HOW GREEN FINANCE AFFECTS AUTOMOBILE INNOVATION? The Perspective of Lasso-Based Multi-Mediation Effect

by

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The world has been working towards carbon neutrality since the signing of the Paris Agreement. With the automobile industry accounting greatly in global energy consumption and GHG emissions, this research believes that it is essential and urgent to reduce carbon emissions through innovation. However, the process of transfer comes with the economic loss and the cost of financing. Green finance could soften the cost of the process of transfer. This sheds new light on how green finance influence innovation in automobile industry by applying Lasso machine learning methods to choose variables. Based on global data from 2018-2020, results of this empirical research show that: there are significant contributions of green finance to automobile innovation, in particular, the marginal benefits are greater in countries on the coast than in the lock-landed countries, carbon neutrality can be looked as the benchmark of the anchoring effect to "nudge" the process of green finance on automobile innovation, and the mechanism behind the effect is the amount of population, human resources, GDP, which provides further enhancement on the process of green finance to automobile innovation. Based on the findings, this study suggests that policymakers should scale up investments in green finance to encourage it to have a greater impact on automobile innovation, while using carbon neutrality targets to "nudge" the effects of green finance, with vital opportunities for lock-landed countries and the value of population, human resources, and GDP taken into consideration.

Key words: *green finance, automobile innovation, carbon neutrality, machine learning*

Introduction

There is no debate now that the primary cause of climatic variation and warming around the globe is the GHG emission [1]. At the end of the Paris Climate Change Conference on December 12, 2015, a new climate treaty was adopted [2], and this treaty calls for keeping the annual average temperature rise around the globe below 2 ℃ (even as an ideal reference of 1.5 ℃ in comparison with that during the period before industrial revolution), Paris Agreement, Article 2.1(a). Aiming to achieve the temperature goals in the long run of the Paris Agreement, the IPCC Spatial Report on Global Warming of 1.5 ℃ places great

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emphasis on the concept of carbon neutrality [3]. In this context, *carbon-neutrality* is a condition of *net zero CO_2 emissions*. To date, 126 countries worldwide (accounting for 51% of global GHG emissions) have formally passed, declared or are in consideration of zero emission targets corresponding to the Paris Agreement [4]. As one of the vital heavily polluted sectors in human's life, it's necessary and urgent for automobile sector to innovate to reduce the carbon emissions. For the aggregate of energy consumption in the world and GHG emission, 27% and 33.7% are attributable to the transportation sector respectively [5].

It should be noted, however, that such CO_2 reductions have resulted in significant economic losses to the world [3]. Renewable energy technologies' electricity costs are significantly associated with financing costs [6]. At the same time, due to the relative maturity of traditional fossil fuel-based vehicle technology, automobile companies appear reluctant to engage in energy-efficient technology innovation [7]. Hence, green finance was come up with to solve the problem and make sure they go through the process smoothly. Environmental protection and sustainable use of resources are the goals of green finance, which is an innovative financial model [6]. In the context of green finance, the term refers to financial products and services designed to encourage responsible investment in environment and incentivize technology, projects, industries and enterprises with lower carbon [8].

Green finance project can provide firms attempting to innovate to achieve carbon neutrality with funds or loans in low interest. A lower cost of capital for the issuer to issue bonds, with interest as a pre-tax expense; relatively lower risk of bond investments and lower demand for yield from investors, resulting in lower per capita costs [6].

Our research aims to solve the complexity of the relations of green finance and automobile innovation. As fundamental component of sustainable financing, green finance in general can be described as inventories and flows of financial resources and assets (in sectors including investment, banking, and insurance) that are consistent with a number of aims: social, environmental, and economic [9]. In contexts that face the difficulty of transferring from oil-fueled automobiles to new energy automobiles, green finance can improve productivity and ease the financing bottleneck combined with reform and innovative financial tools [6]. Hence, green finance has emerged as a financial tool among automobile firms facing the cost of transferring.

Automobile innovation reflects the performance of firm productivity when transferring from oil-fueled automobiles to new-energy automobiles. For green innovation and business performance, positive correlations are shown, as emphasized by most of the literature on automobile innovation, which has become a key issue for most automobile firms in an economic environment where product renewal rates are rising, thus driving competition [10]. Investment in technological innovation is therefore crucial for companies in the automobile industry, which helps them to be innovative in order to keep up with the latest ideas [11]. This understanding of investment ensures that rational market mechanism of green finance is devised to solve the problems to help automobile firms to innovate and reduce carbon emissions.

