referred to here as knowledge capitalism. This process implies, in addition to the consolidation of the new industrial cycle, a change in the technological-productive base and a spatial and hierarchical reconfiguration of the automotive industry, with macro-regions and new leading countries, old macro-regions and countries that were previously leaders and have become second-tier players, and the emergence of new competing countries. This implies the deployment of new global production networks (GPNs) involving the dynamic cores and the hierarchical differentiation of global nodes within macro-regions.

In the following sections the most important moments of this process of technological-productive revolutionization will be analyzed, the macro-regions and the main country nodes where this process is taking place will be identified, and the GPNs between the dynamic cores in these macro-regions and nodes will be studied.

In order to undertake this analysis, in the following section the theoretical perspective of the GPNs will be considered from the vantage point of a theoretical-methodological approach in the study of capitalism in terms of historical-spatial phases of development that imply the existence of industrial cycles differentiated particularly by their dynamic core. The second section will discuss the main moments in the technological-productive revolutionization of the automotive industry; and in the third the main macro-regions and world nodes will be identified, as well as the GPNs that operate around them among the dynamic cores will be analyzed.

2. Global Production Networks and Dynamic Cores

The theoretical perspective of global production networks is connected to at least three political-academic debates in relation to their capacity to account (metaphorically) for fundamental aspects of the new space generated by the globalization process, the foundations of which began to be laid in the mid-1970s and where, therefore, the concern for understanding spatial changes has recently gained unprecedented importance. It is also important in relation to its potential to become a theoretical tool that makes the industrial upgrading of countries and the successful spatial integration of their territories possible, that is, a development tool.

A first debate confronts the GPN perspective in the initial global commodity chain (GCC) outlook introduced by Hopkins and Wallerstein (1977), which, despite the previously referred to process transformations, did not account for the underlying spatial change. This perspective would later evolve into the concept of global value chain (GVC) coined by Gereffi (Gereffi, Humphrey, and Sturgeon 2005), to account for the organizational change of contemporary global industries (Fernández 2017).

Despite the fact that most of the studies spawned by the GPN perspective today are very similar to those from the GCC/GVC analysis (Levy 2008), in the perspective that we are interested in developing here, the main lines of debate are: a) the most suitable metaphorical way to conceptually account for the new reality of globalization and its basis in the processes of the transnationalization of capital, whether as a “network” or as a “chain.” Here the perspective of the GPNs has the advantage of representing the upstream-production-downstream processes (Mudambi 2018; Buckley et al. 2022)¹ as not necessarily sequential and vertical, but also as simultaneous and overlapping, and which are carried out in an equally horizontal or diagonal manner, forming multidimensional and multilayered fields of economic activity (Henderson et al. 2002; Coe, Dicken, and Hess 2008). b) The theoretical-methodological concern for incorporating the spatial dimension of the economic-social processes involved is excluded in the GVC perspective but included in that of the GPNs, where space is conceived not in Euclidean-absolute terms, but, together with time, as a material dimension of the economic-social processes, in which it simultaneously represents a condition inherited from the past, a means and a result of these processes (Benner 2004). This includes flows (of capital, labor, knowledge or power) and their transforming effect on the spaces of localization, at the same time as they condition these flows (Henderson et al. 2002). In a regional development context, the term “strategic coupling process” is introduced to explore the complex ways in which GPNs and regional development interact (Coe et al. 2004).

The second debate concerns the origins of the GVC perspective in world system theory and the discussion in relation to its distancing from it. This would bring with it two types of consequences: a) its inability to identify the limiting effects of the hierarchical structure of the world system (structural limitations for industrial upgrading and the successful integration of territories of developing countries); and b) by linking up with the predominant institutional framework and serving as a policy instrument it becomes functional to the processes of neoliberalization and fragmentation of national spaces promoted by global policy networks led by international financial agencies (Fernández 2017).

Contrary to this critical stance regarding the possibilities provided by the GVC perspective for the industrial upgrading of countries and the successful integration of their territories, the GPN perspective goes further by allowing for greater autonomy of the individual companies integrated into the GPNs and their spaces, as well as a larger margin for the industrial upgrading of countries, as it is a perspective open to the consideration of power as a changing relationship of forces that translates into the capacity to act on others in diverse and interacting dimensions. This can involve firms; institutions in a broad and multiscale sense (national and local, state, international, and interstate agencies, the Bretton Woods institutions, various UN agencies, and international credit rating agencies, etc.); as well as those of collectives of organized social groups (Henderson et al. 2002).

Especially important in the upgrading process are national states, which can exert a material influence over the GPNs traversing their national spaces and can ensure that there are positive national and local benefits (Coe, Dicken, and Hess 2008). Hess (2021) introduces the Gramscian concept of “integral state” by which the state influences GPNs using both coercive means emerging from the political society, such as regulations or buying procurement, as well as consent means emerging from the civil society, such as corporate social responsibility and multi-stakeholder initiatives.

The third debate—and this is the perspective that we intend to introduce into the discussion here—is related to a theoretical-methodological approach to the study of capitalism in terms of historical-spatial phases of development. This implies the existence of industrial cycles differentiated particularly by their dynamic core, or productive complex that articulates and dynamizes world production, growth, and trade in each phase of development (Ordóñez 2021). This approach is complemented by the recognition of the existence of various national modalities and of groups of countries in the development phase, or paths of development, with distinctive socio-spatial and institutional frameworks and different behaviors of the industrial cycle, clearly differentiated articulating and dynamizing capacities of their dynamic core, and various productive-spatial configurations of the GPNs around it. At present, at least three paths of development can be

discerned: the predominant neoliberal model and the Asian and Scandinavian experiences (Ordóñez 2021).

Thus, the transition of capitalism to a new phase of development, or knowledge capitalism, around the 1980s, implies an unprecedented economic preeminence of the knowledge, learning, and innovation processes. These become the main productive forces, and imply the formation of a new industrial cycle, whose dynamic core is represented by the electronic, informatics, and telecommunications sector (EITS), closely articulated with the electrical industry (Ordóñez 2004). The new dynamic core replaces and overlaps the automotive-mechanical-metal-petrochemical industrial complex typical of the industrial cycle of the preceding Fordist-Keynesian development phase, in effect from the 1930s to the 1970s (Mandel 1997; Ordóñez 2004; Dabat and Ordóñez 2009).

On a transnational scale, the new industrial core is the technological foundation for the deployment of a new inter-industrial and inter-company division of labor that enables enterprises to seek the valorization of knowledge through the separation and territorial-scalar dispersion between the stages of the production cycle. That is, the conception and design of processes or products—now carried out by new strata of OEM and ODM companies²—on the one hand, and manufacturing and associated support services carried out in CM and CS companies³—on the other. Buckley and others (2022) show that intangible assets rent in manufacturing GPNs were greater than tangible assets rent by a factor of 1.7 in 2009, and that the upstream stage accounted for almost half (45.2%) of total intangible asset rents (from 40.9% in 2000), whereas both production and downstream stages accounted for a little more than a quarter (27.5 and 27.3%, respectively).

The inter-industrial and inter-company division of labor has taken place through an extensive process of offshoring-outsourcing, and the consequent deployment of the GPNs traversing national spaces that constitute the material underpinning of the new global space.

Within the global space, the macro-regional configuration of GPNs has been gaining importance. Other than the legacy of the benefits of proximity, there is an increasing significance of macro-regional economic arrangements (Coe, Dicken, and Hess 2008). Ordóñez (2022) shows the changes during the 2000s of the productive fragmentation processes and the spatial configuration of the three macro-regional nodes centered upon China, the US and Germany around which the GPNs of the dynamic core unfold, as well as those of their sub-scalar configurations.

Moreover, enhancing capabilities of the industrial cycle, particularly its dynamic core, and upgrading processes have taken place in countries and macro-regions pursuing the Scandinavian and Asian paths of development, in which—unlike neoliberalism—the state has the capability of conditioning GPNs' dynamics to national goals. The Scandinavian model is at the forefront of knowledge

processes, the economic-social incidence of the EITS and participatory forms of civil society, within the framework of a social commitment around the scaling of social scientific-technological and learning-innovation capabilities, including a state action-oriented to the cognitive reproduction of the labor force in direct co-participation with the social democratic trade unionism (Jessop 2008, 2015; Benner 2004; Ordóñez 2021).

Concerning the Asian path of development, its socio-spatial and institutional frameworks include developmental states capable of promoting, centralizing and channeling the energy of social learning-innovation toward specific national development goals (Kim 2015; Kohli 2004; Weiss 2003; Ordóñez 2021).

The consolidation of the new industrial cycle implies the development of a capacity for technological-productive revolutionization of the new dynamic core over the preceding dynamic core, which at the same time has an impact on the technological development trajectory of the former. This translates into the formation of new productive subsectors (generically known as auto-electronics) and new GPNs of inter-industrial supply from the former to the latter at a macro-regional scale, which goes hand in hand with the transition from a mechanical-electrical technological base to an electronic-informatics and telecommunications base of the preceding industrial core, and particularly of the automotive industry (Ardebili, Zhang, and Pecht 2019).

