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INNOVATION AND TRADE IN THE AUTOMOTIVE INDUSTRY: EVIDENCE FROM EUROPEAN COUNTRIES (1990-2018)

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Innovation and trade in the automotive industry: evidence from European countries (1990-2018)

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ABSTRACT

The goal of the paper is threefold: 1) to empirically investigate whether *out-of-equilibrium* conditions in international economic performances (exports & imports) are correlated with greater innovative efforts (R&D expenditures) in the automotive industry, by means of both descriptive and inferential techniques; 2) to explore, by using descriptive means, whether and which countries display the abovementioned path, in search for possible local-specific dynamics; 3) to provide empirical evidence in support of the existence of a self-feeding loop between trade indicators (exports & imports) and R&D expenditures in the European automobile sector, by using an appropriate econometrical strategy inspired by the "Crépon-Duguet-Mairesse" (CDM) method.
Our empirical analysis, based on a panel sample of European countries between 1990-2018, provide substantial support to the hypothesis that a "creative response" to out-of-equilibrium export conditions drives innovation also in the automotive industry.
Finally, our study confirms the existence of a self-reinforcing loop between exports, imports and innovation in the automotive industry, which is yet mediated by the industry size, suggesting that the economies of scale are still the major driver of the sectoral growth and innovation capability.

KEYWORDS: international trade, innovation, creative response, Schumpeterian loop, CDM approach

JEL: O31, O33, O25, O14

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1. INTRODUCTION

The self-reinforcing dynamics of innovation and globalization is a characteristic feature of both advanced and emerging economies in the last decades (IMF, 2018). In this paper, we investigate such relation, its determinants and whether there exists a loop between the two trends for the automotive industry in 21 European countries over the time period between 1990 and 2018.

The global and regional integration in the automotive industry has been widely understood (Sturgeon et al., 2009; Gracia & Paz, 2017). This is especially true in Europe, which is home of some of the major global Original Equipment Manufacturers (OEMs) and where the automotive industry is a major economic player[2].

While the innovation (Smitka & Warrian, 2016) and trade (Sturgeon et al., 2009; Economics C., 2014; Bezic & Galovic, 2015) dynamics of the automobile sector have received scholarly attention *per se*, very few studies have explored the complex interplay between the two dimensions with an exclusive focus the industry (Chamsuk aet al, 2017; Rua & Ferreira, 2021) and no one has focused on the European case as a whole yet.

This paper aims at filling this gap. In fact, our paper is inspired by recent studies investigating the role of international economic performances in shaping countries' innovative effort and intensity in multiple manufacturing sectors (Antonelli and Feder, 2022a; Antonelli and Feder, 2022b; Antonelli and Feder, 2021a; 2021b). It intends to explore the dynamics relating cars' import & export with innovation propensity in the European auto sector, by using the Schumpeterian lens (Schumpeter 1942, 1939).

More specifically, the goal of the paper is threefold: 1) to empirically investigate, by means of both descriptive and inferential techniques, whether innovative effort (R&D expenditures) in the automotive industry is the result of a *"creative response"* deriving from *out-of-equilibrium* conditions in international economic performances (exports & imports); 2) to explore, by using descriptive methods, whether and which countries display the abovementioned path, in search for possible local-specific dynamics; 3) to provide empirical evidence in support of the existence of a "*circular"* relation or a self-feeding loop between trade indicators (exports & imports) and R&D expenditures in the European automobile sector, by using an appropriate econometrical strategy inspired by the "Crépon-Duguet-Mairesse" (CDM) method (Crepon et al, 1998).

Therefore, the ultimate goal of the present study is to investigate whether and how countries' sectoral trade competitiveness and openness affect their propensity to innovate in the automotive industry, by testing the abovementioned specific evolutionary dynamics.

The paper is structured as follows. Section 2 outlines the framework summarizing the most relevant literature exploring the complex interplay between international economic performances and innovation with a focus on the drivers and dynamics characterizing this relation in the automobile industry. Section 3 presents the data and the empirical strategies, while section 4 shows and discusses the results. Finally, section 5 concludes.

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[2] Despite a number of issues and defies, such as, a persistent market saturation and stagnation, overcapacity, increasing international competition and compelling environmental standards, the automotive industry in Europe is responsible for 7% of the EU total GDP (ACEA, 2020), accounts for 7% of EU employment and 11.5% EU manufacturing jobs (ACEA, 2020), exports 126.8 Billion worth of passenger cars per year (ACEA, 2022a) and is the largest innovator not only at EU level accounting for 32% of the EU's total R&D spending, but also with respect to the automobile sectors of the other main world regions (ACEA, 2022b).

2. THEORETICAL FRAMEWORK

2.1 Innovation and economic performances: a complex two-way relation

A long-lasting tradition of studies links innovation to a wide array of factors such as demand conditions (Schmookler, 1966, Kaldor, 1977), competition (Schumpeter, 1942; Scherer, 1967; Aghion and Howitt, 1992), technological opportunities (Dosi, 1982) and institutional backing and barriers (Pierson, 2000; Porter and Stern, 2001) and also firms' heterogeneity, which can be captured for instance by their size, structure, entrepreneurial strategies and economic performances/success.

While some authors focus on the impact of firms' dimensions (small vs big) and business attitudes (entrepreneurial vs managerial) on their growth patterns (Schumpeter, 1942; Penrose, 1959, 1995) and others investigate the role of business structures (vertical integrated vs horizontal vs open access) on firms' innovative outcome and perspectives (Penrose, 1959; Chandler, 1990), a well rooted strand of studies originally focuses on the relation between innovation and firms' or sectors' profitability[3].

Schumpeter (1939) suggested that innovation peaks in the periods of decline in the rates of profitability and growth, with innovation cycle being specular to business cycle. The role of declining profitability as spurring mechanism of innovation has been stressed also by Rosenberg (1969) while Nelson and Winter (1982) provided the formalization of the relationship between negative profitability and innovation.

Such a background paved the way to the introduction of the notion of failure-induced innovation in the Neo-Schumpeterian literature (Antonelli 1989; 1990).

More recently, Antonelli and Scellato (2011), reviving the seminal contribution of Schumpeter (1947) on innovation as an "adaptive" vs "creative" reaction to current economic conditions, provides substantial empirical evidence in favor of the hypothesis that innovation is the result of a "creative response" to out-of-equilibrium profitability conditions (see Figure 1), captured by very low and very high levels of total factor productivity, whose medium levels, on the contrary, are found responsible only for incremental or marginal innovations (adaptive response), leading to path dependency and lock-in.

Insert Figure 1 here

Similarly, Aghion et al (2005) suggests the existence of an inverted U-shaped relationship between competition and innovation, which finds support in the empirical study by Peneder and Woerter (2014) who jointly estimate the opportunity, production, and impact functions of innovation with respect to competition in a simultaneous system.