The peace building literature can be roughly divided into three separate domains for each two pairs, specifically, the relations of green finance and automobile innovation, the effects of five mediations (carbon neutrality, population, location, human resources, and GDP) on green finance, and how five mediations affect automobile innovation. This literature has developed extensively over the period 2010-2021, making the largest contribution in the recent five years. The relations of regulatory green finance and automobile innovation concerns with fact that there are considerable incentives in green finance concerning innovations in automobile. For instance, in some markets like Korea, firms that issue green bonds tend to

be more innovative than other firms. And the subsidies directly released impact much on the input of green innovation for companies working on new energy [12].

The researches about the effects of five mediations (carbon neutrality, population, location, human resources, and GDP) on green finance concentrate on the positive contribution of mediation to the implement of green finance. The studies on how five mediations affect automobile innovation brings the related factors that influence the process into focus, which helps us accurately understand how this process works.

This study sheds new light on how green finance influence automobile innovation: while only a few studies have shown a significant influence that green finance experts on automobile innovation, this paper offers back-up by running natural experiments and the application of machine learning methods.

Green finance is a double-edged sword against the backdrop of automobile innovation. For one thing, green finance is significant for promoting automobile innovation, which can provide continuous financial support and effectively ease financing restraints on automobile innovation [13, 14]. On the other hand, it is possible that green finance may also have perverse effects, weakening the *market incentive* favorable impact for innovations in green technology by environmental regulations, causing a lower level of efficiency in the allocation of social resources [13].

Given these facts, the paper attempts to address academic gaps regarding four major concerns. First, the paper disputes the *double-edged sword* effect which green finance has on the adoption of automobile innovation. Notably, against the opinion of Juan Zhang, the evidence presented in this paper suggests that green finance reduces transfer costs and can have a highly favorable impact on automobile innovation, despite the fact that automobile companies are somewhat less willing to innovate as traditional fossil fuel-based automobile technologies are mature.

Second, this study seeks to extract answers by making comparisons between landlocked and coastal countries to emphasize the importance of location in automobile innovation. Over the course of history, cities and towns along the coast have been melting pots of innovation. It is estimated that among global economic activities, 41-45% take place on coast. In world's 33 megacities, 21 of them are located along the coast, and 40-50% of the human kind's population inhabits within the distance of 100 km to the ocean [15-17].

Third, our paper takes carbon neutrality as a method of *nudge*. It is a concept in behavioral economics and science, as well as in political theory, which presents both positive reinforcement and indirect proposals that serve as a means to shape group behavior and decision-making [18], on the effect of green finance on automobile innovation. To fulfill the carbon neutrality goal, green technology innovations are the essential factors and will directly influence carbon emissions in the nature [19]. However, in the process of achieving the goal, CO_2 emission reductions coincide with a cost to the economy [3]. For the effective mitigation of financing restrictions for green innovation [14], access to green financing is intended to facilitate responsible investments in environment and provide incentives for technologies and enterprises of low-carbon [8]. Carbon neutrality can be looked as the benchmark of the anchoring effect, which seems like the sword of Damocles hanging out on every firms' head.

Finally, this study attempts to obtain answers by applying global data. To date, 126 countries worldwide (accounting for 51% of global GHG emissions) have formally passed declared or are in consideration of zero emission targets corresponding to the Paris Agreement [4]. In the wake of the Paris Climate Conference (COP21), a number of countries have begun to head in the direction of carbon neutrality goals. Hence, contrary to Yu *et al*. [14]

who only focus on one country, this paper use global data to study the relations of green finance and innovations in automobile industry.

Hypothesis

Basic factor that contributes to the goal of carbon neutrality is innovations in green technology [19]. Thus, to satisfy the standard in carbon neutrality and eliminate the cost of transformation from oil-fueled automobiles to new energy automobiles, evaluating the immediate impact of green finance and automobile innovation and effects in combination is crucial.

It's important for automobile sectors to innovate which account for a huge part of carbon emissions. However, the cost of transfer has become an obstacle for automobile sectors, making it difficult to innovate smoothly. For automobile innovation, green finance can reduce the cost and ease the financing bottleneck by providing ongoing financial support. If a reasonable market mechanism that green finance can match is in place, the funds flow can be led by green finance to effectively manage and optimize allocation of resources [6].

Therefore, we propose Hypothesis 1: Green finance could significantly promote automobile innovation.

