HIGH-TECHNOLOGY EXPORTS AND ECONOMIC FREEDOM: NEW INSIGHTS FOR THE TOP HIGH-TECH EXPORTERS[*]

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Abstract

Recent literature emphasizes that if export composition consists mostly of high-tech exports, increasing international competitiveness encourages the production of high-value-added goods and supports productivity enhancements within the country. This study aims to contribute by analyzing this literature by examining the effect of economic freedom, its sub-components, and interactions on high-tech exports for top high-tech exporters by focusing R&D. We calculated the average of high-tech exports from 2009-2023 and then selected the countries whose average high-tech exports are at least the world average. Our analysis reveals two important findings: (i) The aggregated Economic Freedom Index (EFI) and its sub-components—namely, regulatory efficiency, market openness, and the rule of law—have positive and statistically significant effects on HTE. (ii) While R&D and EFI individually contribute positively to HTE, their interaction often yields a counterintuitive negative effect. This suggests that the positive impact of R&D on export performance may be constrained or diluted in highly liberalized institutional settings. Therefore, we provide important implications for policy makers.

Keywords: High-Tech Exports, Economic Freedom, Panel Data Analysis, Institutional Economics.

JEL Codes: O14, O30, F14.

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YÜKSEK TEKNOLOJİ İHRACATI VE EKONOMİK ÖZGÜRLÜKLER: EN YÜKSEK TEKNOLOJİ İHRACATÇILARI İÇİN YENİ ÖNGÖRÜLER

Öz

Son yıllarda literatür, ihracat kompozisyonunun ağırlıklı olarak yüksek teknoloji ihracatından oluşması durumunda, uluslararası rekabet gücünün artırılmasının yüksek katma değerli malların üretimini teşvik ettiğini ve ülke içinde verimlilik artışlarını desteklediğini vurgulamaktadır. Bu çalışma, Ar-Ge'ye odaklanarak en yüksek teknoloji ihracatçıları için ekonomik özgürlüğün, alt bileşenlerinin ve etkileşimlerinin yüksek teknoloji ihracatı üzerindeki etkisini inceleyerek katkıda bulunmayı amaçlamaktadır. Bu bağlamda, yüksek teknoloji ihracatının 2009-2023 yılları arasındaki ortalaması hesaplanmış ve ardından ortalama yüksek teknoloji ihracatı en az dünya ortalaması kadar olan ülkeler seçilmiştir. Analiz, iki önemli bulgu ortaya koymaktadır: (i) Toplulaştırılmış Ekonomik Özgürlük Endeksi ve alt bileşenleri - yani düzenleyici etkinlik, piyasa açıklığı ve hukukun üstünlüğü, yüksek teknoloji ihracatı üzerinde pozitif ve istatistiksel olarak anlamlı etkilere sahiptir. (ii) Ar-Ge ve EFI ayrı ayrı HTE'ye olumlu katkıda bulunurken, etkileşimleri genellikle mantıksız bir şekilde negatif etki yaratmaktadır. Bu durum, Ar-Ge'nin ihracat performansı üzerindeki olumlu etkisinin, son derece liberalleşmiş kurumsal ortamlarda kısıtlanabileceğini veya seyreltilebileceğini göstermektedir. Bu nedenle, politika yapıcılar için önemli çıkarımlar sağlıyoruz.

Anahtar Kelimeler: Yüksek Teknoloji İhracatı, Ekonomik Özgürlük, Panel Veri Analizi, Kurumsal İktisat.

**JEL Kodları:** O14, O30, F14.

1. INTRODUCTION

Institutions are a key factor in both the volume and the direction of international trade, as they contribute to economic activity by influencing the profitability and feasibility of trading goods. The origins of this role can be traced back to the seminal work of North (1991). In his study, he emphasizes the importance of institutions in doing business and participating in long-distance commerce. Following North (1991), Acemoglu and Robinson (2005) also emphasize the importance of institutions for long-run economic activities, especially in doing business and participating in long-distance commerce. The approaches put forward by the subsequent literature on the effects of institutional factors on international trade can be summarized as follows4. (i) Institutions provide a positive contribution to countries' comparative advantage (Krugman, 2010). (ii) They increase trade flows by reducing transaction costs in the short run, and exporters become less sensitive to institutional quality in the long run (Söderlund and Tingvall, 2014). (iii) High institutional quality reduces the monopoly in trade, and prevents abuse of market power, thus enhances bilateral trade flows (Alvarez et al. 2018). Moreover, according to Levchenko (2007), adherence to contract and property rights is more influential in production processes as a technological factor, and therefore these sectors may have more institutional dependence. Also, Manzetti and Osang (2024) emphasize that good governance