In the following section we will study this capacity for technological-productive revolutionization on the preceding dynamic core, which simultaneously implies an impact of the latter on the technological trajectory of the former that will not be explicitly addressed.⁴

3. Technological-Productive Revolutionization of the Previous Dynamic Cores by the New Dynamic Core

The study of the technological-productive revolutionization of the new dynamic core over the preceding one must include the series of industrial activities that make up the latter, i.e., the automotive, metal-mechanical and petrochemical industries. The following analysis is a first approach that will focus on the automotive industry, since it is the activity where the effect of this revolutionization is concentrated and due to its articulating and dynamizing role on the other industries within the preceding core. This is an articulation between activities that also tends to change as a result of the same process, as will be seen.

The technological-productive revolutionization of the automotive industry has been taking place simultaneously with the technological-productive development of the electronic, informatics, and telecommunication sector, although this effect has tended to accelerate with the most recent technological developments of the

latter, at the same time as the former has increased its impact on the technological trajectory of the sector.

Six major moments in the technological-productive revolutionization of the automotive industry by the EITS can be distinguished, each with different distinctive developments. The first moment took place with the introduction of the microprocessor into production equipment and of sensors into the automobile from the 1960s onward, a process that had as its antecedent the invention of the microprocessor itself, i.e., a reprogrammable integrated circuit, which made it possible to insert it into conventional instruments and objects to electronically control their operation (Ordóñez 2004). There were five distinctive developments at this time:

- a) CAD–CAE–CAM systems⁵ in production equipment. The computer-aided design (CAD), computer-aided engineering (CAE) and computer-aided manufacturing (CAM) systems, which were gradually integrated, made it possible to transform an idea in a manual drawing into a machine-readable drawing that could be subsequently modified and translated directly into a prototype in which all its parts adjusted reciprocally. From there, the process led to the factory floor with electronically controlled equipment, with the resulting enormous savings in time and logistics, in addition to the exponential multiplication of the design possibilities and increase in work productivity (Shimokawa 2010).
- b) Electronic injection systems. These systems resolved the ignition problems of gasoline and diesel engines by means of sensors that measure air flow and temperature, in addition to a computerized system that analyzes this data and adjusts the amount of fuel supplied to the engine (Martinez 2021).⁶
- c) Distributionless Ignition Systems (DIS). These consist of sensors that provide data on the position of individual ignition coils, from which embedded software activates the individual coils connected to the spark plugs with exact precision (Martinez 2021).
- d) On board diagnostics (OBD). This is the programming of engine systems to self-diagnose and report faults automatically (Martinez 2021).
- e) Combined safety systems: seat belts and airbags. Under impact, airbag sensors reduce the tension of the seat belts to decrease the kinetic pressure on the human body, while locking the control panel (Martinez 2021).

The second moment consisted of the development of a capacity to react to the surrounding environment (from the information provided by sensors) by means of actuators, with two distinctive moments of their development:

- a) Electronic Stability Control (ESC). Created under the assumption that the driver tends to panic and brake when he loses control of the vehicle, ESC consists of sensors that detect signals of a possible loss of control of the vehicle and trigger actuators (algorithms) that stabilize it, which implies a step toward vehicle automation (Martinez 2021).
- b) Smart keys. Sensors in locks and ignition systems detect the nearby presence of keys, unlocking the lock and activating the ignition system, which is initiated by pressing a button.

The third moment was infotainment and GPS navigation, which transformed the conception of the automobile not only as a computerized system, but also as a mobile space for entertainment and geo-referenced navigation via satellite, with the initial intermediation of the smartphone as a control device around the second decade of the current century.⁷

The fourth moment was networked vehicles in the second decade of the 2000s, which is based on the upgrading of the transmission capacity of interconnection networks, particularly from the third to the fourth generation, and the most recent and current fourth to the fifth generation (5G), with three distinctive moments.

- a) Cloud/edge computing. With the direct antecedent of machine learning and artificial intelligence as recent EITS development trends (Ordóñez 2020), an intense process of algorithm training took place based on providing huge volumes of information in the cloud to automotive factories that prefigure zero-error decision-making. Once the algorithms have been trained and confirmed, they are embedded in the automobile, which itself constitutes a computerized device at the edge of the network. Thus, the trained algorithm is exposed to data from the real world and will make decisions by inference, that is, as a result of the interaction between the new data inputs and the previously received training substrate.
- b) Intercommunication and interaction between vehicles (VtoV) and digital infrastructure. The background of Vehicle to Vehicle Communication dates back to the 2001–2002 world crisis centered on the EITS and the NASDAQ index, which spurred a technological-productive restructuring of that sector, based on the increase of the microprocessor's radius of action, digitization, and connectivity between different devices.

The resulting technological convergence would provide the foundation for the emergence of interactive networks of devices that include, in addition to mobile devices, wearable devices, consumer or home electronics, and vehicles and environmental devices (Ordóñez 2020). The latter would be concretized with

the development of automotive-specific dedicated short-range communication (DSRC) technology, created in the late 1990s, which forms a computerized network in which vehicles and sensor-based nodes along the road intercommunicate, providing safety warnings and traffic information.

- c) Biometrics. It brings the monitoring of vital signs and functions, complemented with the use of biosensors of facial gestures, eye movements, and brain activity direct to the automobile, along with the capacity to recognize mental states and signs of the driver's state of health and alertness. Thus, there is a confluence, overlapping, and new points of contact between the automotive and health care industries, where companies of the latter sector such as Medtronic and Free Logic, for example, have, respectively, adapted their heartbeat sensors to seat belts and created bio-neuro-monitors in the form of headrests, with the capacity to detect states of fatigue, stress, relaxation, etc.

This translates into the transmission of data concerning the driver's state of health, which results in the sending of warning signals to the driver or triggering electronic vehicle stability controls (Martinez 2021).

The fifth moment consisted of the transition from internal combustion engine vehicles to vehicles based on clean energies, among which the most widespread at present involves electric energy generated from batteries,⁸ which began to be marketed around 2010. This implies a change in the technological-productive paradigm in the automotive industry, resulting in the emergence of new manufacturers alongside existing ones, the change in the industry's pattern of competition to a new one based on the electronics and information technology industries, the complete modification of value chains and supply networks, with the resulting international repositioning of macro-regions and countries, as well as the emergence of new countries in the sector.

Electric vehicles (EVs) have a simple power generation system with three basic components. These are the electric motor, a controller, and the battery, in which the controller takes the energy from the battery and conducts it to the motor that transforms electricity into mechanical energy. This is unlike internal combustion vehicles (ICV), whose system is complex and includes the engine, carburetor, oil and water pumps, cooling system, gear, exhaust system, etc. (Idoho National Laboratory 2022; JAMA, n.d.).

The controller is an electronic device consisting of microprocessors that regulate the passage of energy from the battery to the motor, controlling the speed, acceleration (as does the carburetor in an ICV), but also reverses the rotation of the motor to be able to go in reverse, and converts the motor into an electricity generator when the brake is applied by transforming the kinetic energy of the motor in motion into electricity that recharges the battery.⁹

The motor does not differ much from other electric engines that work through the interaction of a magnetic field with electricity, resulting in the movement of a rotor. In addition, there are alternating current (AC) motors, which are the most widely used as the cost of microprocessors in controllers is reduced, since they convert direct current (DC) from the battery to AC, in addition to DC motors (Idaho National Laboratory 2022).

The key and costliest component around which the industry's supply networks are reconfigured (in ICVs these are configured around the engine and transmission), and on which the very future of the EV depends is the battery. Among the various types, the lithium-ion battery accounted for 70% of the rechargeable battery market in 2016 (Coffin and Horowitz 2018), with three stages of production: cells, modules, and packaging, as detailed below.

- a) Cells. This is the device that generates electricity from the basic components of the anode, cathode, and electrolyte. Its constituent materials such as graphite (anode), lithium, cobalt, or manganese for the cathode, have very limited worldwide supply sources with the resulting pressure on prices as demand increases. South America (mainly Argentina, Brazil, and Chile) is the main supplier of lithium; while the Democratic Republic of Congo produces more than half of the world's cobalt, followed by China and Canada with less than 6% each, while China produces just under three-quarters of the graphite. Twenty percent of the value added and 75% of the total cost of packaged batteries (including raw materials) are cells, for the production of which EV manufacturers (traditional and emerging) tend to partner with electronics OEMs, which are suppliers to various manufacturers. Some examples in the case of the US market are Tesla–Panasonic, Chevrolet–LG Chem, Nissan–Automotive Energy Supply Corp, Fiat–SB Limotiv, VW–Samsung SDI, Ford–LG Chem, BMW–Samsung SDI, Kia–SK Innovation (Coffin and Horowitz 2018).¹⁰
- b) Modules. Multiple cells with terminals joined together within a container form a module, which may contain different numbers of cells (4 to 12, for example), constituting 11% of the total cost of the packaged batteries. Modules can be used in different battery packs for various vehicles, and are generally assembled in the same facility where the batteries are packaged, so there is little inter-industry trade in this stage of production (Coffin and Horowitz 2018).
- c) Battery packs, which consist of the assembly of several modules, electrical connections, and cooling equipment¹¹ in a single device that can be assembled manually or by automated equipment. They represent 14% of the total cost of packaged batteries, are specific to a vehicle model, and are commonly assembled near the vehicle assembly plant (Coffin and Horowitz 2018).