[3] The idea of an induced innovation has a long tradition, starting with Marx (1867), whose intuition that technological change is steered by the dynamics taking place in factor markets has been first confirmed by Hicks (1932) and then articulated in a more general theory by Binswanger and Ruttan (1978).

2.2 Innovation and international trade

Within the context of the analysis of the links between innovation and economic performances, a relevant research area is investigating the relation between international competitiveness and innovative results.

According to a large and fertile literature, involvement in international trade spurs superior innovation capabilities (Lileva and Trefler, 2010; Buatos, 2011), which are driven by the so-called exporter productivity premium (Wagner, 2014) that causes positive effects on firm's innovation, that are found even stronger at industry level (Gorodnichenko et al., 2020).

Antonelli and Feder (2022a) confirms also at European country level that the level of openness to international trade promotes innovative efforts that, together with knowledge costs and capital intensity, improve labor productivity, while Antonelli and Feder (2022b) shows that a larger country's trade openness increases the TFP both directly, from market selection, and indirectly, from greater innovative efforts.

Actually, exports exert positive effects on innovation and productivity through several specific mechanisms, that Antonelli and Feder (2021a) summarizes in the following four: 1) demand-pull effect, 2) rivalry-competition effect, 3) international spillovers and 4) learning by exporting.

However, Aghion et al. (2018), Wang (2014) and Wang et al. (2021) highlight positive, but selective effects of exporting on innovation, that are specific to, and stronger in, the high productivity firms as well as in high tech and science-based industries.

Innovation literature also encompasses studies investigating the reverse relation between innovation and firms' international performances, built upon the innovation-led export hypothesis, which has been firstly proposed by the product-life-cycle literature (Posner, 1961, Fagerberg, 1988) and later revitalized by the new growth theory (Aghion and Howitt, 2009).

The empirical evidence in favor of this hypothesis is particularly strong at firm-level (Greenaway and Kneller, 2004; 2007; Bernard and Jensen, 2004; Bernard et al.2007; Wagner, 2006; 2007; Cassiman et al., 2010; Halpern and Murakozi, 2012; Lo Turco and Maggioni, 2015; Dosi, 2015), even though also some industry-level (Guarascio et al, 2016; Guarascio and Pianta, 2017) and country-level empirical studies (Pavitt and Soete, 1980; Dosi, Pavitt and Soete, 1990; Wakelin 1998) confirm it. Damijan & Kostevic (2015) provide further evidence to the learning from trade hypothesis, by finding a robust relationship between imports, exports and innovation, which suggests that firms learn primarily from import links, which enable them to innovate and to 'dress up' for starting to export.

A recent strand of the literature has pushed the bar of the investigations further, by testing the bi-directional relation between innovation and exports (Laursen, 2000; Damijan, 2010; Guarascio et al., 2016).

Rehman (2017) examines the reverse causality between innovation, productivity and exporting, testing the self-selection and learning-by-exporting hypothesis in 29 Eurasian and Central and Eastern European economies, finding support to both the hypothesis, using the Crepon-Duguet-Mairesse empirical model.

The very same model is used by Antonelli and Feder (2021a; 2021b), obtaining very similar results that confirm the existence also in OECD countries of Schumpeterian loops between innovation and exports/imports, inspired by the 'creative response' mechanism.

The presented literature offers a comprehensive overview of the complex and circular nature of the relation between innovation and economic performances, with special focus on the role of the international competitiveness, whose features and trends at the level of the automotive industry are described in detail in the next paragraph.

2.3 Innovation and trade in the automobile industry: analyzing drivers and dynamics

Automotive industry is often described as dynamic, international and high-tech (Smitka & Warrian, 2016), even if it is 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 technology.

From the innovation viewpoint, Breschi and Malerba (1993) depicts the automotive innovation system as characterized by high appropriability, cumulativeness, spatial density, few innovators and a 100-year-old technological paradigm, which make the sector particularly resistant to radical innovations and new technological patterns.

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; 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).

This is the reason why a wide strand of literature has thoroughly investigated the drivers and barriers to green innovation in the automotive industry, with the most recent and conspicuous contributions focusing on the factors enabling the development of clean technologies (Hascic et al, 2008; Dijk and Yarime, 2010; Berggren and Magnusson, 2012; Bergek and Berggren, 2014; Barbieri 2015, 2016), the obstacles hampering their diffusion (Aghion et al, 2015; Gohoungodji et al, 2020) and the systems and complex mechanisms affecting the dynamics that originate and orient green solutions in this sector (Oltra and Saint Jean, 2009a, 2009b; Faria and Andersen 2015, 2017a, 2017b)..

In addition to an increasing interest for the greening of the automotive supply chain (Diabat et al, 2013; Sanghavi et al., 2015) with special focus on the competition and criticalities related to the e-batteries supply chain (Sun et al., 2019; Sun et al., 2021), relevant research efforts are devoted to explore the evolution of the industry's organizational structure to an open innovation model (Consoli and Patrucco, 2008; Dodourova and Bevis, 2014; Patrucco, 2014) and to analyze the patterns of international integration, as well as the domination vs dependency relations of the sector's actors, through the lens of the "global production network" (GPN) approach (Gracia and Paz, 2017).

Globalization, in fact, has been identified as a key feature of the modern economy and global integration is the distinctive trend of the automotive industry (Sturgeon et al., 2009).

Various studies highlight high production fragmentation around few globalized regions and industry concentration in large lead firms as the current scenario of the industry (Dicken, 2003; Domanski and Lung, 2009; Frigant and Zumpe, 2014; Frigant, V., & Zumpe, M. (2017); Gracia and Paz, 2017). Gracia and Paz (2017), in particular, analyzes the geography of the automotive trade flows (exports over imports) in the EU, revealing that "the increase in extra-EU exports is linked to increased regional fragmentation of production in the automotive industry" and concluding that "the governance of this fragmentation process is a key determinant of extra-EU export competitiveness".

Although several studies assess the role of exports and their drivers in steering automotive firms' competitiveness (Truett & Truett, 1994; Chiappini, 2012; Sharma and Mishra, 2012; Imran et al., 2018; Imran & Abbas, 2020; Rua & Ferreira, 2021) and some recent literature investigates the national strategies relating imports and innovation in the auto industry (Athukorala & Veeramani, 2019; King & Vaughn, 2022), to our knowledge, only few researches explore the complex interplay between innovation and trade in this sector (Rua and Ferreira, 2021), opening up room for further investigations.

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 STARTEGY

3.1 Data description

Our study is based on data covering 21 European countries (18 EU + Norway, Switzerland and UK) over the time period between 1990 and 2018, and is built upon a large balanced panel dataset featuring the variables summarised in Table 1.

Insert Table 1 here

The variables are constructed using data retrieved from the under-exploited OECD structural analysis (STAN) dataset that includes information on both aggregated and disaggregated industries; for the purpose of our study, we use data exclusively related to the transport sector to build the six variables employed in our empirical investigations.

