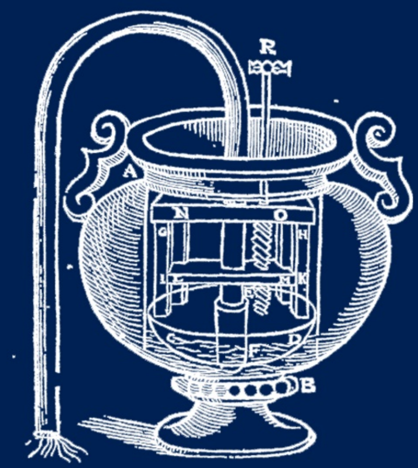
CNR-IRCrES Working Paper

Eco-innovations and labor in the European automotive industry: an econometric study



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Eco-innovations and labor in the European automotive industry: an econometric study

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ABSTRACT
The present paper aims at providing a first comparative ex-post assessment of the extent to which different green technological patterns in the European automobile industry have impacted labor 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 past 20+ years. The exploratory analysis highlight that while average employment in EU OEMs has been substantially stable until the dramatic drop in 2010, followed by a rapid recovery, the workforce in EU auto suppliers has experienced a slow, but steady decline. On the other hand, auto 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 labor levels in the OEMs, the production of BEVs-related technologies, surprisingly, has a statistically significant positive effect on labor among producers of auto equipment, confirming the hypothesis of a labor shift from the OEMs to the suppliers' ecosystem (e.g., batteries, electronics) postulated by Kupper et al., (2020). The analysis on labor productivity shows that innovations related to the electrification process have a positive effect on the OEMs labor productivity, suggesting that the labor demand reduction driven by cleaner technologies, has been compensated by major labor productivity. Our 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 BEVs 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).

KEYWORDS: just transition, eco-innovations, employment, labor productivity, automotive, Europe.

JEL CODES : J23, O31, O33, O25, O14.

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1. INTRODUCTION

Automotive industry is a dynamic, international and high-tech sector (Smitka & 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 (Faria and Andersen, 2015), 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*., 2015).

Despite the existence of different propulsion alternatives for the promotion of more a sustainable mobility (e.g., biofules, synthetic fuels, fuel cell vehicles, battery electric vehicles), whose potentialities and criticalities have been extensively debated (Armaroli *et al*, 2023; Grzesiak, S., & Sulich, A., 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 & Midler, 2019; Covarrubias, 2018).

Thus, the shift to electromobility is a choice that has been made by most of the global carmakers and is currently redefining the geopolitics and the global value chain of the sector (Bridge & Faigen, 2022; Jullien, & 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, 2022; Pardi, 2021).

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, Krzywdzinski, & Pardi, 2023). On the other hand, the EU regulatory proposal to achieve zero emissions from new cars and vans by 2035 (EU, 2023)[1], a measure aiming at substantially phasing out the ICEVs in favor of the diffusion of the electric powertrains (BEVs), has been also harshly criticized as overly ambitious and risky, due to its potentially negative labor implications, especially along the automotive supply chain (CLEPA, 2022; 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 decarbonization 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; Pichler *et al*, 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; Kupper et al., 2020; Bauer et al., 2018), which is challenged by an increasingly ambitious environmental regulatory framework.

[1] 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 CO2 vehicles’ emissions from 2030, with respect to 2021 levels, and the end of sales of CO2 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.

However, since electrification is a process that is accelerating and gaining momentum only in the most recent years in Europe (T&E, 2019), most of the abovementioned studies are predictive and strictly focused on the electrification-only effects on labor.

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 labor 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 analyze the occupational and eco-innovative trends of carmakers and equipment suppliers in Europe to capture trends and breaks occurred over the past 25 years, and 2) to understand, by means of 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 labor 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, summarizing the most relevant literature on socio-technological transitions, with special focus their labor vs environment dynamics, and outlining the state of the art of the research on the labor 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. Theoretical framework

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 fulfills functions in association with human agency, social structures and organizations 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, Loorbach & Rotmans, 2008).

Sustainability transitions are defined as structural changes in the co-dynamics of social, environmental and economic subsystems including technologies, institutions, organizations or behavioral 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 stabilization 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, 2011).

