The greening of the European automobile industry and its labour effects: an empirical and regional analysis

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Abstract: The paper aims at investigating which green technological trajectory has impacted the most the employment and labour productivity levels among European car manufacturers and the auto suppliers over the past 20+ years. Our econometric analyses show that, while eco-innovations related to full hybrid (HEVs) and full electric vehicles (BEVs) have exerted a negative effect on labour levels among original equipment manufacturers (OEMs), the production of BEVs-related technologies has steered a positive effect on labour among suppliers, supporting the hypothesis of a labour shift from the OEMs to the suppliers' ecosystem (e.g., batteries, electronics). On the other hand, electromobility solutions have impacted positively the OEMs' labour productivity, which in turn declined among the suppliers. A regional analysis reveals that our results are driven by 'core automotive' countries, namely Germany, France, and Italy, while the European countries in the semi-periphery and integrated periphery are still lagging in the electrification process.

Keywords: eco-innovations; electrification; employment; labour productivity; just transition; automotive; Europe.

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1 Introduction

The automotive industry is a dynamic, international and high-tech sector (Smitka and Warrian, 2016), yet dominated by incumbent firms, concentrated in few geographical regions and its high levels of R&D investments have been long and mainly devoted to the refinement of an incumbent and polluting technology, the internal combustion engine (ICE).

However, in the last decades, market stagnation, rising environmental concerns, the emergence of new players and the introduction of stringent eco-policies have driven the industry towards a de-maturity process[1] (Faria and Andersen, 2015; Abernathy et al., 1983), in which the polluting dominant design is challenged by green alternatives developed around both radical and incremental clean, low-carbon technologies (Novaresio and Patrucco, 2022; Aghion et al., 2016).

Despite the existence of different propulsion alternatives for the promotion of more a sustainable mobility (e.g., biofuels, synthetic fuels, fuel cell vehicles, battery electric vehicles), whose potentialities and criticalities have been extensively debated (Armaroli et al., 2023; Grzesiak and Sulich, 2022; Del Pero et al., 2018), the battery electric vehicle (BEV) is widely acknowledged as the most mature technological solution to reduce the environmental impact of the mass private mobility (Alochet and Midler, 2019; Covarrubias, 2018).

Thus, electromobility, as a choice and a strategy which most of the global carmakers are investing in and progressing to, is currently redefining the geopolitics and the global value chain of the sector (Bridge and Faigen, 2022; Jullien and Pardi, 2013), with the emergence of new actors and the urge for the incumbent ones to keep up the pace.

Most of these incumbents are located in Europe, which is not only home of some of the historic, most iconic and biggest brands, but it also has a long story of eco-regulations aiming at reducing the environmental impact of the road transport, whose effectiveness and appropriateness have been often under debate (Pardi, 2021, 2022).

For example, the latest post-COVID transport policies promoted in France and Germany have been blamed to be structurally conservative as influenced by pre-existing state-industry dynamics (Lechowski et al., 2023). On the other hand, the EU regulatory proposal to achieve zero emissions from new cars and vans by 2035 (EU, 2023)[2], a measure aiming at substantially phasing out the internal combustion engine vehicles (ICEVs) in favour of the diffusion of the electric powertrains (BEVs), has been also harshly criticised as overly ambitious and risky, due to its potentially negative labour implications, especially along the automotive supply chain (CLEPA, 2021). For this reason, the abovementioned proposal has been recently modified in order to allow the production and sales of ICEVs propelled with alternative fuels (e.g., synthetic fuels) beyond 2035, with the goal to pursue the decarbonisation of the European road transports within the framework of the so-called ‘technological neutrality’.

Europe is thus one of the global regions where the trade-off between environment and jobs seems very hard to reconcile in the automotive industry and different strategies are at stake to purse a ‘just transition’ of the sector (Pichler et al., 2021a, 2021b; Galgóczi, 2020).

On top of this, an emerging line of research is devoting efforts to increase the knowledge on the occupational impacts of the electrification of the European automobile industry (Galgóczi, 2023; Cotterman et al., 2022; BCG, 2021; CLEPA, 2021; Strategy&,

2021; Verhaeghe, 2021; Küpper et al., 2020; Bauer et al., 2018), which is challenged by an increasingly ambitious environmental regulatory framework.

However, since electrification is a process that is accelerating and gaining momentum only in the most recent years in Europe, most of the abovementioned studies are predictive and strictly focused on the electrification-only effects on labour.

The present paper aims at filling this gap, by providing a first comparative ex-post assessment of the extent to which different green technological patterns in the European automobile industry have impacted labour and its productivity not only among the original equipment manufacturers (OEMs), but also among the auto suppliers, by using a sample of 20 European countries inspected over the period between 1995 and 2018.

The goal is twofold:

1 to analyse the occupational and eco-innovative patterns of carmakers and equipment suppliers in Europe to capture trends and breaks occurred over the past 25 years

2 to understand, by means of an appropriate econometric method, whether and which type of eco-innovation, namely 'green' internal combustion engine vehicles (ICEVs)[3], hybrid solutions (HEV) and battery electric vehicles (BEV), have more significantly impacted labour levels and productivity in the European automotive and its traditional supply chain, providing useful policy and industrial advice.

The paper is structured as follows. Section 2 outlines the framework, summarising the most relevant literature on socio-technological transitions, with special focus their labour vs environment dynamics, and outlining the state of the art of the research on the labour effect of green transition in the automotive sector in Europe. Section 3 presents the data and the empirical strategy, while section 4 shows and discusses the results. Finally, section 5 concludes.

2 Background

2.1 The social implications of technological transitions: the role of sustainability issues

Technological transitions have been object of study by a wide strand of the innovation literature, which has investigated the drivers of the technological paradigm shifts using a co-evolutionary, socio-technical and system approach (Geels, 2005, 2006).

In fact, technological transitions do not only involve technological changes, but have also an effect on changes in user practices, regulations, industrial networks, infrastructure or symbolic meaning, affecting societal functions such as transportation, communication, housing, feeding etc (Geels, 2002). Therefore, social dimension is a crucial component of the technological transitions, since social dynamics both affect and are affected by technology, which fulfils functions in association with human agency, social structures and organisations only (Geels, 2002).

As societies orient themselves towards sustainability, increasing research efforts are being devoted to the investigation of the so-called 'sustainability transitions', on which the scientific interest was triggered by the introduction of the term 'sustainable development' in the late 1980s (Lachman, 2013; Loorbach, 2010; Kemp et al., 2007).

Sustainability transitions are defined as structural changes in the co-dynamics of social, environmental and economic subsystems including technologies, institutions, organisations or behavioural patterns towards environmental and social sustainable alternatives (Lachman, 2013) that provide long term human well-being in the face of real bio-physical limits (Meadowcroft, 2011).

These transitions can face different challenges, the first of which is the risk of stabilisation in various lock-in mechanisms (e.g., sunk investments in infrastructures, institutional commitments, power relations, political lobbying by incumbents or consumer lifestyles and preferences that may have become adjusted to existing technical systems) which may create path dependence and therefore make it difficult to dislodge existing systems (Geels, 201).

A second challenge is the long time period until the full effect of some environmental problems becomes apparent, which makes sustainability issues often overlooked and not perceived as urgent (Lachman, 2013). Thirdly, environmental problems have different manifestations like the potential for reparability of environmental damages or the spatial and temporal range of the negative impact.

These challenges indicate that a sustainability transition will need changes in the economic framework conditions (e.g., tax system, subsidies, regulatory frameworks) and changes in law (modifying the regulatory frameworks within which economic actors conduct their affairs), beside changes of individual and societal behaviours, in order to replace existing systems (Geels, 2011; Meadowcroft, 2011).

In addition to these issues, sustainability transitions clearly need to reconcile the traditional trade-off among the three different dimensions of sustainability, for which have been proposed different solutions (Lozano, 2008; Munasinghe, 2007; Ekins, 2000; Meadows, 1998; Daly, 1973;) which ended up to be framed in the green growth approach (Barbier, 2011) and the socio-ecological transition (Dimitrova et al., 2013).

The focus on labour issues, thus, has triggered the development of a strand of studies examining the exacerbation of the so-called ‘jobs vs. environment’ dilemma (Räthzel et al., 2021; Räthzel and Uzzell, 2011), which has led to the introduction of the concept of a ‘just transition’, a term that dates back to the Canadian mining union movements in the 1960s (Greener Jobs Alliance, 2018) and it is now a pillar of international policies and agreements (ETUC, 2018; ILO, 2015; UNFCCC, 2015).

There exist two interpretations of just transition: one with a narrow focus, which intends green transition as a transformation of a given socio-economic framework that does not create further inequality or aggravate the social situation during the transformative process and in its outcome, and broader one, which attributes green transition the role to make society more inclusive with low inequality and quality jobs (Galgóczi, 2020).

Moreover, the broader approach expands from a narrative originally referring to a developed economy to a global one, helping to avoid the concept of just transition becoming an ‘elitist idea’, which does not address the relationship between the global North and the global South and within those societies (Rosemberg, 2017).

Building upon this preliminary distinction, global labour unions, which play a key role in managing and orienting this transition, have developed different visions of what transition and justice mean, ranging from those that focus on just transition in the concrete sectors of their members, to those that propose fundamental changes in the global political economy and make the case for a just transition for all.

Furthermore, we can identify a range of views as affirmative, which call for more equity within the parameters of existing political economy, e.g., green Keynesianism and differentiated responsibility, and other as transformative, which call for more profound changes of the political economy, e.g., the socio-ecological approach (Kreinin, 2020; Stevis and Felli, 2015).

For the purpose of this study, we focus on the peculiarities of the just transition in a specific sector, the automobile one, since it is subject to a profound transformation, which involves all the aspects of the just transitions, from the mitigation and reduction of current and future unemployment trends, to the redefinition of north vs. south relations and the need for changes within and beyond the existing political economy parameters.

2.2 The ecological transition of the automotive industry and its labour effects

Despite transitional theories and forecasts, the automotive mobility system exhibits profound regime stability (or inertia), as it is characterised by path dependence dynamics, which have led the industry to a stubborn lock-in to a century-old technological paradigm (Wells and Nieuwenhuis, 2012).

However, the automotive industry is now challenged by two huge transformations, namely electrification and digitisation (Lüthje, 2021; Wittmann, 2017), which represents the major technological trends shaping the present and the future of this industrial sector, not only in terms of production and sales, but also with relevant environmental and labour implications.

While the impact of automation on automotive's employment and competitiveness has a long story, which has been described with well-documented dynamics (Acemoglu and Restrepo, 2018) and analysed in its most recent trends and evolution related to the so-called 'Industry 4.0' (Calabrese and Falavigna, 2022; Carey and Mordue, 2022; Isac et al., 2020; Pardi, 2019), electrification is the most radical transformative process undergoing in the automotive industry, posing the greatest challenges and concerns in terms of labour perspectives.

The rising 'job-vs-environment dilemma' within the automotive industry has raised growing attention among scholars in the social sciences, where an upsurging strand of studies investigates, mainly theoretically and through case studies, the opportunities and the barriers to a socio-ecological transformation (Pichler et al., 2021a; Pichler et al., 2021b) and a 'just transition' (Galgóczi, 2020) in the automobile sector.

The call for a just transition is felt urgent especially by Europe, a regional area where the automobile industry is, on the one hand, a big economic player responsible for 8% of the EU total GDP (CLEPA, 2022) and a key employer accounting for 7% of EU employment and 11.5% EU manufacturing jobs (ACEA, 2023), and on the other hand, a major air and climate polluter (EEA, 2023).