With the EV, a radical change in the competition pattern of the industry takes place with the following characteristics: (a) the key component, i.e., the battery, is no longer under the technological dominance of the manufacturers (except in some cases of emerging manufacturers) and shifts to the domain of electronic companies (outside the industry); (b) the main supply network is established around the battery and simplified, verifying a drastic reduction in post-sale revenues during the lifetime of the vehicle in parts, components, and maintenance. This is compensated by the revenues generated by the updating of the controller software and the growing series of the electronic devices contained; and c) companies' enclosure strategies tend to be established in the style of so-called technological companies, where automotive parts are only produced by the manufacturer, as the owner does not have access to the source code of the software and its updates—which can be modified at will and without notice by the manufacturer—and sales tend to be online at the manufacturer's website or at their own physical distributors—without the usual dealer network—in the case of emerging manufacturers.¹² This is in addition to the existence of supercharging networks exclusive to the brand, which operate as validation networks for vehicles that are kept within the electromechanical and legal parameters established by the manufacturer.¹³

This process spatially reconfigures the industry in terms of the trend on the part of the Asian macro-region to position itself at the forefront with China and its emerging manufacturers such as BYD or traditional manufacturers that have carried out a rapid transition and position themselves in the market, such as Geely (Teece 2019). Also present are companies from countries that were formerly leaders in the industry where new manufacturers have broken in and positioned themselves at the forefront of the market, such as Tesla in the United States (Martinez 2021). In this regard, there are also companies from Japan and the European macro-region that are leaders in the production of ICVs that were late in starting the transition, even though the former has an important supply network for both batteries and electronic systems and components (Digitimesasia 2022), while the latter is in decline (Poplawski 2020). Furthermore, we have the entry of emerging economies into the industry, such as China's Taiwan or Vietnam (Nguyen et al. 2022), as will be seen below.

The sixth moment consists of the development of the autonomous vehicle utopia. The utopia of the autonomous vehicle (AV) consists of the synthesis of the moments of the revolutionizing of the automotive industry by the new dynamic core in pursuit of the goal—not yet realized—of a vehicle that guides itself without human intervention. There is the development and multiplication of types of sensors involving a considerable number of individual cameras, radar units, short-, medium-, and long-range laser sensors, GPS, etc., which, combined with other types of sensors, can be used in the vehicle. These, together with other types of sensors on driver alertness or

parking assistants, and in interaction with the digital infrastructure—if present—send synchronized signals to the control processors, where the previously trained algorithm is exposed to the data coming from the real world and makes decisions by inference as explained before (Koon 2022; Martinez 2021).

These include the following degrees or levels of autonomy in commercial cars: a) the vehicle brakes or accelerates in accordance with the speed of the vehicle in front of it, maneuvers to park, and senses when it leaves the lane; b) the vehicle can brake, accelerate, and turn on its own even though the driver must supervise and take control if necessary (the degree of autonomy of most cars today); c) the vehicle senses its location in the specific context, is able to make predictions and substitute for the driver in certain situations such as on a straight road, but the driver must supervise and be ready to take control if necessary (only in some high-end cars) (Martinez 2021). This has gone hand in hand with the incursion of large companies such as Google, Uber, Tesla, and more recently Amazon with the acquisition of Zoox, in the development of autopilot systems, with the resulting marginalization of traditional manufacturers.

4. The Main Macro-Regions and World Nodes

If we consider the volume of the flow of goods from the electronics industry earmarked to the automotive industry that passes through the GPNs between countries on a global scale, both in terms of exports (sales) and imports (purchases), we can distinguish the existence of three main GPNs' macro-regional deployments in Asia, North America and Europe, with six main global nodes within them.

The increasing significance of macro-regional economic arrangements (i.e., ASEAN, USMCA and European Union), as previously indicated, has been recently accelerated by issues of global scope, such as the US–China technological and trade war, the irruption of COVID-19, and the Russian dispute with Ukraine; which tend to add a geo-economical and political conditioning to the macro-regional deployment of GPNs.

Concerning the GPNs resulting from the technological-productive revolutionization of the previous dynamic core by the new dynamic core, the US–China technological and trade war is especially important as it entails a further regionalization of the GPNs within the three macro-regions. In this, the sourcing and processing of rare earth minerals become critical for several reasons: a) they are inputs of the permanent magnets used in electric motors (consuming around 30% of their total output in 2020) and of batteries (around 8%) (Dempsey 2022), which implies both a great intensity of value added creation in the context of the whole value network, and a key role in determining the technological standard of EVs; b) their actual natural provision is concentrated in few countries, as previously indicated, with

China having almost the exclusivity of the mastership of their processing (80% of global market share) (Dempsey 2022); and c) the long time required to discover new natural sources and put in operation new mines (between 5 to 25 years), the environmental issues and the growing resistance of environmental collectivities.

In what follows the six global nodes will be studied considering some of the geo-economical and political conditioning of GPNs deployment.

4.1. China

The early action by the Chinese state aimed at positioning the country in the production of AVs and EVs and not having previously consolidated an ICV industry of global dimensions (despite having surpassed the United States in sales in 2009) (Teece 2019)—without the consequent need for reconversion from a well-established global base—has enabled a rapid technological-productive transition of the automotive industry and the positioning of the country at the forefront in the process with the most developed industry and the largest volume of global trade involving more than US\$13.5 billion in exports and US\$5.6 billion in imports in 2018 (OECD 2021), making it a benchmark for others. For this reason, it will be studied first.

The ICV-based automotive industry is comprised of Chinese state-owned automakers in joint ventures with multinational manufacturers, which have global first-circle suppliers from North America, Europe, and East Asia. At the same time, several smaller privately owned or “hybrid” manufacturers have emerged, such as Geely, Chery, or BYD, which challenged the large state-owned companies in some important markets. These manufacturers receive support from local governments to build networks of suppliers, infrastructure, and technological resources.

The ownership modalities in the auto parts industry are varied, since, as already indicated, they include first-circle suppliers global firms resulting from foreign direct investment or in joint ventures with Chinese state-owned enterprises, which predominate, while in the lower circles hybrid and privately owned firms of all sizes are to be found, along with overseas Chinese companies from Taiwan (China’s province) and Hong Kong (China’s Special Administrative Region). These, as a whole, mostly partner with village and municipal governments, which provide cheap land, housing for workers, and cover for “flexible interpretations” of regulations and laws (Lüthje 2021).

The technological-productive transition is being carried out by existing and emerging industry segments, as detailed below based on Lüthje (2021):

- a) The previously mentioned independent car and EV-AV manufacturers such as Geely,¹⁴ Chery, JAC, and BYD—which have a varied portfolio of small and medium-sized vehicles, as well as buses and utility vehicles—that are

vertically integrated into Chinese-style conglomerates (*jituan*), with their own factories and extensive production networks with considerable cost advantages, from which they seek to establish strategic partnerships with foreign manufacturers.

- b) New EV-AV start-ups backed by large internet companies, global venture capitalists, and large Chinese commercial entrepreneurs, such as NextEV/NIO,¹⁵ LeEco/Faraday, and Baoneng, which mostly center their activities on developing high-end vehicles (in competition with market leader Tesla), focusing on design and development, and delegating the assembly of the cars and the supply of their electronic systems to contract manufacturers.
- c) Manufacturers that integrate EV and battery production such as BYD and CATL, which gives them the strongest positioning in the global market, where BYD is a traditional battery manufacturer,¹⁶ while CATL is an emerging manufacturer from Ningde (Fujian), in addition to the major Korean and Japanese battery manufacturers in China.¹⁷
- d) The previously mentioned first-circle transnational auto parts suppliers are repositioning themselves in response to the development of advanced driving assistance systems (ADAS), that is, self-driving cars, and entering into strategic alliances with the big internet companies, Bosch–Ali Baba, and Continental–Baidu. However, there is no major Chinese auto parts supplier that can play the role of integrator and potentially position itself globally in the digital and EV supply network. Most of the smaller suppliers remain trapped at the lower end of the centralized supply networks.
- e) Electronics contract manufacturers, mostly based in Taiwan (China's province), supply automakers and auto parts suppliers, and are moving into EVs and digital-electronic supplies for automobiles.¹⁸

Most of the new participants and industry segments are outside the traditional automotive manufacturing centers. This is the case with Shenzhen and the Pearl River Delta (with BYD, Tencent, Foxconn, and a large electronics supply manufacturing base); Hangzhou (with Geely and Ali Baba); and Fujian province (with CALT) (Lüthje 2021).