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 behaviors, 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; Ekins, 2000; Hart, 2000) 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 labor issues, thus, has triggered the development of a strand of studies examining the exacerbation of the so-called "jobs vs environment" dilemma (Rahtzel, Uzzel and Stevis; 2021; Rahtzel and Uzzel, 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 (ILO 2015; UNFCCC, 2015; ETUC, 2018).

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 (Galgoczi, 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 labor 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 labor effects

The automotive industry is experiencing two huge transformations, namely electrification and digitization (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 labor 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 analyzed in its most recent trends and evolution related to the so-called "industry 4.0" (Calabrese and Falavigna, 2022; Carey and Mordue, 2022; Isac, Dobrin & Badshah, 2020; Pardi, 2019), electrification is the most radical transformative process undergoing in the automotive industry, posing the greatest challenges and concerns in terms of labor 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, 2020), 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, 2021a; 2021b). 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 labor 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 labor demand involved with setting up and maintaining the charging infrastructure (CLEPA, 2021b). 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[2], 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, summarizing 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 concertation* (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 (Galgóczi, 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

[2] 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).

the traditional automotive supply chain and by 30% across the new industrial battery-based ecosystem (Naso & 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 labor intensive than ICEVs (Bauer et al., 2018), even though their labor requirements are substantially comparable since the value added in automotive manufacturing just shifts from OEMs to tier-one suppliers (Kupper 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 labor 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 labor effect of the greening process of the European automotive industry yet.

Following the way paved by a conspicuous and consolidated economic literature (Rennings & Zwick, 2002; Pfeiffer & Rennings, 2001; Pianta, 2000; 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, Zigler & Zwick (2004), which have performed the first econometric analysis assessing the labor 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 labor 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 & Shenshinov, 2020; Woo *et al*., 2014), we test the hypothesis of the existence of a relation between eco-innovations and labor productivity in the European automotive ecosystem.

The ultimate goal is to provide useful policy advice on the relation between eco-innovations, labor 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 & EMPIRICAL STRATEGY

3.1. Data description

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

Table 1. The variables

Variable	Definition	Source	Literature	Role
EMPL_OEMs	Level of total employment (number of persons engaged) in the core automotive industry (Original Equipment Manufacturers)	OECD STAN - dataset	Employment and innovation literature	Dependent var.
EMPL_EQUIP	Level of total employment (number of persons engaged) in the automotive suppliers' industry	OECD STAN - dataset	Employment and innovation literature	Dependent var.
LABOUR_PROD_OEMs	Level of labour productivity in the core automotive industry (Original Equipment Manufacturers)	OECD STAN - dataset	Employment and literature	Dependent var.
LABOUR_PROD_EQUIP	Level of labour productivity in the automotive suppliers' industry	OECD STAN - dataset	Employment literature	Dependent var.
GREEN_INNO_TRANSPORT	Total number of green patents in the transport sector - climate change mitigation technologies related to transportation	ENV- OECD iLibrary	Green innovation literature	Explanatory variable
GREEN_ICE_ADJ	Total number of green patents related to the improvement of Internal Combustion Engine	ENV- OECD iLibrary	Green innovation literature	Explanatory variable
HYBRID_ADJ	Total number of green patents related to the Hybrid Electric Vehicles	ENV- OECD iLibrary	Green innovation Literature	Explanatory variable
ELECTRIC_ADJ	Total number of green patents related to the Battery Electric Vehicles	OECD STAN - dataset	Green innovation literature	Explanatory variable
BERD_AUTO	Level of business expenditures in R&D of the core automotive industry (Original Equipment Manufacturers)	OECD STAN - dataset	Innovation literature	Control variable
BERD_EQUIP	Level of business expenditures in R&D of the automotive suppliers' industry	OECD STAN - dataset	Innovation literature	Control variable
PROD_AUTO	Level of production in the core automotive industry (Original Equipment Manufacturers)	OECD STAN - dataset	Innovation literature	Control variable
PROD-EQUIP	Level of production in the automotive suppliers' industry	OECD STAN - dataset	Innovation literature	Control variable
WAGES_AUTO	Level of the wages in the core automotive industry (Original Equipment Manufacturers)	OECD STAN - dataset	Employment literature	Control variable
WAGES_EQUIP	Level of the wages of the automotive suppliers' industry	OECD STAN - dataset	Employment literature	Control variable
EXPORT_AUTO	Level of the exports from the automotive industry - exports from j country to the rest of the world	OECD STAN - dataset	Innovation literature	Control variable
IMPORT_AUTO	Level of imports from the automotive industry – imports from j country to the rest of the world	OECD STAN - dataset	Innovation literature	Control variable
CAR_SALES	Number of car sales in the country	OECD STAN - dataset	Innovation literature	Control variable
POP	Number of population (in thousand)	OECD Stat	Innovation literature	Control variable
GDP_PC	Gross Domestic Product per capita	OECD Stat	Innovation literature	Control variable

Source: author's elaboration.