Moreover, the European automotive industry is now challenged by an ambitious EU environmental regulation (EU, 2023), promoting the progressive phase-out of the internal combustion engine vehicles (ICEV) by 2035, whose consequences on the European automotive ecosystem are still controversial.

According to many industry statements and studies, in fact, the electric shift will radically reduce the number of employees in European countries, especially along the powertrain supply chain, whose stakeholders call for a 'mixed technology approach' and a strong policy support to maintain jobs while creating added value (CLEPA, 2021).

However, electrification is also expected to trigger the creation and expansion of new industrial ecosystems, and the loss of 'traditional jobs' is supposed to be offset by the diffusion of 'green' ones in adjacent industries (ILO, 2022, 2021; BCG, 2021).

Therefore, a growing number of scientific works are empirically investigating the labour effects of electrification in Europe, providing contrasting evidence and scenarios.

A study by the European association of the automotive original equipment suppliers (OES) points to potential job losses in EU automotive manufacturing by 2040 of between 275,000 and 410,000, which are expected to be partially compensated by the increasing value added from electronics and autonomous drive systems (within the industry) and the labour demand involved with setting up and maintaining the charging infrastructure (CLEPA, 2021). These findings are confirmed by the European Commission, which points out at the countries with the main producers of the electronic components embedded in the world production of cars, namely Germany and Italy[4], as those which could have a potential first-mover advantage in the transformation of cars towards electric vehicles (EC, 2020).

A research work by the European Trade Unions Institute, summarising the main employment and technological trends and scenarios for the automobile industry in Europe, reveals that France and Germany have already experienced significant job losses in the sector and are expected to suffer from a further job contraction in the short to medium term (Galgóczi, 2023). However, after a long period when both policymakers and companies were hesitant about investing in electromobility, the COVID-19 crisis has created a window of opportunity for these countries to seize the opportunities of the EV transition, pushing them to diversify their technological and competence portfolio and to promote new 'employment pacts', even if mainly in the name of corporatism concentration (Galgóczi, 2023).

On the other hand, EV transition in Eastern European countries is expected to be slower, more gradual and unlikely to lead to dramatic changes in the development model of the automotive industry in countries and in the integrated periphery of the wider region, provided that the national policies are regularly rethought and adjusted along strategic lines (Pavlínek, 2023).

A recent scientific report based on Italian data highlights that, while the ICE-related employees are expected to drop by 42% by 2030, the non-ICE ones are foreseen to increase by 10% along the traditional automotive supply chain and by 30% across the new industrial battery-based ecosystem (Naso and Artico, 2023). These findings, which forecast a rather full offset between job losses and gains in Italy, sound strongly in line with the expectations for the country of the European Commission (EC, 2020).

The abovementioned dynamics can be explained by the fact that BEVs are less labour intensive than ICEVs (Bauer et al., 2018), even though their labour requirements are substantially comparable since the value added in automotive manufacturing just shifts from OEMs to tier-one suppliers (Küpper et al., 2020).

Moreover, a recent piece of research reveals that electrification may lead to more jobs in powertrain manufacturing, at least in the short to medium term (Cotterman et al., 2022).

A common feature of all the employment forecasts is that they acknowledge that jobs in the industry will be fundamentally transformed in terms of skills, place, contract type and working conditions and these changes will be on a massive scale (BCG, 2021).

Since electrification is a process that is accelerating and gaining momentum only in the most recent years in Europe, most of the abovementioned studies are predictive.

However, the greening of the automotive industry has a long and multifaceted story (Calabrese, 2016) and its past labour dynamics offer an interesting subject, which has been little investigated. To our knowledge, in fact, no study has provided an ex-post assessment of the labour effect of the greening process of the European automotive industry yet.

Following the way paved by a conspicuous and consolidated economic literature (Rennings and Zwick, 2002; Pfeiffer and Rennings, 2001; Pianta, 2000; Kosz, 1997; Köppl and Pichl, 1997; Van Reenen, 1997), which examines the effect of technology on employment through case study analysis, surveys and econometric tests, and inspired by the seminal work of Rennings et al. (2004), which have performed the first econometric analysis assessing the labour effects of incremental vs. radical eco-innovations, the present study aims to provide a first assessment of the extent to which different green technological patterns in the auto industry have impacted labour levels in OEMs and their suppliers, using a sample of 20 European countries over the past 20+ years.

Similarly, following trail blazed by recent studies (Dragunov and Shenshinov, 2020; Woo et al., 2014), we test the hypothesis of the existence of a relation between eco-innovations and labour productivity in the European automotive ecosystem.

Finally, inspired by the countries' classification developed by Carey and Mordue (2022) and spurred by the scenario of a differentiated pace of diffusion of green cars in the Eastern European countries depicted by Pavlínek (2023), we perform multiple regional analyses aimed at detecting possible regional specificities in the labour effects of the eco-transition within the European automotive sector, while controlling for different temporal frames of diffusion of the sectoral green techs.

The ultimate goal is to provide useful policy advice on the relation between eco-innovations, labour and its efficiency in the European automotive industry, building upon reliable OECD-based data, a solid empirical strategy and a sound scientific background.

Next two sections are devoted first to present the data and the empirical strategies, and secondly to show and discuss the results within the framework of the literature just discussed.

3 Data and empirical strategy

3.1 Data description

Our study is based on data covering 20 European countries (18 EU + Norway and UK)[5] over the time period between 1995 and 2018, and is built upon a large balanced panel dataset featuring the variables summarised in Table 1.

The variables are constructed using data retrieved from three main OECD datasets: the Environmental OECD Library, the OECD structural analysis (STAN) dataset that includes information on both aggregated and disaggregated industries and General OECD Statistics. For the purpose of this study, we use data exclusively related to the transport sector to build 15 out of the seventeen variables employed in our empirical investigations.

Table 1 The variables

Variable	*Definition*	*Unit of measurement*	*Source*	*Literature*	*Role*
EMPL_OEMs	Level of total employment in the core automotive industry (original equipment manufacturers)	Number of persons engaged (total employment) in thousand	OECD STAN – dataset	Employment and innovation literature	Dependent var. and control
EMPL_EQUIP	Level of total employment in the automotive suppliers' industry (suppliers)	Number of persons engaged (total employment) in thousand	OECD STAN – dataset	Employment and innovation literature	Dependent var. and control
LABOUR_PROD_OEMs	Level of labour productivity in the core automotive industry (original equipment manufacturers)	US dollar per person	OECD STAN – dataset	Employment and literature	Dependent var. and control
LABOUR_PROD_EQUIP	Level of labour productivity in the automotive suppliers' industry	US dollar per person	OECD STAN – dataset	Employment literature	Dependent var. and control
GREEN_ICE	Total number of green patents related to the improvement of internal combustion engine	Number of patents with country fractional value	ENV-OECD iLibrary	Green innovation literature	Explanatory variable ECO-INNOVATION
HYBRID	Total number of green patents related to the hybrid electric vehicles	Number of patents with country fractional value	ENV-OECD iLibrary	Green innovation Literature	Explanatory variable ECO-INNOVATION
ELECTRIC	Total number of green patents related to the battery electric vehicles	Number of patents with country fractional value	OECD STAN – dataset	Green innovation literature	Explanatory variable ECO-INNOVATION
BERD_AUTO	Level of business expenditures in R&D of the core automotive industry (original equipment manufacturers)	US dollar	OECD STAN – dataset	Innovation literature	Control variable INDUSTRY FACTOR
BERD_EQUIP	Level of business expenditures in R&D of the automotive suppliers' industry	US dollar	OECD STAN – dataset	Innovation literature	Control variable INDUSTRY FACTOR

Note: [a]This indicator is calculated as the ratio of production (gross output) in current prices (PROD) in a certain economic activity to production (gross output) in volumes (PRDK) in that economic activity after being transformed to USD dollars. These deflators incorporate fluctuations in exchange rates which for specific economic activities, mainly producing tradable goods and services, can serve better for cross country comparison (OECD-Stat, 2023)

Source: Author's elaboration

Table 1 The variables (continued)

Variable	*Definition*	*Unit of measurement*	*Source*	*Literature*	*Role*
PROD_AUTO	Level of production in the core automotive industry (original equipment manufacturers)	Index of production – reference period 2015 = 100[a]	OECD STAN – dataset	Innovation literature	Control variable INDUSTRY FACTOR
PROD-EQUIP	Level of production in the automotive suppliers' industry	Index of production - Reference period 2015 = 100	OECD STAN – dataset	Innovation literature	Control variable INDUSTRY FACTOR
WAGES_AUTO	Level of the wages in the core automotive industry (original equipment manufacturers)	US dollar, millions	OECD STAN – dataset	Employment literature	Control variable INDUSTRY FACTOR
WAGES_EQUIP	Level of the wages of the automotive suppliers' industry	US dollar, millions	OECD STAN – dataset	Employment literature	Control variable INDUSTRY FACTOR
EXPORT_AUTO	Level of the exports from the automotive industry - exports from j country to the rest of the world	US dollar, thousands	OECD STAN – dataset	Innovation literature	Control variable MARKET FACTOR
IMPORT_AUTO	Level of imports from the automotive industry – imports from j country to the rest of the world	US dollar, thousands	OECD STAN – dataset	Innovation literature	Control variable MARKET FACTOR
CAR_SALES	Number of car sales in the country	Index – reference period 2015 = 100	OECD STAN – dataset	Innovation literature	Control variable MARKET FACTOR
POP	Population	Number of person (in thousand)	OECD Stat	Innovation literature	Control variable COUNTRY FACTOR
GDP_PC	Gross domestic product per capita	US dollar, constant prices, 2015 PPP	OECD Stat	Innovation literature	Control variable COUNTRY FACTOR

Note: [a]This indicator is calculated as the ratio of production (gross output) in current prices (PROD) in a certain economic activity to production (gross output) in volumes (PRDK) in that economic activity after being transformed to USD dollars. These deflators incorporate fluctuations in exchange rates which for specific economic activities, mainly producing tradable goods and services, can serve better for cross country comparison (OECD-Stat, 2023)

Source: Author's elaboration

Table 2 The variables' summary statistics[a]