Carbon neutrality, defined as the situation when net zero CO_2 emissions happen, can be realized by the elimination of social emissions to balance CO_2 emissions. The achievement of carbon neutrality is critical for countries with different development levels worldwide [20]. Automobile innovation is a key factor in the attainment of carbon neutrality ambition [19]. Moreover, for the aggregate of energy consumption in the world and GHG emission, 27% and 33.7% are attributable to the transportation sector respectively [5]. Therefore, for the purpose of carbon neutrality, it's urgent for automobile firms to innovate to reduce carbon emissions.

However, there are substantial economic losses associated with CO_2 emission reductions [3]. Meanwhile, due to the relative maturity of traditional technology for fossil fuel-based vehicles, automobile companies are unlikely to engage in energy-efficient technology innovation. The green finance effectively alleviates the financing constraints of automobile innovation and realize a *win-win* for not only the economic development but also the environmental preservation [13, 14].

The goal of carbon neutrality can be looked as the benchmark of the anchoring effect to 'nudge' the green finance course on automobile innovation. This seems like a sword of Damocles hanging out on every automobile firms' head.

Therefore, we propose Hypothesis 2: The goal of carbon neutrality positively mediates the effect of green finance on automobile innovation.

The location of the company does wield an effect on innovation capacities [21]. The coastal towns have been a melting pot of innovation for a long time. Innovation in automobile industry should focus more on the competitive advantage that coastal countries obtain. This exhibits higher rates of population growth [22, 23]. In addition, shorter distance among enterprises to the coastal areas exhibits higher rates of urbanization, the greater their capacity to innovate, which can be explained by the better condition of transport infrastructure [23].

In addition to this, coastal areas are remarkably more densely populated than their non-coastal counterparts, and among human population, 40-50% inhabits within the distance of 100 km to the ocean [23]. And population growth induces automobile innovation [24]. Coastal communities thrive thanks to innovation in governance arrangements at multiple chronological and geographic scales, which can be helpful for the implement of green finance policies.

Therefore, we propose Hypothesis 3: the country's coastal locations positively influences green finance on automobile innovation.

The number of populations in a country should be considered. Population is the major impulse to increase CO_2 emissions in both developed and developing countries [24]. According to Birdsall [25], in developing countries, the increase in population leads to significant GHG emissions due to an increase in energy needs for electricity generation, industry and transportation, and this in turn increases fossil fuel consumption. Additionally, population aging is known to positively associated with carbon emissions [26], in which case population growth is necessary. Potential constraints on both population growth and utilization of resources will be tackled through technological innovation and investment, making the business sustainable [27].

There is another obvious fact that, the more people who will take in the oxygen and breath out CO_2, the more carbon emissions. Hence, it's more urgent for countries with larger population to innovate for reducing carbon emissions.

To arrive at the level of net-zero carbon emissions (carbon neutrality), this paper come up with a model:

- Carbon emission = Carbon absorption.
- Carbon emission is positively correlated with population: Emission = a population + k (a > 0) f'(population) > 0.
- Carbon absorption is also positively correlated with population: Carbon absorption = b population + k' (b > 0).

Therefore, we propose Hypothesis 4: The population of a country positively mediates the effect that green finance has on automobile innovation.

According to Montes *et al*. [28], with greater innovation capabilities, firms will be better able to respond more successfully to an evolving environment and develop new competencies to enable them to perform better in terms of innovation. In turn, innovation initiatives often rely to a large extent on the amount of knowledge, expertise and loyalty of employees and serve as important inputs in the value creation procedures [29]. Moreover, positive association between strategic human resource practices and knowledge management capabilities is demonstrated, and this in turn positively affect innovation performance [30].

Hence, we propose Hypothesis 5: the country's human resources positively affects green finance on automobile innovation.

New opportunities for companies will be created by better economic activity and innovation will be stimulated. In turn, meanwhile, economic activity would positively affect innovation and company activities [31].

There are proven positive relations of in finance and development in economy [32].

Green finance provides a significant win-win condition for creating growth in economy [33]. What's more, green finance shares the same features with conventional finance. As a result, the development of green finance, just like financial development, can also contribute to economic growth [33].

There are many abbreviations that economists use to refer to the economy. Of these, the most common is GDP, signifying gross domestic product, and serves as one of the indicators to describe size of the economy and its performance [34]. In addition, GDP positively and carbon emissions are positively linked [26], which will request automobile firms to innovation to reduce carbon emissions if there is a rapid development of GDP.