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[4] While some of these examine the impact of institutions on total international trade (e.g. Dollar and Kraay, 2003; Levchenko, 2007 and, Alvarez et al. 2018), others have focus on their link with exports (e.g. Meon and Sekkat, 2008 and Zhu and Fu, 2013) and, more specifically, with high-tech exports (e.g. Ferragina and Pastore, 2007; Tebaldi, 2011 and, Kalkan and Pala, 2022).

such as professional bureaucracy, corruption control, and stability and sustainability of political and other institutions can shape high-technology exports.

Following the fourth industrial revolution, which was promoted by high technology and innovation systems, the composition of exports also became prominent. With the integration of technology into all production processes, industries' characteristics are changing according to the intensity of research and development expenditures. In this context, industries with above-average R&D expenditures are defined as high-tech industries. In recent years, it has been frequently emphasized that if the production and trade composition consist mostly of high-tech exports, increasing the international competitiveness of the countries encourages the production of high-value-added goods and supports the formation and dissemination of productivity enhancement within the country. Consequently, the policy challenge of enhancing high-technology exports has emerged as a critical research question. While existing literature has established a robust framework for analyzing export determinants, incorporating institutional factors may address persistent constraints in current theoretical models"

Figure 1. High Technology Exports and Economic Freedom
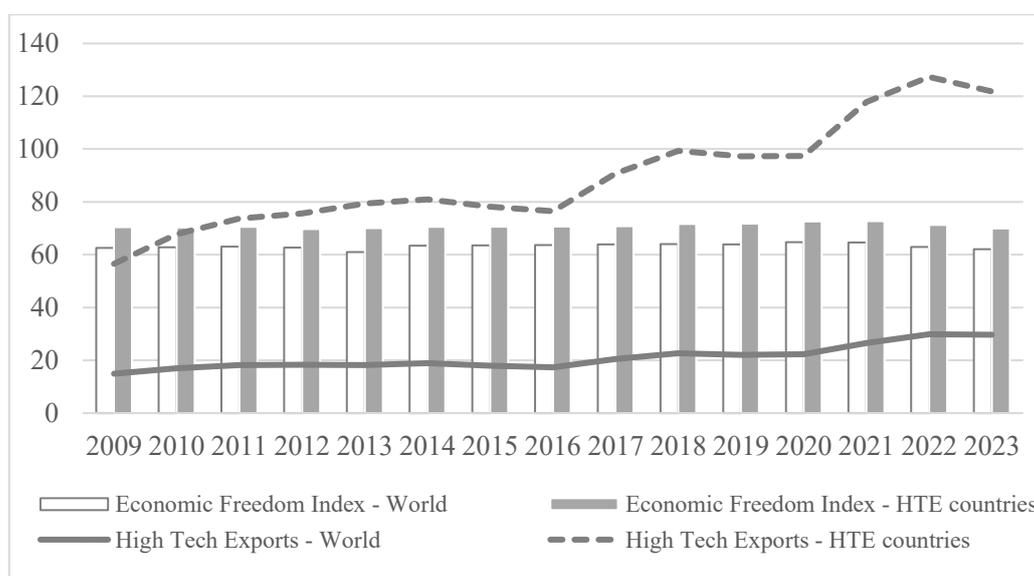
Source. World Bank, World Development Indicators and Heritage Foundation.
Notes. The numbers in the figures show the group (world or HTE countries) averages for the relevant year. The average values for the world are calculated by the authors using 123 countries data whose data can be available. The HTE countries include 28 countries exporting high-tech products with an average of over $10 billion for the relevant period. High Tech Exports: High Technology Exports (current billion US$) and Economic Freedom Index: Overall score of Economic Freedom Index of Heritage Foundation.