VarName	*Unit of measurement*	*mean*	*median*	*sd*	*xtsdb*	*xtsdw*	*min*	*xtminb*	*xtminw*	*max*	*xtmaxb*	*xtmaxw*	*xtn*	*obs*
EMPL_OEMs	Number of persons engaged (total employment), in thousand	115.0	47.0	184.9	187.8	21.5	1.9	3.3	24.1	915.0	844.9	191.5	20	477
EMPL_EQUIP	Number of persons engaged (total employment), in thousand	35.6	13.2	43.4	43.9	7.0	0.2	1.2	–5.4	152.5	133.5	84.6	20	477
ADDVALUE_AUTO	US dollar per person	98.7	96.6	20.3	14.1	15.0	49.2	79.5	53.4	174.5	136.2	157.2	20	478
ADD_VALUE_EQUIP	US dollar per person	80.0	84.9	24.8	16.4	18.9	7.7	44.7	40.1	172.9	104.5	208.2	20	478
GREEN_ICE	Number of patents with country fractional value	39.2	5.0	101.3	100.1	27.0	0.0	0.0	–232.2	587.4	449.2	177.4	20	480
HYBRID	Number of patents with country fractional value	8.7	0.0	27.8	23.8	15.3	0.0	0.0	–83.2	231.8	105.9	134.5	20	480
ELECTRIC	Number of patents with country fractional value	1.6e+09	1.4e+08	4.8e+09	4.0e+09	2.1e+09	0.0	179,873.0	–9.9e+09	3.7e+10	1.8e+10	2.0e+10	20	355
BERD_AUTO	US dollar	5.4e+08	5.7e+07	9.7e+08	1.0e+09	1.9e+08	0.0	1,522,806.5	–4.8e+08	4.3e+09	3.6e+09	1.5e+09	20	355
BERD_EQUIP	US dollar	20.0	2.0	71.5	54.1	48.2	0.0	0.3	–205.1	702.6	242.0	480.6	20	480
WAGES_AUTO	US dollar, millions	4,529.4	1,062.6	10,540.9	10,429.1	2,716.6	24.6	48.5	–12,104.1	67,568.3	47,305.8	24,791.9	20	479
WAGES_EQUIP	US dollar, millions	1,490.5	416.1	2,268.9	2,211.4	697.5	11.2	20.5	–1,228.4	10,120.8	7,004.1	4,938.8	20	479
PROD_AUTO	Index of production – reference period 2015 = 100	103.8	102.8	17.9	4.6	17.4	60.3	98.7	64.1	157.3	116.5	146.1	17	401
PROD_EQUIP	Index of production – Reference period 2015 = 100	96.3	100.0	20.0	5.8	19.2	45.6	84.1	52.6	139.7	104.0	145.3	17	401
EXPORT_AUTO	US dollar, thousands	1.3e+07	4,153,745.5	2.6e+07	2.4e+07	9,875,001.0	99,31.9	35,198.5	–4.8e+07	1.6e+08	1.1e+08	6.4e+07	20	480
IMPORT_AUTO	US dollar, thousands	1.0e+07	4,095,195.0	1.2e+07	1.1e+07	4,640,699.5	204,233.3	1,202,836.5	–7.4e+06	6.2e+07	3.7e+07	3.5e+07	20	480
CAR_SALES	Index – reference period 2015 = 100	109.2	100.0	49.1	35.0	34.8	44.9	75.4	–51.7	382.9	238.0	254.1	20	445
POP	Number of person (in thousand)	2.3e+07	1.0e+07	2.4e+07	2.5e+07	1,119,885.0	1,982,603.0	2,022,573.8	1.9e+07	8.3e+07	8.2e+07	2.8e+07	20	480
GDP_PC	US dollar, constant prices, 2015 PPP	31,708.8	29,692.2	12,415.2	8,611.0	9,140.5	7,726.8	17,479.8	7,058.4	84,575.4	48,967.4	72,872.4	20	480

Note: [a]The summary statistics refers to the mean values over the time period considered (1995–2018).

Source: Author's elaboration

First of all, we use the variables EMPL_AUTO and EMPL_EQUIP to capture the levels of employment, specifically the total number of persons engaged, in the core automotive industry and along the traditional auto supply chain[6]. Then, we use the variables LAB_PROD_AUTO and LAB_PROD_EQUIP to catch the levels of labour productivity in the core automotive industry and along the traditional auto supply chain.

Second, we have a set of exploratory variables capturing the levels and types of green innovations produced in the automotive sector, that are GREEN_INNO_TRANSPORT, which represents the total number of climate change technologies (patents) related to transportation, GREEN_ICE, HIBRID and ELECTRIC, which count the number of green patents filed in three different technological domains of the auto sector: internal combustion engines, hybrid electric vehicles and battery electric vehicles. The use of patents as a proxy of eco-innovation is backed by a well-established literature (Hascic and Migotto, 2015) with an extensive application in the automobile field (Novaresio and Patrucco, 2022; Aghion et al., 2016).

Third, the dataset features three groups of variables, which respectively help controlling for the industrial ecosystem, auto market related and country-specific factors affecting the dynamics between green innovation and employment concerning carmakers and auto equipment suppliers.

The first group of automotive-related factors takes into account the level of wages in both the original equipment manufacturers, WAGES_AUTO, and among the automotive equipment suppliers, WAGES_EQUIP, since wages are positively related with employment and productivity levels (Meager and Speckesser, 2011; Bester and Petrakis, 2003).

This group also includes the levels of industrial production, captured by PROD_AUTO and PROD_EQUIP, as well as R&D business expenditures in the automotive industry and its supply chain, captured by BERD_AUTO and BERD_EQUIP, to control for the level of productivity and innovation propensity among carmakers and equipment providers.

The second group of control variables, the car-related ones, encompasses the levels of car exports, EXPORT_AUTO, and imports, IMPORT_AUTO, as well as the number of car sales, CAR_SALES, with the aim to control for the dimension of the countries' domestic and foreign auto market size.

Finally, the third group of control variables, the country-specific ones, features the level of population, POP, and of the internal gross domestic product per capita, GDP-PC, in order to capture countries' demographic and economic trends.

The inspiring literature and the role in which the variables are employed are summarised in columns 4 and 5 of Table 1, while their relevant statistics are presented in Table 2.

3.2 The empirical model: detecting trends and causality concerning employment and green innovation

The empirical investigation of our study consists in two steps:

1 an exploratory and descriptive analysis aimed at detecting trends and changes in the level and direction of employment and green innovation in the automotive industry and its ecosystem

2 an econometric analysis aimed at verifying whether and which types of green innovations has been associated with occupational and labour productivity changes in the automotive industry and its supply chain.

While the exploratory analysis requires the inspection of employment and green innovation trends, the econometric model used is an OLS panel regression with country fixed effect[7], α_i, and time fixed effect γ_t (Wooldridge, 2010), which relates the level of employment and labour productivity in the carmakers and their suppliers with three different types of eco-innovation produced in the automotive industry, while controlling for industry, market and country-specific factors, as described in equations (1), (2), (3) and (4).

Equations (1) and (2) depict the relation of the level of employment in the original equipment manufacturers (OEMs), EMPL_AUTO, a discrete variable expressed in thousand persons, and the level of labour productivity in OEMs, LAB_PROD_AUTO, with four matrices of variables, which respectively capture the influence of eco-innovations in the automotive sector, GREEN_INNO, the automotive industry characteristics, OEMs, the automotive market features AUTO_MARKET and country socio-economic specificities, COUNTRY.

The first matrix of variables, GREEN_INNO, encompasses three count variables proxying the level of eco-innovation in three distinct technological domains of the automotive industry: green internal combustion engines, GREEN_ICE, hybrid engines, HYBRID, and electric engines, ELECTRIC. All these variables represent the explanatory variables of the model, which aims to test whether and which type of eco-innovations have affected employment and labour productivity levels in the automotive industry the most.

The second matrix of variables represents the first set of controls used in the model and encompasses three variables proxying the main industry's characteristics specific to the carmakers: the level of business expenditures in R&D activities, BERD_AUTO, the level of industry production, PROD_AUTO, and the level of the wages, WAGES_AUTO.

The third matrix of variables includes a second set of controls, which proxy for the automotive market characteristics, namely the level of auto exports, EXPORT_AUTO, the level of auto imports, IMPORT_AUTO and the number of car sales, CAR_SALES.

The fourth and last matrix of variables controls for the main countries' socio-economic specificities with two variables, the level of country population, POP, and the level of gross domestic product per capita, GDP-PC.

$$\begin{aligned} EMPL\_AUTO_{i,t} = {} & \beta_0 + \beta_1\_GREEN\_INNO_{i,t} + \beta_2\_OEMs_{i,t-2} \\ & + \beta_3\_AUTO\_MARKET_{i,t-2} + \beta_4\_COUNTRY_{i,t-2} \\ & + \alpha_i + \gamma_t + \varepsilon_{it} \end{aligned} \tag{1}$$

$$\begin{aligned} LAB\_PROD\_AUTO_{i,t} = {} & \beta_0 + \beta_1\_GREEN\_INNO_{i,t-2} + \beta_2\_OEMs_{i,t-2} \\ & + \beta_3\_AUTO\_MARKET_{i,t-2} + \beta_4\_COUNTRY_{i,t-2} \\ & + \alpha_i + \gamma_t + \varepsilon_{it} \end{aligned} \tag{2}$$

Similarly, equations (3) and (4) outline the relation of the level of employment among the automotive suppliers, EMPL_EQUIP, a discrete variable expressed in thousand persons, and the level of labour productivity along the supply chain, LAB_PROD_EQUIP, with four matrices of variables, which respectively capture the influence of eco-innovations in the automotive sector, GREEN_INNO, the suppliers' ecosystem characteristics, AUTO_EQUIP, the automotive market features AUTO_MARKET and country socio-economic specificities, COUNTRY.

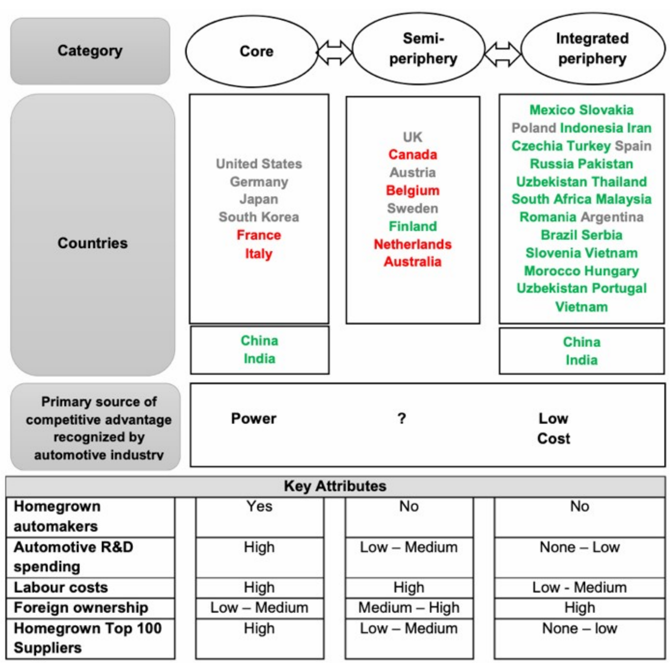
Therefore, these equations differ from equations (1) and (2) only for the second matrix of variables, which is now composed by three variables proxying the industry characteristics specific to the suppliers' ecosystem, namely the level of business expenditures in R&D activities, BERD_EQUIP, the amount of suppliers' production, PROD_EQUIP, and the level of the wages in the supply chain, WAGES_EQUIP.

$$\begin{aligned} EMPL\_EQUIP_{i,t} = {} & \beta_0 + \beta_1\_GREEN\_INNO_{i,t-2} + \beta_2\_AUTO\_EQUIP_{i,t-2} \\ & + \beta_3\_AUTO\_MARKET_{i,t-2} + \beta_4\_COUNTRY_{i,t-2} \\ & + \alpha_i + \gamma_t + \varepsilon_{it} \end{aligned} \quad (3)$$

$$\begin{aligned} LAB\_PROD\_EQUIP_{i,t} = {} & \beta_0 + \beta_1\_GREEN\_INNO_{i,t-2} + \beta_2\_AUTO\_EQUIP_{i,t-2} \\ & + \beta_3\_AUTO\_MARKET_{i,t-2} + \beta_4\_COUNTRY_{i,t-2} \\ & + \alpha_i + \gamma_t + \varepsilon_{it} \end{aligned} \quad (4)$$

Both country and time dummies are included in all model specifications, in order to control for persistent unobserved heterogeneity among countries and general macroeconomic demand shocks.

