TECHNOLOGICAL DEVELOPMENT AND PERIPHERAL INDUSTRIALISATION WITHIN THE FRAMEWORK OF GLOBAL VALUE CHAINS: THE CASES OF THE AUTOMOTIVE CHAIN IN THE EU AND MERCOSUR

Federico Dulcich[1]

The objective of this paper is to analyse the automotive value chains in the Southern Common Market (Mercado Común del Sur – Mercosur) and the European Union (EU), focusing on the ability to develop technology endogenously, distinctive of the developed countries. The methodology will focus on the descriptive analysis of variables relevant to this object of study, such as production, foreign trade and technological development of the automotive chain in both regions. The main results show that the efforts and results of innovation are concentrated in the traditional European automotive core; while the production activities that are located in the European automotive periphery and in Mercosur are dissociated from those of technological development, given that the technology is mainly adopted from the automotive technological development core countries.

Keywords: automotive value chain; technological change; core-periphery relations; Mercosur; European Union.

DESENVOLVIMENTO TECNOLÓGICO E INDUSTRIALIZAÇÃO PERIFÉRICA NO ÂMBITO DAS CADEIAS DE VALOR GLOBAIS: OS CASOS DA CADEIA AUTOMOTIVA NA UE E NO MERCOSUL

O objetivo deste artigo é analisar as cadeias de valor automotivas no Mercado Comum do Sul (Mercosul) e na União Europeia (UE), com foco na capacidade de desenvolver tecnologia endogenamente, característica dos países desenvolvidos. A metodologia terá como foco a análise descritiva de variáveis relevantes para este objeto de estudo, como produção, comércio exterior e desenvolvimento tecnológico da cadeia automotiva em ambas as regiões. Os principais resultados mostram que os esforços e resultados da inovação estão concentrados no tradicional núcleo automotivo europeu; enquanto as atividades produtivas localizadas na periferia automotiva europeia e no Mercosul são dissociadas daquelas de desenvolvimento tecnológico, uma vez que a tecnologia é adotada principalmente dos países núcleos de desenvolvimento tecnológico automotivo.

Palavras-chave: cadeia de valor automotiva; mudança tecnológica; relações centro-periferia; Mercosul; União Europeia.

1. PhD in economics from the University of Buenos Aires (UBA); Conicet researcher at National Technological University, General Pacheco Regional Faculty, Buenos Aires, Argentina; researcher at National University of La Matanza, Buenos Aires, Argentina. E-mail: <federicomd2001@gmail.com>. Orcid: <https://orcid.org/0000-0002-3375-1906>.

DESARROLLO TECNOLÓGICO E INDUSTRIALIZACIÓN PERIFÉRICA EN EL MARCO DE LAS CADENAS GLOBALES DE VALOR: LOS CAOS DE LA CADENA DEL AUTOMÓVIL EN LA UE Y EL MERCOSUR

El objetivo de este artículo es analizar las cadenas de valor automotrices en el Mercado Común del Sur (Mercosur) y la Unión Europea (UE), haciendo eje en la capacidad de desarrollar tecnología endógenamente, distintiva de los países desarrollados. La metodología se centrará en el análisis descriptivo de variables relevantes para este objeto de estudio; como la producción, el comercio internacional y el desarrollo tecnológico de la cadena automotriz en ambas regiones. Los principales resultados muestran que los esfuerzos y resultados de innovación se concentran en los tradicionales polos automotrices europeos; mientras que la producción automotriz que se localiza en la periferia automotriz europea y en el Mercosur se disocia de las actividades de desarrollo tecnológico, dado que la tecnología es principalmente adoptada desde los tradicionales polos automotrices.

Palabras clave: cadena de valor automotriz; cambio tecnológico; relaciones centro-periferia; Mercosur; Unión Europea.

JEL: O30; O14; L62.

DOI: http://dx.doi.org/10.38116/rtm29art13

Data de envio do artigo: 5/7/2022. Data de aceite: 24/8/2022.

1 INTRODUCTION

The automotive value chain is made up of two sectors that stand out in the productive structure of the Southern Common Market (Mercado Común del Sur – Mercosur) countries and the European Union (EU): the automotive and auto parts industries. The EU is the cradle of large automotive production and technological development hubs, such as Germany, France and Italy. Before the pandemic, automotive production in the EU accounted for 8% of manufacturing employment, in a region that concentrated 20% of global motor vehicle production (Acea, 2020). In the case of Mercosur, the automotive chain concentrated 4% of the gross domestic product (GDP) in Brazil (Anfavea, 2019), and 1% of the GDP in Argentina (SPE, 2018). Likewise, it represented 11% of total exports and 6% of formal industrial employment in Argentina (SPE, 2018), and 22% of the GDP of the manufacturing industry in Brazil (Anfavea, 2019).

In light of the relevance of the automotive chain in both regions, and their dissimilar trajectories in productive and technological terms, the objective of this paper is to analyse the automotive chains in Mercosur and the EU, considering that the ability to develop technology endogenously is characteristic of a small group of developed countries (Dosi, Freeman and Fabiani, 1994). In contrast, the industrialisation of peripheral countries is mainly based on the adoption and adaptation of external technology, a process that once consolidated confronts them with the challenge of making the leap to endogenous development of technology to promote *upgrading* towards segments with greater technological intensity of global value chains (Dulcich, 2018a; Humphrey and Schmitz, 2002).

The methodology will concentrate on the descriptive analysis of variables relevant to this object of study, such as production, foreign trade and technological development of the automotive chain in both regions, focusing on particular countries of them. This analysis will be complemented by a review of specialized literature on the subjectf, to address specific phenomena which are not captured by statistics. In the case of the traditional automotive hubs, the focus will be on Germany, France, and Italy, which belong to the contemporary core of the global automotive industry (Pavlínek, 2012). The analysis of the automotive periphery will focus on studying countries with automotive production but dissociated from sectoral technological development. In the case of the EU, within the automotive periphery of Central and Eastern Europe, the Czech Republic and Hungary stand out for their larger stocks of automotive foreign direct investment (FDI) per capita (Pavlínek et al., 2017). Consequently, this research will focus on those countries, together with Spain, a country with a strong automotive tradition but which has not managed to position itself in the technological development of the sector. In Mercosur, Brazil and Argentina are the relevant automotive producers in the region and on which we will focus in this investigation.

The main results show that the efforts and results of innovation are concentrated in the traditional European automotive core, while production activities dissociated from those of technological development are located in the European automotive periphery and in Mercosur, given that technology is mainly transferred from the automotive technological development cores.

As a corollary, these productive capacities dissociated from innovation activities restrict the peripheral automotive industry from upgrading towards segments with greater technological intensity, which is a key process for the productive development of the automotive chain in those countries, and therefore for their economic development.

2 THEORICAL FRAMEWORK

At a theoretical level, the issue of global value chains (GVCs) has been widely addressed by specialised literature. In a renowned work on the subject, Gereffi, Humphrey and Sturgeon (2005) highlight five forms of governance of global value chains by their leading companies, determined by the complexity of the transactions involved, the ability to codify the technical knowledge of the goods or services to be exchanged, and the productive and technological capacities of the suppliers. *Market* relations, with low levels of asymmetry, occur in low-complexity, highly codable transactions, and with suppliers with good techno-productive capabilities.

In *modular* relations, the complexity of transactions increases, and standards tend to unify product and component specifications, so that they can be produced in a modular way.[2] In the case of *relational* value chains, the capability to codify technical knowledge is low (with a product architecture that tends to be integral), consequently the need for interaction between supplier and customer at a productive and technological level increases. In the case of *captive* value chains, the complexity of the transactions and the possibility of codifying the technical knowledge involved remains high, like in modular chains. However, the techno-productive capacity of suppliers is low, which generates greater control of it by the leading company, which usually confines the supplier to a small number of activities of lower complexity (such as assembly) increasing the asymmetry between them. Lastly, in this context of complex transactions and low supplier capacity, if the capacity to codify the technical knowledge involved is also low, the leading firms tend to vertically integrate the productive activity in question, in order to make the transmission of technical knowledge effective and to control the quality of the process and product.

In empirical terms, Timmer et al. (2014) have highlighted several stylised facts about the evolution of manufacturing GVCs in the last decades. Among others, an increase in the international fragmentation of production, as well as an increase in the participation of capital and of highly qualified workers, is identified in the distribution of income within the GVCs, which contrasts with a reduction in the participation of low-skilled workers. This would be explained by the globalisation of chains towards low-wage countries, whose effect is intensified with China's entry into the World Trade Organization in 2001. Given the strong automation of various industrial processes and the capability to coordinate them on a global scale originated by information and communications technology, these relocations would have been carried out with low productivity losses, which, along with relatively low wages at an international level, would have generated conditions of greater profitability (Baldwin, 2011), explaining the increase of the participation of capital in the distribution of income.