Our review exhibits several weaknesses of the previous literature on this topic and contributes to the growing literature in several aspects. First, in this study, we examine the link between institutions (by employing economic freedom index and its sub-components) and high-tech

exports of countries, rather than their total trade or total exports. As mentioned above, it is more likely that there is a relationship between technology-intensive sectors and institutions. Analyzing the nexus between institutional frameworks and high-tech export performance, this research specifically concentrates on the world's leading high-technology exporting countries. For this purpose, we calculated the average high-tech exports during 2009-2023 and then selected the countries whose average high-tech exports are at least 10 billion US$. As can be seen from Figure 1, the volume of high-tech exports has been increasing at a flatter pace across the world, but the rate of increase in high-tech exporting (hereafter, HTE) countries[5] has been much greater, and the gap is gradually widening, especially since 2020. Moreover, it is seen that the high-tech exports of HTE countries have increased significantly since 2020, even though they follow a similar trend to the world. That is why this study focuses on this group of countries. To measure institutional quality, we used the Economic Freedom Index and its sub-components[6]. Figure 1 also demonstrates that the economic freedom (hereafter, EF) of the HTE countries is continuously above the world average.

Changes in goods characteristics have also significantly altered the composition of countries' foreign trade in our sample. For example, according to 2023 data, Hong Kong, where the share of high-tech exports in manufactured exports is the highest at 70%, had only 33.78% in 2009. When we glance at the group of countries with high-tech exports above the world average, which constitutes the scope of this study, it is seen that European Union countries are in the majority between 2009 and 2023. Although these countries are more in number, the ratio of high-tech exports to manufactured exports is around 15-20% on average and has been at a similar level over the years. A remarkable situation within this group is the significantly high share of Asian countries. Although countries such as Malaysia, China, and Singapore have been exporting high-tech exports at a high rate (approximately 50 %) over the years, this ratio has not changed much. However, the ratio of high-tech exports to manufactured exports in Vietnam and Hong Kong has increased by 4 times and 2.5 times, respectively, since 2009.

Our second purpose is to investigate the contingency in the relationship between EFI and high-tech exports and add an interaction term constructed as the product of R&D and the EF index (i.e., R&D*EFI). To do this, we aim to investigate whether the effect of EFI on high-tech

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[5]Austria Belgium Canada China Czechia Denmark France Germany Hong Kong Hungary India Ireland Israel Italy Japan Korea Malaysia Mexico Netherlands Poland Singapore Spain Sweden Switzerland Thailand Vietnam UK USA.

[6]Economic freedom data is provided by Heritage foundation which is also used by many empirical studies as an indicator of institutional factors due to its comprehensive and regular data set (Ciftci and Durusu-Ciftci, 2022).

exports increases monotonically with the R&D or not. In other words, we test whether improvements in R&D expenditures are needed to facilitate economic freedom spillovers. We carry out regressions based on alternative interaction specifications using interaction terms between R&D and the EFI to reveal the indirect effects of economic freedom on high-tech exports.

The rest of the study continues with a brief literature review. In Section 3, we introduce data and methodology. Section 4 presents the empirical findings and discusses the results. Section 5 presents the supplementary empirical results. The study concludes with the final remarks in section 6.

2. LITERATURE REVIEW

The trade-institutions nexus has gained prominence in recent studies, with empirical evidence consistently positioning institutional quality is among the driving forces of export. The literature can be divided into three categories: trade and institutional quality relationship (e.g. Dollar and Kraay, 2003; Levchenko, 2007; Alvarez et al., 2018), export and institutional quality relationship (e.g. Meon and Sekkat, 2008; Zhu and Fu, 2013), and high-tech export and institutional quality relationship (e.g. Ferragina and Pastore, 2007; Tebaldi, 2011; Kalkan and Pala, 2022). There is a prevalent finding in the literature that institutional quality affects exports positively (e.g. Dollar and Kraay, 2003; Meon and Sekkat, 2008; Öztürk and Topcu, 2024). According to Levchenko (2007) institutional comparative advantages also affect comparative trade advantages. Because it is assumed that the incomplete contracts (i.e. in trade) are more extensive where the institutions are worse. Also, the channel may occur that insecurity, which is linked to ineffective contract enforcement and corruption, inhibits commerce since it raises the cost of commodities that are sold globally. Öztürk and Topcu (2024) emphasize that economic freedom in detail rule of law, government size, and market openness affect positively the export sophistication by possibly supporting the business environment, innovation, and competition. Besides, some studies (e.g. Briggs, 2013; Zhu and Fu, 2013; Lin et al., 2020) find that better institutions may damage the trade. Possibly because the presence of strong institutions can lead to strong trade policies and barriers, which in turn can be a soft pedal on exports.