First of all, we build the variable log_BERD_AUTO, taking the logarithm of the R&D expenditures of the automotive industry that we have retrieved the R&D section (ANBERD) of the STAN dataset. The use of the logarithm is intended to smooth the effects of possible outliers in the data and it will be further motivated in the models' description.

Second, we have the variable log_EXPORT_AUTO, which consists in the logarithm of the amount of the exports of the automotive industry from one country towards the rest of the world.
The dataset also features a set of control variables, represented by Log_EMPL_AUTO, Log_CAR_SALES, Log_PATENT_STOCK, Log_VALUE_LABOR, Log_PROD and GDP-PC.

While Log_EMPL_AUTO and Log_CAR_SALES are the logarithm of the employees in the auto industry and the logarithm of the car sales, and stand as the proxies of the industry size and the domestic auto market dimension, Log_VALUE_LABOR and Log_PROD are the logarithm of the ratio between the added value (deflator) produced by the industry and its level of employment and the logarithm of the automotive production (gross output deflator), and they respectively capture labour and industry productivity in the automobile sector.
Log_PATENT_STOCK is the logarithm of the country's patents stock, which captures the level of knowledge that is available in the country and accessible[4] by the industry's R&D departments.

[4] The knowledge embedded in the patents is only accessible upon fee payment in most of the European patent system.

Finally, the Gross Domestic Product Per Capita (GDP-PC) represents a proxy of the domestic market size and vitality.

The models and the role in which the variables are employed are summarised in columns 5 and 6 of Table 1, while their relevant statistics are presented in Table 2.

Insert Table 2 here

3.2 The empirical models: testing for the "U-shaped" relationship and "circularity" between trade and innovation

The first empirical investigation of our study consists in two steps: 1) an exploratory and descriptive analysis aimed at testing the Schumpeterian hypothesis of the existence of a positive quadratic function, alias a U-shaped relationship, between exports/imports and innovation; 2) an inferential analysis aimed at verifying the very same hypothesis on a causal basis, namely whether innovation is originated by a 'creative response' triggered by out-of-equilibrium conditions in the exports.
The underlying assumption is that the greater the participation in international product markets, the better will be the access to knowledge spillovers, imitation opportunities and interactions with users in those international markets, leading to larger innovation activity driven by the so-called "learning by trade".

While the exploratory analysis requires to simply relate the logarithms of exports/imports and innovation, testing for a positive quadratic function (U-shaped) between the two variables, the econometric model used to test this hypothesis is an OLS log-log regression, with country random effect[5] and time fixed effect, controlling for auto industry size (Log_EMPL_AUTO), as described by Equation 3.1. In order to tackle possible endogeneity issues, we lag the exploratory and control variables by one year. To resolve heteroskedasticity bias, we use robust standard errors in each step. Finally, to correctly calculate the error terms in all three steps of the empirical regressions, we bootstrap (1) with 1000 repetitions (Mairesse & Robin, 2017). A similar model is applied to test the possible "creative response" between imports and innovation.

$$Log\_BERD\_AUTO_{i,t} = \alpha_i + \beta_1 Log\_EMPL\_AUTO_{i,t-1} + \beta_2 Log\_EXPORT\_AUTO_{i,t-1} + \beta_3 Log\_EXPORT\_AUTO^2_{i,t-1} + \gamma_t + \varepsilon_i \quad (3.1)$$

The second analysis consists in a descriptive exploration of the countries distribution along the two Cartesian axes, represented by the average level of exports/imports (x-axis) and average level of R&D expenditures (y-axis); the goal is to search for possible geographical patters or local specific dynamics in accordance with the abovementioned Schumpeterian hypothesis.

In the third analysis, we employ our balanced panel data to apply a structured econometric model inspired by the CDM approach in order to test our hypothesized Schumpeterian loop between exports/imports and innovation, via productivity (Crépon et al., 1998). The use of this model is backed by its application in a wide innovation literature, such as Loof & Heshmati (2006), Marin (2014), Marin & Lotti (2017), Rehman (2017) and Antonelli and Feder (2021a; 2021b).

The model consists in three main steps and two sub-steps: 1) to estimate the impact of the auto exports/imports on the R&D expenditures in the automotive industry; 1a) to calculate the predicted

[5] The Hausman test results in the rejection of the alternative hypothesis postulating the presence of country fixed effect.

values of the R&D expenditures in auto industry, on the basis of the previous estimation obtained at step 1); 2) to estimate the impact of the predicted values of R&D expenditures calculated from the previous estimation on auto industry's productivity; 2b) to calculate the predicted values of the productivity, on the basis of the estimation at step 2); and to estimate the impact of the predicted values of productivity calculated from the previous estimation on the automotive exports/imports.

The sequential timing of exports/imports and innovation is particularly relevant to the overall empirical process in order to show the endogeneity of the Schumpeterian loop. To tackle any endogeneity issue, we lag our explanatory variables in each step by one and in the final step also we also test the model with a two-year lag. To reduce "omitted variables" bias in the estimation process, we use fixed effect estimates (αi), year dummies (+ γt), and additional control variables as industry and market size (Log_EMPL_AUTO and GDP_PC) as well as labor productivity (Log_VALUE_LABOR).
In order to resolve heteroskedasticity bias, we use robust standard errors in each step. Finally, to correctly calculate the error terms in all three steps of the empirical regressions, we bootstrap (3.2), (3.3), and (3.4) with 300 repetitions (Mairesse & Robin, 2017).

The main equations of our structured model are the Eq 3.2, Eq. 3.3 and Eq. 3.4:

$$Log\_BERD\_AUTO_{i,t}=\beta_1 Log\_PATENT\_STOCK_{,t-1}+\beta_2 GDP\_PC_{i,t-1}\ \beta_3 Log\_EXPORT\_AUTO_{i,t-1} + \alpha_i + \gamma_t + \varepsilon_i \quad (3.2)$$

$$Log\_PROD_{i,t} = \beta_1 Log\_VALUE\_LABOR_{i,t-1} + \beta_2 Pred.Log\_BERD\_AUTO_{i,t-1} + \alpha_i + \gamma_t + \varepsilon_i \quad (3.3)$$

$$Log\_EXPORT\_AUTO_{i,t} = \beta_1 EMPL\_AUTO_{i,t-1} + \beta_2 Pred.Log\_PROD_{i,t-1} + \alpha_i + \gamma_t + \varepsilon_i \quad (3.4)$$

A similar system of equations is used to test the existence of the abovementioned loop between imports and innovation, having exports as final output, following the example provided by Antonelli and Feder (2021b).

The use of the logarithm in the econometric models has a twofold purpose: to smooth data tackling the disturbance due to the presence of possible outliers and to allow the interpretation of the regression coefficients in terms of elasticity.