In contrast, highly-skilled workers, fundamental in the tasks of learning and technological development, have segmented labour markets with wage premiums, which explains that they have increased their participation in the income distribution of GVCs. These activities, especially those of technological development, are concentrated in developed countries at an international level,

2. In product architecture (the physical and functional decomposition of products, according to Muniz and Belzowski (2017), *modularity* represents a one-to-one correspondence between functional and structural elements. Thus, the components can be developed and produced with a certain independence from each other. In contrast, an *integral* architecture does not have such a one-to-one correspondence, requiring a lot of coordination to adapt and optimize the different components in the integrity of the product. At the same time, the interfaces between those components can be of *open* standards for the whole industry, associated to a *modular* architecture, or *closed*, where those interfaces belong to firms with rights over them. Closed interfaces can appear in either a modular or an integral architecture (Fujimoto, 2017).

determined by the attributes of the National Systems of Innovation (NSI) (Dosi, Freeman and Fabiani, 1994; Lundvall, 1992). This is consistent with the third stylised fact highlighted by Timmer et al. (2014), which posits a specialisation in intensive activities in highly qualified labour in high-income countries, while the fourth stylised fact highlights a specialisation in capital-intensive activities in developing countries. Both phenomena are consistent with the propositions of the new international division of labour (NIDL), where the developed countries specialise in the provision of technology at an international level, while the developing countries are net adopters of technology, on which various countries base their industrialisation (of greater intensity of capital than the activities of technological change). Once the industrialisation process has been consolidated based on the adoption of external technology, the peripheral countries face the challenge of making the leap to endogenous technology development (Dulcich, 2018a), in order to promote *upgrading* towards the segments of global value chains with greater technological intensity (Humphrey and Schmitz, 2002).

Unlike global value chains such as those of electronics, the automotive production chain tends to generate regional trade structures. The above mentioned chains are coordinated by the leading firms of the automotive industry, with a supply highly concentrated in a few transnational corporations (TNCs), mainly from Western developed countries, Japan and South Korea (Sturgeon et al., 2009).

These firms, in general, locate the finalisation of vehicles near the end markets, to take advantage of tax incentives, to get around trade protectionism and to adapt the design to the preferences of local consumers, national environmental and safety regulations, road infrastructure etc. (Pavlínek, 2012; Cantarella, Katz and Monzón, 2017).

The relationship between automakers and their auto parts suppliers tends to be *relational* or *captive* (Gereffi, Humphrey and Sturgeon, 2005; Sturgeon, Biesebroeck and Gereffi, 2008; Sturgeon et al., 2009), depending on the degree of asymmetry between them. The low *modularity* in parts and components increases the need for technology transfer and cooperation in research and development (R&D) between automotive companies and tier 1 auto part manufacturers. In these activities, the existence of tacit knowledge (not codifiable and transmissible mainly through exhibition and practice) and the need for interaction to make components and systems compatible in the integrality of the product encourage the co-location of automakers and their tier 1 suppliers. This agglomeration is also motivated by the fact of avoiding high costs of transportation of auto parts of high weight, volume and fragility (boards, seats etc.), and of achieving a just-in-time supply of the required parts and/or components (Sturgeon et al., 2009; MacDuffie, 2013; Cabigiosu, Zirpoli and Camuffo, 2013; Pavlínek, 2012).

In this context, various tier 1 auto parts manufacturers became "global suppliers" of the leading automakers, adopting a growing role in productive and technological terms, and accompanying the location of investments by automotive companies (Sturgeon et al., 2009).

In technological terms, the automotive chain is one of the industries that invests the most in R&D, as can be seen in the European case, where it leads the ranking of R&D expenses in 2018 (Acea, 2020). However, these activities have a low degree of internationalisation, and are mainly concentrated in the countries of origin of the parent companies of the global automakers or in other developed countries (Miller, 1994; Carrincazeaux, Lung and Rallet, 2001). Internationalised activities beyond those destinations are usually those linked to product development and adaptation to regional and national conditions (Pavlínek, 2012).

In fact, within the framework of Toyotism, automotive companies faced the challenge of reconciling scale economies with product differentiation (Coriat, 2000); and since the nineties the main strategy to address it was the use of platforms shared by different models. The platform typically consists of the chassis, the structure, and diverse mechanical subsystems shared by different models, allowing production to get scale economies with them. This lower part of the vehicles is less determinant of their aesthetics, and it is in the upper part where the differentiation of the product unfolds, from which the economies of scope benefit. R&D in platforms and modules is usually concentrated in the core of automotive technological development; while in some cases the product differentiation activities on the upper part of vehicles have been located in the most important production centres at a regional level (Lung, 2004; Pavlínek, 2012; Muniz and Belzowski, 2017).

Nowadays the automotive chain is facing a transition in the techno-economic paradigm of the chain, focused on the emergence of electric mobility.[3] Despite the fact that electric vehicles (EVs) still account for a small fraction of the world automotive production, they present a growing productive and technological dynamic, higher than that of internal combustion engine vehicles (Icev); and they have currently positioned themselves as predominant within the universe of alternative technologies to these vehicles (Dulcich, Otero and Canzian, 2019). The development and production of EVs at an international level is highly influenced by the incentives generated by different policies in various countries (demand subsidies, R&D financing, regulations that limit tailpipe gas emissions etc.),

3. The techno-economic transition of the automotive chain is also determined by other new forms of mobility, such as connected, shared and autonomous mobility. For more details, see Public Sector Consultants and CAR (2017), Bahrani Fard and Brugeman (2019), Nikitas et al. (2017), among others.

which promote the transition to electric mobility to mitigate the emission of greenhouse gases (GHG), that boost climate change,[4] as well as to reduce urban pollution (IEA, 2020).

At an industrial level, this transition opens windows of opportunity for the repositioning of companies and countries, and the emergence of new competitors, as well as a major challenge for the current leaders of the automotive value chain. In this context, at the meso-economic level different strategies are open for developing countries to speed up convergence to the sectoral technological border (*catch up*) or even for making the leap to leadership (leapfrogging). Wang and Kimble (2011) point out that *leapfrogging* is not merely an acceleration in the course of the different stages of a technological trajectory (such as *catch up*), but rather it focuses on skipping stages in the transition to the border (the so-called *stage skipping leapfrog*), exploring new stages untraveled by the current leaders (*path creating leapfrog*) and even developing a new techno-economic paradigm that alters technologies, institutions and market structure of the sector, positioning the developing country as the pioneer and new leader within the new paradigm (*paradigm changing leapfrog*). In fact, China sees this context of transition as an opportunity to leapfrog into a sector globally dominated by large Western, Japanese and South Korean firms (Wang and Kimble, 2011).[5]

To make this potential technological transition effective, the relationships established between the niches (where new technologies emerge and are developed) and the current techno-economic regime are decisive. This interaction can be neutral coexistence, integration, or it can lead to the disappearance of one of the entities, where the regime displacement by the niche opens a transition path of the techno-economic paradigm (Dijk, 2014). A key role for the State is the Strategic Niche Management (Kemp, Schot and Hoogma, 1998), to channel the transition towards a desirable outcome (contemplating environmental objectives, for example). From an evolutionary perspective, given the uncertainty inherent to technological development, the State must favour technological variety (Schot and Geels, 2007): the emergence of various technological niches in "protected spaces" (Kemp, Schot and Hoogma,1998). Then, it must rectify the

4. According to Stern (2008), the emission of GHG is a negative externality that is the largest existing market failure in historical and geographical terms, for which it has various peculiarities: it is an externality of causes and effects of a global nature, with significant lags between the causes and effects (which are potentially catastrophic), whose potential solutions require complex negotiations and international institutions, as well as involving ethical aspects linked to intergenerational tradeoffs.

5. In this sense, China's strategy focuses on taking advantage of (and promoting) the technological transition to make the leap to leadership in the automotive chain, in the so-called *paradigm changing leapfrog* (Wang and Kimble, 2011). This objective is promoted through measures such as the financing of R&D and recharging infrastructure, a system of production targets for *powertrain* technology for automakers, public purchases, subsidies and tax exemptions for private purchases, and preferences in granting patent licenses and in circulation in restricted areas at the local level, among others (Zheng et al., 2012; Wang, Pan and Zheng, 2017; IEA, 2018).

regulatory and institutional attributes that could obstruct the necessary selectivity process, since they can generate a *lock-in* in the current regime (Kemp, Schot and Hoogma, 1998; Dijk, 2014).

These topics show the incidence of institutional frameworks to favour the technological transition and to achieve a successful leap to leadership, where science and technology institutions are especially relevant, as well as productive policies, in order to focus on innovations in a systemic framework (as noted by the authors of the NSI, such as Lundvall, 1992). Among others, it can be highlighted the significance of innovation policies (such as R&D policy), technology adoption and diffusion policies (educational policy, the one related to intellectual property rights – IPR – etc.), policies aimed to the structure of different markets or production chains, and sectoral regulations (tariffs, subsidies etc.). However, when applying these instruments, rent-seeking behaviour by companies must be avoided, through internal competition or other selectivity mechanisms from the State (Cimoli et al., 2009).

A special consideration merits the potential existence of "coordination failures": the inability to coordinate complementary investments merely through market signals. This coordination failure would be slowing down private investments in EV production and charging infrastructure. State intervention coordinating these investments would make it possible to overcome the mentioned failures and take advantage of increasing returns to scale (Altenburg, Bhasin and Fischer, 2012).

3 CURRENT SITUATION OF THE AUTOMOTIVE CHAIN IN THE EU AND MERCOSUR

In table 1, it can be appreciated that the volume of production in the EU and the European selected countries is much higher than that of Argentina and Brazil, even in per capita terms. These differences reflect both differences in the size of the domestic market and in the use of vehicles per capita, as well as in the export orientation of both regions. In 2019, while Argentina exported 71% of its production and Brazil 15% (which includes intra-Mercosur exports, which represented more than 60% of the total, see Dulcich, Otero and Canzian, 2019), EU extra-regional exports accounted for 30% of its automotive production, overtaking Brazil. In the case of individual European countries, such as Germany, Italy, or the Czech Republic, the ratio between exports and vehicle production (including exports to other EU countries) exceeds 80% (table 1), outperforming both Brazil and Argentina.