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 fifteen out of the seventeen variables employed in our empirical investigations.

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[3]. 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, 2015; Faria & Andersen, 2015).

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 & PROD_EQUIP, as well as R&D business expenditures in the automotive industry and its supply chain, captured by BERD_AUTO & 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] 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.

Table 2. The variables' summary statistics

VarName	mean	median	sd	xtsdb	xtsdw	min	xtminb	xtminw	max	xtmaxb	xtmaxw	xtn	obs
EMPL_OEMs	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	35.6	13.2	43.4	43.9	7.0	0.2	1.2	-5.4	152.5	133.5	84.6	20	477
LABOUR_PROD_OEMs	67505.8	60261.8	39115.4	33792.3	21082.1	1933.3	16632.9	10734.4	184949.0	126673.3	150184.6	20	477
LABOUR_PROD_EQUIP	114588.1	87489.4	219044.9	140887.3	170302.1	3080.4	17642.0	-476310.5	2888641.2	668761.2	2334468.2	20	477
GREEN_INNO_TRANSPORT	50.2	6.0	135.8	117.8	72.2	0.0	0.7	-372.8	896.3	506.3	440.1	20	480
GREEN_ICE	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	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	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	4529.4	1062.6	10540.9	10429.1	2716.6	24.6	48.5	-12104.1	67568.3	47305.8	24791.9	20	479
WAGES_EQUIP	1490.5	416.1	2268.9	2211.4	697.5	11.2	20.5	-1228.4	10120.8	7004.1	4938.8	20	479
BERD_AUTO	1.6e+09	1.4e+08	4.8e+09	4.0e+09	2.1e+09	0.0	179873.0	-9.9e+09	3.7e+10	1.8e+10	2.0e+10	20	355
BERD_EQUIP	5.4e+08	5.7e+07	9.7e+08	1.0e+09	1.9e+08	0.0	1522806.5	-4.8e+08	4.3e+09	3.6e+09	1.5e+09	20	355
PROD_AUTO	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	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	1.3e+07	4153745.5	2.6e+07	2.4e+07	9875001.0	9931.9	35198.5	-4.8e+07	1.6e+08	1.1e+08	6.4e+07	20	480
IMPORT_AUTO	1.0e+07	4095195.0	1.2e+07	1.1e+07	4640699.5	204233.3	1202836.5	-7.4e+06	6.2e+07	3.7e+07	3.5e+07	20	480
CAR_SALES	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	2.3e+07	1.0e+07	2.4e+07	2.5e+07	1119885.0	1982603.0	2022573.8	1.9e+07	8.3e+07	8.2e+07	2.8e+07	20	480
GDP_PC	31708.8	29692.2	12415.2	8611.0	9140.5	7726.8	17479.8	7058.4	84575.4	48967.4	72872.4	20	480

Source: author's elaboration.

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 inferential analysis aimed at verifying whether and which types of green innovations has been causing occupational 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[4], αi, and time fixed effect γt (Woolridge, 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 Eq. 1, Eq. 2, Eq. 3 and Eq. 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.

$$
\begin{aligned}
EMPL\_AUTOi,t &= \beta 0 + \beta 1\_GREEN\_INNOi,t-2 + \beta 2\_OEMSi,t-2 \\
&+ \beta 3\_AUTO\_MARKETi,t-2 + \beta 4\_COUNTRYi,t-2 + \alpha i + \gamma t + \varepsilon i
\end{aligned}
\qquad \text{(Eq. 1)}
$$

$$
\begin{aligned}
LAB\_PROD\_AUTOi,t &= \beta 0 + \beta 1\_GREEN\_INNOi,t-2 + \beta 2\_OEMSi,t-2 \\
&+ \beta 3\_AUTO\_MARKETi,t-2 + \beta 4\_COUNTRYi,t-2 + \alpha i + \gamma t + \varepsilon i
\end{aligned}
\qquad \text{(Eq. 2)}
$$

[4] 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 labor and labor productivity levels.