Figure 1 The countries' classification within the automotive panorama (see online version for colours)



Source: Carey and Mordue (2022)

In order to tackle possible endogeneity issues, we lag the exploratory and control variables by two years. To resolve heteroskedasticity bias, we use robust standard errors in each model.

In the regional analyses we use different the time lags for each region, namely 2 for core countries, 3 for semi-peripheral and 4 for integrated periphery, in order to control for possible delayed labour effects of the green transition in these regions due to a more slow-paced diffusion of green techs in peripheral regions as postulated by Pavlínek (2023).

Finally, Table 3 lists the European countries examined in the regional analysis, grouping them in three clusters inspired by the classification identified by Carey and Mordue (2022), *core*, *semi-periphery* and *integrated periphery*, depicted in Figure 1.

Table 3 The list of the countries grouped according to the taxonomy proposed by Carey and Mordue (2022) – Denmark, Greece, Ireland and Spain which were not considered by Carey and Mordue (2022) are not included in the regional analysis

CORE	*SEMI-PERIPHERY*	*INTEGRATED PERIPHERY*
France, Germany, Italy	Austria, Belgium, Finland, Netherlands, Sweden, UK	Czechia, Hungary, Poland, Portugal, Slovakia, Slovenia

Source: Author's elaboration

4 Results

4.1 Exploratory analysis

First, the study analyses the evolution of the employment level among carmakers and equipment suppliers between 1995 and 2018, revealing that, while average employment in European OEMs has been substantially stable until a dramatic drop in 2008, followed by a rapid recovery, the workforce in EU auto suppliers has experienced a slow, but steady decline, as Figure 2 shows.

Figure 3 depicts the evolution of the employment level in OEM and suppliers across the 20 European countries examined over the time period considered, providing a more insightful picture of the European labour trends.

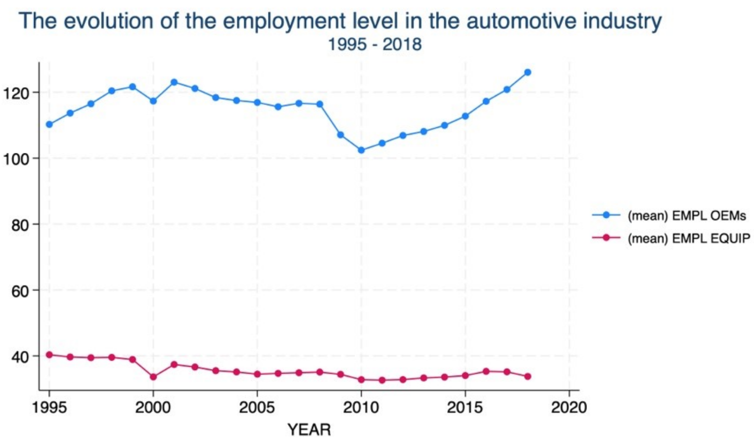
This analysis, in fact, reveals that only Germany shows a huge difference in the employment levels between OEMs and suppliers, probably because it is home of a relevant number of big global brands, which are likely to steer employment mainly within the 'core' auto manufacturing industry. On the other hand, in most of the other countries the labour levels in OEMs and suppliers are not only considerably lower, but they also substantially overlap. These findings confirm that both car manufactures and auto parts' suppliers play a relevant role as source of employment in Europe, even if the size of the suppliers is relatively small.

Secondly, the study analyses the evolution of the labour productivity in carmakers and equipment suppliers over the time period between 1995 and 2018, revealing that average labour productivity has been always higher among suppliers rather than in OEMs, even though their trends tend to converge from 2010 onwards, as Figure 4 shows.

The higher levels of labour productivity among the suppliers before the dramatic drop occurred at the time of the 2008 financial crisis could be explained with the presence of very innovative and IT-oriented firms along the European automotive supply chain (EC,

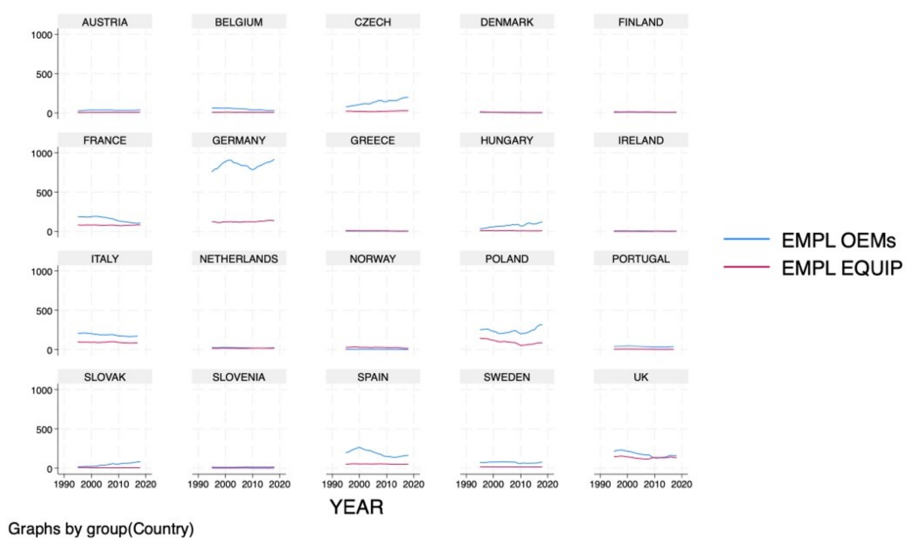
2020) which reaped the benefits of the ICT revolution, the main driver of labour productivity gains during the past decades, better than the car producers (ECB, 2006)[8].

Figure 2 The evolution of the average level of employment among car manufacturers (OEM) and auto equipment/parts suppliers in Europe between 1995 and 2018 (see online version for colours)



Source: Author's elaboration

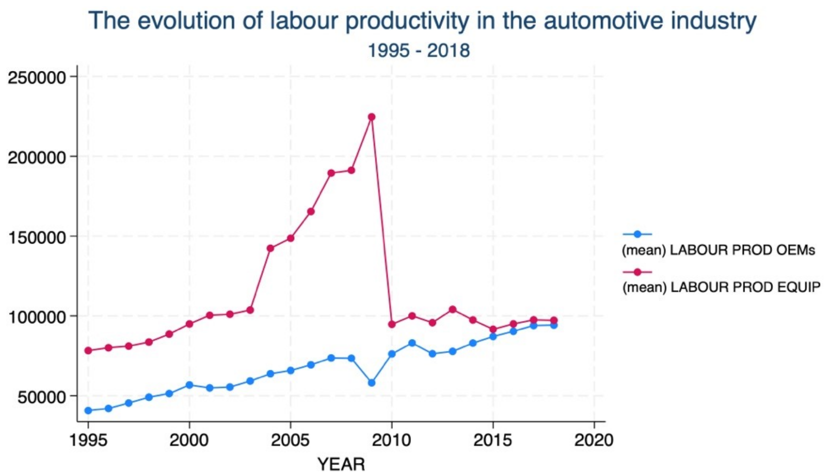
Figure 3 The evolution of the average level of employment among car manufacturers (OEM) and auto equipment/parts suppliers across 20 European countries between 1995 and 2018 (see online version for colours)



Source: Author's elaboration

However, the decline in labour productivity seems to be more permanent only among suppliers since, because of their small-medium dimensions, many of them ran out of business or significantly reduced their production and staff as a result of the loss of orders, while OEMs, as bigger entities, has been more effective in reorganising their business activities, for example through M&As, bouncing back better from the crisis.

Figure 4 The evolution of the average level of labour productivity among car manufacturers (OEM) and auto equipment/parts suppliers in Europe between 1995 and 2018 (see online version for colours)



Source: Author's elaboration

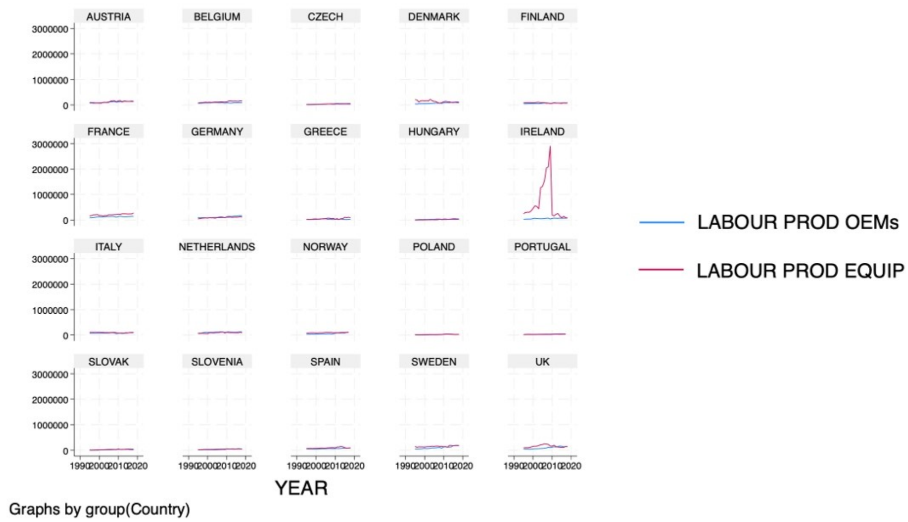
Figure 5 describes the evolution of the labour productivity in OEM and suppliers across the 20 European countries examined over the time period considered, showing substantially overlapping trends between OEMs and OESs in almost all countries, except in France, UK and Ireland where a slightly higher level of labour productivity among suppliers rather than in car manufacturers is detected.

Finally, the study analyses the evolution of the European production of automotive-related eco-innovations, namely vehicles propelled with green endothermic engines (green ICEV), hybrid solutions (HEV), electric engines (BEV), as well as climate change mitigation technologies for transport system, over the time period between 1995 and 2018.

Figure 6 depicts their average trends, revealing that patents related to the green ICEV are the most numerous and show a steady increase rate until 2015, when their production started to decline, while patents related BEV are those with the sharpest increase rate since 2005 and patents related to HEV show low levels of both production and increase rate.

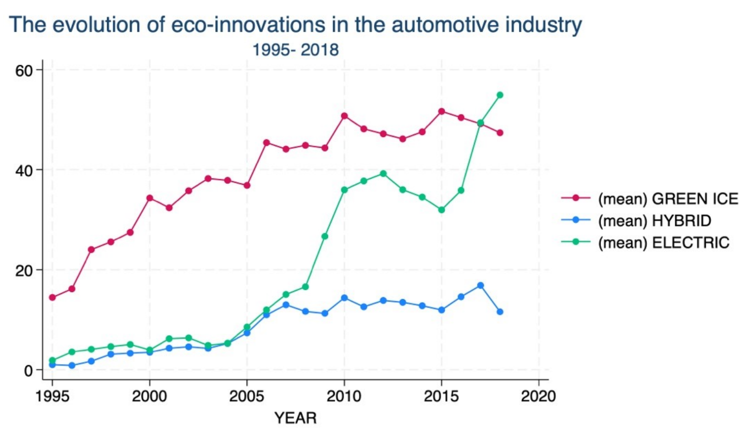
Finally, Figure 7 outlines the evolution of the eco-innovation patterns across the 20 European countries examined between 1995–2018, showing that Germany is the country with the greatest production of patents in all three technological domains, followed by France and Italy.