TABLE 1
Analysis of selected variables of the automotive and auto parts industry in Argentina, Brazil and the EU

Industry	Variable	Argentina	Brazil	EU28	Germany	France	Italy	Spain	Czech Republic	Hungary
Automotive industry	Vehicle production (units) (2019)	314,787	2,944,988	18,507,834	5,164,528	2,303,699	879,724	2,915,432	1,428,620	498,158
	Automobiles (%)	**34**	**83**	**85**	**90**	**73**	**62**	**77**	**100**	**100**
	Light commercial vehicles (%)	**66**	**12**	**12**	**7**	**24**	**3**	**22**	**0**	**0**
	Others (%)	**0**	**5**	**3**	**3**	**3**	**35**	**1**	**0**	**0**
	Vehicle production per 1,000 inhabitants (units) (2019)	7	14	41	62	34	15	62	134	51
	Motorization rate (vehicles in use per 1,000 inhabitants) (2015)	316	206	544	593	598	706	595	559	337
	Vehicle sales (units) (2019)	368,806	2,787,850	17,884,926	4,017,059	2,755,695	2,131,916	1,501,260	281.423	190,084
	Imports/sales (units) (2019)[1]	72	11	23	92[6]	n.d.	88	77	98	n.d.
	Exports/production (units) (2019)[1]	71	15	30	94	n.d.	84	79	97	n.d.
	Trade balance (USD million) (2019)[1,2]	824	-1.029	83.145	75,026	-14,640	-14,627	16,740	18,172	8,317

(Continues)

(Continuation)

Industry	Variable	Argentina	Brazil	EU28	Germany	France	Italy	Spain	Czech Republic	Hungary
Auto parts industry	Trade balance (USD million) (2019)[1,3]	-2,543	-6,532	41,596	37,994	-2,964	8,875	-7,163	3,238	5,113
	Average imports of auto parts per produced vehicle (2019)[1,3,4]	11,477	4,015	2,748	12,978	11,611	17,935	8,492	11,584	21,556
Automotive value chain	Total labour cost per employee per hour worked (€ in full-time equivalent) (2016)[5]	n.d.	n.d.	n.d.	53	41	29	25	12	10

Source: Oica, Acea, United Nations, Adefa, Anfavea, Anfac, Anfia, and World Bank.
Prepared by the authors.
Notes: [1] In European countries, this variable includes intra-EU28 trade. At the same time, in Argentina and Brazil it includes intra-Mercosur trade.
[2] Includes buses and coaches (HS02 8702), automobiles (HS02 8703), and motor vehicles for the transport of goods (HS02 8704).
[3] Includes transmission belts (HS02 401031/39), new tires (HS02 401110/20), gasoline engines (HS02 840731/34), diesel engines (HS02 840820), engine parts (HS02 840991/99), transmission shafts (HS02 8483), electric accumulators (HS02 850710) and other auto parts (bumpers, safety seat belts, brakes, gearboxes, shock absorbers, radiators, clutches, steering wheels, exhaust pipes etc.; belonging to HS02 8708).
[4] Includes auto parts for the aftermarket.
[5] Corresponds to companies producing motor vehicles, trailers, and semi-trailers of the Nace (which includes the auto parts sector) with at least 10 employees. It does not include trainees.
[6] Own estimate of imports assuming zero variation in stocks.
Obs.: n.d. – no data available.

In terms of import penetration, the EU is located in an intermediate position between Argentina's great opening to imports (72% of imports over sales) and the closed Brazilian market (11%); since in the EU imports represented 23% of vehicle sales.

The EU significant extra-regional export orientation, greater than its import penetration, in a context of a volume of production much higher than that of Argentina and Brazil, explains the superlative commercial surplus in EU vehicles, which exceeds USD 80 thousand millions. In contrast, Brazil has a meager surplus and Argentina has a trade deficit in vehicles.

In auto parts, once again the EU has significant extra-regional competitiveness, which contrasts with the trade deficits of Argentina and Brazil (table 1). The incorporation of imported auto parts per produced vehicle in the EU28 is slightly lower than that of Brazil (USD 2,748 vs. USD 4,015 of imports of auto parts per produced vehicle), but this variable is much higher in the disintegrated automotive industry in Argentina (USD 11,477 of imports of auto parts per produced vehicle).[6]

4 ANALYSIS OF THE AUTOMOTIVE CORE PERIPHERY RELATIONSHIP IN THE EU AND MERCOSUR

4.1 Analysis based on innovation results

In table 2, which shows the evolution of economic high-impact patent applications for conventional vehicles and electric vehicles in various countries, it can be appreciated five stylised facts.

In the first place, the development of automotive chain technology in the last three decades has been concentrated in the main automotive hubs: the US, the EU (particularly Germany, France and Italy), Japan, South Korea and, to a lesser extent, China. Among them, they account for 90% or more of patent applications globally for both technologies and almost all periods considered.

The second stylised fact to highlight is that the role of countries that are relevant in terms of global automotive and auto parts production is marginal in terms of the technological development of the automotive value chain. Patent applications from Spain, the Czech Republic, Hungary, Brazil and Argentina are insignificant when compared to those of the traditional automotive core, a situation that is repeated in all the technologies analysed (see table A.1 of the appendix, where motorization technologies are detailed and technologies related

6. In this regard, the hypothetical static effect of the Mercosur-EU agreement for the automotive value chain would imply important benefits for the EU in terms of increasing bilateral trade balances with Argentina and Brazil in a large part of the automotive and auto parts subsectors, based on the strong international competitiveness of the EU (Dulcich, 2022).

to electric mobility are added, such as batteries and recharging infrastructure). Perhaps the most remarkable case is that of Spain, which for technologies associated with electric mobility (electric vehicles, hybrid vehicles, fuel cell electric vehicles (FCEVs), batteries, and recharging infrastructure) narrows the gap with Italy, which is the EU automotive hub with the least relative technological development.

Thirdly, these results reflect that the automotive core-periphery dichotomy not only is deployed at a global level, but it can also be reproduced at an intra-regional level, as can be seen in the case of the EU. The technological development concentrated in Germany, and to a lesser extent in France and Italy, substantially outpaces the already mentioned scarse patents in Spain, the Czech Republic and Hungary (table 2), which are positioned in the automotive periphery in technological terms.

Fourthly, table 2 allows us to assess the evolution of the technological transition towards EVs and their associated technologies. While in the 1990s there was a clear predominance of patent applications for conventional vehicles, since the mid-2000s the combination of hybrid, electric and hydrogen vehicles has accounted for more patent applications than conventional technology, as they have had a much bigger technological dynamic. Meanwhile, the applications for technologies associated with electric mobility such as batteries and recharging infrastructure have also experienced a much higher growth in patent applications than that of conventional vehicles in the last three decades at a global level (table A.1 of the appendix).

Finally, associated with this dynamic, the fifth stylised fact is the growing role of China in the technological development of the automotive chain, associated with its technological developments in electromobility. As can be seen in table A.1 of the appendix, while in conventional vehicles it barely accounts for 1% of patent applications worldwide at present, this participation amounts to 2% in FCEVs, 3% in hybrid vehicles, 6% in electric vehicles and charging infrastructure, and 8% in the case of batteries; all of which are participations that have experienced a growing trend in the last two decades.

TABLE 2
High economic impact patent applications[1] by residents by innovating country for conventional vehicles and electric vehicles

Technology domain	Inventor country[2,3]	Average (1990-1994)	Average (1995-1999)	Average (2000-2004)	Average (2005-2009)	Average (2010-2014)	Average (2015-2018)	Variation (2015-2018 and 1990-1994) (%)
Conventional vehicles (based on internal combustion engine)	World	575	875	1,410	1,684	2,078	1,858	223
	United States	106	125	215	366	552	445	320
	Japan	250	376	596	618	603	583	133
	Korea	3	8	23	45	113	145	4,427
	China	2	2	4	10	22	22	1,033
	EU27	162	303	470	538	633	538	232
	Germany	**106.0**	**206.1**	**298.8**	**322.5**	**367.6**	**316.3**	198
	France	**17.6**	**31.4**	**69.4**	**91.2**	**93.6**	**59.1**	236
	Italy	**7.9**	**12.6**	**25.5**	**29.4**	**38.4**	**49.8**	528
	Spain	**1.4**	**1.1**	**1.9**	**2.7**	**5.2**	**3.8**	171
	Czech Republic	**0.1**	**0.4**	**0.8**	**0.7**	**3.0**	**7.6**	7,460
	Hungary	**1.2**	**0.2**	**0.4**	**1.5**	**0.2**	**1.1**	-10
	Brazil	1.0	0.4	1.1	2.6	2.7	2.0	100
	Argentina	0.2	0.0	0.7	0.6	0.3	0.0	-100
	Others	50	61	101	102	152	123	144
	China (% of world)	0	0	0	1	1	1	
	US + Japan + Korea + China + EU27 (% of world)	91	93	93	94	93	93	

(Continues)

(Continuation)

Technology domain	Inventor country[2,3]	Average (1990-1994)	Average (1995-1999)	Average (2000-2004)	Average (2005-2009)	Average (2010-2014)	Average (2015-2018)	Variation (2015-2018 and 1990-1994) (%)
Electric vehicles[4]	World	185	436	905	1,914	3,359	3,246	1,651
	United States	30	58	172	443	630	629	1,998
	Japan	79	252	488	899	1,400	1,204	1,417
	Korea	2	3	16	69	359	389	18,433
	China	1	1	5	35	68	161	24,037
	EU27	52	95	169	377	721	660	1,182
	Germany	**31.0**	**64.6**	**103.6**	**239.4**	**438.6**	**447.7**	1,344
	France	**5.9**	**14.6**	**35.2**	**66.2**	**144.5**	**77.8**	1,218
	Italy	**7.2**	**4.2**	**4.3**	**19.1**	**28.7**	**30.1**	317
	Spain	**0.4**	**0.7**	**3,6**	**3.1**	**8.9**	**5.7**	1,327
	Czech Republic	**0.0**	**0.0**	**1.2**	**0.3**	**0.4**	**1.6**	n.c.
	Hungary	**0.0**	**0.4**	**0.0**	**0.3**	**1.3**	**1.5**	n.c.