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 Eq. 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.

$$EMPL\_EQUIPi,t = \beta 0 + \beta 1\_GREEN\_INNOi,t-2 + \beta 2\_AUTO\_EQUIPi,t-2 + \beta 3\_AUTO\_MARKETi,t-2 + \beta 4\_COUNTRYi,t-2 + \alpha i + \gamma t + \varepsilon i \quad \text{(Eq. 3)}$$

$$LAB\_PROD\_EQUIPi,t = \beta 0 + \beta 1\_GREEN\_INNOi,t-2 + \beta 2\_AUTO\_EQUIPi,t-2 + \beta 3\_AUTO\_MARKETi,t-2 + \beta 4\_COUNTRYi,t-2 + \alpha i + \gamma t + \varepsilon i \quad \text{(Eq. 4)}$$

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.

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.

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 2010, followed by a rapid recovery, the workforce in EU auto suppliers has experienced a slow, but steady decline.

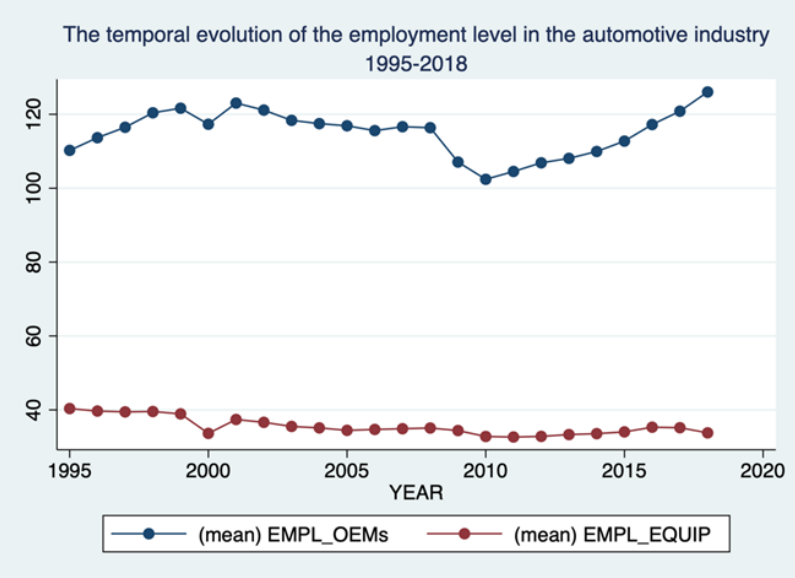

Figure 1. The evolution of the average level of employment among car manufacturers (OEM) and auto equipment/parts suppliers in Europe between 1995 and 2018. Source: author's elaboration.

Figure 2 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 labor 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 labor 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 their dimensions are relatively small.

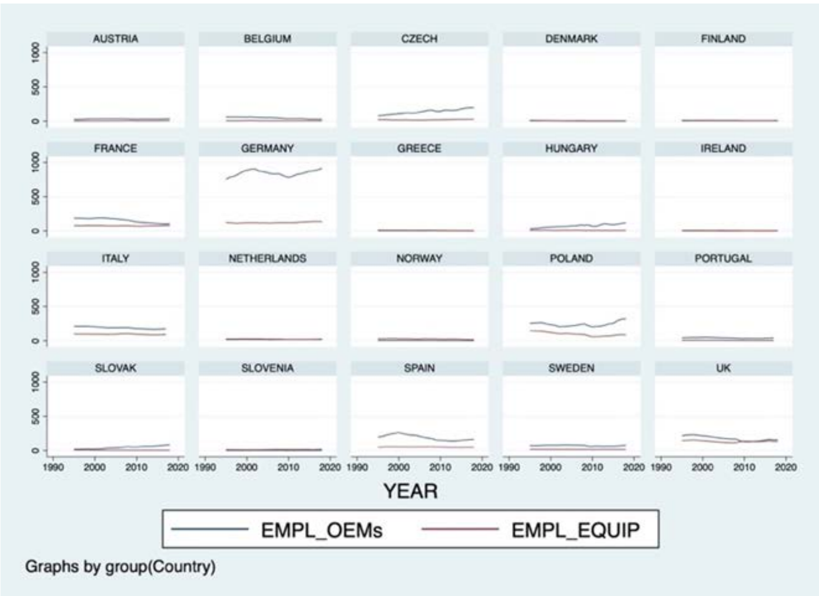

Figure 2. The evolution of the average level of employment among car manufacturers (OEM) and auto equipment/parts suppliers across 20 European countries between 1995 and 2018. Source: author's elaboration.