Figure 5 The evolution of the average level of labour productivity among car manufacturers (OEM) and auto equipment/parts suppliers across 20 European countries between 1995 and 2018 (see online version for colours)



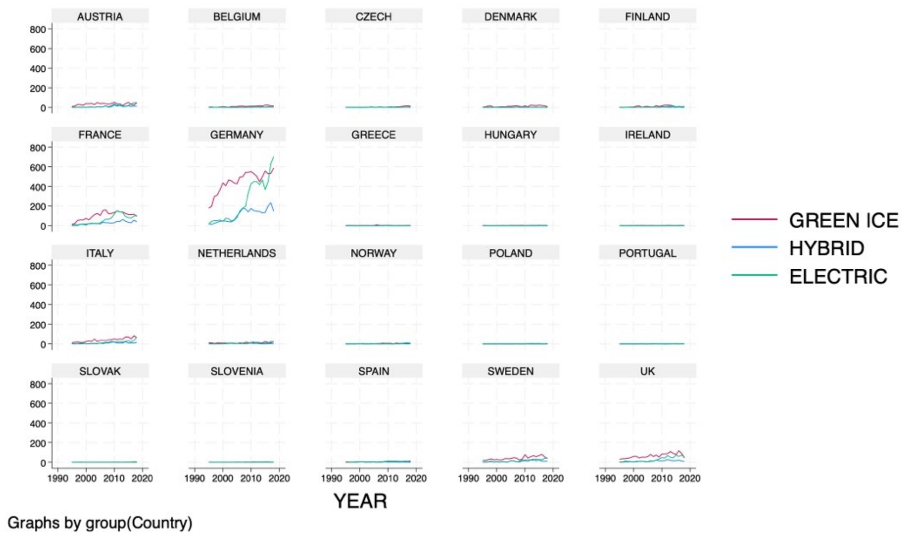
Source: Author's elaboration

Figure 6 The evolution of the average level of eco-innovations among car manufacturers (OEM) and auto equipment/parts suppliers in Europe between 1995 and 2018 (see online version for colours)



Source: Author's elaboration

Figure 7 The evolution of the average level of eco-innovations among car manufacturers (OEM) and auto equipment/parts suppliers across 20 European countries between 1995 and 2018 (see online version for colours)



Source: Author's elaboration

4.2 Econometric analysis

4.2.1 Main analysis

The econometric model aims at analysing the relation between the production of eco-innovations in the automotive industry, specifically patents concerning green ICEV, HEV and BEV, and labour and labour efficiency in the sector, while controlling for relevant industry, market and country factors. The main outcomes of the model are summarised in Tables 3 and 4.

Table 3 shows the results of the basic model focused on labour effects of eco-innovations, revealing that patents related to HEV and BEV are negatively associated with labour levels among the 'core' car manufacturers (column 1), while positively associated with labour levels among the auto equipment suppliers (column 3). These findings provide support to the hypothesis of a labour shift from the OEMs to the suppliers' ecosystem (e.g., batteries, electronics) postulated by Küpper et al. (2020) and providing evidence backing the forecasts formulated by EC (2020) and Naso and Artico (2023).

However, the results from the dynamic model highlight a positive association between patenting activity for BEVs' development and the employment both in the OEMs (Column 2) and along the supply chain (Column 4), backing the hypothesis that electrification may lead to more jobs in powertrain manufacturing, at least in the short to medium term, formulated by Cotterman et al. (2022).

Table 4 Results of the econometric analysis relating employment levels and eco-innovation in the automotive industry

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	EMPL_OEMs	*EMPL_OEMs*	*EMPL_EQUIP*	*EMPL_EQUIP*
L2.EMPL_OEMs		0.779***		
		(0.153)		
L2.EMPL_EQUIP				0.571***
				(0.0386)
L2.GREEN_ICE	0.0382	–0.165***	0.00742	0.00429
	(0.0643)	(0.0387)	(0.0128)	(0.00746)
L2.HYBRID	–0.401***	–0.0452	–0.0184	–0.0153
	(0.0833)	(0.0802)	(0.0335)	(0.0151)
L2.ELECTRIC	–0.124***	0.151***	0.0347**	0.0310***
	(0.0334)	(0.0511)	(0.0120)	(0.00640)
L2.BERD_AUTO	8.33e-09***	2.22e-09*		
	(9.60e-10)	(1.24e-09)		
L2.PROD_AUTO	–0.183	–0.141		
	(0.257)	(0.222)		
L2.WAGES_AUTO	–0.00309	–0.00154		
	(0.00196)	(0.00166)		
L2.EXPORT_AUTO	2.01e-07	–2.85e-07	1.97e-08	7.91e-08
	(6.68e-07)	(4.72e-07)	(1.46e-07)	(7.65e-08)
L2.IMPORT_AUTO	1.12e-07	3.25e-07	2.28e-07	1.63e-07
	(5.56e-07)	(2.22e-07)	(2.23e-07)	(2.13e-07)
L2.CAR_SALES	0.0235	–0.0208	0.00740	0.00626
	(0.0576)	(0.0144)	(0.0176)	(0.00751)
L2.POP	–1.29e-05***	–2.69e-06	–8.75e-07	2.02e-07
	(4.23e-06)	(3.58e-06)	(1.44e-06)	(6.78e-07)
L2.GDP_PC	0.000351	0.000279	1.52e-05	0.000174
	(0.000293)	(0.000167)	(0.000141)	(0.000147)
L2.BERD_EQUIP			5.33e-10	1.88e-09
			(4.55e-09)	(2.27e-09)
L2.PROD_EQUIP			–0.0402	–0.0905
			(0.0760)	(0.0855)

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.
Source: Author's elaboration

Table 4 Results of the econometric analysis relating employment levels and eco-innovation in the automotive industry

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	EMPL_OEMs	*EMPL_OEMs*	*EMPL_EQUIP*	*EMPL_EQUIP*
L2.WAGES_EQUIP			5.37e-06	–0.00240**
			(0.000988)	(0.000942)
Constant	427.9***	113.0	54.28	13.58
	(86.12)	(80.90)	(31.35)	(16.51)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Observations	261	261	261	261
R-squared	0.553	0.740	0.350	0.607

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.
Source: Author's elaboration

Table 4 shows the results of the basic model focused on labour efficiency effects of eco-innovations in the automotive industry, revealing that the production of patents for BEVs' development is positively associated with labour productivity of car manufacturers (column 1), while no statistically significant effect of any of the green technological domains is detected on labour productivity among the suppliers (column 3).

Table 5 Results of the econometric analysis relating labour productivity and eco-innovation in the automotive industry

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	LABPROD_ OEMs	*LABPROD_ OEMs*	*LABPROD_ EQUIP*	*LABPROD_ EQUIP*
L2.LABOUR_PROD_OEMs		0.346***		
		(0.0969)		
L2.LABOUR_PROD_EQUIP				0.560***
				(0.0466)
L2.GREEN_ICE	24.88	41.84	12.09	–2.958
	(33.42)	(31.39)	(62.91)	(35.88)
L2.HYBRID	0.531	–5.448	135.8	7.951
	(122.1)	(124.5)	(121.1)	(64.94)
L2.ELECTRIC	48.86**	46.93*	48.36	45.64
	(23.90)	(28.36)	(42.90)	(41.84)
L2.BERD_AUTO	1.08e-06*	7.74e-07		
	(5.20e-07)	(4.55e-07)		

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.
Source: Author's elaboration

Table 5 Results of the econometric analysis relating labour productivity and eco-innovation in the automotive industry (continued)

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	LABPROD_ OEMs	*LABPROD_ OEMs*	*LABPROD_ EQUIP*	*LABPROD_ EQUIP*
L2.PROD_AUTO	–357.5	–212.6		
	(346.8)	(275.3)		
L2.WAGES_AUTO	0.875	1.087**		
	(0.596)	(0.508)		
L2.EXPORT_AUTO	–8.98e-05	–0.000197	7.86e-05	0.000124
	(0.000268)	(0.000236)	(0.000278)	(0.000216)
L2.IMPORT_AUTO	–0.000781*	–0.000930***	0.000447	0.000355
	(0.000415)	(0.000276)	(0.000509)	(0.000471)
L2.CAR_SALES	40.78	25.76	–9.636	–43.86
	(25.32)	(19.39)	(53.84)	(53.76)
L2.POP	6.31e-05	0.00136	–0.00211	0.00121
	(0.00166)	(0.00136)	(0.00467)	(0.00255)
L2.GDP_PC	1.339***	0.929***	1.291**	0.275
	(0.133)	(0.227)	(0.578)	(0.354)
L2.BERD_EQUIP			3.84e-06	–2.38e-06
			(4.98e-06)	(2.13e-06)
L2.PROD_EQUIP			–539.7	53.82
			(462.0)	(256.3)
L2.WAGES_EQUIP			–10.36	–5.918
			(6.123)	(4.957)
Constant	67,173**	15,477	155,494	12,746
	(27,055)	(24,304)	(98,407)	(54,820)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Observations	261	261	261	261
R-squared	0.679	0.713	0.284	0.483

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.
Source: Author's elaboration

These findings are substantially confirmed by the dynamic model, which highlights a weakly significant, but positive association between BEVs-related patents and labour productivity among OEMs, while no sign of any type of association between eco-innovations in the three technological domain and labour efficiency along the automotive supply chain.

These results are in line with the evidence produced by the main literature on the topic, in particular Woo et al. (2014), which found significant effects of the introduction of green innovations on labour productivity, especially in pollution-intensive industries, as automotive is.

These results are substantially robust to a test running the model over data excluding Germany and Norway, as they represent two outliers[9].

In fact, while Table 5 shows that BEV-related patents associate to an increase in labour among suppliers, Table 6 highlights that eco-innovations related to BEVs lead to a decrease in labour productivity among OEMs, revealing that productivity gains displayed by the main model (Table 4) were substantially driven by German innovators.

Table 6 Results of the econometric analysis relating employment levels and eco-innovation in the automotive industry – excluding Germany and Norway

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	EMPL_OEMs	*EMPL_OEMs*	*EMPL_EQUIP*	*EMPL_EQUIP*
L2.EMPL_OEMs		0.758***		
		(0.210)		
L2.EMPL_EQUIP				0.574***
				(0.0459)
L2.GREEN_ICE	–0.0293	0.0179	–0.0628*	–0.0393
	(0.114)	(0.0775)	(0.0373)	(0.0306)
L2.HYBRID	–0.200	–0.200	–0.0392	–0.0913
	(0.245)	(0.225)	(0.0768)	(0.107)
L2.ELECTRIC	0.0224	0.0266	0.0326	0.0445**
	(0.101)	(0.0536)	(0.0262)	(0.0203)
L2.BERD_AUTO	3.11e-08	2.17e-08**		
	(2.15e-08)	(1.04e-08)		
L2.PROD_AUTO	–0.377*	–0.436*		
	(0.203)	(0.239)		
L2.WAGES_AUTO	0.0145**	0.00495		
	(0.00580)	(0.00454)		
L2.EXPORT_AUTO	–2.02e-07	–8.54e-07	–1.01e-07	–7.09e-08
	(1.18e-06)	(8.86e-07)	(4.12e-07)	(1.96e-07)
L2.IMPORT_AUTO	–6.31e-07*	3.19e-07	2.49e-07	2.81e-07
	(3.32e-07)	(4.15e-07)	(2.31e-07)	(2.31e-07)
L2.CAR_SALES	0.0268	–0.00599	0.00430	0.000329
	(0.0342)	(0.0144)	(0.0224)	(0.00828)
L2.POP	–1.96e-05***	–7.10e-06	–1.64e-06**	4.68e-07
	(7.37e-06)	(4.73e-06)	(6.41e-07)	(6.51e-07)
L2.GDP_PC	0.00101	0.000610	0.000204	0.000313
	(0.000966)	(0.000766)	(0.000168)	(0.000363)