Although the determinants of high-tech exports have received much attention in the literature (e.g. Seyoum, 2005; Sahoo and Dash, 2022), few studies have dealt with the role of institutions. The growing literature, which is also our focus, pays attention to the importance of trade composition (especially high-tech export) and institutional quality links. One of the pioneering

studies on the relationship between high-technology export and institutional quality was carried out by Farragina and Pastore (2007). Farragina and Pastore (2007) state that the quality of structural, technological, and institutional variables such as human capital, physical capital, R&D, total factor productivity, monetization of the economy, level of governance development, and political and macroeconomic conditions such as degree of economic freedom strengthen high-tech exports.

Considering the limited number of studies, it is possible to generalize that the results suggest that institutions have a positive effect on high-tech exports. For example, Gökmen and Türen (2013) for EU-15 countries and Kalkan and Pala (2022) for high-middle income countries, using the Economic Freedom Index (hereafter EFI), report that as economic freedom increases, high-tech exports will also increase. However, the results indicate that the impact of institutions on high-tech exports is larger for high-middle-income countries. The fact that the effect is relatively higher in the high-middle income country group, where EFI is relatively lower, may also indicate that improvements in economic freedoms may lead to higher effects in these countries. Moreover, Zapata et al. (2023), in their study of 35 OECD countries, find that institutional quality has no effect on high-tech exports, and they claim that the reason behind this finding may be that the institutional performance of these countries is already good enough.

Economic freedom or other institutional quality indices are composed of sub-index components. When these sub-indices are evaluated separately, they sometimes show different results from the combined index. The selected sub-indices differ according to the focus of the studies. For example, Bayar et al. (2020) focus on the impact of intellectual property rights. The results indicate that stronger intellectual property rights protection generates positive spillover effects through enhanced R&D activity in EU transition economies, ultimately fostering both economic growth and high-technology export performance. Therefore, the technological development of countries and the increase in technology-oriented exports are closely linked to property rights. Mehrara et al. (2017) and Fonkam (2023), who examine the relationship between high-tech exports and institutional quality, employ only the rule of law from the WGI index in their analysis. Although both studies confirm the positive impact of rule of law on high-technology exports and highlight institutions' complementary role in enhancing other determinants (e.g., FDI, GDP), their analyses do not consider potential interaction effects among these variables.

Table 1. Summary of the Panel Studies for High-Tech Export and Institutional Quality

Author(s)	Sample	IQ Indicator	Methodology	Findings
Ferragina and Pastore (2007)	84 countries 1994-2003	WGI, Fraser Index, EFI	FE, RE	Positive effect
Tebaldi (2011)	95 countries 1980-2008	Polity IV Project Index (political institutions)	FE	Positive effect when proximate factors (human capital and/or FDI) are included.
Gökmen and Turen (2013)	EU-15 countries 1995-2010	EFI	FMOLS	Positive effect
Mehrara et al. (2017)	34 developing countries 1996-2013	ROL in WGI	BMA and WALS	Positive effect
Özsoy (2020)	70 developing countries 2002-2015	WGI	GMM	Positive effect only high quality and financial development level
Güneş et al.(2020)	48 countries 1920-2017	POL	ARDL	Positive effect
Bayar et al. (2020)	EU transition economies 2000-2016	Protection of property rights index (EFI)	AMG, DH causality	Positive effect HTE => IQ
Veliev (2021)	49 countries 2008-2019	GCI	2SLS	Positive effect
Kalkan and Pala (2022)	26 High-middle-income countries 2000-2019	EFI	Panel ARDL	Positive effect
Fonkam (2023)	33 African countries 1995-2017	ROL	Panel IV regression	Positive effect
Zapata et al. (2023)	35 OECD Countries 2004-2018	WGI	GMM	Insignificant

Note. WGI: World Governance Indicators, EFI: Economic Freedom Index, MAE: Manufacturing Export, HTE: High Tech Export, ROL: Rule of Law, FE: Fixed Effect, RE: Random Effect, GCI: Global Competitiveness, Pol: Adjusted combined index of democracy and autocracy, BMA: Bayesian Model Averaging, WALS: Weighted Average Least Square, AMG: Augmented Mean Group, DH: Dumitrescu and Hurlin.