Hence, we propose Hypothesis 6: The GDP plays as moderating role in a positive way to mediate the four mechanisms (carbon neutrality, location, population, human resources).

Data analysis and methodology

Data

This study selected secondary data from the Global Green Finance Index (GGFI) from Long Finance (https://www.longfinance.net/programmes/financial-centre-futures/global-green-finance-index/), Shunyi index (The Development Report of Connected Automated Automobile Industry), CO_2 emissions per year [tone] of each countries and regions from Our World Data (https://ourworldindata.org/CO_2-emissions).The location of the country from Google Map, World Bank Indicators. The data are from 2018-2020. The samples we collected were based nationally and included 192 countries and areas. However, it's not long after the definition of green finance was proposed, so there exists the lack of some countries' data. Hence, there are 39 countries left to be studied. And there are only 78 cities recorded by GGFI, in which case this paper studies 39 countries equaling as the average of the cities of its country's data

The list of countries are as bellows, which includes six continents globally. Hence, this paper's data could be a representative for global data, tab. 1.

Table 1. The list of countries

Continent	Country
Europe	Holland, Luxembourg, Denmark, Switzerland, Sweden, United Kingdom, France, Germany, Austria, Norway, Belgium, Italy, Malta, Czech, Ireland, Spain. Russia, Poland, Liechtenstein
Americas	Canada, United States, Brazil, Mexico
Oceania	Australia
Africa	Morocco, Mauritania, South Africa
Asia	China, Korea, Singapore, Israel, Japan, The United Arab Emirates, Qatar Malaysia, Turkey, Thailand, Indonesia, India

Descriptions of variables

Descriptions of the dependent variables

The major dependent variable selected and described for this paper is automobile innovation, which indicates the ability to reduce carbon emissions from burning the fossil fuels for energy production. The source of the automobile innovation is the Shunyi index.

Descriptions of the independent variable

The independent variable selected and described for this paper is green finance, whose source is the GGFI (the ranks and ratings of green finance penetration), which is compiled using 143 instrumental factors. This provides a useful reference for policy and investment decision makers to develop green finance.

Mediation variable

The mediation variables are population, human resources, carbon neutrality and location.

The source of population is from World Bank Indicator. The source of human resources is Total Labor force of each countries and regions from International Labour Organization, ILOSTAT database. The source of carbon neutrality is CO_2 per year [tone] of each country and regions from Our World Data. The location of each countries and regions depends on whether the country is coastal state (if yes: 1; if no: 0) from Google map.

Control variable

The lasso method (least absolute shrinkage and selection operator;) is often regarded and applied as regression analysis in statistics and of course, in machine learning where both selection and regularization of variables are performed so that the resulting statistical model is enhanced in terms of predictive accuracy and interpretability.

The coefficients can be set to zero by lasso, which is not the case for the superficially similar ridge regression. The difference is due to their constrained boundaries having different shapes. Lasso and ridge regression can both be explained as the minimization of the same objective function:

$$\min_{\beta_0,\beta}\left\{\frac{1}{N}\left\|y-\beta_0-X\beta\right\|_2^2\right\} \tag{1}$$

However, about different constraints: $\|\beta\|_1 \le t$ for lasso and $\|\beta\|_2^2 \le t$ for ridge. The fig. 1 shows that the regions of constraints determined by the L^1_{norm} are rotated squares which makes their corners lie on the axes (usually a cross-polytope), meanwhile, the regions specified by the L^2_{norm} are circles (usually n-spheres) being rotationally invariant and have no corners.

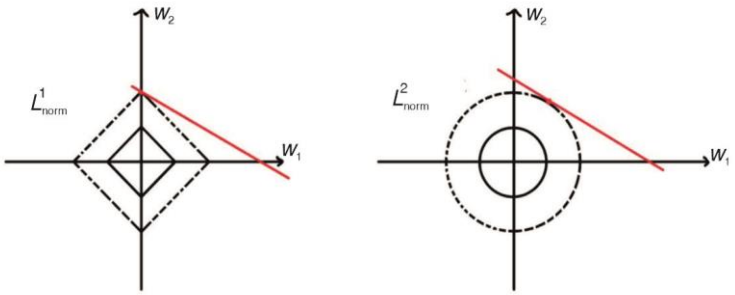

Figure 1. Lasso and ridge regression when constrained regions occur
Source: *https://en.wikipedia.org/wiki/Lasso_(statistics)*

Therefore, a penalized regression in Lasso was used to lower dimension of the control variables as a consequence of the high dimensionality of the World Bank indicator. To start with, covariates with samples less than 100 (eigenvectors) are removed. Also, for other covariates, we replaced the missing values from the World Bank. This leaves 60 covariates and a sample of 117. We run a lasso regression using conflict ranking as dependent variable with covariates of all kinds selected as explanatory variables.