4. RESULTS

4.1 Main analysis

4.1.1. Tests for "creative response" to out-of-equilibrium conditions

A preliminary exploratory analysis is performed with the aim of testing the hypothesis that international economic performances, alias exports, and innovative activities in the European auto industry are related by a positive quadratic function, c'est à dire by a U-shaped relationship.

The results of this analysis, depicted in Figure 2, reveal the existence of a more "J-shaped" relationship between auto exports and the industry's innovation, suggesting that only above-average conditions in the international markets are related to higher level of innovative effort in the automotive industry, while below-average conditions are not associated to greater performances in the R&D.

This “semi-positive” quadratic function can be explained with the strong path dependency dynamics that characterize the auto industry, which induce average and low performative firms to prefer to exploit increasing economies of scale and rely on incremental types of innovation rather than to bet on and invest in more disruptive, but also more costly and risky innovative activities, in order to increase their profitability.

[insert Figure 2 here]

In order to verify whether innovation activities are actually caused by a “creative response” triggered by out of equilibrium conditions experienced by the auto industry in the international markets, we perform an inferential analysis based on a log-log OLS regression, controlling for random country effects and time fixed effects.
The results, summarized in Table 3, confirm the hypothesis of the existence of a positive quadratic function between R&D expenditures and exports (column 1), which is found robust also with respect to the checks controlling for the auto industry size (column 3) and an additional time lag of the explanatory variables (columns 2 and 4).

[insert Table 3 here]

Furthermore, the existence of a positive quadratic function is also confirmed by an additional graphical analysis (see Fig 3 in Appendix) relating the ratio between R&D expenditures and employment in automotive sector and its level of exports.

4.1.2 The country-based analysis in search for local-specific dynamics

A second exploratory analysis, depicted in Figure 3, is performed with the goal to examine countries’ position with respect to exports and innovation, in search for emergent geographical distributions and local specificities that could corroborate the results found in the previous analyses.

[insert Figure 4 here]

The results of this second exploratory analysis confirm the presence of geographical specificities mainly related to the countries’ historical background in the auto industry.

In fact, countries with a long established and well rooted automotive tradition, such as Germany, France, UK, Italy and Spain, are those showing a higher correlation between sectoral exports and innovative efforts. On the other hand, countries with a less marked or absent tradition in the auto industry, like Northern and Eastern European ones, display only an average correlation between exports and investments in R&D, which declines in very low levels of R&D expenditures associated to a below-average degree of exports, with no sign of out-of-equilibrium innovative activity in correspondence to and as a reaction to weak performances in international markets.

Therefore, these results do corroborate the findings highlighted in the first analyses, not only confirming the ‘smoothed’ U-shaped relation between export and innovation, but also suggesting that the positive quadric function found between exports and innovation in the inferential analysis could be mostly driven by countries featuring an auto industry with a solid tradition and whose out-of-equilibrium, namely above-average, performances in the international auto markets are the trigger behind their higher levels of investment in R&D.

This dynamic can be explained also with path dependence, which locks automotive sector in well-established development paths.

Overall, these findings are substantially in line with the results of the Schumpeterian literature postulating the hypothesis of innovation as a "creative response" to out of equilibrium market conditions (Antonelli and Scellato, 2011; Antonelli and Feder, 2022a; 2022b), even though they are compatible with those highlighting path dependency as major innovation dynamic, which the auto industry is still dominated by (Aghion et al., 2015; Novaresio and Patrucco, 2022).

Now, it is object of interest to understand whether exports and innovation are intertwined in an endogenous self-feeding relation, whose test is the purpose of the next analysis.

4.1.3 Test for "self-feeding loop" between export and innovation

The third and last analysis consists in an inferential test aimed at verifying the existence of an endogenous and self-reinforcing relation between exports and innovation activities in the auto industry, by using an empirical strategy inspired by the CDM model, whose results are shown in Table 4.

[insert Table 4 here]

Column 1 displays the results of the first step of the model, which relates international market performances and innovation propensity, captured by R&D expenditures in the auto industry, while controlling for the available external knowledge[6] and the domestic market size, proxied by GDP per capita. This step confirms that higher levels of exports are associated with higher levels of innovation activities with a 5% level of statistical significance.

Column 2 summarizes the results of the second step of the model, which verifies the impact of innovative activities induced by higher exports[7] on the industry productivity, captured by a deflator of the national gross output, while controlling for sectoral labour productivity, given by the ratio between industry value added and sectoral employment level. This step reveals that innovative activities induced by exports are associated with higher levels of productivity, with a 5% level of statistical significance.

Column 3 shows the results of the third and final step of the model, which closes the loop by testing the impact of productivity induced by higher innovative[8] activities on the auto industry's performances in the international auto markets, captured by the automotive exports, while controlling for industry size (level of employment) and internal market size (level of car sales). This step does not confirm that higher endogenous productivity levels of the auto industry are associated with higher

[6] In order to capture the level of external knowledge, we tested different proxies besides the level of patent stock, such as the Government global level of R&D expenditures, the Government level of R&D expenditures in the engineering and technology area and the total number of researchers in the country, which all resulted as not or mildly statistically significant and with little to no effect on our model.

[7] We calculated the predicted values of the auto expenditures in R&D based on the estimations obtained in the first step. This calculation allows to obtain the endogenous component of the auto R&D expenditures, which is useful for the purpose of the next step envisaged by the empirical model.

[8] We calculated the predicted values of the productivity (deflator of the automotive national gross output) based on the estimations obtained in the first step. This calculation allows to obtain the endogenous component of the auto productivity, which is useful for the purpose of the next step envisaged by the empirical model.

performances in the international auto markets, even though column 4 shows that the interaction between endogenous productivity and industry size exerts a relevant positive impact on exports, which is statistically significant at the 0,1% level.
Therefore, our findings, which are robust to a test for an additional time lag, see Table 5, confirm the hypothesis of 'circularity' between export and innovation in the auto industry only when this is mediated by the industry size, revealing that automotive exports and innovation dynamics strongly depend on the industrial dimension, thus on the logic of the economies of scale.

[insert Table 5 here]

4.2 Further analysis: focus on import

4.2.1 Tests for "creative response" to out-of-equilibrium conditions

In this section we outline the result of the analysis aimed at testing the hypothesis postulating the existence of an out-of-equilibrium relation between innovation and imports.

While the graphical analysis suggests the presence of a smoothed, yet convex relationship between import and innovation (see Fig 5), the econometric model reveals the existence of a negative quadratic function.

[insert Figure 5 here]

The results shown in columns 1 and 2 of Table 6, in fact, are specular to the one concerning exports and innovation, as they imply that out-of-equilibrium conditions in car imports are associated with low levels of investment in R&D activities in the auto sector. This finding may have two parallel explanations: on the one hand, the restricted openness to international products may reduce the exposure to external knowledge which is embedded in international technological solutions and contributes to trigger national innovative activities in the auto sector; on the other hand, the relatively larger dependence on imports may induce firms to replace the promotion of business investments in domestic R&D to reach the technological frontier in favour of the adoption of cheaper imitative behaviors as main industrial strategy.