Notes: Robust standard errors in parentheses.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Source: Author’s elaboration

Table 6 Results of the econometric analysis relating employment levels and eco-innovation in the automotive industry – excluding Germany and Norway (continued)

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	EMPL_OEMs	*EMPL_OEMs*	*EMPL_EQUIP*	*EMPL_EQUIP*
L2.BERD_EQUIP			7.20e-09**	5.03e-09
			(3.18e-09)	(3.65e-09)
L2.PROD_EQUIP			0.0209	–0.0449
			(0.0803)	(0.0919)
L2.WAGES_EQUIP			–0.00129	–0.00396***
			(0.00181)	(0.00103)
Constant	180.9***	89.11***	15.40**	–3.325
	(57.50)	(33.80)	(7.216)	(8.617)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Observations	217	217	217	217
R-squared	0.6236	0.7384	0.2362	0.5609

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Source: Author's elaboration

Table 7 Results of the econometric analysis relating labour productivity and eco-innovation in the automotive industry – excluding Germany and Norway

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	LABPROD_ OEMs	*LABPROD_ OEMs*	*LABPROD_ EQUIP*	*LABPROD_ EQUIP*
L2.LABOUR_PROD_OEMs		0.339***		
		(0.0995)		
L2.LABOUR_PROD_EQUIP				0.555***
				(0.0573)
L2.GREEN_ICE	–9.247	–60.50	–161.7	–15.16
	(132.8)	(61.34)	(269.1)	(185.6)
L2.HYBRID	798.4	814.4	646.8	–100.8
	(568.1)	(561.8)	(474.6)	(478.8)
L2.ELECTRIC	–77.37	–156.3*	–16.75	77.96
	(89.00)	(86.62)	(153.0)	(115.8)
L2.BERD_AUTO	1.66e-05	8.56e-06		
	(1.50e-05)	(1.09e-05)		

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Source: Author's elaboration

Table 7 Results of the econometric analysis relating labour productivity and eco-innovation in the automotive industry – excluding Germany and Norway (continued)

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	LABPROD_ OEMs	*LABPROD_ OEMs*	*LABPROD_ EQUIP*	*LABPROD_ EQUIP*
L2.PROD_AUTO	53.72	82.31		
	(182.1)	(127.8)		
L2.WAGES_AUTO	1.864	1.995		
	(2.650)	(2.212)		
L2.EXPORT_AUTO	0.000266	0.000180	–0.000470	–0.000358
	(0.000464)	(0.000406)	(0.00101)	(0.000703)
L2.IMPORT_AUTO	–0.00127**	–0.00131***	0.00122	0.00102
	(0.000503)	(0.000356)	(0.00117)	(0.000884)
L2.CAR_SALES	39.29*	30.70	–6.324	–39.87
	(23.06)	(22.87)	(40.26)	(45.50)
L2.POP	–0.00754	–0.00302	–0.000168	0.00340
	(0.00661)	(0.00442)	(0.00658)	(0.00375)
L2.GDP_PC	1.054***	0.313	0.479	–0.272
	(0.361)	(0.460)	(1.768)	(0.986)
L2.BERD_EQUIP			9.68e-06	2.05e-06
			(1.23e-05)	(9.76e-06)
L2.PROD_EQUIP			–440.1	66.07
			(519.0)	(311.9)
L2.WAGES_EQUIP			–26.66***	–19.03***
			(7.834)	(6.295)
Constant	118,031**	74,218*	164,523**	46,335
	(49,575)	(39,158)	(76,027)	(39,655)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Observations	218	218	218	218
R-squared	0.5514	0.6041	0.2774	0.4703

Notes: Robust standard errors in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
Source: Author's elaboration

4.2.2 Regional analysis: core vs semi-periphery vs integrated periphery

The regional analyses aim at detecting possible regional specificities in the labour effects of the eco-transition within the European automotive sector, while controlling for different temporal frames of diffusion of the sectoral green techs.

The focus of the regional analyses is on three main areas identified by Carey and Mordue (2022) as pivotal in the current automotive's panorama: core, semi-periphery and integrated periphery.

The 'core region' includes countries with homegrown automakers, homegrown and top suppliers and persistent high levels of R&D investments and labour costs. The 'semi-periphery' encompasses countries without homegrown automakers, a low-medium level of homegrown suppliers and automotive R&D expenditure, while a high level of foreign ownership and labour costs. The 'integrated periphery' embraces countries without homegrown automakers and suppliers, low levels of auto R&D spending and labour costs.

Therefore, the European countries examined in the present study have been clustered according to the abovementioned classification, which is depicted in Figure 1[10].

For each regional area we perform an econometric analysis examining the impact of eco-innovations on labour and its productivity, while controlling for relevant industry, market and country factors. Moreover, each regional analysis is based on a different temporal lag, in order to control for different times of propagation of green innovations towards the most peripheral areas and capture their postponed effects on the labour dimensions.

The first regional analyses focus on the so-called 'core countries' within the European automotive panorama, namely Germany, France, and Italy.

The results of the econometry study on labour levels in the core region, depicted in Table 8, confirm the relatively negative impact of the greener technological solutions (HEVs and BEVs) on employment levels among OEMs, while the small but statistically positive effect of BEV-related techs on labour levels among the European automotive suppliers. Table 9, on the other hand, confirms that in core countries BEV-related technologies steered a statistically significant increase of the labour productivity at least among OEMs.

Table 8 Results of the regional econometric analysis relating employment level and eco-innovation in the automotive industry: *core region* – Germany, France, Italy

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	EMPL_OEMs	*EMPL_OEMs*	*EMPL_EQUIP*	*EMPL_EQUIP*
L2.EMPL_OEMs		0.372**		
		(0.113)		
L2.GREEN_ICE	–0.115	–0.182**	0.0374	0.0324*
	(0.101)	(0.0544)	(0.0167)	(0.0134)
L2.HYBRID	–0.434***	–0.233**	–0.0379*	–0.0214
	(0.0732)	(0.0596)	(0.0125)	(0.00995)
L2.ELECTRIC	–0.111**	–0.00392	0.0324*	0.0334*
	(0.0550)	(0.0773)	(0.0183)	(0.0192)
L2.BERD_AUTO	1.06e-08***	7.05e-09***		
	(7.51e-10)	(8.95e-10)		

Notes: Robust standard errors in parentheses.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Source: Author's elaboration

Table 8 Results of the regional econometric analysis relating employment level and eco-innovation in the automotive industry: *core region* – Germany, France, Italy (continued)

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	EMPL_OEMs	*EMPL_OEMs*	*EMPL_EQUIP*	*EMPL_EQUIP*
L2.PROD_AUTO	–3.682	–2.672		
	(1.787)	(1.535)		
L2.WAGES_AUTO	–0.00624**	–0.00511**		
	(0.00146)	(0.00134)		
L2.EXPORT_AUTO	5.93e-07	2.82e-07	–1.12e-07	–7.25e-08
	(3.60e-07)	(3.16e-07)	(7.82e-08)	(8.65e-08)
L2.IMPORT_AUTO	1.43e-06	5.35e-07	2.01e-07	1.37e-07
	(1.15e-06)	(1.06e-06)	(4.08e-07)	(3.54e-07)
L2.CAR_SALES	0.140	0.0208	–0.00372	0.0284
	(0.103)	(0.158)	(0.0223)	(0.0211)
L2.POP	–8.97e-06	–8.63e-06	–1.75e-07	–4.29e-07
	(4.49e-06)	(6.26e-06)	(1.72e-06)	(1.75e-06)
L2.GDP_PC	–0.00124	0.000607	0.00121	0.000562
	(0.00260)	(0.00340)	(0.000622)	(0.000869)
L2.BERD_EQUIP			7.59e-10	7.28e-10
			(1.31e-09)	(1.09e-09)
L2.PROD_EQUIP			0.0269	0.0552
			(0.143)	(0.144)
L2.WAGES_EQUIP			0.00242	0.000814
			(0.00230)	(0.00269)
L2.EMPL_EQUIP				0.260
				(0.121)
Constant	1,331**	1,065*	59.41	64.11
	(309.5)	(434.5)	(110.8)	(115.0)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Observations	60	60	60	60
R-squared	0.919	0.932	0.887	0.890

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Source: Author's elaboration

Table 9 Results of the regional econometric analysis relating labour productivity and eco-innovation in the automotive industry: *core region* – Germany, France, Italy

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	LABPROD_ OEMs	*LABPROD_ OEMs*	*LABPROD_ EQUIP*	*LABPROD_ EQUIP*
L2.LABOUR_PROD_OEMs		0.212		
		(0.400)		
L2.LABOUR_PROD_EQUIP				0.520**
				(0.215)
L2.GREEN_ICE	25.58	39.55	169.1**	184.4**
	(79.95)	(88.83)	(66.36)	(69.22)
L2.HYBRID	–176.0*	–145.3	85.03	15.59
	(83.07)	(92.54)	(105.5)	(141.8)
L2.ELECTRIC	179.7*	151.5+	–28.75	–25.80
	(91.66)	(78.10)	(53.50)	(84.28)
L2.BERD_AUTO	1.87e-06	1.83e-06		
	(1.27e-06)	(1.25e-06)		
L2.PROD_AUTO	1,356	1,280		
	(828.8)	(930.5)		
L2.WAGES_AUTO	0.976	1.183		
	(0.747)	(1.220)		
L2.EXPORT_AUTO	0.000374	0.000177	–5.63e-05	5.18e-06
	(0.000239)	(0.000535)	(0.000330)	(0.000317)
L2.IMPORT_AUTO	–0.00128	–0.00166***	0.00171	0.00201
	(0.000657)	(0.000273)	(0.00168)	(0.00217)
L2.CAR_SALES	243.0	230.7	–146.8	–231.7
	(217.5)	(206.6)	(181.2)	(216.3)
L2.POP	0.00696	0.00540	–0.00840	–0.00878
	(0.00963)	(0.00883)	(0.00708)	(0.00623)
L2.GDP_PC	–3.345	–2.979	–5.561	–3.504
	(2.129)	(1.775)	(4.912)	(4.615)
L2.BERD_EQUIP			8.58e-06	2.93e-06
			(6.55e-06)	(8.21e-06)
L2.PROD_EQUIP			–86.84	1,059
			(747.4)	(891.4)
L2.WAGES_EQUIP			8.018	–3.707
			(16.23)	(22.56)

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Source: author's elaboration

Table 9 Results of the regional econometric analysis relating labour productivity and eco-innovation in the automotive industry: *core region* – Germany, France, Italy (continued)

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	LABPROD_ OEMs	*LABPROD_ OEMs*	*LABPROD_ EQUIP*	*LABPROD_ EQUIP*
Constant	–425,090	–341,308	699,612	572,008
	(604,252)	(569,125)	(414,376)	(388,884)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Observations	61	61	61	61
R-squared	0.927	0.928	0.725	0.779

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Source: author's elaboration

The second round of regional analyses focuses on the so-called 'semi-peripheral countries' within the European automotive panorama, namely Austria, Belgium, Finland, Netherlands, Sweden and UK.

Tables 10 and 11 respectively show that greener technologies have exerted a positive effect on labour – among suppliers – and its productivity – among the OEMs, confirming the findings of the main analyses.