Results from 10-fold cross-validation and 100 iterations indicate an optimal value of λ was 5.352, with 2 covariates having coefficients significantly different from 0. They were used as control variables in panel fixed model of this study, tab. 2.

Table 2. Results of panel fixed model of this study

Innovation (1)	
GDP	0.001
Imports	–0.140
In parentheses: *t* statistics $^{*}P < 0.1$, $^{**}P < 0.05$, $^{***}P < 0.01$	

GDP (current US$) is from World Bank indicators
World Bank indicators provides Imports of goods and services (% of GDP)

Model

A panel fixed-effects model is used in this paper. For statistical purposes, a fixed-effects model is applied, and in this model, the parameters are fixed or non-random quantities. They are consistent in the long time series limit.

Accordingly, the primary underlying empirical formulation is the fixed effects model:

$$\text{Innovation}_{it} = \alpha_0 + \alpha_1 \text{Green} + \alpha_2 \text{Control} + \text{year}_t + v_i + \varepsilon_{it} \tag{2}$$

where i and t represent countries and timing, Innovation_{it} represents automobile innovation, Green represents the green finance index, Control are a set of control variables (GDP current US dollars, Imports of Goods and Services % of GDP), year_t is the chronological effect, v_i is the individual effect, and ε_{it} is the residual, fig. 2.

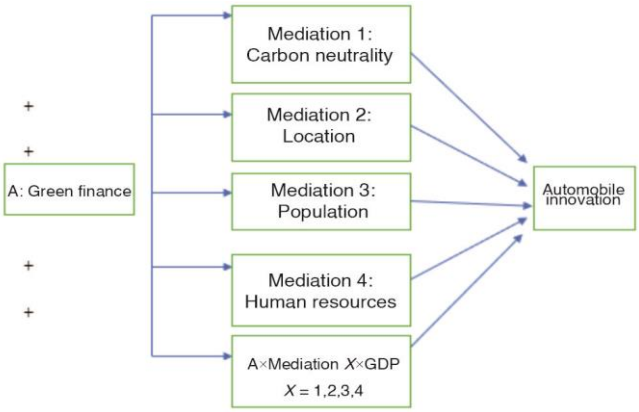

Figure 2. The theoretical framework of green finance on automobile innovation
Note: + indicates positive impact and - indicates negative impact

An upcoming challenge is the identification of the ways in which green finance affects automobile innovation. In a theoretical analysis, this paper argues that there are different mechanisms through which green finance can positively affect automobile innovation. In the model design, mediating variables were added to the baseline model to examine whether the effect mechanism was significant.

The design of mediation model is:

$$\text{Innovation}_{it} = \alpha_0 + \alpha_1 \text{Green} + \alpha_2 \text{Mediation} \times \text{Green} + \alpha_3 \text{Control} + \text{year}_t + v_i + \varepsilon_{it} \tag{3}$$

where Green × Mediation is a set of the intersection of different mechanism (population, location, human resources, carbon neutrality) and green finance, tab. 3.

Table 3. Green × Mediation

Green × Mediation	
gfa	Green finance × Carbon neutrality
gfb	Green finance × Location
gfb1	Green finance × coastal location
gfb2	Green finance × lock-landed location
gfc	Green finance × Population
gfd	Green finance × Human resources
gfa 1	Green finance × Carbon neutrality × GDP
gfb 1	Green finance × Location × GDP
gfc 1	Green finance × Population × GDP
gfd 1	Green finance × Human resources × GDP

- gfa: This paper use carbon emissions from Our world In data to represent carbon neutrality and choose green finance and carbon neutrality as the intersections and construct a fixed effect model.
- gfb: This paper chooses GGFI and whether the country is coastal state (if yes:1 if no:0) from Google map. A fixed effect model is built by generating intersections.
- gfc: This paper selects GGFI and population from The World Bank. A fixed effect model is built by generating intersections.
- gfd: This paper uses labor force from World Bank Indicators to represent human resources and choose GGFI and human resources as the intersections and a fixed effect model is built.
- gfe: This paper use carbon emissions from Our world In data to represent carbon neutrality and choose green finance and carbon neutrality as the intersections and construct a fixed effect model.
- gf$x$1(x = 1,2,3,4): This paper uses GDP (current US$) from World Bank Indicators and choose gf$x$1(x = 1,2,3,4) and GDP as the intersections and construct a fixed effect model.