As previously stated, China dominates the production and processing of rare earth minerals, which makes it possible for it to control its prices by fixing annual mining output quotas (Dempsey 2022). The GPNs of electronic products centered around the Chinese node, both in terms of the country's automotive industry imports as well as exports to the industry in other countries are shown in Figures 1 and 2.

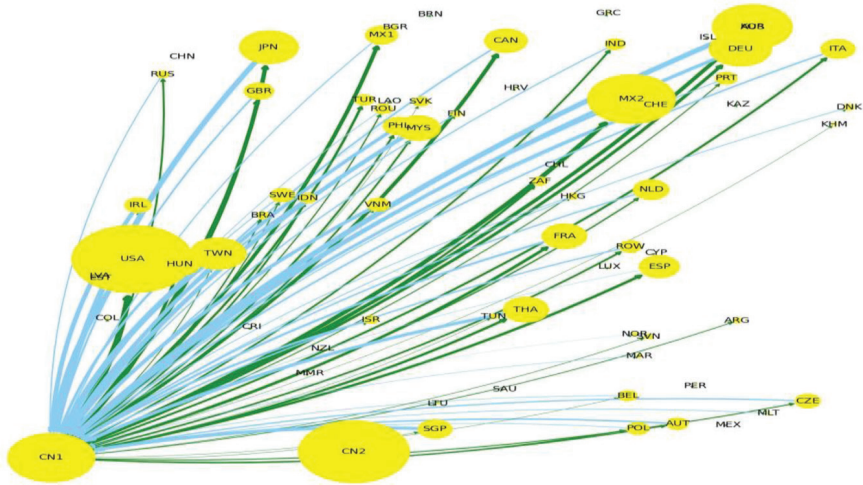


Figure 1. GPNs Centered in China of Traditional Electronics-Automotive Trade (CN1), 2018

Note: The green arrows (dark black arrows in black and white printing) indicate export from the central node and the blue ones (light gray ones in black and white printing) indicate imports. Here China (CN) refers to China's mainland, Taiwan (TWN) is China's province, and Hong Kong (HKG) is China's Special Administrative Region.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

GPNs centered on imports from Southeast Asia, some European countries (Germany, Ireland, France, Great Britain, Italy, Switzerland, Holland, and Hungary), North America (the United States, Mexico, and Canada), as well as Israel are deployed around the Chinese node.

The auto industry segment that does not operate under duty-free import for re-exports regulations (CN1), and is therefore more oriented to the domestic market, has the most differentiated volumes of electronic imports among countries and regions, with the main suppliers being South Korea, China's Taiwan, Japan, Malaysia, Singapore, Thailand, Vietnam, and the Philippines in Asia, in addition to the United States, Germany, and Ireland outside the region, as shown in Figure 3.

The duty-free imports for the re-exports segment of the electronics industry (CN2) is the sector with the most differentiated export volumes to countries, with the main recipients being the United States, Mexico for re-exports to the United States (MX2), Canada in North America and Asia including India. In addition, it exports to the industrial sector that does not operate under Mexican duty-free imports for re-export (MX1) and European countries as shown in Figure 4.

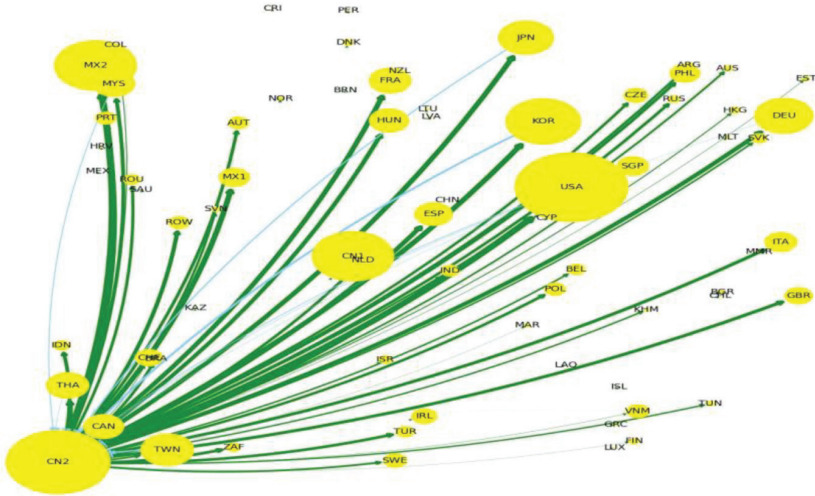


Figure 2. GPNs Centered in China of Duty-Free Imports for Re-exports Electronics-Automotive Trade (CN2), 2018

Note: The green arrows (dark black arrows in black and white printing) indicate export from the central node and the blue ones (light gray ones in black and white printing) indicate imports. Here China (CN) refers to China’s mainland, Taiwan (TWN) is China’s province, and Hong Kong (HKG) is China’s Special Administrative Region.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

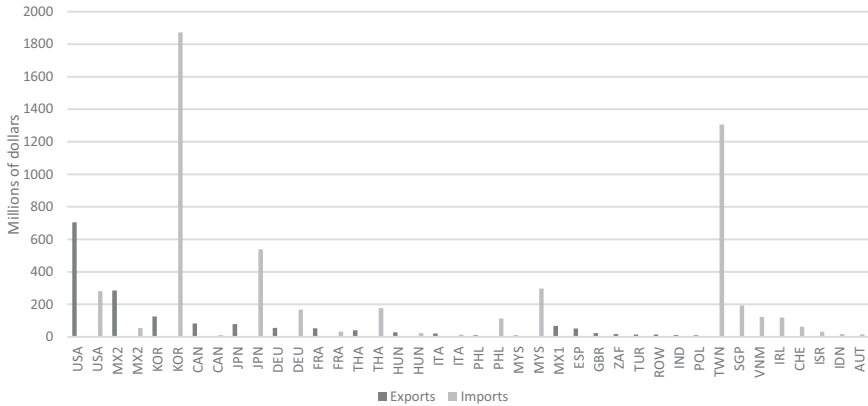


Figure 3. Traditional Electronics-Automotive Trade of China (CN1), 2018

Note: Here China refers to China’s mainland, and Taiwan (TWN) is China’s province.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

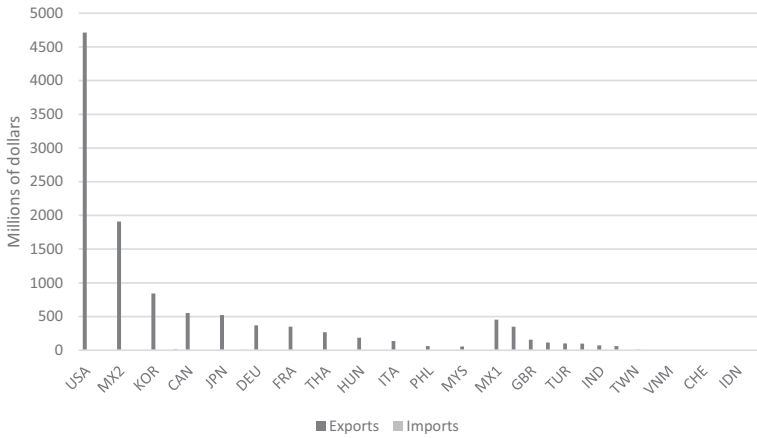


Figure 4. Duty-Free Imports for Re-exports Electronics-Automotive Trade of China (CN2), 2018

Note: Here China refers to China's mainland, and Taiwan (TWN) is China's province.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

4.2. Japan

Japan is a leader in the production of internal combustion vehicles based on globally positioned brand-name manufacturers (OEMs) seeking capacity building and upgrading of suppliers for the design and development of parts and components, and has seen a significant reduction in their number (Shimokawa 2010).

Automakers, with Toyota being the largest manufacturer, have been late on the scene in making the transition to EVs. They have concentrated on producing hybrid cars since the late 1990s in response to environmental regulations in the United States, Europe, Japan, and China. It has only been in recent years that they have transitioned to EV production, resulting in an EV share of total car sales in Japan (the third largest market) of just 1%, compared to 26% in Germany, 16% in China, and 4.6% in the United States (Sugiura and Campbell 2022), with a world trade volume of just over US\$ 2 billion in exports and almost US\$ 1.3 billion in imports (OECD 2021).