However, column 3 reveals that the abovementioned bell-shaped relation between R&D expenditures and imports is not statistically significant when controlling for the auto industry size, even though a further graphical analysis relating the ratio of R&D expenditure and employment over imports provides clear additional evidence in support of the existence of a negative quadratic function between R&D commitment and imports (see Figure 6).

[insert Table 6 here]

As these results marks a sign with respect to the findings of previous innovation literature with a broader industrial focus, such as Antonelli and Feder (2021b), they represent an original and valuable contribution which sheds light on the peculiar dynamics of imports and innovation automotive industry. In fact, our study reveals that car imports do stir innovation (positive sign of the non-quadratic variable) in auto industry, but the pattern of innovation is not driven by out-of-equilibrium values of the imports (negative sign of the quadratic variable).

4.2.2 The country-based analysis in search for local-specific dynamics

As second exploratory analysis, we examine countries' position with respect to imports and innovation, in search for emergent geographical distributions and local specificities that could corroborate the results found in the previous analyses.

As Figure 7 shows, we find that countries which do not have a long tradition in cars production, such as the East European ones, and some of those that are home of historical original equipment manufacturers (OEMs), like Portugal and Norway, display average to low levels of both imports and R&D investments.

On the other hand, countries with well-established OEMs, like Germany, France and Italy, show high levels of both imports and R&D investments, which can have two parallel explanations.

First, the high level of R&D expenditures associated to these countries can be due to the fact that they are home of OEMs' headquarters where innovation is developed and R&D activities are performed and funded. Second, the high level of car imports can be due to the widespread industrial strategy hinged upon the offshoring of car production in other countries (e.g., because of lower labor costs), which can result in higher level of car imports in countries which are still home of the OEMs and their R&D departments, even though they host fewer and fewer production lines on their home ground (e.g., see the case of Italy and Fiat-Stellantis).

[insert Figure 7 here]

These results, which confirm the evidence of a 'smoothed' U-shaped relation between import and innovation identified in the first exploratory analysis (see Figure 5), are only apparently in contradiction with the previous econometric findings (and the additional graphical inspection depicted in Fig 6) reporting a bell-shaped relation between R&D expenditures and imports; in fact, on average and in the long-run, the association of relatively high levels of car imports in countries with high level of R&D expenditures in automotive can be related more to globalization dynamics (offshoring cost-opportunity) rather than innovation ones (knowledge spillovers and imitative behaviors).

In order to dig deeper in the complex relation between car imports and the commitment in R&D, the next analysis is aimed at performing a test for an endogenous self-feeding loop.

4.2.3 Test for "self-feeding loop" between import, innovation and export

The third and last analysis consists in an inferential test aimed at verifying the existence of an endogenous and self-reinforcing relation between imports and innovation activities in the auto industry, by using an empirical strategy inspired by the CDM model, whose results are shown in Table 7.

[insert Table 7 here]

Column 1 displays the results of the first step of the model, which relates imports and innovation propensity, captured by R&D expenditures in the auto industry, while controlling for the level of external knowledge available and the domestic market size, proxied respectively by the logarithm of patent stock and the GDP per capita. This step reveals that higher levels of imports are associated with higher levels of innovation activities with a 5% level of statistical significance.

Column 2 summarizes the results of the second step of the model, which verifies the impact of innovative activities induced by higher imports on the industry productivity, captured by a deflator of the national gross output, while controlling for sectoral labor productivity, given by the ratio between industry value added and sectoral employment level. This step reveals that innovative activities induced by higher imports are associated with higher levels of productivity, with a 10% level of statistical significance.

Column 3 shows the results of the third and final step of the model, which closes the loop by testing the impact of productivity induced by higher innovative activities on car exports, while controlling for industry size (level of employment) and internal market size (level of car sales).
This step does confirm the presence of a "virtuous cycle" in auto trade, with the import-induced, via innovation, productivity stirring the expansion of car exports, but only when the endogenous production is mediated by industry size, thus economies of scales are at stake, as column 4 shows.

Our findings, which are also robust to a test with an additional time lag, see Table 8, partially confirm the hypothesis of 'endogeneity' and 'circularity' among import, innovation and exports in the auto industry and are in line with the most recent research contribution in the field (Antonelli and Feder, 2021b).

[insert Table 8 here]

CONCLUSIONS

Peter Drucker called the automobile industry "the industry of industries" in 1946, and there are good reasons why this label is still relevant today (Sako, 2008). In the face of the growing and self-reinforcing trend in innovation and globalization that characterised the last decades of the XXI century and the firsts of the XXII one, this paper investigates the complex relation between innovation and trade in the automotive sector in a panel sample of 21 EU countries, between 1990-2018.

Revisiting Antonelli and Scellato (2011) and inspired by Antonelli and Feder (2022a; 2022b), the first goal of the present paper was to empirically investigate whether out-of-equilibrium conditions in international economic performances (exports and imports) are correlated with greater innovative efforts (R&D expenditures) in automotive industry, testing the Schumpeterian hypothesis of endogenous innovation as a "creative response" to 'out-of-equilibrium' scenarios (Antonelli, 2017), by mean of both descriptive and inferential techniques.

The second aim, which is ancillary to the first, was to explore, by using descriptive means, whether and which countries display the abovementioned path, in search for possible local-specific dynamics.

Third, following the way paved by Antonelli and Feder (2021a; 2021b), and by using an appropriate econometrical strategy inspired by the "Crépon-Duguet-Mairesse" (CDM) method (Crépon et al., 1998) we aimed to provide empirical evidence, testing the existence of a circular relation or a self-feeding loop among international economic performances (exports and imports), innovative activities (R&D efforts) and productivity (value added) in the European automobile sector.

Thus, the ultimate goal of the present study is to investigate whether and how countries' sectoral trade competitiveness and openness affect their propensity to innovate in the automotive industry, by testing the above-mentioned specific Schumpeterian dynamics.

The results provide substantial empirical support to the hypothesis that a "creative response" to out-of-equilibrium export performances drives innovation also in the automotive industry, even though the innovation patterns shown by the countries with low levels of international competitiveness of their auto industry reveal the persistence of path dependency dynamics in the sector.

On the other hand, opposing results have been found concerning car imports and innovative propensity; in fact, while our econometric analysis reveals that car imports do stir innovation (positive sign of the non-quadratic variable) in auto industry, but the pattern of innovation is not driven by out-of-equilibrium values of the imports (negative sign of the quadratic variable), our graphical inspection reveals a 'smoothed' U-shaped relation between import and innovation. The apparent contradiction of these findings can be overcome by analysing the average distribution of imports over innovation expenditures, where we observe relatively high levels of car imports in countries with high level of R&D expenditures in automotive, that can be explained by the prevalence of globalization dynamics, e.g., offshoring cost-opportunity, over innovation ones, e.g., knowledge spillovers and imitative behaviours.