Empirical findings

The regression result of main model is as below in tab. 4.

Table 4. The regression result of main model

Innovation	
Green	0.011^{***} (3.755)
GDP	0.001^{***} (4.688)
Imports	0.017 (0.314)
In parentheses: t statistics $^{*}P < 0.1$, $^{**}P < 0.05$, $^{***}P < 0.01$	

Table 4 shows that green finance of model (1) is significant at the level of 1%. In this context, the absolute value is 0.011, which indicates that Hypothesis 1: green finance could significantly promote automobile innovation is proved.

Green finance is based on reducing the cost of transfer from oil-fueled automobiles to new energy automobiles. This paper holds that green finance can influence automobile innovation through five channels: the standard of carbon neutrality; the country's coastal locations; the country's population; the country's human resources. Hence, this paper uses mediation effect of different mechanism as shown in tabs. 3-9. The results analysis are:

- (1) Carbon neutrality

Carbon neutrality can be looked as the benchmark for the effects that green finance have on the innovation of automobile industry, and meanwhile to nudge the process, in which the green finance could help to push automobile innovation.

Table 5 shows that green finance × carbon neutrality of model is significant at the level of 1%. And in this context, the absolute value is 0.001, which indicates that Hypothesis 5 that the standard on how carbon neutrality positively mediates green finance on automobile innovation is justified.

Table 5. The mediation effects of mechanism 4: Green finance & carbon neutrality (gfa)

Innovation (1)	
Green	0.011*** (3.755)
gfa	0.001*** (4.238)
GDP	0.001* (1.658)
Imports	–0.029 (–0.580)
In parentheses: t statistics *$P < 0.1$, **$P < 0.05$, ***$P < 0.01$	

The coefficient that green finance represents is greatly significant at the level of 5% in tab. 6 which indicates Hypothesis 2 is proved.

Table 6. The mediation effect of mechanism 2: Green finance × location (gfb)

Innovation (1)	
Green	0.002 (0.462)
gfb	0.012** (2.558)
GDP	0.001*** (4.833)
Imports	0.028 (0.534)
In parentheses: *t* statistics *$P < 0.1$, **$P < 0.05$, ***$P < 0.01$	

– (2) Location

The larger the extent of closeness in distance of a company to the coastal areas, the better they innovate, which can be explained by the better condition of transport infrastructure.

Table 7. The mediation effect of mechanism 2: Green finance × lock-landed location (gfb1)

Innovation (1)	
Green	0.001 (1.532)
gfb1	0.001 (.)
_cons	59.917*** (100.742)
In parentheses: *t* statistics *$P < 0.1$, **$P < 0.05$, ***$P < 0.01$	

The intersection of green finance × location (gfb) is significant at the level of 1%. In this context, absolute value is 0.012. Since 0.10 > 0.01, the marginal benefit of green finance on automobile innovation is greater for coastal countries than for lock-landed countries which indicates Hypothesis 3 that the country's coastal locations influences in a positive way on the green finance effect on automobile innovation is proved.

Table 8. The mediation effect of mechanism 2: Green finance × coastal location (gfb2)

Innovation (1)	
Green	0.010*** (3.809)
gfb2	0.001 (.)
_cons	63.772*** (23.847)
In parentheses: *t* statistics *$P < 0.1$, **$P < 0.05$, ***$P < 0.01$	

– (3) Population

Human take in oxygen and breathe out CO_2 which accounts for a large amount of carbon emissions. Hence, there is necessity for countries with large populations to innovate to reduce carbon emissions. Except that, the country with large population has a higher demand for new-energy automobiles.

Table 9. The mediation effect of mechanism 1: Green finance × Population (gfc)

Innovation (1)	
Green	0.007*** (2.619)
gfc	0.001*** (2.935)
gdp	0.001*** (3.604)
Imports	0.006 (0.107)
In parentheses: *t* statistics *$P < 0.1$, **$P < 0.05$, ***$P < 0.01$	

The intersection of green finance × population (gfa) is significant at the level of 1%. In this context, the absolute value is 0.001, which indicates Hypothesis 2 that the population of a country positively mediates the green finance effect on automobile innovation is justified.

The coefficient that green finance presents is positively significant at the level of 1% (in tab. 2), which indicates Hypothesis 1 is proved.