Table 10 Results of the regional econometric analysis relating employment level and eco-innovation in the automotive industry: *semi periphery* – Austria, Belgium, Finland, Netherlands, Sweden and UK

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	EMPL_OEMs	*EMPL_OEMs*	*EMPL_EQUIP*	*EMPL_EQUIP*
L3.EMPL_OEMs		0.861**		
		(0.309)		
L3.EMPL_EQUIP				0.0524
				(0.155)
L3.GREEN_ICE	0.0423	0.0277	0.0106	0.0107
	(0.0327)	(0.0191)	(0.0113)	(0.0120)
L3.HYBRID	0.203	0.244	0.126***	0.126***
	(0.141)	(0.130)	(0.0226)	(0.0211)
L3.ELECTRIC	–0.111	–0.0349	–0.0105	–0.0121
	(0.0642)	(0.0639)	(0.0394)	(0.0420)

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Source: Author's elaboration

Table 10 Results of the regional econometric analysis relating employment level and eco-innovation in the automotive industry: *semi periphery* – Austria, Belgium, Finland, Netherlands, Sweden and UK (continued)

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	EMPL_OEMs	*EMPL_OEMs*	*EMPL_EQUIP*	*EMPL_EQUIP*
L3.BERD_AUTO	5.22e-08**	3.46e-08*		
	(1.29e-08)	(1.41e-08)		
L3.PROD_AUTO	0.344	0.278		
	(0.188)	(0.210)		
L3.WAGES_AUTO	–0.00562*	–0.00829**		
	(0.00214)	(0.00207)		
L3.EXPORT_AUTO	–7.82e-08	–7.76e-07**	–1.35e-08	–1.58e-08
	(2.41e-07)	(1.77e-07)	(7.91e-08)	(7.40e-08)
L3.IMPORT_AUTO	3.35e-08	1.05e-06**	–3.05e-08	–2.44e-08
	(2.48e-07)	(2.87e-07)	(9.37e-08)	(7.86e-08)
L3.CAR_SALES	–0.0293	–0.0964	0.00125	0.000299
	(0.0505)	(0.0517)	(0.0231)	(0.0206)
L3.POP	–3.85e-05***	–1.40e-05	3.91e-06***	3.81e-06**
	(6.54e-06)	(1.32e-05)	(8.34e-07)	(1.05e-06)
L3.GDP_PC	–0.000614	–0.000406	0.000319	0.000306
	(0.000654)	(0.000450)	(0.000270)	(0.000278)
L3.BERD_EQUIP			–9.09e-09**	–9.22e-09**
			(2.36e-09)	(2.60e-09)
L3.PROD_EQUIP			–0.120**	–0.115*
			(0.0389)	(0.0428)
L3.WAGES_EQUIP			0.00337	0.00283
			(0.00371)	(0.00392)
Constant	338.5***	108.6	–21.84*	–21.32*
	(56.81)	(114.9)	(8.708)	(9.513)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Observations	74	74	74	74
R-squared	0.885	0.907	0.780	0.780

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Source: Author's elaboration

Table 11 Results of the regional econometric analysis relating labour productivity and eco-innovation in the automotive industry: *semi periphery* – Austria, Belgium, Finland, Netherlands, Sweden and UK

VARIABLES	*(1)* *LABPROD_ OEMs*	*(2)* *LABPROD_ OEMs*	*(3)* *LABPROD_ EQUIP*	*(4)* *LABPROD_ EQUIP*
L3.LABOUR_PROD_OEMs		–0.129		
		(0.161)		
L3.LABOUR_PROD_EQUIP				0.317*
				(0.169)
L3.GREEN_ICE	116.8	152.4	150.2	72.43
	(131.7)	(101.7)	(425.0)	(383.5)
L3.HYBRID	887.8*	844.2*	1,488	636.1
	(457.3)	(468.6)	(1,220)	(1,002)
L3.ELECTRIC	–108.1	–20.35	218.6	411.0
	(315.2)	(354.2)	(549.7)	(529.4)
L3.BERD_AUTO	5.06e-05	6.75e-05		
	(4.33e-05)	(5.77e-05)		
L3.PROD_AUTO	1,796**	1,927**		
	(802.4)	(860.8)		
L3.WAGES_AUTO	11.68	9.767		
	(12.99)	(14.97)		
L3.EXPORT_AUTO	–0.00148	–0.00146	0.00259	0.00202
	(0.00122)	(0.00105)	(0.00246)	(0.00214)
L3.IMPORT_AUTO	–0.00124	–0.00110	–0.00104	0.000646
	(0.000930)	(0.000814)	(0.00264)	(0.00240)
L3.CAR_SALES	157.6	147.3	–319.1	–465.1
	(243.5)	(262.3)	(441.6)	(515.8)
L3.POP	–0.0184**	–0.0245*	0.128***	0.105**
	(0.00719)	(0.0134)	(0.0458)	(0.0475)
L3.GDP_PC	–1.094	–0.632	–0.139	–0.544
	(1.674)	(1.893)	(4.026)	(3.068)
L3.BERD_EQUIP			–0.000105	–0.000128
			(6.46e-05)	(8.12e-05)
L3.PROD_EQUIP			170.3	903.1
			(890.7)	(626.0)
L3.WAGES_EQUIP			99.22	111.2*
			(73.03)	(57.64)

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Source: Author’s elaboration.

Table 11 Results of the regional econometric analysis relating labour productivity and eco-innovation in the automotive industry: *semi periphery* – Austria, Belgium, Finland, Netherlands, Sweden and UK (continued)

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	LABPROD_ OEMs	*LABPROD_ OEMs*	*LABPROD_ EQUIP*	*LABPROD_ EQUIP*
Constant	9,954	37,855	–924,532**	–821,578*
	(110,755)	(98,257)	(426,163)	(436,173)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Observations	74	74	74	74
R-squared	0.8427	0.8476	0.6717	0.6997

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.
Source: Author's elaboration.

The third round of regional analyses focuses on the so-called 'integrated peripheral countries' within the European automotive panorama, namely Czechia, Hungary, Poland, Portugal, Slovakia, Slovenia and Spain.

Tables 12 and 13 respectively show that none of the green techs under examination has exerted a substantial influence on labour neither among OEMs nor OES, while BEV-related technologies have steered a relevant increase in labour productivity among suppliers.

Table 12 Results of the regional econometric analysis relating employment level and eco-innovation in the automotive industry: *integrated periphery* – Slovakia, Slovenia, Poland, Portugal, Czechia and Hungary

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	EMPL_OEMs	*EMPL_OEMs*	*EMPL_EQUIP*	*EMPL_EQUIP*
L4.EMPL_OEMs		0.416**		
		(0.134)		
L4.GREEN_ICE	0.665	–0.365	0.308	–0.467
	(1.116)	(1.172)	(0.557)	(0.286)
L4.HYBRID	–1.491	0.115	–1.484	–0.588
	(2.610)	(2.670)	(1.395)	(0.873)
L4.ELECTRIC	2.655	1.824	0.368	0.552
	(2.130)	(2.292)	(0.793)	(0.805)
L4.BERD_AUTO	9.32e-08***	9.12e-08***		
	(1.44e-08)	(2.03e-08)		

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p <0.1.
Source: Author's elaboration

Table 12 Results of the regional econometric analysis relating employment level and eco-innovation in the automotive industry: *integrated periphery* – Slovakia, Slovenia, Poland, Portugal, Czechia and Hungary (continued)

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	EMPL_OEMs	*EMPL_OEMs*	*EMPL_EQUIP*	*EMPL_EQUIP*
L4.PROD_AUTO	–0.611	–0.658*		
	(0.305)	(0.312)		
L4.WAGES_AUTO	0.0134	0.00276		
	(0.00731)	(0.00686)		
L4.EXPORT_AUTO	–1.48e-06	–1.57e-06	–3.16e-07	–3.21e-07
	(1.55e-06)	(1.36e-06)	(4.80e-07)	(2.60e-07)
L4.IMPORT_AUTO	–4.27e-06	–3.37e-06	8.69e-08	2.20e-06
	(3.44e-06)	(4.26e-06)	(1.81e-06)	(3.34e-06)
L4.CAR_SALES	–0.0519*	–0.0795**	–0.00444	–0.0309
	(0.0236)	(0.0304)	(0.0126)	(0.0228)
L4.POP	4.30e-05**	7.59e-05***	5.61e-06	2.04e-05*
	(1.16e-05)	(1.13e-05)	(9.79e-06)	(8.74e-06)
L4.GDP_PC	0.00512**	0.00518**	0.000656	0.00129
	(0.00162)	(0.00180)	(0.000468)	(0.000864)
L4.BERD_EQUIP			1.49e-07**	1.53e-07**
			(5.32e-08)	(5.56e-08)
L4.PROD_EQUIP			–0.0970	–0.242
			(0.131)	(0.209)
L4.WAGES_EQUIP			–0.0335**	–0.0379*
			(0.0119)	(0.0164)
L4.EMPL_EQUIP				0.391*
				(0.175)
Constant	–400.2*	–811.3***	–40.75	–215.7*
	(156.4)	(147.2)	(126.0)	(98.35)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Observations	80	80	80	80
R-squared	0.895	0.902	0.660	0.762

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p <0.1.

Source: Author's elaboration

Table 13 Results of the regional econometric analysis relating labour productivity and eco-innovation in the automotive industry: *integrated periphery* – Slovakia, Slovenia, Poland, Portugal, Czechia and Hungary

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	LABPROD_ OEMs	*LABPROD_ OEMs*	*LABPROD_ EQUIP*	*LABPROD_ EQUIP*
L4.LABOUR_PROD_OEMs		0.0717		
		(0.236)		
L4.GREEN_ICE	–120.1	–112.4	350.6	334.7
	(403.5)	(381.7)	(449.0)	(437.8)
L4.HYBRID	523.6	521.8	–2,344	–2,344
	(1,056)	(1,082)	(1,276)	(1,291)
L4.ELECTRIC	–1,010	–997.2	2,905**	2,910**
	(1,065)	(1,095)	(913.3)	(918.2)
L4.BERD_AUTO	–5.58e-06	–5.55e-06		
	(1.24e-05)	(1.29e-05)		
L4.PROD_AUTO	145.4	184.2		
	(126.5)	(166.7)		
L4.WAGES_AUTO	0.653	–0.205		
	(6.095)	(5.947)		
L4.EXPORT_AUTO	1.38e-05	–4.19e-06	–0.000305	–0.000277
	(0.000727)	(0.000788)	(0.000487)	(0.000469)
L4.IMPORT_AUTO	0.00127	0.00151	–0.00424	–0.00426
	(0.00205)	(0.00245)	(0.00222)	(0.00241)
L4.CAR_SALES	–17.28	–21.61	112.7***	112.0***
	(36.82)	(43.58)	(27.20)	(24.81)
L4.POP	–0.0164	–0.0167	–0.0442**	–0.0439**
	(0.0159)	(0.0163)	(0.0140)	(0.0129)
L4.GDP_PC	1.695	1.805	–0.779	–0.820
	(0.859)	(1.236)	(1.319)	(1.151)
L4.BERD_EQUIP			–4.08e-05	–4.10e-05
			(7.95e-05)	(8.03e-05)
L4.PROD_EQUIP			–462.7**	–462.6**
			(141.9)	(146.9)
L4.WAGES_EQUIP			54.37**	54.80**
			(14.97)	(18.18)

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Source: Author's elaboration

Table 13 Results of the regional econometric analysis relating labour productivity and eco-innovation in the automotive industry: *integrated periphery* – Slovakia, Slovenia, Poland, Portugal, Czechia and Hungary (continued)

VARIABLES	*(1)*	*(2)*	*(3)*	*(4)*
	LABPROD_ OEMs	*LABPROD_ OEMs*	*LABPROD_ EQUIP*	*LABPROD_ EQUIP*
L4.LABOUR_PROD_EQUIP				0.0229
				(0.210)
Constant	186,050	183,629	591,480**	587,770**
	(194,194)	(199,393)	(169,743)	(159,931)
Observations	80	80	80	80
R-squared	0.705	0.706	0.729	0.729
Number of ID_COUNTRY	6	6	6	6

Notes: Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.
Source: Author's elaboration

To sum up, the results of the regional analyses reveal that our main results are driven by the three core countries. In fact, while the results of the regional test in the 'core' countries, Germany, France and Italy, are substantially in line with those of the main model, the test in the 'semi-periphery' countries reveals that it is HEV-related patents that have an impact: they increase employment at suppliers and productivity among OEMs. That means that countries in the 'semi-periphery' are a 'step-behind' in the electrification process in comparison with the 'core' ones

Finally, none of the patent variables are found to be statistically significant in the integrated periphery, with the exception of BEVs-related innovations with respect to labour productivity among suppliers.