In addition, electric vehicles are marketed through rentals, rather than purchase, by users, so that the manufacturer can retain ownership of the vehicle battery and recycle it with 70–80% of its useful capacity, avoiding the loss of the raw materials (rare earth elements) that comprise it and their departure from Japan, given the global shortage (Sugiura and Campbell 2022).¹⁹

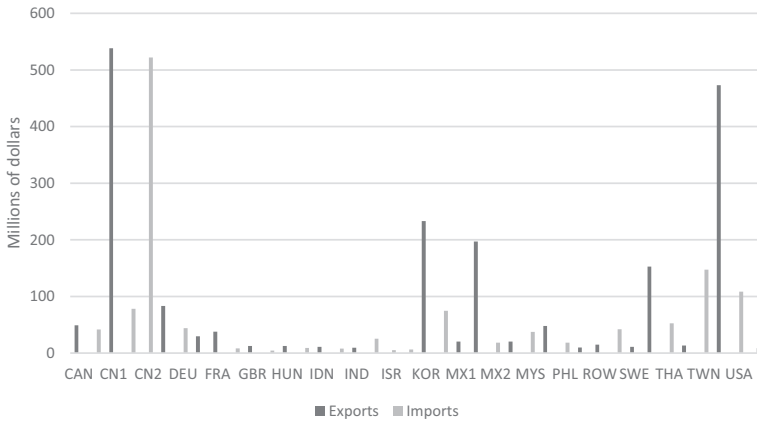


Figure 6. Electronics-Automotive Trade of Japan, 2018

Note: Here China (CN) refers to China's mainland, and Taiwan (TWN) is China's province.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

4.3. South Korea

South Korea's ICV industry has achieved a recent global positioning and is making an early transition to EV production underpinned by development programs that combine state action with private business participation. This occurs within the framework of a developmental strategy that includes R&D oriented to the creation of proprietary technology, the development of a charging station infrastructure, the promotion of commercialization, and the determination of safety standards (Lee and Mah 2020).²⁰

Leading manufacturers Kia Co and Hyundai Motors have seen their fortunes improve based on proprietary EV technology that they sell in South Korea and major world markets, with antecedents dating back to the 1980s when they early on developed non-commercial EVs—reaching a global trade volume of nearly US\$3.9 billion for exports and US\$2.3 billion for imports in 2018 (OECD 2021). In this business, they are dependent on imports of parts and components for motors and batteries, as well as electronic systems, as the country has not yet been able to develop its own supply network (Lee and Mah 2020; Digitimesasia 2022).

However, after China, South Korea is in second place, with an important domestic battery production base with three major electronics OEMs with global positioning. These are LGES with a presence in the country, China, Poland, and

re-export to the United States (MX2) in North America; and also with Germany and Switzerland in Europe (Figures 7 and 8).

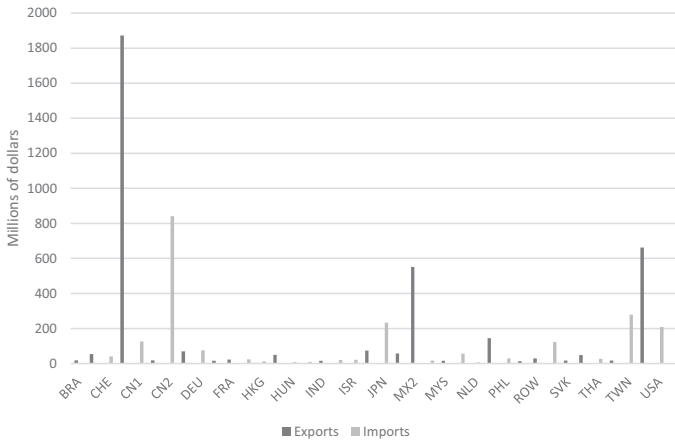


Figure 8. Electronics-Automotive Trade of South Korea, 2018

Note: Here China (CN) refers to China’s mainland, Taiwan (TWN) is China’s province, and Hong Kong (HKG) is China’s Special Administrative Region.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

4.4. The United States

Having been overtaken by Japanese competitors since the 1980s, and subsequently unable to regain the global dominance it previously had enjoyed in ICV production, the US auto industry is lagging considerably behind China, Japan, and South Korea in the transition to EV production. Still, it has the emerging Tesla brand that is a world leader and flagship company in the technological-productive revolutionization and the introduction of so-called technology companies’ “business models” in the automotive industry, as well as a global trade volume of nearly US\$ 2.4 billion in export and US\$ 11.7 billion in imports (OECD 2021).

This lag is the result of the fact that the transition had not taken place until very recently as a competitive response of the large manufacturers with a global presence, such as General Motors and Ford ICVs, and not as part of a state strategy of positioning the country in the technological-productive transition of the industry in the perspective of a broader response to the ecological crisis and to the lagging behind China.

The recently passed Inflation Reduction Act (IRA) involves the largest state investment effort to promote the energy transition, address climate change and try to position the US in the technological and trade war with China. This includes a policy of tax credits for using EVs that utilize critical minerals for battery components mined, processed, or recycled in the United States or United States–Mexico–Canada Agreement (USMCA) countries, initially at 40% in 2023 with annual increments of 10% to reach 80% in 2026, while 50% of components must be manufactured or assembled in the region by 2023 with annual increments of 10% to 100% in 2028 (Forbes 2022).²¹

At the same time IRA has created friction with US-allied countries, notably South Korea and the European Union, as their firms remain excluded from the benefits and are constrained to invest in USMCA countries to do so.

The policy measure addresses a situation in which the United States accounts for a minimal part of the world's reserves of rare earths, specifically 4% of lithium and 1% of cobalt and nickel. Therefore, in addition to the need to relax the restrictions on mining in the country, the United States is highly dependent on imports of these minerals particularly from China (Mayoral 2022), and an intense process of ensuring their processing and recycling in North America will be required, as it is currently underway in Canada with the realization of one of largest known reserves and resources of rare earth in the world, estimated at over 15.1 million tons of rare earth oxide in 2022, and several recent projects of exploration, feasibility and processing (Government of Canada 2023).

At the same time, the United States has only approximately 10% of the world's installed capacity for the manufacturing of battery anodes, 2% of electrolytes, and 6% of separators, which implies, due to the lack of installed capacity for cathodes, a reduced creation of value added in the production of cells, as cathodes represent 51% of the total value added (Mayoral 2022).²²

This is the result of the non-existence of domestic battery-producing companies (except Tesla in association with Panasonic, as indicated above), which means that the foreign firms that produce them engage in the production of the cells in other countries (75% of the total cost of the battery and 20% of the value added, as indicated above), to develop the modules and the final assembly (packaging) of the batteries in the United States (11% and 14%, respectively, of the total cost) (Coffin and Horowitz 2018). Therefore, as a whole, the country and US companies have a reduced impact not only on the generation of value in the battery production cycle, but also on the ability to impose technological standards and manage supply in response to changes in demand (Mayoral 2022).

Tesla is a leader in EV production and a company that has disrupted the traditional organization of the industry.²³ At the same time, it incorporates a mode of operation of a technology company that includes software updates “over the air” (OTA) and

online sales without distributors, operates on the basis of a vertical integration strategy focused on the United States and in-house production of most of its main components, with a vertically integrated supplier network, and the aspiration to replicate the same strategy in the other major markets of China (where it already has a 100% owned plant in Shanghai) and Europe (Martinez 2021; Mayoral 2022).

The node centered in the United States deploys GPNs involving imports mainly with China’s mainland, based on the duty-free imports for re-export policy (CN2) and with considerably lower volumes with China’s mainland without duty-free imports for re-export (CN1), South Korea, Malaysia, Japan, China’s Taiwan, and Thailand in Asia; Mexico with duty-free imports for re-export (MX2), Canada and Mexico without duty-free imports for re-export (MX1) in North America, in addition to Germany, Switzerland, and Ireland in Europe, as shown in Figures 9 and 10.

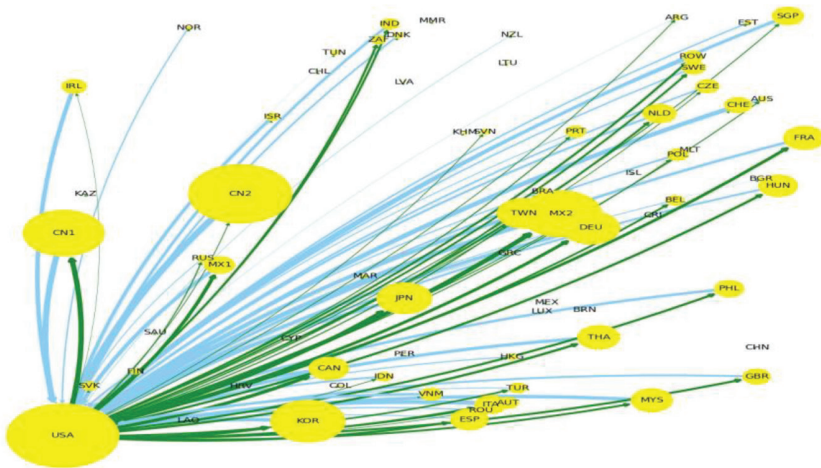


Figure 9. GPNs Centered in the United States (Exports and Imports, 2018)

Note: The green arrows (dark black arrows in black and white printing) indicate export from the central node and the blue ones (light gray ones in black and white printing) indicate imports. Here China (CN) refers to China’s mainland, Taiwan (TWN) is China’s province, and Hong Kong (HKG) is China’s Special Administrative Region.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

On the export side, the US node deploys GPNs mainly with Mexico for duty-free imports for re-exports (MX2), and with a considerably smaller volume with Canada and the Mexican domestic market (MX1) in North America and for the domestic market of China (CN1), South Korea and Japan in Asia; and Germany and France in Europe (Figures 9 and 10).