– (4) Human resources

The more innovative companies are, the more successful they will be. Innovativeness depends on human resources such as employee's knowledge. The intersection of green finance × human resources (gfc) is significant at the level of 1%. In this context, the absolute value is 0.001, which indicates that Hypothesis 4, the country's human resources positively affect green finance on automobile innovation, is proved.

The coefficient that green finance represents is positively significant at the level of 5% (in tab. 4), which indicates Hypothesis 1 is proved.

– (5) GDP

Positive correlations are found in GDP per person and the consumption of renewable energy, with GDP per person promoting it [35]. This is an indirect boost to automobile innovation as GDP per capita increases the demand for renewable energy.

Therefore, based on the process that other factors such as population, human resources, carbon neutrality and location influence the effect of green finance on automobile innovation, GDP positively mediates among the four mechanisms (carbon neutrality, location,

population, human resources). Hence, this paper constructs the moderation effect of GDP on these four mediations effect. The results are as below in tab. 11.

Table 10. The mediation effect of mechanism 3: Green finance × human resources (gfc)

Innovation (1)	
Green	0.006** (2.175)
gfc	0.001*** (3.884)
GDP	0.001** (2.554)
Imports	–0.012 (–0.226)
In parentheses: *t* statistics $^{*}P < 0.1$, $^{**}P < 0.05$, $^{***}P < 0.01$	

Table 11. The moderation effect of GDP on these four mediations effect

	Innovation				
	(1)	(2)	(3)	(4)	(5)
Green	0.011***(3.755)	0.009**(2.149)	0.014***(4.640)	0.007***(2.619)	0.022(1.074)
GDP	0.001***(4.688)	0.001***(4.113)	0.001***(4.833)	0.001***(3.604)	0.001***(3.924)
Imports	0.017 (0.314)	0.004 (0.067)	0.028 (0.534)	0.006 (0.107)	0.034 (0.435)
gfa		0.001 (0.568)			
gfb			0.012**(2.558)		
gfc				0.001***(2.935)	
gfd					0.001 (0.048)
_cons	56.620*** (14.657)	56.923*** (13.898)	55.564*** (14.644)	58.357*** (15.254)	51.312*** (10.166)
In parentheses: *t* statistics $^{*}P < 0.1$, $^{**}P < 0.05$, $^{***}P < 0.01$					

Table 11 shows that the moderation effects of GDP (gfa1, gfb1, gfc1, gfd1) are all significant at the level of 1%. In this context, the absolute value becomes all near to 0.001, which indicates Hypothesis 6 that GDP plays a moderating role on the mediation effect of these four mechanisms is justified.

The coefficient that green finance represents are all positively significant at the level of 1% in Model (1)-(5) of tab. 6 which indicates Hypothesis 1 is proved.

Conclusion and prospects

This study sheds new light on the effects of green finance on automobile innovation: while there are only few studies showing that green finance is quite clear when it comes to its effect on automobile innovation. Non-etheless, by conduction of natural experiments and applying method of machine learning, this paper provides support for the finding.

- First, green finance can significantly alleviate automobile firm' s constrains by providing continuous financial support for automobile innovation, which proved Hypothesis 1 and reduce the cost of transferring from oil-fueled automobiles to new energy automobiles.
  Hypothesis 1 has the practical implication that more reliance should be placed on the involvement and co-operation of local governments for the successful automobile innovation, particularly in the area of green finance. A high-level dialogue between local gov-

ernments and any efforts to break down administrative and technical barriers should be part of this. Local government involvement in green finance policy can enhance the ability to develop *market-incentive* environmental regulations and improve the efficiency of automobile innovation. In addition, green finance combined with environmental regulations is a way to alleviate financial pressures on firms as they upgrade their technologies and make them more innovative, thus a *win-win* balance of economic growth and environmental preservation can be accomplished [13]. On a broader basis, there is a need to further expand the scale of green finance investment with the goal of encouraging it for greater impact in automobile innovation [13].