Secondly, the study analyses the evolution of the labor productivity in carmakers and equipment suppliers over the time period between 1995 and 2018, revealing that average labor productivity has been always higher among suppliers rather than in OEMs, even though their trends tend to converge from 2010 onwards, as Figure 3 shows.

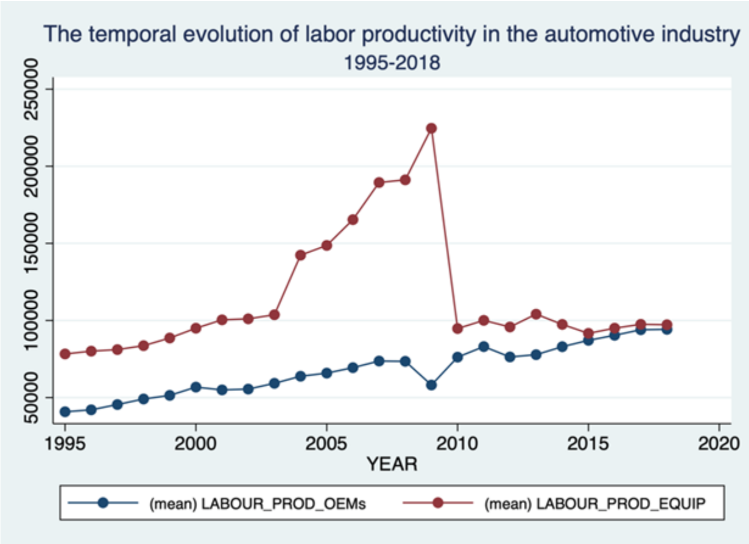

Figure 3. The evolution of the average level of labor productivity among car manufacturers (OEM) and auto equipment/parts suppliers in Europe between 1995 and 2018. Source: author's elaboration.

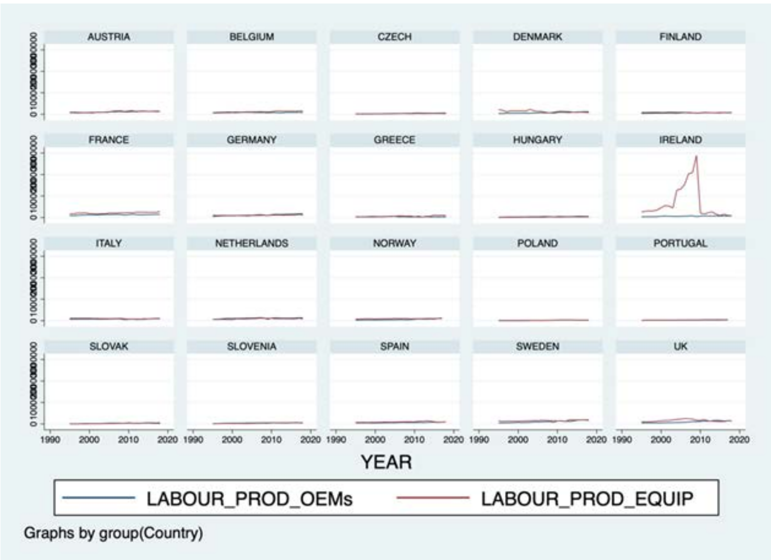

Figure 4. The evolution of the average level of labor productivity among car manufacturers (OEM) and auto equipment/parts suppliers across 20 European countries between 1995 and 2018. Source: author's elaboration.

To conclude, 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 5 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. The comprehensive category of patents including all climate change mitigation technologies applied to the transport system confirms the upward trend of technologies devoted to the decarbonization of the transports, which dates to the early 2000s.