These findings are consistent with what Pavlínek (2023) reports.

All these findings are substantially robust to the tests in a dynamic model and to multiple tests using different time lags.

5 Conclusions

The greening of the automotive industry has gained increasing scholarly attention during the last period, as it is a hot topic on the table of the policy makers, especially in Europe, where electromobility is experiencing a boost since the COVID-19 pandemic (Rokicki et al., 2021).

A wide strand of literature has thoroughly investigated the drivers and barriers to clean technologies in the automotive industry (Gohoungodji et al., 2020; Aghion et al., 2016; Barbieri, 2015, 2016; Bergek et al., 2014; Berggren and Magnusson, 2012; Dijk and Yarime, 2010; Hascic et al., 2008), as well as the systems and complex mechanisms affecting the dynamics that originate and orient green solutions in this sector (Novaresio and Patrucco, 2022; Faria and Andersen, 2015, 2017a, 2017b; Oltra and Saint-Jean, 2009a, 2009b).

As the importance of the social dimension of the transition to the electromobility is widely acknowledged, especially the role of market demand (Lanzini, 2018) and behavioural change (Rezvani et al., 2015; Axsen, 2012; Barbarossa et al., 2017, 2015), growing research efforts are devoted to investigate also the labour impacts of this disruptive technological transformation.

In particular, the rising 'job-vs-environment dilemma' within the automotive industry has raised debate among policy makers, leading scholars in the social sciences to explore, mainly theoretically and through case studies, the opportunities and the obstacles to a 'just' transition in the automobile sector (Pichler et al., 2021a, 2021b; Galgóczi, 2020).

Furthermore, a relevant number of economic researches empirically investigate the electrification's labour effects, providing contrasting evidence and scenarios, whose common feature is to be mainly predictive (Galgóczi, 2023; Cotterman et al., 2022; BCG, 2021; CLEPA, 2021; Strategy&, 2021; Verhaeghe, 2021; Küpper et al., 2020; Bauer et al., 2018).

However, the greening of the automotive industry has a long and multifaceted story (Calabrese, 2016) and its past labour dynamics offer an interesting subject, which has been little investigated.

Following the way paved by a consolidated literature addressing the relation between technology and labour, the aim of the present study is to provide a first assessment of the extent to which different green technological patterns in the auto industry have impacted labour and its productivity in OEMs and auto suppliers, using a sample of 20 European countries over the time period from 1995 to 2018.

The choice to focus on Europe is motivated by the current debate around the EU proposal to achieve 'carbon neutrality' of the road transport sector by means of the 'technological neutrality' approach, in order to preserve employment in the automotive industry, especially along its supply chain.

Therefore, the paper aims to analyse the occupational and eco-innovative evolution among carmakers and equipment suppliers in Europe as well as to understand, by using an appropriate econometric method, whether and which type of eco-innovation, namely green ICE, hybrid solutions (HEV) and battery electric vehicles (BEV), have more significantly impacted labour and its efficiency in the European automotive and its traditional supply chain, providing useful industrial policy advice.

The findings of our exploratory analysis highlight that while average employment in EU OEMs has been substantially stable until the dramatic drop in 2008, followed by a rapid recovery, the workforce in EU auto suppliers has experienced a slow, but steady decline, which reflects in a higher labour productivity, whose recent trends among OEMs and suppliers tend to converge after the financial crisis.

As far as the evolution of auto-related eco-innovations are concerned, green patents show increasing average trends in all three categories over time, with BEVs displaying the most impressive growth pattern and peak in the last years.

The results of our econometric analysis reveal that while eco-innovations related to HEVs and BEVs show a statistically significant negative association with labour levels in the OEMs, the production of BEVs-related technologies has a statistically significant positive effect on labour among producers of auto equipment, supporting the hypothesis of a labour shift from the OEMs to the suppliers' ecosystem (e.g., batteries, electronics) postulated by Küpper et al. (2020) and providing evidence backing the forecasts formulated by EC (2020) and Naso and Artico (2023).

The study on labour productivity highlights that innovations related to the electrification process have a positive effect on the car manufactures' labour productivity, suggesting that the labour demand contraction driven by more sustainable technologies, can be compensated by major labour productivity, at least among countries with a long-standing OEMs' tradition, like Germany.

These findings, which show how the electrification process has the potential for driving OEMs and suppliers to a 'win-win' outcome, are substantially robust to a test in a dynamic model including past employment levels, which reveals that patenting activity in the BEV domain can actually steer a positive effect on jobs demand even among car manufacturers, backing the hypothesis that the transition to the electromobility may lead to more jobs in powertrain manufacturing formulated by Cotterman et al. (2022).

Furthermore, our results are robust to a regional analysis inspired by the countries' classification proposed by Carey and Mordue (2022) and in which we take into account the differentiated pace of diffusion of the green technologies postulated by Pavlínek (2023). The regional analysis reveals that our main results are driven by the three 'core' countries, Germany, France and Italy, while the countries in the semi-periphery and integrated periphery are still lagging behind in the electrification process, consistently with what Pavlínek (2023) reports. These findings suggest that long-term and country-wise policies should be promoted to take care of the country-specific effects of the green transition of the automotive sector.

Therefore, the empirical analyses suggest that, since in the past 'mixed technology' regime (Calabrese, 2016; CLEPA, 2021) the growth of electric solutions has been steering both labour – among suppliers – and labour productivity – among OEMs – increases, the full electrification of the sector, postulated by the most ambitious eco-policies, should not be feared as a source of socio-economic loss, but rather fostered as an opportunity to set new goals and collaborations as well as achieve green growth for the auto industry and its supply chain.

In fact, this assessment counters the more plumbeous industrial claims about the negative effects of the electrification on the automotive supply chain, showing that suppliers have already been, and thus, can be, the main beneficiaries of the transition to the electromobility.

Moreover, the analysis suggests that the surge of the e-mobility can be beneficial also for the 'core' automotive industry, both in terms of labour (in the dynamics model) and labour productivity gains, which can steer carmakers' production and competitivity, strengthening their global market position, with positive long-term occupational benefits.

On top of this, the paper provides empirical evidence in support of the most ambitious European policies, which should no longer hesitate to spur a radical EV transition, by leveraging on the product and labour opportunities emerging for the automotive supply chain and highlighting the risk of competitivity loss for those OEMs who do not catch up with the current *BEVs revolution*.

This study represents the first contribution to assess the actual impact of the green transition not only on the core European automotive industry, but also along its supply chain; thus, in spite of the fact that the study relies on data mainly focused on 'core' manufacturers and 'traditional' suppliers, it offers interesting insights on past and recent occupational and eco-innovation dynamics occurred in the European automotive ecosystems.

Further research efforts should be devoted to analyse the wider auto supplier ecosystem, in order to understand which types of 'old' and 'new' suppliers are benefiting from the green transition the most, and to examine the electrification's impacts in terms of labour quality and structure, investigating the upskilling, reskilling and reshoring of competences dynamics occurring within the European automotive ecosystem.

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Notes

1 A de-maturity process describes the evolutionary phase when an industry or a technology has reached its maturity peak and instead of entering a 'decline and disappear' phase, it is directed towards new solutions that rejuvenate and relaunch it. In the case of the automotive industry, after a period of market stagnation and mere price competition, the industry is being steered to a 'green relaunch' by disruptive innovators (Tesla and Chinese emerging firms) and progressively ambitious eco-policies (US and EU eco-regulations).

2 The initial agreement, that marked the first step in the adoption of the 'Fit for 55' legislative proposals tabled by the Commission in July 2021, implied 55% lower CO_2 vehicles' emissions from 2030, with respect to 2021 levels, and the end of sales of CO_2 emitting vehicles by 2035, in order to put EU's transport system on the path on carbon neutrality. However, the agreement has been modified on February 2023 to give the EU carmakers the possibility to sale endothermic engine vehicles propelled with e-fuels also beyond 2035.

3 As green ICEVs we intend the technological solutions intended to improve the environmental performances of the endothermic engine of motor vehicles (e.g., end of pipe gears and/or changes in the structure of the engine)

4 Germany and Italy are the only member states in the EU27 that enter in the top-10 ranking of the largest contributors of the electronic components in the global supply chains of cars (EC, 2020).

5 The paper focuses on 20 European countries, namely 14 Western European countries (the core EU countries, including UK, but excluding Luxembourg), five Eastern European countries (Czech, Hungary, Poland, Slovakia and Slovenia) and Norway. The choice of the countries has been oriented towards those that are historically home of car manufacturers and suppliers (headquarters and/or manufacturing plants). The analysis also includes Norway, even if it does not have a long tradition in car manufacturing, as it is a country with strong investments in clean techs and a big BEV market.

6 The variables related to the automotive core manufacturing and its supply chain, respectively labelled with the suffices -AUTO (1) and -EQUIP (2), refer to data from the car manufacturers (1) and all the automotive equipment suppliers (2), the latter with no distinction among first-tier, second-tier, third-tier and subcontractors. We base our distinction on the OECD Stat classification, which simply distinguishes transport producers between 'motor vehicles, trailers and semi-trailers' ones, that we consider the original equipment manufacturers (OEMs), and 'other transport equipment' ones, that we consider generic suppliers, including original equipment suppliers (EOSs) and other types of suppliers and subcontractors.

7 The results of the Hausman test and the test for time fixed effects suggest the application of a country and time 'fixed effect' model for every regression on labour and labour productivity levels.

8 ECB (2006) highlights that the industries not producing or using intensively information and communication technology (ICT) appeared mostly responsible for the decline in average labour productivity growth in the euro area since the mid-1990s.

9 Germany is an 'upper-bound' outlier since it produces many more green patents in the automotive domain that the other countries, as Figure 7 shows, while Norway is a 'lower-bound' outlier as it almost does not have a national automotive industry and for this reason its data could bias the results of the main econometric analysis.

10 Since not all the countries encompassed in the main analysis are included in the Carey and Mordue (2022) taxonomy inspiring this regional analysis – namely Denmark, Greece, Ireland and Spain – the number of countries included in the regional analysis is smaller (16) than the number of countries included in the aggregate analysis (20).