(Continues)

(Continuation)

Technology domain	Inventor country[2,3]	Average (1990-1994)	Average (1995-1999)	Average (2000-2004)	Average (2005-2009)	Average (2010-2014)	Average (2015-2018)	Variation (2015-2018 and 1990-1994) (%)
Electric vehicles[4]	Brazil	0.2	0.4	0.2	1.5	1.1	1.9	845
	Argentina	0.0	0.2	0.0	0.2	0.0	0.3	n.c.
	Others	22	26	54	90	179	200	829
	China (% of world)	0	0	1	2	2	5	
	US + Japan + Korea + China + EU27 (% of world)	88	94	94	95	95	94	

Source: Organisation for Economic Co-operation and Development (OECD).
Prepared by the authors.
Notes: [1] Only technological developments with patent applications in three or more markets ("patent family size" 3 or higher) are considered. According to the OECD, the patent family size correlates positively with the value of the invention, which is why they were classified here as having "high economic impact".
[2] For patents developed by residents of more than one country, the OECD splits the statistical value of the variable among all developers to avoid double counting. For example, an invention developed by residents of two countries obtains a value of 0.5 in each of those countries.
[3] Decimal values are shown only for member countries of the EU27, Argentina, and Brazil. In all other cases, they are rounded to the nearest whole number.
[4] Includes patents related to hybrid vehicles, electric vehicles, and application of hydrogen technology to transportation (e.g. using fuel cells).
Obs.: n.c. – not calculated.

4.2 Analysis based on innovation efforts

In addition to the analysis carried out in terms of patent applications by technology and country, in table 3 it can be appreciated the investments in R&D and in physical capital (both physical capital expenses, as a percentage of sales, and physical capital stock per worker) of mostly US-owned transport equipment companies in Argentina, Brazil, and the EU.[7] There it can be highlighted two main phenomena.

On the one hand, the innovation efforts of these companies reflect the results already obtained in terms of patent applications: in the regions analysed, the greatest R&D as a percentage of their total sales is concentrated in the traditional European automotive core (Germany, France and Italy), while it is marginal in the European automotive periphery and in Argentina. The main exception regarding the results obtained in terms of patent applications is the case of Brazil, with a higher R&D intensity than that of the already mentioned countries of the automotive periphery, and converging with that of Italy.[8] In this regard, it is important to highlight that in Brazil product developments and adaptations are usually carried out for the regional market (Obaya, 2014), which may require R&D activities despite being based on technology patented in the traditional automotive core, which could explain this difference. This topic will be further developed in section 5.2.

On the other hand, while innovation efforts are concentrated in the traditional automotive core, there are no important differences between the countries analysed in terms of physical capital expenditures as a percentage of sales, or in the stock of physical capital per worker. This shows that this convergence of productive capacities does not necessarily imply a convergence of technological capacities, which continue to be concentrated in the traditional automotive hubs.

7. This cut of the object of study has been made due to the lack of information on these variables that is comparable and disaggregated at the sectoral level, and that is available to all the countries considered.

8. Data from a July 2021 report on the Rota 2030 program in Brazil, which has R&D incentives, shows that the 59 companies in the automotive value chain enabled in the program in 2019 had an R&D/sales ratio of 2.07% (available at: <http://bit.ly/3tOqKYB>), corroborating the results of Table N° 3 and demonstrating the existence of a slight upturn in innovation efforts compared to the 2014-2018 period. At the same time, this would show that these levels of innovation efforts are not exclusive to the subsidiaries of US firms.

TABLE 3
Analysis of investment in R&D and physical capital of subsidiaries of US majority owned transportation equipment companies in the EU, Brazil and Argentina

Variable	Country/region	Average (2009-2013)	Average (2014-2018)	Variation (2014-2018 and 2009-2013)
R&D expenditures/ total sales (%)	EU	3.2	2.6	-18
	Germany	**5.3**	**4.2**	**-21**
	France	**3.8**	**4.2**	**11**
	Italy	**1.5**	**1.8**	**26**
	Spain	**0.4**	**0.4**	**-2**
	Czech Republic	**0.3**	**0.2**	**-15**
	Hungary	**0.1**	**n.d.**	**n.d.**
	Brazil	2.2	1.8	-17
	Argentina	0.2	0.1	-38
Capital expenditures[1]/total sales (%)	EU	2.3	2.5	8
	Germany	**2.0**	**2.1**	**2**
	France	**2.0**	**2.2**	**14**
	Italy	**2.9**	**2.8**	**0**
	Spain	**2.3**	**1.6**	**-31**
	Czech Republic	**2.8**	**3.7**	**32**
	Hungary	**2.2**	**2.2**	**-4**
	Brazil	3.8	2.9	-23
	Argentina	1.5	1.8	24
Net physical capital[2] per worker	EU	USD 66,496	USD 61,244	-8%
	Germany	**USD 67,516**	**USD 70,248**	**4%**
	France	**USD 49,396**	**USD 47,363**	**-4%**
	Italy	**USD 56,595**	**USD 53,562**	**-5%**
	Spain	**USD 107,432**	**USD 128,947**	**20%**
	Czech Republic	**USD 43,894**	**USD 38,960**	**-11%**
	Hungary	**USD 35,610**	**USD 41,118**	**15%**
	Brazil	USD 50,432	USD 69,820	38%
	Argentina	USD 46,781	USD 61,110	31%

Source: US Bureau of Economic Analysis.
Prepared by the authors.
Notes: [1] Capital expenditures include expenditures to acquire or improve physical capital. Physical capital is made up of land, mining rights, buildings, structures, machinery, and equipment (production, office, and transportation equipment).
[2] This variable records the value of physical capital in net terms, after deduction of accumulated depreciation.
Obs.: Includes transport equipment according to the US NAICS classification. This includes motor vehicles and auto parts, aircraft and aerospace vehicles, railroads, ships, and other vehicles.

5 AUTOMOTIVE PERIPHERAL INDUSTRIALISATION BASED ON THE ADOPTION AND ADAPTATION OF EXTERNAL TECHNOLOGY

5.1 The European automotive periphery

Since the 1990s, within the framework of the processes of transition to market economies, with legislation favourable to FDI, and later in the context of integration into the EU, the automotive and auto parts industry in Central and Eastern Europe has significantly expanded and modernised. These transformations have been led almost exclusively by global automotive companies, followed by their tier 1 global suppliers (Pavlínek et al., 2017).

In this way, the automotive production of the EU has been relocated in the last three decades from the traditional automotive core countries (such as Germany, France, and Italy) to countries of the so-called "European automotive periphery" (Pavlínek et al., 2017), with emphasis on the countries that joined the EU as members in the 2000s, such as the Czech Republic and Hungary, among others. In the case of Spain, this process began earlier, as it joined the European Community in the mid-1980s, and it is a country with a long automotive tradition (Ruiz, 2001). However, these production localisations were not accompanied by technological development activities, which continued to be concentrated in the European automotive core countries.

Easy accessibility to Western Europe (where the largest automotive markets are found) has been one of the advantages of the localisation of the automotive periphery in Eastern Europe, to which its significant salary advantages must be added, combined with important productive capacities accumulated in a region with a considerable industrial tradition (Pavlínek et al., 2017).

To delve into the salary advantages that the region presents, in table 1 it can be appreciated that the total labour cost per hourly employee in the automotive chain in the Czech Republic or Hungary in 2016 was between a quarter and a fifth of that in Germany. These salary advantages have motivated a significant number of productive relocations of automotive and auto part manufacturers in Europe. For example, between the 1990s and 2000s, Audi relocated its engine production from Ingolstadt (Germany) to Gyor (Hungary), to take advantage of lower wage costs and more flexible working conditions, among others (Pavlínek et al., 2017).

In the Czech Republic, the expansion of the automotive industry in the 1990s was dominated by Volkswagen's investments in Škoda Auto and subsequent investments by its suppliers. In the 2000s, the investments in new production plants by Toyota Peugeot Citroën Automobile (TPCA), a local joint venture between the Toyota and PSA groups, and by Hyundai stand out. Both phenomena triggered investments by Japanese and South Korean auto parts suppliers (Pavlínek et al., 2017).

The case of Hyundai is paradigmatic of productive investments with little product development: the models produced at its plant in Nosovice, the Czech Republic, were designed at Hyundai Motor Europe Technical Center in Russelsheim, Germany. Along the same lines, the TPCA plant produced three city car models (Citroen C1, Toyota Aygo and Peugeot 107) that shared an important part of systems and components, as in the case of Toyota 1.0 L engines and transmissions (Jacobs, 2017); which also accounts for low product development at the local level.

In Hungary, on the other hand, Suzuki, GM Opel and Audi investments in the 1990s, and those of Mercedes Benz towards the end of the 2000s stand out, the latter accompanied by investments in new facilities of more than thirty foreign suppliers (Jacobs, 2017; Pavlínek et al., 2017).