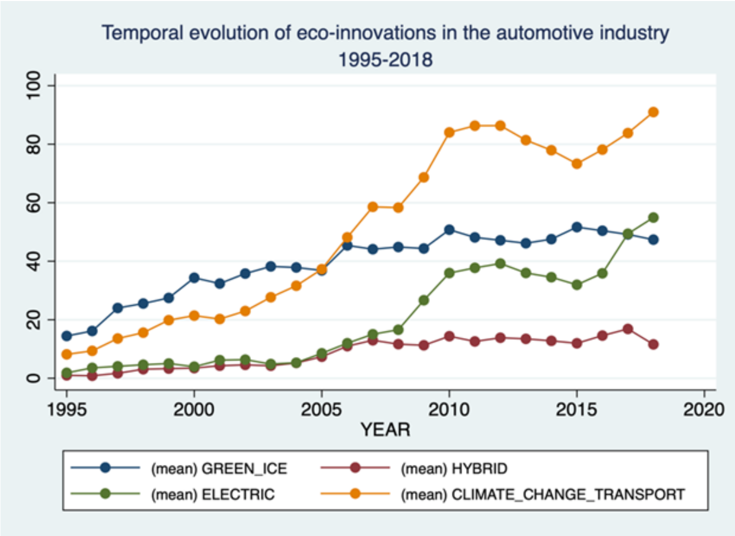

Figure 5. The evolution of the average level of eco-innovations among car manufacturers (OEM) and auto equipment/parts suppliers in Europe between 1995 and 2018. Source: author's elaboration.

Finally, figure 6 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.

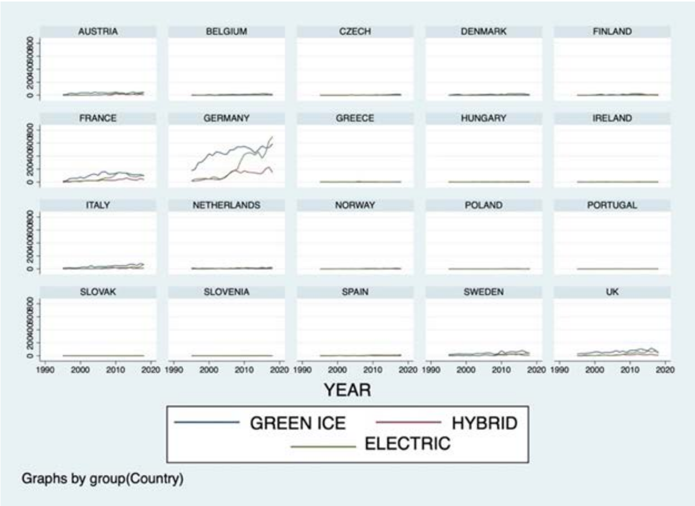

Figure 6. The evolution of the average level of eco-innovations among car manufacturers (OEM) and auto equipment/parts suppliers across 20 European countries between 1995 and 2018. Source: author's elaboration.

4.2. Econometric analysis

The econometric model aims at analyzing the relation between the production of eco-innovations in the automotive industry, specifically patents concerning green ICEV, HEV and BEV, and labor and labor efficiency in the sector, while controlling for relevant industry, market and country factors. The main outcomes of the model are summarized 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 labor shift from the OEMs to the suppliers' ecosystem (e.g., batteries, electronics) postulated by Kupper et al (2020) and providing evidence backing the forecasts formulated by EC (2020) and Naso & 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 3. Results of the econometric analysis relating employment levels and eco-innovation in the automotive industry

	(1)	(2)	(3)	(4)
VARIABLES	EMPL_OEMs	EMPL_OEMs	EMPL_EQUIP	EMPL_EQUIP
L2.EMPL_OEMs		0.779***		
		(0.153)		
L2.GREEN_ICE_ADJ	0.0382	-0.165***	0.00742	0.00429
	(0.0643)	(0.0387)	(0.0128)	(0.00746)
L2.HYBRID_ADJ	-0.401***	-0.0452	-0.0184	-0.0153
	(0.0833)	(0.0802)	(0.0335)	(0.0151)
L2.ELECTRIC_ADJ	-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)
L2.WAGES_EQUIP			5.37e-06	-0.00240**
			(0.000988)	(0.000942)
L2.EMPL_EQUIP				0.571***
				(0.0386)
Constant	427.9***	113.0	54.28	13.58
	(86.12)	(80.90)	(31.35)	(16.51)
Country effects	YES	YES	YES	YES
Time effects	YES	YES	YES	YES
Observations	261	261	261	261
R-squared	0.553	0.740	0.350	0.607

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).