- Second, we find that carbon neutrality, serving as a method of *nudge* theory, promotes the process of green finance on automobile innovation, which proved Hypothesis 2. The standard of carbon neutrality can be looked as the benchmark of the anchoring effect, which seems like the sword of Damocles hanging out on every automobile firms' head.
  What Hypothesis 2 means in practical terms is that investment in technology for carbon accounting markets (with the potential to assist companies measure and report carbon emissions) can enhance regulation and facilitate feedback and disclosure. In the USA, the Securities and Exchange Commission has proposed a requirement for some companies to report their scope - three emission kinds [36]. In addition, the suggestion of this research is that government can require direct carbon tax based on carbon-accounting technology on automobile firms and promote the carbon emission trading mechanism, which are often regarded as emission reduction strategies to achieve carbon neutrality [36]. By imposing a tax or a fine on cars that pollute the environment, the carbon tax is compatible with liberal paternalism because companies can reduce their carbon emissions to avoid paying taxes [37]. Automakers would have sufficient incentive for new technologies that cater to more fuel-efficient vehicles with increased carbon taxes [37].
  However, in highly developed countries, their economic development and consumption in energy are important carbon emissions origins, which are not linked to those of developing countries. This is due to the fact that most developing nations use cheap energy to generate electricity, while developed countries have active measures and policies [38]. This paper proposes that countries increase their technological research expenditures on automobile innovation for the development of an economy with a low carbon cycle achieved on the basis of technological innovation. In addition, it is essential that governments apply a carbon tax on the automobile industry to force their installation of carbon treatment technologies to achieve carbon neutrality. Some countries that reported promising results imposed such taxes earlier [38].
  In addition, carbon emission trading can also be used to *nudge* the process. One after another, five Chinese cities and provinces, including Shanghai, saw the launch of their own pilot market for carbon trading in 2013 [39]. Organizations and individuals in an increasing number will take part in the carbon exchanging market. This will bring in trade volumes, trading transparency, and more liquidity to the carbon trading market [40].
- Third, the marginal benefits of green finance for automobile innovation are found to be higher in coastal countries than in land-locked countries, which proved the country's coastal locations impact green finance positively on automobile innovation (Hypothesis 3). Hypothesis 3 is practically significant in that:
  - The government could firstly apply green finance policies on automobile firms in coastal section, which possess a high efficiency.
  - The strengthened cooperation between coastal countries should be achieved, and green finance policies need to be abated.

- Fourth, we found the mechanism behind the effect of green finance on innovation in automobile industries: the population of the country, which further supports automobile innovation (Hypothesis 4).

  Hypothesis 4 is practically significant in that:
  - Given that population growth has far more significant impacts on carbon emissions in developing countries than it has in the countries that are developed and a positive correlation of population ageing and carbon emissions is shown, the countries, especially in developed countries, the government should make policies and incentives to increase the birthrate [26].
  - Since continuous education is likely to contribute to more people being conscious of low carbon consumption [26], there is a need to increase the understanding and innovation of the population to protect the environment through education.
- Fifth, we find that the second mechanism behind process is the country's human resources, and it positively influences the role of green finance for automobile innovation (Hypothesis 5).

  Hypothesis 5 is practically significant in that:
  - Given that automobile innovation is highly dependent on knowledge and expertise of employees, and strategic human resources are positively related to innovation performance [30], the companies should have a higher level of knowledge management, and this inspires innovative thoughts to make a better innovation performance for automobile firms.
  - Since human factors are involved in the whole automobile innovation process which is a key element of the successful automobile innovation, the automobile companies should strive to build a working environment where executives really care about employees' welfare to make them feel at home.
- Finally, we find that GDP behind process is the country's human resources positively moderates and mediates the four mechanisms (carbon neutrality, location, population, human resources), which proved Hypothesis 6.

  The practical implications of Hypothesis 6 are that:
  - Although a rapid development of GDP is positively related with carbon emissions, it represents an economic growth. Hence, the government should urge automobile firms to innovate for emission reduction.
  - The government should encourage people to buy more new-energy automobiles instead of oil-fueled automobiles by reducing the tax for purchasing new-energy automobiles.

In this research, the limitation is the lack of data because there are only 78 cities recorded by GGFI, in which case this paper studies 39 countries equalling as the average of the cities of its country's data. Based what we have, we have done our best in empirical study section. If there are better data in the future, our paper will continue to study. The exploratory study reported in this paper, however, elicits further in-depth research:

- First, carbon neutrality serving as a method of *nudge* on how green finance affect innovation in automobile industry may be a potential focus for future research.
- Second, the distinction between lock-landed and coastal countries on the effect of process may be beneficial for empirical studies based on big data.
- Third, the mediations of the process, such as location, population, human resources, GDP, also need to be studied in a more profound way.
- Finally, this study can serve as a start to explore how green finance influence innovation in automobile industry and their degree of correlation.

Data availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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