Both Opel and Audi produce engines at their plants in Hungary; the first of them has specialised in this production, since it stopped producing vehicles in 1999. More than 500,000 engines were produced there in 2015, mainly destined to supply through exports to the plants of Opel in other countries in the region which produce vehicles for the European market. Audi, on the other hand, produced 2 million engines at its Gyor plant in 2015 along with 160,000 vehicles, which shows a strong export orientation to supply Volkswagen and Audi models produced in the region (Jacobs, 2017; Pavlínek et al., 2017). This production and exports of engines by Opel and Audi are consistent with the significant participation that Hungary had in world exports of petrol engines (8%) and diesel engines (6%) in the period 2014-2016 (Dulcich, Otero and Canzian, 2018).

It is important to note that Audi has an engine development center and an integral vehicle development area in Gyor, where virtual developments are carried out and the properties of the vehicles and their powertrains (thermal and energy management, acoustics etc.) are analysed through numerical simulations. At the same time, since 2020 it has been producing electric engines as well as PHEV versions of the Audi Q3 Sportback,[9] joining the transition to electric mobility.

Finally, in the case of Spain, the productive presence of the main global automotive companies stands out, such as Volkswagen, PSA, Renault, GM and Ford, among others (Pavlínek et al., 2017). This industry is consolidated in the sixties; and it makes the export leap in the 1970s, within the framework of integration into the European Economic Community and of regulatory changes that favoured automotive production and the settlement of investments (Ruiz, 2001). Its specialisation within

9. Available at: <https://www.audi-mediacenter.com/en/gyoer-hungary-207>. Accessed on: Apr. 2021.

the EU automotive production was focused on mid-range and low-end models, which might have been changing in recent years. In a context of installed capacity excess at the regional level, especially after the 2009 international crisis, the closure of some plants in the traditional automotive core countries may have favoured the productive relocation of certain models with higher added value towards Spain (Pavlínek et al., 2017).

For example, after the closure of three other plants in Europe, the Ford plant in Valencia got hold of significant investments for the production of three models between 2014 and 2015: the Mondeo, the S-Max and the Galaxy (Pavlínek et al., 2017). In recent years, Ford has made significant investments to produce hybrid vehicles in Valencia, such as the S-Max Hybrid, the Galaxy Hybrid, and new versions of the Kuga Hybrid, as well as to assemble batteries for these vehicles.[10] Another example is the start of production of the Audi Q3 at the Seat Barcelona plant (belonging to the Volkswagen group) in 2011, which competed against the Volkswagen group plant in Brussels to win the above-mentioned model (Pavlínek et al., 2017).

However, not all automotive companies with productive capacity in Spain have followed virtuous paths in the last years. For example, in May 2020, Nissan announced the closure of its Barcelona production plant.[11]

5.2 Mercosur

The South American region has a long history of automotive production, which was catapulted in the mid-20th century in the framework of policies aimed at import substitution industrialisation (Dulcich, Otero and Canzian, 2020; Marx, Mello e Lara, 2020). Currently, the automotive chain in Mercosur is protected by a common external tariff on imports of 35% for vehicles and between 14% and 18% for auto parts,[12] with a regulation of automotive trade between Argentina and Brazil that limits bilateral trade inequalities (Dulcich, Otero and Canzian, 2020).[13] These measures encourage global automotive companies to jump that tariff barrier and to invest in installed capacity in both countries.

10. Available at: <https://media.ford.com/content/fordmedia/feu/en/news/2020/01/16/Valencia.html>. Accessed on: Feb. 2022.

11. Available at: <https://www.elespanol.com/invertia/empresas/20200528/produccion-nissan-barcelona-asumida-plantas-renault/493450945_0.html>. Accessed on: July 2021.

12. In contrast, EU import tariffs on automobiles and light commercial vehicles range between 10% and 14%, and those on auto parts range between 2% and 7% (Dulcich, 2022).

13. This regulation is based on the Aladi Economic Complementation Agreement No. 14, signed by Argentina and Brazil. There, the flex coefficient, which relates bilateral imports and exports of the automotive value chain, marks the limits within which this trade between Argentina and Brazil is free of import tariffs. In the early 2000s, this coefficient was close to 1, and in subsequent years it was widened to 2,6 in 2005, and then phased down again to a value of 1,5 in 2014 (Dulcich et al., 2020). In mid-2019, Argentina and Brazil agreed on a trend increase in the flex coefficient for 10 years, until converging to free bilateral automotive trade by mid-2029 (Dulcich, 2022).

In the case of Argentina, the automotive chain has been exposed to the macroeconomic and sectoral regulatory fluctuations that the country has suffered since the 1970s. Thanks to the aforementioned regional automotive integration with Brazil since the 1990s, the automotive industry has managed to strongly increase its export orientation, at the cost of losing national integration of production, significantly increasing the auto parts deficit. As can be seen in table 1, the automotive industry in Argentina has tended to specialise in the light commercial vehicle segment, unlike Brazil, which specialises in car production (Dulcich, Otero and Canzian, 2020).

Brazil, on the other hand, has an automotive industry with a larger scale and national integration of production (table 1), and with an auto parts complex with greater export insertion and diversification of export markets (Dulcich, Otero and Canzian, 2019). The automotive industry of that country has been encouraged by various promotion plans, among which we can highlight the "Carro Popular" programme in the early 1990s to promote low-cylinder vehicles and equipment, the Automotive Regime in the mid-1990s that encouraged export-oriented production, various subnational incentives and local development programmes, and the Innovar-Auto programme, launched in 2013 to encourage production and investment through fiscal benefits (Marx, Mello e Laura, 2020; Sierra and Katz, 2002; Fiuza, 2002). However, the macroeconomic crisis that began in the middle of that decade strongly affected the automotive market, and consequently automotive production, as well as Argentine automotive exports to that destination (Dulcich, Otero and Canzian, 2020); triggering a crisis in automotive production at a regional level.[14]

In terms of technology, both countries tend to adopt technology developed abroad, mainly the automotive technology development core countries (Dulcich, Otero and Canzian, 2020; Marx, Mello e Lara, 2020), although there is an asymmetry between them (Obaya, 2014). Adaptations and product development for the region tend to take place in Brazil,[15] while in Argentina R&D activities in the sector are marginal, as can be seen in the difference between the two countries in both innovation efforts (table 3) and patent applications for automotive technology (table 2).

The automotive innovation performance of both countries (table 2) is far behind that of the traditional automotive core, both in conventional and

14. In this regard, it is important to note that Ford has recently announced the closure of its three production plants in Brazil. Available at: <https://media.ford.com/content/fordmedia/fsa/ar/es/news/2021/01/01/ford-avanza-en-la-reestructuracion-de-sudamerica--cesara- sus-ope.html>. Accessed on: July 2021.

15. An example of this is the Fiat Toro, the pickup truck designed at the Fiat Design Center Latam in Brazil and developed based on FCA's Small Wide global platform. Available at: <https://www.carbodydesign.com/2016/04/fiat-toro-design-story/>. Accessed on: Aug. 2022.

alternative technologies. However, the innovation efforts in Brazil (but not in Argentina) of transport companies of US origin (table 3) are close to the average of such efforts in the EU, and exceed those of the European periphery. This difference would demonstrate the existence of innovation efforts oriented towards product development and the adaptation of technology to the regional and national environment (adjusting it to safety and environmental regulations, the quality of road infrastructure, consumer preferences, fuels used etc.), and not towards the development of global technology.

A paradigmatic case in this respect is the development of ethanol as a fuel in Brazil, a Brazilian state policy that has been in place for decades, and whose history has undergone important transformations in the 2000s. As can be seen in figure A.1 of the appendix, flex-fuel engine technology (which can burn different combinations of ethanol and gasoline) has been developing for decades in Brazil, with a first stage of engines that burned only ethanol, which had a significant boom in the 1980s. In the context of the oil crisis of the 1970s, the motivation of the Brazilian State to develop this technology was the scarcity of conventional oil in its territory, since the increase in its international price led to a significant increase in imports and generated tensions in the balance of payments.

This shortage contrasted with its large supply of sugar cane, from which ethanol is produced, so the objective was to take advantage of the resource to produce fuel, catapulting a production that had had some previous experiences at the local level (Saravanan, Pugazhendhi and Mathimani, 2020). Under the National Alcohol Programme (Proalcohol) launched in 1975, tax cuts were applied to ethanol vehicles and ethanol fuel for consumers, among other measures. Then, in the 1990s, the price ratio between gasoline and ethanol fell again, which made ethanol vehicles less competitive, causing demand and production to drop (figure A.1 of the appendix). In those years, however, flex-fuel engine technology was consolidated; such technology allows greater flexibility in consumption by combining different proportions of gasoline and ethanol, one of the main reasons why it became the predominant technology in the Brazilian automotive market (Brito et al., 2019). It is important to point out that Brazil occupied a relevant place in the race for the development of this technology, where global automotive companies associated with different tier 1 auto part manufacturers, such as Volkswagen – Magneti Marelli and GM – Delphi, competed, with Bosch as a technology supplier common to both automotive companies (Yu et al., 2009; Yu et al., 2010). In fact, Volkswagen has recently announced investments in Brazil to set up an R&D centre for flex-fuel and ethanol-fuelled engines.[16]

16. Available at: <https://www.automotivebusiness.com.br/pt/posts/noticias/brasil-tera-centro-mundial-de-pesquisas-de-etanol-e-motor-flex-da-volkswagen/>. Accessed on: Feb. 2022.