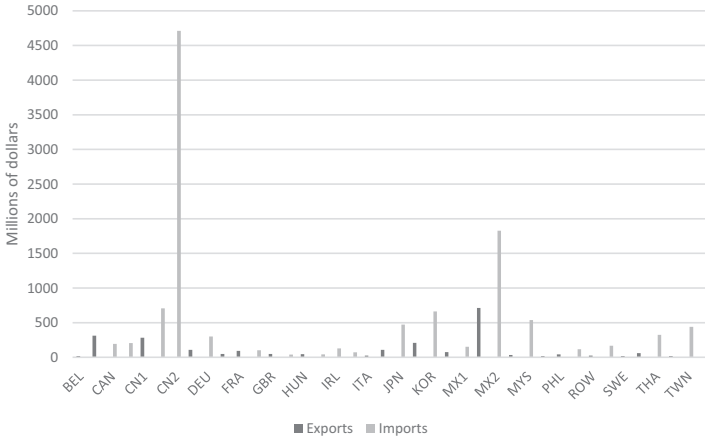


Figure 10. Electronics-Automotive Trade of the United States, 2018

Note: Here China (CN) refers to China’s mainland, and Taiwan (TWN) is China’s province.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

4.5. Mexico

The integration of the Mexican automotive industry with its US counterpart means that the technological-productive revolutionization of the former follows that of the latter. This will accelerate in the next few years under the effect of the USMCA, through the following processes: a) the supply of parts and components to EV manufacturers in the United States, particularly Tesla; b) the initiatives of several manufacturers to install EV assembly plants in the country; c) from which other initiatives derive to install factories for the development of modules and the final assembly (packaging) of batteries; d) plus initiatives on the part of electronic contract manufacturers to install factories to supply the automotive industry in the United States and Mexico; and e) the incorporation of the country’s lithium reserves for manufacturing batteries.

Mexico has a global trade volume of about US\$ 2.4 billion in exports and more than US\$ 6 billion in imports in 2018, with more than US\$ 5 billion of duty-free imports with almost US\$ 2.2 billion earmarked for re-export (OECD 2021). This indicates that the largest volume of trade involves the supply of parts and components for EV manufacturers in the United States, where Tesla has an exclusive customs station at the Nuevo León/Texas border to facilitate the most rapid supply of products for its mega-plant in this state (Xataka Auto 2022a). This is in addition to the initiative recently announced by the same manufacturer to build an assembly plant in Nuevo León, which adds to Ford’s production of EVs at its Cuatitlán

plant (Mustang Mach-E) and the plans of other manufacturers to build or refurbish assembly plants for the production of EVs (El Economista 2023).²⁴

Meanwhile, the Chinese battery manufacturer CATL has unveiled its initiative to build battery manufacturing plants to supply Tesla and Ford, in addition to China’s Taiwan manufacturing contractor Compal’s plan to manufacture electronic components for the automotive industry in Mexico in 2023 (Digitimesasia 2023). In addition to all this, Mexico’s existing lithium reserves, which could represent 2% of the world total,²⁵ have recently been nationalized, so their exploitation will be carried out by a state company in majority association with private enterprises that will provide the technology for its extraction and processing, which will have to take place in the state of Sonora (where the deposits are located) and as an exclusive input for the automotive industry (Xataka Auto 2022b).

The main activity of the GPNs centered in Mexico involves duty-free imports from countries and regions such as China’s mainland (duty-free for re-export: CN2), the United States, South Korea, Malaysia, China’s Taiwan, Thailand, Japan, the Philippines, Germany, and Singapore for re-export (MX2) mainly to the United States, and to a lesser extent to Canada, China’s mainland (non-duty-free for re-export: CN1), Germany, France, Japan, and South Korea, as shown in Figures 11 and 12.

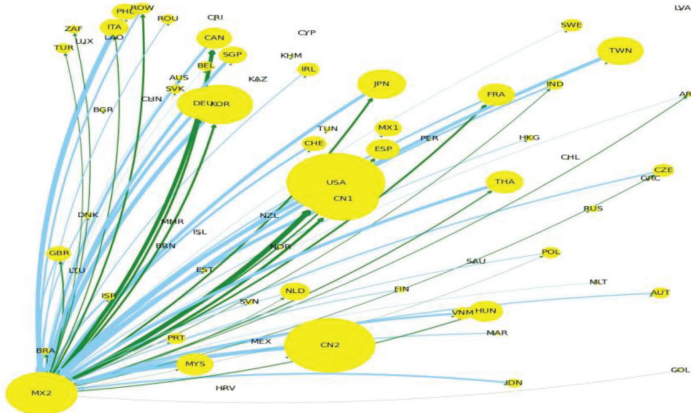


Figure 11. GPNs Centered in Mexico of Duty-Free Imports for Re-exports Electronics-Automotive Trade (MX2), 2018

Note: The green arrows (dark black arrows in black and white printing) indicate export from the central node and the blue ones (light gray ones in black and white printing) indicate imports. Here China (CN) refers to China’s mainland, Taiwan (TWN) is China’s province, and Hong Kong (HKG) is China’s Special Administrative Region.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

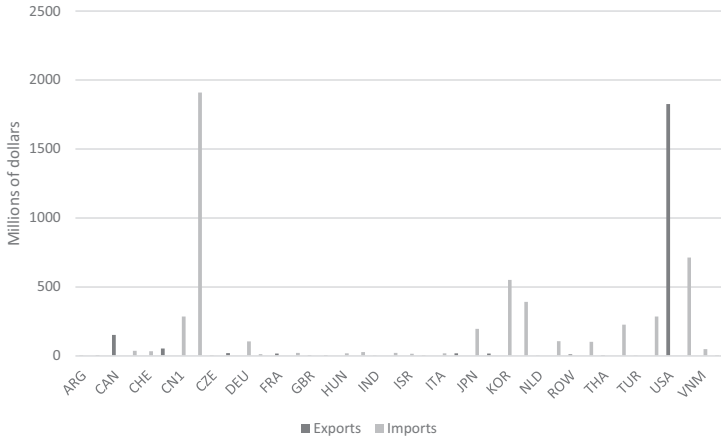


Figure 12. Duty-Free Imports for Re-exports Electronics-Automotive Trade of Mexico (MX2), 2018

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

Complementing this is the deployment of GPNs for non-duty-free imports to Mexico for re-export purposes (MX1) from the same countries, although with a greater dynamism in relation to China as a whole (that is, duty-free and non-duty-free: CN2 and CN1), and of GPNs for exports, also mainly to the United States, and secondarily to Canada, China (non-duty-free: CN1), as can be seen in Figures 13 and 14.

4.6. Germany

As in the case of Japan, Germany is a world leader in ICV production with several specialized brand names in high-end cars (Daimler, BMW, and Porsche), which has belatedly transitioned to EV production, with Volkswagen leading the entry into this market (Poplawski 2020). The transition is set to transform the spatio-temporal configuration of production and GPNs in Europe, which has Germany as its central node along with other secondary countries with their own brands such as France and Italy. In addition, there are differentiated concentric localized spaces that include what has been called the semi-periphery with countries such as Great Britain, Sweden, or Spain that once had their own car brands and retain industrial know-how as well as old and new integrated peripheries with nations such as Belgium, Portugal, or the Netherlands in the first case, and Central and Eastern Europe in the second, with geographical advantages, access to large markets, and low labor costs. Then there are the new peripheries such as Romania, Turkey, Ukraine, and North Africa, with relative geographical advantages and even lower labor costs (Simonazzi, Sanginés, and Russo 2020).