Finally, our study reveals the existence of a self-reinforcing loop between exports, import and innovation in the automotive industry mediated by the industry size, thus the economies of scale, which are confirmed as the dominant dynamics guiding the sector.

This study opens up interesting opportunities for further investigations on the role of trade competitiveness in steering the so-called "twin transition", namely the ecological and digital transformation of the auto industry, which is at the core of the European agenda

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Table 1. The variables (Source: authors' elaboration)

Variable	Definition	Source	Literature	Model	Role
Log_BERD_AUTO	Logarithm of the business expenditures in R&D of the automotive industry	OECD Stat	Innovation literature	M1 – M2	Dependent var. (M1) Independent var. (M2)
Log_EXPORT_AUTO	Logarithm of the exports from the automotive industry (exports from j country to the rest of the world)	OECD Stat	Antonelli and Feder (2021a) and trade literature	M1 - M2	Explanatory var. (M1-M2) Dependent var. (M2)
Log_IMPORT_AUTO	Logarithm of the imports from the automotive industry (exports from j country to the rest of the world)	OECD Stat	Antonelli and Feder (2021a) and trade literature	M1 - M2	Explanatory var. (M1-M2) Dependent var. (M2)
Log_EMPL_AUTO	Logarithm of the employment in the automotive industry	OECD Stat	Innovation Literature	M1-M2	Control var. (M1-M2)
Log_VALUE_LABOR	Logarithm of the Added Value of the Labour in automotive industry	OECD Stat	Innovation literature	M2	Control var. (M2)
Log_PROD	Logarithm of the Production in the automotive industry	OECD Stat	Innovation literature	M2	Control var. (M2)
Log_PATENT_STOCK	Logarithm of the Stock of Patents in the country	OECD Stat	Innovation literature	M2	Control var. (M2)
GDP_PC	Gross Domestic Product per capita	OECD Stat	Innovation literature (Stern, 2000)	M2	Control var. (M2)

Table 2 The summary statistics (Source: authors' elaboration)

VarName	mean	sd	xtsdb	xtsdw	min	xtminb	xtminw	max	xtmaxb	xtmaxw	xtn	obs
log_BERD_AUTO	4.7	2.4	2.4	0.9	-2.7	-0.0	1.1	10.5	9.6	7.4	20	369
log_EXPORT_AUTO	14.5	2.3	2.2	0.8	7.9	10.1	10.2	18.9	18.3	16.9	21	590
log_IMPORT_AUTO	15.3	1.3	1.1	0.6	11.7	13.8	13.2	17.9	17.3	16.8	21	590
log_EMPL_AUTO	3.7	1.6	1.6	0.2	0.3	1.0	2.9	6.8	6.7	4.4	20	513
log_VALUE_LABOR	0.9	1.6	1.6	0.3	-2.7	-2.3	-0.1	4.3	3.6	2.0	20	511
log_PROD	4.5	0.1	0.1	0.1	3.8	4.4	3.9	4.8	4.6	4.7	18	463
log_PAT_STOCK	6.9	1.7	1.7	0.5	2.7	4.3	5.1	10.4	10.2	8.5	21	609
GDP_PC	29993.2	13226.2	8173.2	10548.3	5935.1	15569.6	4343.1	84575.4	44079.5	76016.1	21	601

Table 3. Results of the OLS log-log regression testing the hypothesis of innovation as "creative response" from *out-of-equilibrium* conditions in the car exports (source: authors' elaboration)

	(1) log_BERD_AUTO	(2) log_BERD_AUTO	(3) log_BERD_AUTO	(4) log_BERD_AUTO
L.log_EXPORT_AUTO	-1.4342		-1.4434	
	(0.9933)		(0.9421)	
L.log_EXPORT_AUTO^2	0.0819**		0.0618*	
	(0.0342)		(0.0346)	
L2.log_EXPORT_AUTO		-1.4741		-1.6361
		(1.1416)		(0.9253)
L2.log_EXPORT_AUTO^2		0.0832**		0.0689**
		(0.0391)		(0.0339)
L.log_EMPL_AUTO			0.8581**	
			(0.3365)	
L2.log_EMPL_AUTO				0.8382***
				(0.3194)
_cons	8.1914	8.2811	7.6709	10.0470
	(6.7149)	(8.0759)	(5.6938)	(6.1486)
Country effects	YES	YES	YES	YES
Time effects	YES	YES	YES	YES
N	358	347	334	325
$R^2 within$	0.4364	0.4534	0.4944	0.4931
$R^2 overall$	0.7154	0.7135	0.7769	0.7846

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4. Results of the system of equations testing the hypothesis of a "loop" between exports and innovation - 1 time lag (source: authors' elaboration)

	(1) log_BERD_AUTO	(2) log_PROD	(3) log_EXPORT_AUTO	(4) log_EXPORT_AUTO
L.log_EXPORT_AUTO	0.2677*			
	(0.1187)			
L.log_PAT_STOCK	0.9009*			
	(0.3879)			
L.GDP_PC	-0.0000			
	(0.0000)			
L.pred_BERD		0.0786*		
		(0.0394)		
L.log_VALUE_LABOR		0.1338**		
		(0.0510)		
L.pred_PROD			0.1061	
			(1.5505)	
L.log_CAR_SALES			0.0895	0.1209
			(0.1804)	(0.1879)
L.log_EMPL_AUTO			1.1142***	
			(0.2189)	
L.int_PROD_EMPL_AUTO				0.2400***
				(0.0451)
_cons	-4.5573	4.0035***	8.8835	9.4403***
	(2.7566)	(0.1902)	(7.7137)	(1.1504)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
N	357	408	436	436
R^2	0.567	0.600	0.4239	0.4161

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5. Results of the system of equations testing the hypothesis of a "loop" between exports and innovation – 2 time lag (source: authors' elaboration)

	(1) log_BERD_AUTO	(2) log_PROD	(3) log_EXPORT_AUTO	(4) log_EXPORT_AUTO
L2.log_EXPORT_AUTO	0.3405***			
	(0.1027)			
L2.log_PAT_STOCK	0.7917*			
	(0.3624)			
L2.GDP_PC	-0.0000*			
	(0.0000)			
L2.pred_BERD		0.0554+		
		(0.0298)		
L2.log_VALUE_LABOR		0.1409**		
		(0.0457)		
L2.pred_PROD			-0.7372	
			(1.6382)	
L2.log_CAR_SALES			0.0760	0.1259
			(0.1689)	(0.1742)
L2.log_EMPL_AUTO			1.0776***	
			(0.2410)	
L2.int_PROD_EMPL_AUTO				0.2391***
				(0.0496)
_cons	-4.6783	4.0903***	13.3081	9.9344***
	(2.5055)	(0.1479)	(8.0918)	(1.3265)
Country fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
N	346	384	394	394
R^2	0.591	0.618	0.338	0.332