6 DISCUSSION AND CONCLUSIONS

As can be seen in this article, the efforts and results of innovation of the automotive value chain are concentrated in the traditional automotive core, while in the periphery there are production activities dissociated from those of technological development, which is mainly adopted from such automotive core countries.

These productive capacities dissociated from innovation activities prevent the peripheral automotive industry from upgrading towards the segments with the highest technological intensity in the automotive value chain, which would allow it to take advantage of the differential benefits generated by innovations in foreign trade (Dulcich, 2018a; Humphrey and Schmitz, 2002). At the same time, they place it in a position of dependence on technology developed abroad, which generates significant foreign exchange expenses for the payment of royalties for technology licenses and for imports of auto parts of higher technological intensity, impacting on the external restriction to the economic growth of countries, as is the case in Argentina (Bekerman, Dulcich and Vázquez, 2015; Dulcich, 2018b).

Currently, the techno-economic paradigm of the automotive chain is in full transition towards electric mobility, which opens windows of opportunity for the repositioning of companies and countries, and the emergence of new competitors, as in the case of China. However, the European automotive periphery, Brazil and Argentina have not managed to position themselves in the technological development of the new electric paradigm.

In the case of the European periphery, the production of EVs has advanced to a greater extent than in Brazil or Argentina, driven by significant incentives existing at the regional level and by access to the markets with the largest market share of EVs (Dulcich, Otero and Canzian, 2019; IEA, 2020). In the case of Brazil, the capabilities and resources accumulated in flex-fuel motorisation technology, the important primary production on which it is based (ethanol), as well as the interests created around them (automotive companies, agribusiness etc.) could hinder the transition to EVs in Brazil and generate a lock-in in flex-fuel engine technology (Mello, Marx e Souza, 2013). Argentina, for its part, presents opportunities within the framework of the electric paradigm linked to the availability of qualified human resources, the supply of lithium and the scientific capabilities developed around such resource, among others. However, this potential is being hindered by the limited extension of the recharging infrastructure, the delay in the readjustment of regulatory frameworks and the volatility of the automotive market, among others (Dulcich, 2021).

Some examples of policies that could promote the endogenous development of technology in the countries of the automotive periphery, and their transition to the electric paradigm, are outlined here. On the one hand, R&D activities present market failures (uncertainty, appropriability etc., see Arrow, 1962; Romer, 1994; Teece, 1986; among others) that justify State intervention to encourage them. This is particularly important in the case of R&D in the auto parts sector, which is the one that makes the greatest innovation efforts within the automotive value chain (Wiesenthal, Condeço-Melhorado and Leduc, 2015; Dulcich, 2022). At the same time, auto parts companies are the ones who command the production of the main components of the electric powertrain, where they participate to a greater extent than they do in the production of internal combustion engines and transmission systems (Cepal, 2017). On the other hand, the literature highlights the importance of expanding the market to take advantage of economies of scale, avoiding "coordination failures" between the production of electric vehicles and the deployment of recharging infrastructure (Altenburg, Bhasin and Fischer, 2012). On this last topic, it is also important that the State promote the interoperability of the recharging infrastructure, to reduce the cost of users and favor the expansion of electromobility (IEA, 2018).

To conclude, it is important to emphasize the fact that boosting the path of peripheral countries so that the productive capacities of the automotive value chain are combined with technological development activities is a substantial challenge, which requires the allocation of resources for R&D, training of specialised human resources, and coordination of scientific-technological, productive and foreign trade incentives, among other initiatives. Its potential yields are promising, both for the automotive value chain in these countries and for their economic development.

REFERENCES

ACEA – EUROPEAN AUTOMOBILE MANUFACTURERS' ASSOCIATION. **The automobile industry pocket guide 2020/2021**. [s.l.]: Acea, 2020.

ALTENBURG, T.; BHASIN, S.; FISCHER, D. Sustainability-oriented innovation in the automobile industry: advancing electromobility in China, France, Germany and India. **Innovation and Development**, v. 2, n. 1, p. 67-85, 2012.

ANFAVEA – ASSOCIAÇÃO NACIONAL DOS FABRICANTES DE VEÍCULOS AUTOMOTORES. **Anuário da indústria automobilística brasileira 2019**. São Paulo: Anfavea, 2019.

ARROW, K. **Economic welfare and the allocation of resources for invention**. Princeton: Princeton University Press, 1962.

BALDWIN, R. **Trade and industrialisation after globalisation's 2nd unbundling**: how building and joining a supply chain are different and why it matters. Cambridge, Massachusetts: NBER, 2011. (Working Paper, n. 17716).

BAHRANI FARD, Z.; BRUGEMAN, V. S. **Technology roadmap**: intelligent mobility technologies. Ann Arbor: CAR, 2019. Retrieved Sept. 2021, from: <https://www.cargroup.org/wp-content/uploads/2019/09/Technology-Roadmap-White-Paper.pdf>.

BEKERMAN, M.; DULCICH, F.; VÁZQUEZ, D. Restricción externa al crecimiento de Argentina. El rol de las manufacturas industriales. **Problemas del Desarrollo**, v. 46, n. 183, p. 59-88, 2015.

BRITO, T. et al. Transitions between technological generations of alternative fuel vehicles in Brazil. **Energy Policy**, n. 134, 2019.

CABIGIOSU, A.; ZIRPOLI, F.; CAMUFFO, A. Modularity, interfaces definition and the integration of external sources of innovation in the automotive industry. **Research Policy**, v. 42, n. 3, p. 662-675, 2013.

CANTARELLA, J.; KATZ, L.; MONZÓN, N. Argentina: factores que debilitan la integración de autopartes locales. In: PANIGO, D. et al. (Coord.). **La encrucijada del autopartismo en América Latina**. Buenos Aires: Undav, 2017.

CARRINCAZEAUX, C.; LUNG, Y.; RALLET, A. Proximity and localisation of corporate R&D activities. **Research Policy**, v. 30, n. 5, p. 777-789, 2001.

CEPAL – COMISIÓN ECONÓMICA PARA AMÉRICA LATINA Y EL CARIBE. **La inversión extranjera directa en América Latina y el Caribe**. Santiago: División de Desarrollo Productivo y Empresarial/Cepal, 2017.

CIMOLI, M. et al. Institutions and policies shaping industrial development: an introductory note. In: CIMOLI, M.; DOSI, G.; STIGLITZ, J. E. **Industrial policy and development**: the political economy of capabilities accumulation. Oxford: Oxford University Press, 2009.

CORIAT, B. **El taller y el robot**: ensayos sobre el fordismo y la producción en masa en la era de la electrónica. Buenos Aires: Siglo XXI, 2000.

DIJK, M. A socio-technical perspective on the electrification of the automobile: niche and regime interaction. **International Journal of Automotive Technology and Management**, v. 14, n. 2, p. 158-171, 2014.

DOSI, G.; FREEMAN, C.; FABIANI, S. The process of economic development: introducing some stylized facts and theories on technologies, firms and institutions. **Industrial and Corporate Change**, v. 3, n. 1, p. 1-45, 1994.

DULCICH, F. **Desarrollo y adopción de tecnología a nivel internacional**: su impacto en el Producto Bruto Interno per cápita según niveles de ingreso. 2018. Dissertation (Doctoral Degree) – Facultad de Ciencias Económicas de la Universidad de Buenos Aires, Buenos Aires, 2018a.

______. Especialización internacional y el escaso desarrollo endógeno de tecnología en la Argentina. **Ciencia, Docencia y Tecnología**, v. 29, n. 56, p. 74-108, 2018b.

______. Oportunidades y amenazas para la cadena automotriz en la Argentina en el marco de la transición a la electromovilidad. **H-industri@**: Revista de Historia de la Industria, los Servicios y las Empresas en América Latina, n. 28, p. 197-221, 2021.

______. **La cadena automotriz en Argentina**: trayectoria reciente y perspectivas en un contexto global de reconfiguración tecnológica y geográfica. [s.l.]: Argentina Productiva 2030; Ministerio de Desarrollo Productivo, 2022. (Documento, n. 32). Retrieved Aug. 2021, from: <https://www.argentina.gob.ar/sites/default/files/2021/03/32_-_cadena_automotriz_-_arg._productiva_0.pdf>.

DULCICH, F.; OTERO, D.; CANZIAN, A. **Evolución histórica, situación actual y perspectivas de la cadena automotriz a nivel global y regional**: ¿son los vehículos eléctricos una oportunidad para la Argentina? Buenos Aires: Universidad Tecnológica Nacional Facultad Regional General Pacheco, 2018. (Working Paper, n. 01/2018).

______. Evolución reciente y situación actual de la producción y difusión de vehículos eléctricos a nivel global y en Latinoamérica. **Asian Journal of Latin American Studies**, v. 32, n. 4, p. 21-51, 2019.

______. Trayectoria y situación actual de la cadena automotriz en la Argentina y el Mercosur. **Ciclos en la Historia, la Economía y la Sociedad**, n. 54, p. 93-130, 2020.

FIUZA, E. P. **Automobile demand and supply in Brazil**: effects of tax rebates and trade liberalization on price-marginal cost markups in the 1990s. Brasília: Ipea, 2002. (Discussion Paper, n. 119).

FUJIMOTO, T. An architectural analysis of green vehicles-possibilities of technological, architectural and firm diversity. **International Journal of Automotive Technology and Management**, v. 17, n. 2, p. 123-150, 2017.

GEREFFI, G.; HUMPHREY, J.; STURGEON, T. The governance of global value chains. **Review of International Political Economy**, v. 12, n. 1, p. 78-104, 2005.