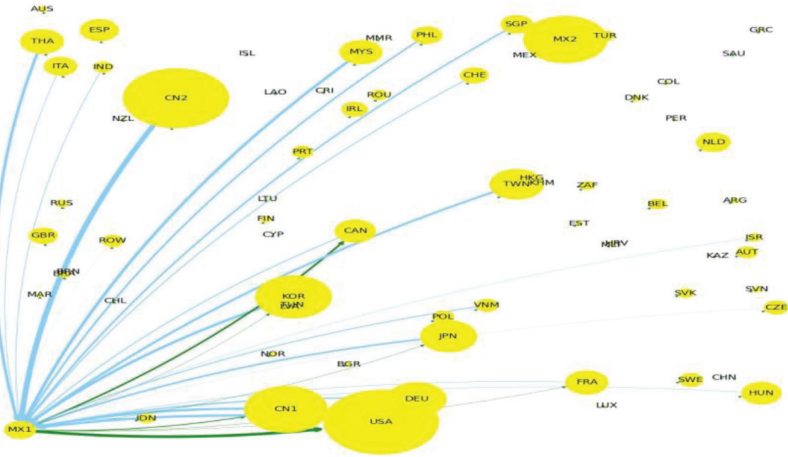


Figure 13. GPNs Centered in Mexico of Traditional Electronics-Automotive Trade (MX1), 2018

Note: The green arrows (dark black arrows in black and white printing) indicate export from the central node and the blue ones (light gray ones in black and white printing) indicate imports. Here China (CHN) refers to China’s mainland, Taiwan (TWN) is China’s province, and Hong Kong (HKG) is China’s Special Administrative Region.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

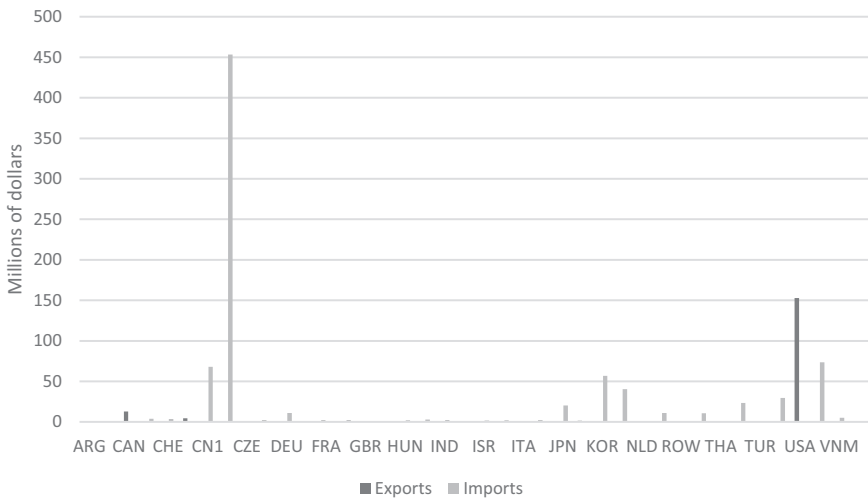


Figure 14. Traditional Electronics-Automotive Trade of Mexico (MX1), 2018

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

German and European manufacturers are partnering with what are known as tech companies such as Google, Uber, and Amazon to manufacture autopilot systems, while transnational suppliers such as Bosch, Continental, and ZF are moving into electronics manufacturing, and Asian and European battery manufacturers from the electronics industry are entering the supply network (Poplawski 2020).

The transition is set to be accelerated under the effect of the recently proposed Green Deal Industrial Plan, which tries to position the European Union in green energies technologies and EVs *vis-à-vis* China and the US.

The German node has a world trade volume of more than US\$ 2.1 billion for exports and US\$ 1.6 billion for imports (OECD 2021), with GPNs for exports to the United States and Mexico for re-export operations to the United States (MX2) in the North American region; as well as to Hungary, Spain, Italy, France, Portugal, Sweden, Austria, Great Britain, and Romania in Europe; and mainly non-duty-free imports for re-export to China (CN1) and South Korea in East Asia, as shown in Figures 15 and 16.

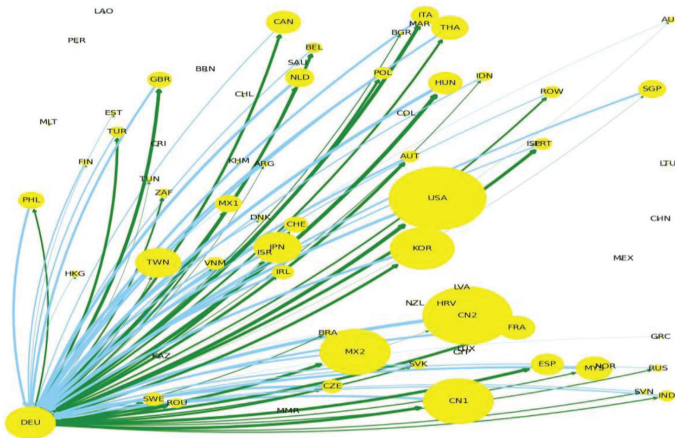


Figure 15. GPNs Centered in Germany (Exports and Imports, 2018)

Note: The green arrows (dark black arrows in black and white printing) indicate export from the central node and the blue ones (light gray ones in black and white printing) indicate imports. Here China (CN) refers to China’s mainland, Taiwan (TWN) is China’s province, and Hong Kong (HKG) is China’s Special Administrative Region.

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

On the import side, GPNs are deployed mainly in relation to China’s mainland for duty- and non-duty-free imports for re-export (CN2 and CN1), Japan, South Korea, and China’s Taiwan in East Asia; with Hungary, the Czech Republic, Switzerland, and the Netherlands in Europe; and the United States in North America (Figures 15 and 16).

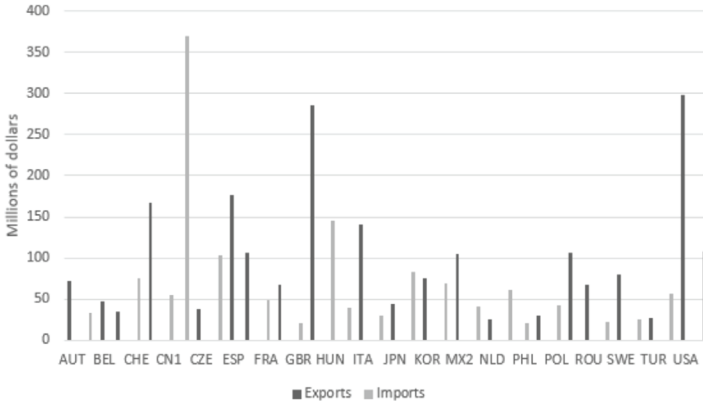


Figure 16. Electronics-Automotive Trade of Germany, 2018

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

5. Conclusion

The contribution of the theoretical perspective of the GPNs to account for key aspects of the new global space, as well as their potential to become a theoretical device for the development of countries and their territories, takes on its full dimension from a theoretical-methodological approach to the study of capitalism in terms of historical-spatial phases of development. This implies the existence of industrial cycles differentiated particularly by their dynamic core, which is complemented by the recognition of the existence of various paths of development or national modalities and groups of countries engaged in the phase.

Enhancing capabilities of the industrial cycle, particularly its dynamic core, and upgrading processes have taken place in countries and macro-regions pursuing the Scandinavian and Asian paths of development, in which—unlike neoliberalism—the state has the capability of both promoting the creation of a knowledge internal cycle and conditioning GPNs' dynamics to national goals.

In the current phase, the consolidation of the new industrial cycle around the EITS implies the development of a capacity for technological-productive revolutionization in relation to the preceding dynamic core, and in particular in the automotive industry. This entails a transition from a mechanical-electrical technological base to an electronics-informatics and telecommunications base in the industry. This, in turn, reconfigures it spatially and hierarchically with the formation of new productive subsectors (generically known as auto-electronics) and new GPNs of inter-industrial supply in a macro-regional scale in Asia, North America and Europe, with six global nodes within them.

The US–China technological and trade war tends to add a geo-economical and political conditioning to the macro-regional deployment of GPNs, as it entails a further regionalization of the GPNs within the three macro-regions, in which the sourcing and processing of rare earth minerals become critical, due to the key role of batteries in determining the technological standard of EV, the concentration in few countries of their actual natural provision, and the long time required to discover new natural sources and put in operation new mines, as well as the environmental issues related with.

The Asian macro-region and particularly China lead the process with the latter's emerging manufacturers, in addition to the traditional ones that carry out a rapid technological-productive transition, resulting in the most developed automotive industry based on its new foundations and the global positioning of the country, in addition to registering the largest volume of world trade. China, as well, dominates the production and processing of rare earth minerals, which makes it possible for it to control its prices by fixing annual mining output quotas, leaving it with great leverage over the development of the whole global industry. Japan, meanwhile, being a leader in the production of ICVs, is late in the technological-productive transition but has a consolidated segment of suppliers of electronic parts and systems with a global positioning. South Korea is developing its own technology for the production of EVs that are sold in the main world markets and, after China, is the second most important country in this regard with a domestic production base for EV batteries, whose manufacturers are associated with global automakers, internationalizing their location and trade. And then there is the emergence of new competing economies such as China's Taiwan and Vietnam.