Standard errors in parentheses
$^{+}$ $p < 0.1$, $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6. Results of the OLS log-log regression testing the hypothesis of innovation as "creative response" from *out-of-equilibrium* conditions in the car imports (source: authors' elaboration)

	(1) log_BERD_AUTO	(2) log_BERD_AUTO	(3) log_BERD_AUTO	(4) log_BERD_AUTO
L.log_IMPORT_AUTO	5.7666*		2.9449	
	(2.1816)		(2.3600)	
L.log_IMPORT_AUTO2	-0.1883*		-0.1057	
	(0.0765)		(0.0799)	
L2.log_IMPORT_AUTO		5.8045*		-1.8393
		(2.1435)		(2.9414)
L2.log_IMPORT_AUTO2		-0.1992*		0.0801
		(0.0756)		(0.0970)
L.log_EMPL_AUTO			1.2697**	
			(0.4060)	
L2.log_EMPL_AUTO				0.9298***
				(0.1671)
_cons	-39.5802*	-37.8239*	-22.0848	10.5266
	(15.7044)	(15.2998)	(16.8422)	(22.1683)
Country effects	YES	YES	YES	YES
Time effects	YES	YES	YES	YES
N	358	347	334	325
R^2	0.521	0.506	0.585	0.477

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7. Results of the system of equations testing the hypothesis of a “loop” among import, innovation and exports – 1 time lag (source: authors' el.)

	(1) log_BERD_AUTO	(2) log_PROD	(3) log_EXPORT_AUTO	(4) log_EXPORT_AUTO
L.log_IMPORT_AUTO	0.5586*			
	(0.2225)			
L.log_PAT_STOCK	0.9153*			
	(0.3719)			
L.GDP_PC	-0.0000			
	(0.0000)			
1991.YEAR	0.0000			
	(0.0000)			
L.pred_BERD		0.0754 +		
		(0.0436)		
L.log_VALUE_LABOR		0.1320*		
		(0.0517)		
L.pred_PROD			-1.1880	
			(1.3964)	
L.log_EMPL_AUTO			0.8884**	
			(0.3178)	
L.log_CAR_SALES			0.0976	0.1455
			(0.1801)	(0.1923)
L.int_PROD_EMPL_AUTO				0.1951*
				(0.0780)
_cons	-8.8289*	4.0262***	15.4857*	10.0647***
	(4.1737)	(0.2105)	(6.9551)	(1.3964)
N	357	408	436	436
R^2	0.560	0.600	0.429	0.415

Standard errors in parentheses
$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8. Results of the system of equations testing the hypothesis of a “loop” among import, innovation and exports – 2 time lags (source: authors' el.)

	(1) log_BERD_AUTO	(2) log_PROD	(3) log_EXPORT_AUTO	(4) log_EXPORT_AUTO
L2.log_IMPORT_AUTO	0.4010			
	(0.2196)			
L2.log_PAT_STOCK	0.9034*			
	(0.3647)			
L2.GDP_PC	-0.0001*			
	(0.0000)			
L2.pred_BERD		0.0582		
		(0.0357)		
L2.log_VALUE_LABOR		0.1323**		
		(0.0445)		
L2.pred_PROD			-1.0872	
			(1.1434)	
L2.log_EMPL_AUTO			0.8351**	
			(0.3134)	
L2.log_CAR_SALES			0.1100	0.1592
			(0.1857)	(0.1838)
L2.int_PROD_EMPL_AUTO				0.1885*
				(0.0769)
_cons	-6.1369	4.0829***	15.6278**	10.5947***
	(3.9303)	(0.1768)	(5.8786)	(1.5517)
N	346	384	394	394
R^2	0.555	0.618	0.343	0.337

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 1. The convex relationship between profitability and innovation (source: Antoneli and Scellato, 2011)

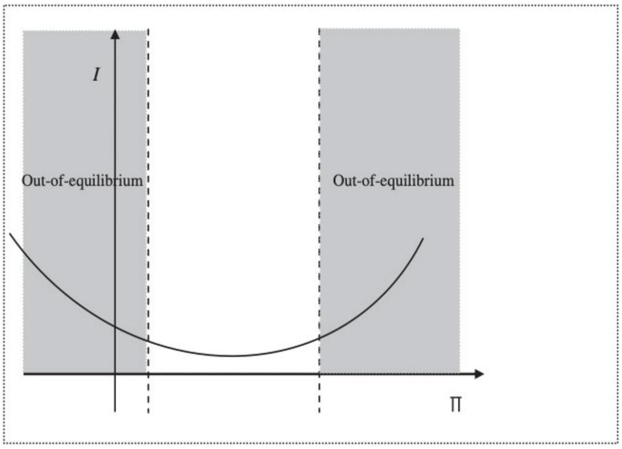

Figure 1. The convex relationship between profitability and innovation.

Figure 2. The relationship between exports and innovation (source: authors' el.)

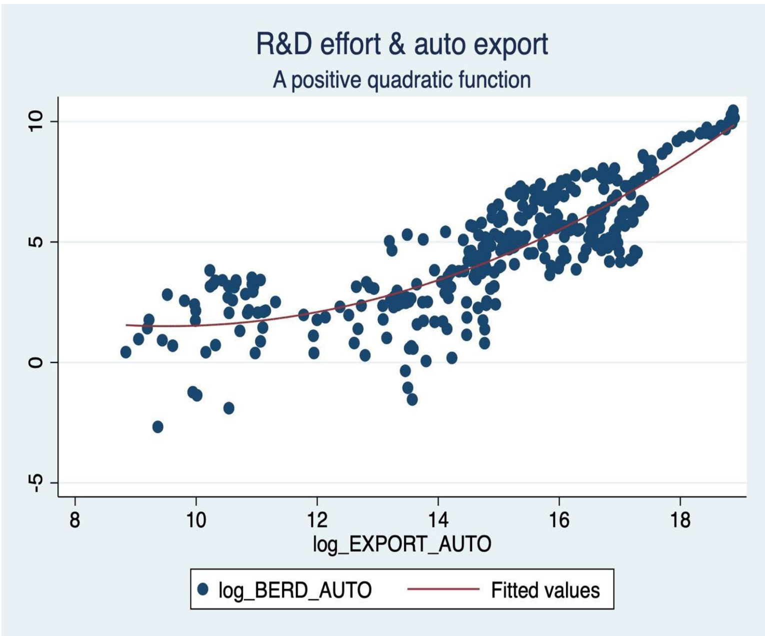

Figure 3. The relationship between exports and ratio between innovation and employment (source: authors el.)