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.

Table 4. Results of the econometric analysis relating labor productivity and eco-innovation in the automotive industry

	(1)	(2)	(3)	(4)
VARIABLES	LABPROD_OEMs	LABPROD_OEMs	LABPROD_EQUIP	LABPROD_EQUIP
L2.LABOUR_PROD_OEMs		0.346***		
		(0.0969)		
L2.GREEN_ICE_ADJ	24.88	41.84	12.09	-2.958
	(33.42)	(31.39)	(62.91)	(35.88)
L2.HYBRID_ADJ	0.531	-5.448	135.8	7.951
	(122.1)	(124.5)	(121.1)	(64.94)
L2.ELECTRIC_ADJ	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)		
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)
L2.LABOUR_PROD_EQUIP				0.560***
				(0.0466)
Constant	67,173**	15,477	155,494	12,746
	(27,055)	(24,304)	(98,407)	(54,820)
Country effects	YES	YES	YES	YES
Time effects	YES	YES	YES	YES
Observations	261	261	261	261
R-squared	0.679	0.713	0.284	0.483

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

Source: author's elaboration.

5. Conclusion

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).

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 behavioral change (Rezvani *et al.*, 2015; Axsen, 2012; Barbarossa *et al.*, 2017), growing research efforts are devoted to investigate also the labor 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 labor 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; Kupper 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 labor dynamics offer an interesting subject, which has been little investigated.

Following the way paved by a consolidated literature addressing the relation between technology and labor, 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 labor 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.

The paper's goal is twofold: 1) to analyze the occupational and eco-innovative trends of carmakers and equipment suppliers in Europe to capture potential trends and breaks over the past 20+ years, and 2) to understand, by means of 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 labor 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 2010, followed by a rapid recovery, the workforce in EU auto suppliers has experienced a slow, but steady decline. On the other hand, labor productivity has been always higher among supplier rather than in OEMs, even if, from 2010 onwards, trends in car manufacturers and suppliers tend to converge.

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 labor levels in the OEMs, the production of BEVs-related technologies surprisingly has a statistically significant positive effect on labor among producers of auto equipment, confirming the hypothesis of a labor shift from the OEMs to the suppliers' ecosystem (e.g., batteries, electronics) postulated by Kupper et al (2020) and providing evidence backing the forecasts formulated by EC (2020) and Naso & Artico (2023).

The study on labor productivity highlights that innovations related to the electrification process have a positive effect on the OEMs labor productivity, suggesting that the labor demand contraction driven by more sustainable technologies in OEMs, can be compensated by major labor productivity, which has been invariant among the suppliers, whose labor productivity is traditionally higher and where major job gains occurred.

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 BEVs 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).

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 labor – among suppliers – and labor 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 labor (in the dynamics model) and labor productivity gains, which can steer carmakers' production and competitivity, strengthening their global market position, with positive long-term occupational benefits.

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 analyze 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 labor quality and structure, investigating the upskilling, reskilling and reshoring of competences dynamics occurring within the European automotive ecosystem.

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Numeri precedenti/Previous issues

The present paper aims at providing a first comparative ex-post assessment of the extent to which different green technological patterns in the European automobile industry have impacted labor 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 past 20+ years. The exploratory analysis highlight that while average employment in EU OEMs has been substantially stable until the dramatic drop in 2010, followed by a rapid recovery, the workforce in EU auto suppliers has experienced a slow, but steady decline. On the other hand, auto 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 labor levels in the OEMs, the production of BEVs-related technologies, surprisingly, has a statistically significant positive effect on labor among producers of auto equipment, confirming the hypothesis of a labor shift from the OEMs to the suppliers' ecosystem (e.g., batteries, electronics) postulated by Kupper et al., (2020). The analysis on labor productivity shows that innovations related to the electrification process have a positive effect on the OEMs labor productivity, suggesting that the labor demand reduction driven by cleaner technologies, has been compensated by major labor productivity. Our 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 BEVs 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).

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