In the North American macro-region, the United States lags considerably behind China, Japan, and South Korea, but has an emerging and world-leading brand, which is the result of a transition taking place as a competitive response by large manufacturers rather than as part of a broader state strategy to address the ecological crisis and the lagging behind China, until the recent Inflation Reduction Act. Meanwhile, the integration of the automotive industry in Mexico with that of its northern neighbor means that the transition of the Mexican industry follows that of the United States. This will accelerate in the coming years under the combined effect of the Inflation Reduction Act and the USMCA, with GPNs based on duty-free imports to Mexico from countries such as China, the United States, other Asian countries and Germany, for re-export mainly to the United States, largely being predominant at present. In this, the North American industry is highly dependent on imports of rare earth minerals particularly from China, so an intense process of ensuring their processing and recycling in North America will be required, as it is currently underway in Canada.

Finally, in the European macro-region, Germany is a leader in the production of ICVs and, like Japan, is starting its transition late in the game, with a node smaller than Mexico's in terms of world trade volume.

Further regionalization within the three macro-regions is to be expected with the actual geo-economical-political conditioning of GPNs' deployment between the two dynamic cores, which is in contradiction to the necessarily global sourcing of key components for the whole automotive industry based on its new foundations, such as the software and semiconductors design from the United States, the sourcing and processing of rare earth minerals from China, the provision of batteries from South Korea and China's mainland or the semiconductor manufacturing from China's Taiwan. For how long and how far this contradiction will unfold?

Methodology Appendix

In order to elaborate the macro-regional and world nodes we used Gephi for Windows, Version 0.10.1, since this program handles large networks (up to 50,000 nodes and one million edges), and provides a visualization tool which enables us to efficiently analyze world trade.

The data source is provided by the Inter-Country Input–Output Tables (ICIO) from the OECD, which are a series of Multiregional Input–Output Matrices (MRIO) containing 45 industries for 67 countries from 1995 to 2018.

The information provided allows us to reconstruct the fragmentation process of world production and to demonstrate nodes and their connections since the matrix are composed of inter-country sectors that produce and require intermediate inputs to produce, containing intermediate input matrix, thus bi-sectoral transactions, as well as bilateral ones in the case of MRIOT.

Division 26 is considered for the electronic industry and Division 29 for the automotive industry (data with two-digit disaggregation).

Once the main macro-regional nodes were identified, we subsequently identified the six main country nodes within them and the 20 countries with which each of them have the most trade. From those 20 countries in each case, we considered only the first ten countries' trade with, in turn, their ten main partners, in order not to visually overcharge the figure.

To determine the size of the nodes, the value of the main node was determined and the other nodes are proportional to it, these values can be seen in Table 1.

Table 1. Trade Volume Determining the Countries' Nodes

Country	CN1	CN2	DEU	JPN	MX1	MX2	KOR	USA
Millions of dollars	7,150.93	11,419.42	3,445.90	3,239.07	2,351.23	5,942.81	5,992.10	13,585.90

Source: Developed by the author based on information provided by the ICIO. Accessed June 26, 2023. www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

Notes: Regarding CN1 and MX1, they refer to traditional trade between China and Mexico, that is, it does not include re-imports and re-exports. On the other hand, CN2 and MX2 refer to the duty-free imports for re-exports.

Notes

1. The activities stages of firms' GPNs can be categorized as: a) upstream, including R&D, product design, process engineering, and technical services; b) production, including the provision of the intermediate goods and the assembly, testing, and packaging of the final product; and c) downstream, including sales, marketing, distribution, and after-sales service.
2. According to business terminology, not very precise in the specialization activities of these types of companies: *Original Equipment Manufacturing* and *Original Design Manufacturing*.
3. *Contract Manufacturing* and *Contract Servicing*.
4. In other words, how the revolution in the automotive industry affects the technological trajectory of items and activities such as semiconductors, software, or digitization–virtualization processes.
5. The full potential of the revolutionization of the automotive industry through the introduction of computer-assisted design, engineering and manufacturing systems did not manifest itself immediately, but rather in the long term, as it constituted the technological-productive foundation of processes such as the outsourcing of the manufacturing of key parts and components by manufacturers with their suppliers and their differentiation in relation to the development of new related capabilities, as well as the processes of mergers and global strategic alliances between manufacturers that would develop respectively from the 1980s and 1990s onward (Shimokawa 2010).
6. The success of the 1967 Volkswagen 1600 model led Mercedes and BMW to co-develop similar systems with Bosch which had originally imposed the new standard. Years later, the 1976 Cadillac Seville, the 1979 Toyota Supra, and the 1981 Chrysler Imperial were models that entered the market with this paradigm-transforming technology (Martinez 2021).
7. Initially the smartphone acted as an infotainment control device, which would later evolve into a car connected to mobile networks.
8. There are three basic types of clean energy vehicles: hybrid vehicles (IC and electric), battery electric vehicles, and hydrogen cell electric vehicles. In the latter, hydrogen enters the cell on the anode side and is ionized (separated from its electrons), which generates a flow of electrons that is routed to produce electrical energy. The ionized hydrogen passes to the cathode side where it is bonded with oxygen, which produces wastewater (Semiconductor Engineering 2016).
9. The vehicle as an energy generator has brought with it the development of technologies for connecting the vehicle to the electric grid, not only to receive but also to provide electricity, with connection variants such as vehicle-to-home or vehicle-to-building, which enable the integral generation and distribution of electricity on demand in real time (Martinez 2021).
10. The main installed production capacity of cells and their components corresponds to China, while the United States accounts for 0% of cathode component production, 10% of anode, 6% of separator, and 2% of electrolyte (Mayoral 2022).
11. Temperature sensors within the battery pack ensure that if a cell overheats, it is immediately isolated so that the other cells around it are conserved by pumping liquid through the required areas to keep the temperature down (Martinez 2021).
12. In an effort to compete with Tesla's distribution and sales model, Ford recently established new rules for the sale of its EVs by retailers, including limits on the pricing of its vehicles and the need to make investments to install charging centers in its stores (Eckert 2022).
13. When an insurer de-registers a Tesla, the company stops supporting the vehicle by denying it access to the supercharge network, even if the car was successfully repaired and passed inspection by the company's own repair personnel. This access is canceled remotely, without the user having any say in the matter (Martinez 2021). In February 2023 the White House said Tesla will open part of its network to

- other kinds of vehicles so as to qualify for a share of billions of federal dollars on offer to build a national network of electric-vehicle chargers (Hiller 2023).
14. Geely has made investments in autonomous driving technology. In June, the company launched nine low-orbit satellites to help autonomous vehicles navigate better. In addition, its electric-vehicle transport subsidiary, Cao Cao, has established fleets of robotic cabs (Digitimesasia 2022).
 15. The NIO is one of the leading battery-swapping technology providers in China. It has built more than 1,100 swapping stations in the country and has brought the technology to Norway. It plans to establish 4,000 swapping stations worldwide by 2025 (Digitimesasia 2022).
 16. The BYD was originally a supplier of lithium batteries for computers and smartphones for Foxconn and other large contract manufacturers. In 2017 it was ranked as the largest lithium battery producer worldwide, leveraging vertical integration effects from various end markets, such as automobiles, buses, electronic-informatics technologies or new energy systems (Lüthje 2021).
 17. In 2017, eight of the world's top 13 lithium battery manufacturing sites were in China (Lüthje 2021).
 18. For example, Foxconn supplies electronics to the automotive industry, with major facilities in the United States as a supplier to Tesla, among others (Lüthje 2021).
 19. The rental contracts have a maximum duration of ten years, the estimated lifetime of the battery (Sugiura and Campbell 2022).
 20. In 2004, the government enacted the Green Vehicle R&D Act for the development of that industry, which could be considered the first R&D project in the electric-vehicle industry in South Korea (Lee and Mah 2020).
 21. The tax credits include restrictions related to the consumer's income level and the price of the EV.
 22. The anode accounts for 12%, the separators 7%, and the electrolyte 4% (Mayoral 2022).
 23. At its Shanghai plant, Tesla produces lithium-iron-phosphate batteries that are more economical and safer, and is the manufacturer that produces batteries with the longest range on the market, close to 600 miles. Tesla's co-founders in 2003, M. Eberhard and M. Tarpennig, were not mechanical engineers, but computer specialists with proven experience in launching the first versions of cloud computing software (Martinez 2021; Mayoral 2022).
 24. Stellantis NV plans to renovate its Saltillo plant for the production of hybrid and electric vehicles (El Financiero 2022).
 25. Mexico has approximately 1.7 million tons of the mineral, while Bolivia has 21 million tons, Argentina has 19.3 million tons and Chile has 9.6 million tons (Xataka Auto 2022a, 2022b).

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