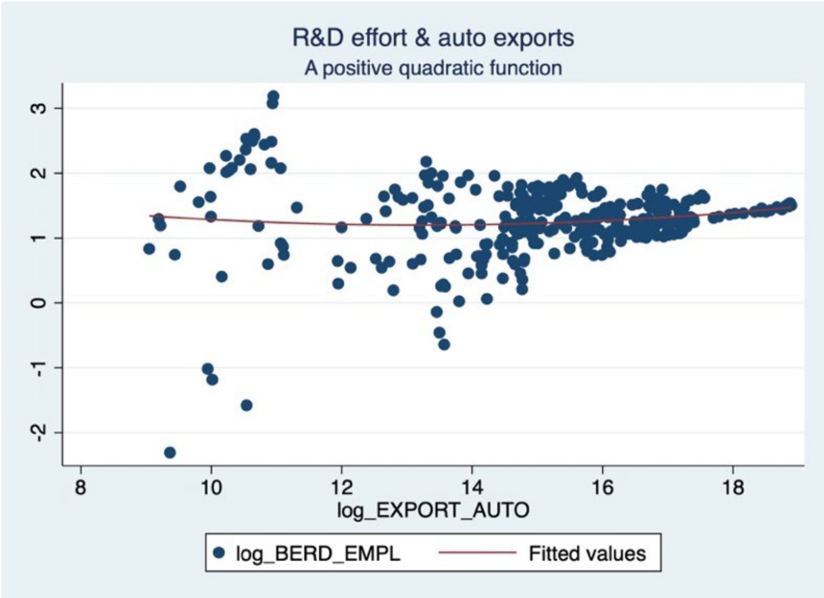

Figure 4. The countries' distribution along exports and R&D - average values (Source: authors' el.)

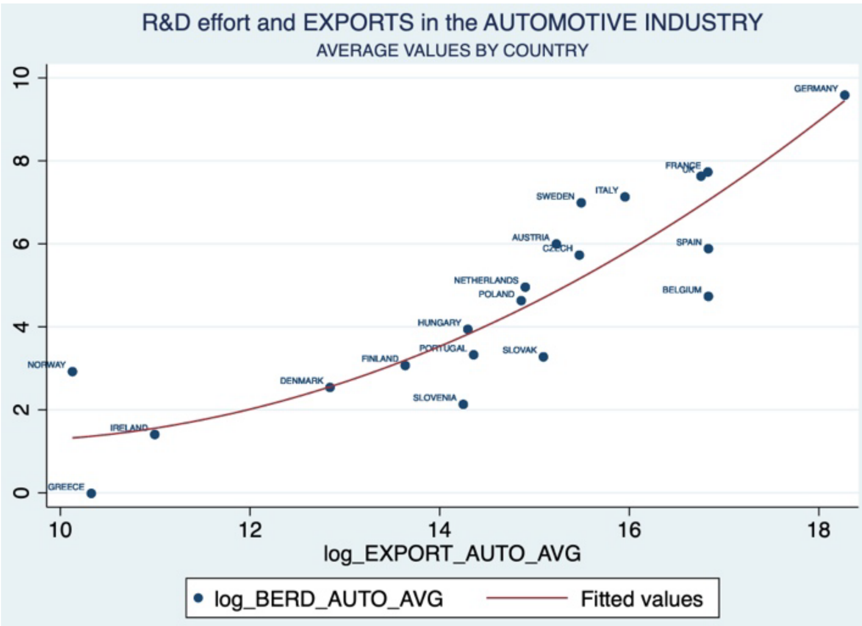

Figure 5. The relationship between imports and innovation (source: authors' el.)

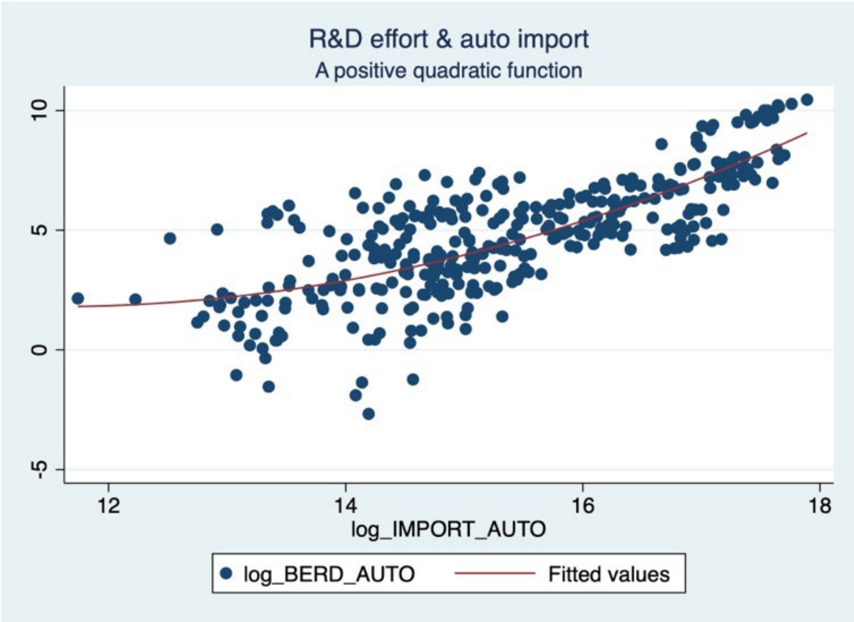

Figure 6. The relationship between imports and the ratio between innovation and employment (source: authors' el.)

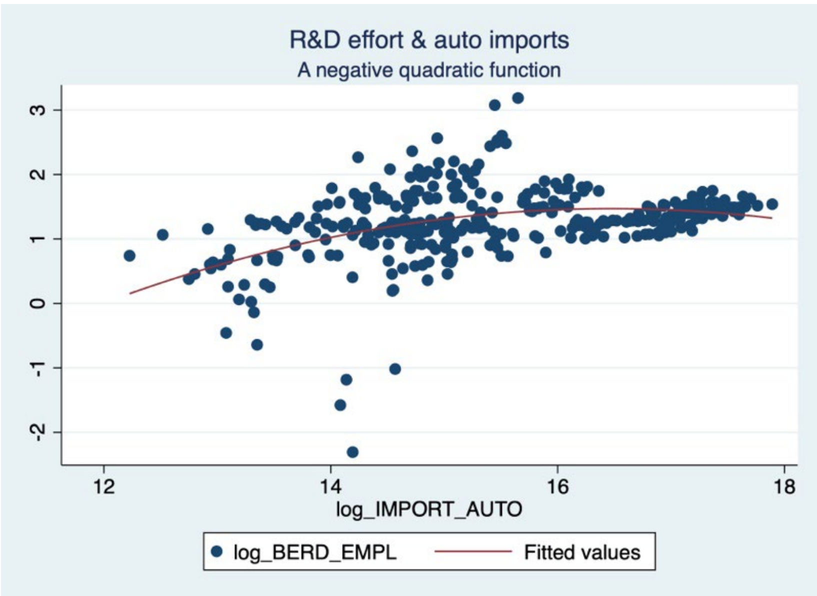

Figure 7. The countries' distribution along imports and R&D – average values (Source: authors' elaboration)