HUMPHREY, J.; SCHMITZ, H. How does insertion in global value chains affect upgrading in industrial clusters? **Regional Studies**, v. 36, n. 9, p. 1017-1027, 2002.

IEA – INTERNATIONAL ENERGY AGENCY. **Global EV outlook**. Paris: IEA, 2018.

______. **Global EV outlook**. Paris: IEA, 2020.

JACOBS, A. J. **Automotive FDI in emerging Europe**: shifting locales in the motor vehicle industry. New York: Springer, 2017.

______. **The automotive industry and European integration**: the divergent paths of Belgium and Spain. New York: Springer, 2019.

KEMP, R.; SCHOT, J.; HOOGMA, R. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. **Technology Analysis and Strategic Management**, v. 10, n. 2, p. 175-198, 1998.

LUNDVALL, B. **National systems of innovation**. London: Pinter Publishers, 1992.

LUNG, Y. The changing geography of the European automobile system. **International Journal of Automotive Technology and Management**, v. 4, n. 2-3, p. 137-165, 2004.

MACDUFFIE, J. P. Modularity-as-property, modularization-as-process, and 'modularity'-as-frame: lessons from product architecture initiatives in the global automotive industry. **Global Strategy Journal**, v. 3, n. 1, p. 8-40, 2013.

MARX, R.; MELLO, A. M. de; LARA, F. F. D. The new geography of the automobile industry: trends and challenges in Brazil. In: COVARRUBIAS, A.; PEREZ, S. **New frontiers of the automobile industry**. London: Palgrave Macmillan, 2020. p. 349-375.

MELLO, A. M. de; MARX, R.; SOUZA, A. Exploring scenarios for the possibility of developing design and production competencies of electrical vehicles in Brazil. **International Journal of Automotive Technology and Management**, v. 13, n. 3, p. 289-314, 2013.

MILLER, R. Global R&D networks and large-scale innovations: the case of the automobile industry. **Research Policy**, v. 23, n. 1, p. 27-46, 1994.

MUNIZ, S. T. G.; BELZOWSKI, B. M. Platforms to enhance electric vehicles' competitiveness. **International Journal of Automotive Technology and Management**, v. 17, n. 2, p. 151-168, 2017.

NIKITAS, A. et al. How can autonomous and connected vehicles, electromobility, BRT, hyperloop, shared use mobility and mobility-as-a-service shape transport futures for the context of smart cities? **Urban Science**, v. 1, n. 4, 2017.

OBAYA, M. Geographical distribution of product development capabilities in the automobile industry: towards a hierarchical division of labour in Mercosur. **International Journal of Automotive Technology and Management**, v. 14, n. 2, p. 102-120, 2014.

PAVLÍNEK, P. The internationalization of corporate R&D and the automotive industry R&D of East-Central Europe. **Economic Geography**, v. 88, n. 3, p. 279-310, 2012.

PAVLÍNEK, P. et al. **Foreign direct investment and the development of the automotive industry in Eastern and Southern Europe**. European Trade Union Institute, 2017. (Working Paper, n. 3).

PUBLIC SECTOR CONSULTANTS; CAR – CENTER FOR AUTOMOTIVE RESEARCH. **Planning for connected and automated vehicles**. Lansing; Ann Arbor: Public Sector Consultants; CAR, 2017. Retrieved Sept. 2021, from: <https://www.cargroup.org/wp-content/uploads/2017/03/Planning-for-Connected-and-Automated-Vehicles-Report.pdf>.

ROMER, P. The origins of endogenous growth. **Journal of Economic Perspectives**, v. 8, 1994.

RUIZ, J. L. G. La evolución de la industria automovilística española, 1946-1999: una perspectiva comparada. **Revista de Historia Industrial**, n. 19-20, p. 133-163, 2001.

SARAVANAN, A.; PUGAZHENDHI, A.; MATHIMANI, T. A comprehensive assessment of biofuel policies in the BRICS nations: Implementation, blending target and gaps. **Fuel**, n. 272, 2020.

SCHOT, J.; GEELS, F. W. Niches in evolutionary theories of technical change. **Journal of Evolutionary Economics**, v. 17, n. 5, 2007.

SIERRA, P.; KATZ, L. **La industria automotriz de cara a su futuro**. Escenarios. Buenos Aires: Universidad Nacional de General Sarmiento, 2002.

SPE – SECRETARÍA DE POLÍTICA ECONÓMICA. **Informes de cadenas de valor**: automotriz y autopartista. Buenos Aires: SEP, 2018. Retrieved Feb. 2022, from: <https://www.argentina.gob.ar/sites/default/files/sspmicro_cadenas_de_valor_automotriz.pdf>.

STERN, N. The economics of climate change. **American Economic Review**, v. 98, n. 2, p. 1-37, 2008.

STURGEON, T.; BIESEBROECK, J. van; GEREFFI, G. Value chains, networks and clusters: reframing the global automotive industry. **Journal of Economic Geography**, v. 8, n. 3, p. 297-321, 2008.

STURGEON, T. et al. Globalisation of the automotive industry: main features and trends. **International Journal of Technological Learning, Innovation and Development**, v. 2, n. 1/2, p. 7-24, 2009.

TEECE, D. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. **Research Policy**, n. 15, p. 285-305, 1986.

TIMMER, M. P. et al. Slicing up global value chains. **Journal of Economic Perspectives**, v. 28, n. 2, p. 99-118, 2014.

WANG, H.; KIMBLE, C. Leapfrogging to electric vehicles: patterns and scenarios for China's automobile industry. **International Journal of Automotive Technology and Management**, v. 11, n. 4, p. 312-325, 2011.

WANG, N.; PAN, H.; ZHENG, W. Assessment of the incentives on electric vehicle promotion in China. **Transportation Research Part A**: Policy and Practice, n. 101, p. 177-189, 2017.

WIESENTHAL, T.; CONDEÇO-MELHORADO, A.; LEDUC, G. Innovation in the European transport sector: a review. **Transport Policy**, v. 42, p. 86-93, 2015.

YU, A. et al. Supplier involvement in flex-fuel technology development: the General Motors and Volkswagen Brazilian cases. In: INTERNATIONAL CONFERENCE ON MANAGEMENT OF ENGINEERING AND TECHNOLOGY, 2009, Portland. **Proceedings**… Portland: IEEE, 2009. p. 1616-1625.

YU, A. et al. The evolution of flex-fuel technology in Brazil: the Bosch case. In: PICMET 2010 TECHNOLOGY MANAGEMENT FOR GLOBAL ECONOMIC GROWTH, 2010, Phuket. **Proceedings**… Phuket: IEEE, 2010. p. 1-11.

ZHENG, J. et al. Strategic policies and demonstration program of electric vehicle in China. **Transport Policy**, v. 19, n. 1, p. 17-25, 2012.

APPENDIX

TABLE A.1
High economic impact patent applications[1] by residents by innovating country for different technologies in the automotive value chain

Technology domain	Inventor country[2,3]	Average (1990-1994)	Average (1995-1999)	Average (2000-2004)	Average (2005-2009)	Average (2010-2014)	Average (2015-2018)	Variation (2015-2018 and 1990-1994) (%)
Conventional vehicles (based on internal combustion engine)	World	575	875	1,410	1,684	2,078	1,858	223
	United States	106	125	215	366	552	445	320
	Japan	250	376	596	618	603	583	133
	Korea	3	8	23	45	113	145	4,427
	China	2	2	4	10	22	22	1,033
	EU27	162	303	470	538	633	538	232
	Germany	**106.0**	**206.1**	**298.8**	**322.5**	**367.6**	**316.3**	198
	France	**17.6**	**31.4**	**69.4**	**91.2**	**93.6**	**59.1**	236
	Italy	**7.9**	**12.6**	**25.5**	**29.4**	**38.4**	**49.8**	528
	Spain	**1.4**	**1.1**	**1,9**	**2.7**	**5.2**	**3.8**	171
	Czech Republic	**0.1**	**0.4**	**0.8**	**0.7**	**3.0**	**7.6**	7,460
	Hungary	**1.2**	**0.2**	**0.4**	**1.5**	**0.2**	**1.1**	-10
	Brazil	1.0	0.4	1.1	2.6	2.7	2.0	100
	Argentina	0.2	0.0	0.7	0.6	0.3	0.0	-100
	Others	50	61	101	102	152	123	144
	China (% of world)	0	0	0	1	1	1	
	US + Japan + Korea + China + EU27 (% of world)	91	93	93	94	93	93	

(Continues)

(Continuation)

Technology domain	Inventor country[2,3]	Average (1990-1994)	Average (1995-1999)	Average (2000-2004)	Average (2005-2009)	Average (2010-2014)	Average (2015-2018)	Variation (2015-2018 and 1990-1994) (%)
Hybrid vehicles	World	31	140	295	601	715	660	2,043
	United States	5	12	54	175	187	152	3,005
	Japan	12	92	161	249	254	243	1,995
	Korea	0	0	3	11	59	69	n.c.
	China	0	0	1	10	15	19	n.c.
	EU27	10	31	61	132	171	154	1,454
	Germany	**6.1**	**21.6**	**33.6**	**87.6**	**95.3**	**102.8**	1,584
	France	**0.2**	**4.8**	**15.3**	**18.9**	**31.9**	**22.8**	11,275
	Italy	**2.0**	**0.8**	**1.6**	**7.4**	**10.7**	**7.1**	256
	Spain	**0.0**	**0.0**	**1.6**	**0.5**	**0.5**	**0.3**	n.c.
	Czech Republic	**0.0**	**0.0**	**0.8**	**0.1**	**0.1**	**0.3**	n.c.
	Hungary	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**	**0.1**	n.c.
	Brazil	0.0	0.2	0.2	0.0	0.2	0.0	n.c.
	Argentina	0.0	0.0	0.0	0.2	0.0	0.0	n.c.
	Others	4	5	15	24	30	23	417
	China (% of world)	0	0	0	2	2	3	
	US + Japan + Korea + China + EU27 (% of world)	86	96	95	96	96	97	

(Continues)

(Continuation)

Technology domain	Inventor country[2,3]	Average (1990-1994)	Average (1995-1999)	Average (2000-2004)	Average (2005-2009)	Average (2010-2014)	Average (2015-2018)	Variation (2015-2018 and 1990-1994) (%)
Electric vehicles	World	147	252	460	1,130	2,425	2,364	1,508
	United States	24	35	82	231	403	454	1,786
	Japan	66	143	257	561	1,068	860	1,196
	Korea	2	3	13	49	260	279	13,207
	China	0	1	3	25	52	136	29,166
	EU27	38	51	77	205	502	469	1,143
	Germany	**21.6**	**32.0**	**44.7**	**121.3**	**309.6**	**317.9**	1,372
	France	**5.3**	**9.4**	**15.9**	**41.2**	**103.8**	**50.0**	844
	Italy	**5.2**	**3.0**	**2.8**	**10.7**	**17.3**	**22.6**	334
	Spain	**0.4**	**0.7**	**1.9**	**2.4**	**6.9**	**5.2**	1,202
	Czech Republic	**0.0**	**0.0**	**0.4**	**0.2**	**0.2**	**1.0**	n.c.
	Hungary	**0.0**	**0.2**	**0.0**	**0.1**	**1.3**	**1.4**	n.c.
	Brazil	0.2	0.2	0.0	1.5	1.0	1.9	845
	Argentina	0.0	0.2	0.0	0.0	0.0	0.3	n.c.
	Others	16	18	28	58	139	163	914
	China (% of world)	0	0	1	2	2	6	
	US + Japan + Korea + China + EU27 (% of world)	89	93	94	95	94	93	

(Continues)

(Continuation)

Technology domain	Inventor country[2,3]	Average (1990-1994)	Average (1995-1999)	Average (2000-2004)	Average (2005-2009)	Average (2010-2014)	Average (2015-2018)	Variation (2015-2018 and 1990-1994) (%)
Application of hydrogen technology to transportation, e.g. using fuel cells	World	8	45	150	183	220	222	2,821
	United States	1	11	37	37	41	23	2,188
	Japan	1	17	71	89	78	101	7,105
	Korea	0	0	1	9	40	41	n.c.
	China	0	1	1	0	2	5	2,400
	EU27	4	13	31	40	48	38	866
	Germany	**3.3**	**11.0**	**25.3**	**30.6**	**33.7**	**27.0**	719
	France	**0.4**	**0.4**	**3.9**	**6.1**	**8.8**	**5.0**	1,150
	Italy	**0.0**	**0.4**	**0.0**	**1.1**	**0.7**	**0.4**	n.c.
	Spain	**0.0**	**0.0**	**0.1**	**0.2**	**1.5**	**0.3**	n.c.
	Czech Republic	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.3**	n.c.
	Hungary	**0.0**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	n.c.
	Brazil	0.0	0.0	0.0	0.0	0.0	0.0	n.c.
	Argentina	0.0	0.0	0.0	0.0	0.0	0.0	n.c.
	Others	1	3	10	8	11	15	1,237
	China (% of world)	3	1	0	0	1	2	
	US + Japan + Korea + China + EU27 (% of world)	86	94	93	96	95	93	

(Continues)

(Continuation)

Technology domain	Inventor country[2,3]	Average (1990-1994)	Average (1995-1999)	Average (2000-2004)	Average (2005-2009)	Average (2010-2014)	Average (2015-2018)	Variation (2015-2018 and 1990-1994) (%)
Batteries	World	394	850	1,266	1,881	4,057	4,322	997
	United States	99	197	226	267	524	591	499
	Japan	179	444	672	923	1.856	1.732	866
	Korea	3	44	142	274	732	888	27,658
	China	1	7	15	59	165	360	24,982
	EU27	66	96	124	235	553	501	657
	Germany	**31.8**	**44.4**	**62.9**	**134.9**	**363.2**	**312.9**	885
	France	**16.1**	**27.2**	**28.1**	**50.6**	**103.1**	**83.2**	417
	Italy	**5.7**	**5.1**	**6.1**	**8.3**	**17.6**	**17.9**	213
	Spain	**0.7**	**0.5**	**1.9**	**2.6**	**5.2**	**7.8**	1,019
	Czech Republic	**0.0**	**0.1**	**0.7**	**0.8**	**0.9**	**1.4**	n.c.
	Hungary	**0.4**	**0.2**	**0.4**	**0.2**	**1.3**	**0.8**	103
	Brazil	0.2	0.3	0.0	1.8	0.2	2.3	1,035
	Argentina	0.2	0.3	0.1	0.1	0.7	0.3	56
	Others	45	62	87	122	226	247	451
	China (% of world)	0	1	1	3	4	8	
	US + Japan + Korea + China + EU27 (% of world)	89	93	93	93	94	94	

(Continues)

(Continuation)

Technology domain	Inventor country[2,3]	Average (1990-1994)	Average (1995-1999)	Average (2000-2004)	Average (2005-2009)	Average (2010-2014)	Average (2015-2018)	Variation (2015-2018 and 1990-1994) (%)
Electric vehicle charging	World	39	54	68	250	893	1,013	2,471
	United States	10	12	21	73	194	214	2,109
	Japan	19	27	24	92	337	302	1,495
	Korea	1	1	2	7	66	102	14,436
	China	0	0	1	4	19	61	n.c.
	EU27	6	8	12	51	210	239	3,878 %
	Germany	**2.2**	**4.3**	**7.7**	**28.1**	**128.1**	**169.5**	7,605 %
	France	**2.0**	**1.8**	**1.6**	**11.5**	**43.3**	**23.8**	1,088 %
	Italy	**0.6**	**0.6**	**1.2**	**1.7**	**7.1**	**8.3**	1,285 %
	Spain	**0.2**	**0,0**	**0,0**	**1,0**	**4,0**	**3,3**	1,525 %
	Czech Republic	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0,6**	n.c.
	Hungary	**0.0**	**0.2**	**0.0**	**0.1**	**0.2**	**0.0**	n.c.

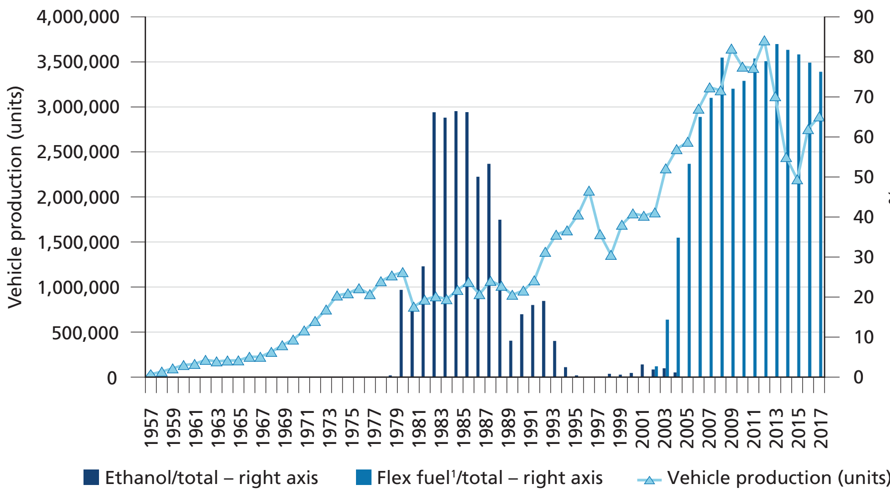
(Continues)

(Continuation)

Technology domain	Inventor country[2,3]	Average (1990-1994)	Average (1995-1999)	Average (2000-2004)	Average (2005-2009)	Average (2010-2014)	Average (2015-2018)	Variation (2015-2018 and 1990-1994) (%)
	Brazil	0.0	0.0	0.0	1,1	0,8	1.0	n.c.
	Argentina	0.0	0.0	0.0	0.0	0.0	0.3	n.c.
Electric vehicle charging	Others	4	6	8	23	66	94	2,198%
	China (% of World)	0	0	1	1	2	6	
	US + Japan + Korea + China + EU27 (% of world)	90	88	88	90	93	91	

Source: Organisation for Economic Co-operation and Development (OECD).
Prepared by the authors.
Notes: [1] Only technological developments with patent applications in three or more markets ("patent family size" 3 or higher) are considered. According to the OECD, the patent family size correlates positively with the value of the invention, which is why they were classified here as having "high economic impact".
[2] For patents developed by residents of more than one country, the OECD splits the statistical value of the variable among all developers to avoid double counting. For example, an invention developed by residents of two countries obtains a value of 0.5 in each of those countries.
[3] Decimal values are shown only for member countries of the EU27, Argentina, and Brazil. In all other cases, they are rounded to the nearest whole number.
Obs.: n.c. – not calculated.

FIGURE A.1
Evolution of automotive production in Brazil and incidence of alternative powertrains in this production



Source: Anfavea, 2019.
Prepared by the authors.
Note: [1] Flex fuel vehicle is a vehicle with an internal combustion engine designed to run on ethanol fuel blended with gasoline.