The empirical literature in this area also shows that the contribution of institutions to the high-tech exports is higher in some countries and some institutional economics scholars attribute this variation primarily to spillover effects they generate. As emphasized by Acemoglu and Johnson (2005), institutions are more related to social and economic interactions, and their final effect is more pronounced when interacting with economic variables. Because of this characteristic of institutions, the relationship between institutional quality and economic variables has also been evaluated generally through interactions in recent years. For example, Okada (2013) argues that

the effect of financial openness and institutions on international capital emerges in interaction rather than individually. Zghidi et al. (2016) and Azman-Saini et al. (2010) examine the interaction of economic freedom and foreign direct investment, while Salman et al. (2019) examine the interaction of carbon emissions and institutional quality on economic growth. Similar approaches in the literature mostly report the effect of interaction terms as statistically significant and larger than individual effects.

For this purpose, interactions, which have been the subject of empirical studies in recent years, have also been studied for the institutions-high-tech export nexus, albeit in small numbers. In this context, Tebaldi (2011) reports that institutions do not have a direct effect on high-tech exports, but the interaction of institutions with human capital and foreign direct investment, which he defines as proximate factors, has a positive effect. Also, Özsoy (2020) categorizes countries according to both their institutional capacity and financial development and finds that the positive effect is significant at high levels of institutional quality and financial development. Furthermore, she concludes that the effect of foreign direct investment is dependent on regulatory quality for the whole sample. Bournakis and Tsoukis (2016) analyze the export performance of 18 OECD countries by taking into account the interactions between government size indicators and R&D. The results suggest that although government size has a significant effect on export performance, the relationship may be non-linear, especially when R&D and government size are considered together.

3. DATA AND METHODOLOGY

In this study, the impact of economic freedom and its sub-components on high technology exports (HTE) is analyzed with the panel regression modelling using data of 28 countries with high technology exports of more than 10 billion dollars between 2009-2023 period. To mitigate potential multicollinearity issues, we estimate five separate specifications of the export model: one including the composite EFI and four additional models incorporating each of the EFI's subcomponents individually.

$$HTE_{i,t} = \bar{\eta} + \eta_i + \beta_1 GFCF_{i,t} + \beta_2 FDI_{i,t} + \beta_3 FORGDP_{i,t} + \beta_4 R\&D_{i,t} + \beta_5 EFI_{i,t} \qquad (1)$$
$$+ \beta_6 ROL_{i,t} + \beta_7 GS_{i,t} + \beta_8 REG_{i,t} + \beta_9 MO_{i,t} + \beta_{10} EDUC_{i,t} + \varepsilon_{i,t}$$

where the subscripts i and t represent country and time period, respectively. ηi is the country fixed effect. the set of explanatory variables, namely GFCF, FDI, FORGDP, R&D, EDUC and overall score or sub-components of EFI. Lastly, $\varepsilon_{i,t}$ is the error term.

HTE is measured by high technology exports (current US$) and physical capital (GFCF) is measured by gross fixed capital formation (current US$)[7]. Foreign direct investment (FDI) is proxied by FDI net inflows (% of GDP), FORGDP is measured by trade-weighted of GDPs of trade partners for each country (current US$), innovations are measured by R&D expenditures of the country (% of GDP), EDUC is tertiary school enrollment rate. All these data are taken from the World Development Indicators database of the World Bank.

Economic freedom data is obtained from the Economic Freedom Index (EFI) of the Heritage Foundation. The 12 different aspects of economic freedom are grouped into 4 broad categories: (i) the rule of law (property rights, judicial effectiveness, and government integrity), (ii) government size (tax burden, government spending, and fiscal health), (iii) regulatory efficiency (business freedom, labor freedom, and monetary freedom) and (iv) market openness (trade freedom, investment freedom, and financial freedom). In the analysis, all series are in natural logarithms.

As a first step, to determine which model fits our panel data, we employ the Hausman test, which tests the null hypothesis of no correlation between cross-sectional units and explanatory variables. Hence, if the result of the test suggest cannot be rejected of the null hypothesis, random effects should be used in estimation. After the Hausman test which provides results on which model should be used to estimate Equation (1), we conclude to employ fixed effects model.

4. EMPIRICAL FINDINGS AND DISCUSSION

Table 2 presents the results of 5 different models with different economic freedom indicators. When the findings are generally evaluated, it is observed that the determinants of high-technology exports are not limited solely to technological and human capital elements, but that institutional and structural factors also have significant effects. The results of the analysis conducted using the aggregated economic freedom index are presented as Model 1. According to Model 1, a 1% increase in economic freedom leads to an average increase of 1.21% in high-technology exports. This result is consistent with, for example, the findings of Öztürk and

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[7]Instead of focusing on high-tech exports of the whole world, this study focuses on the relationship between these exports and economic freedoms in countries that export the most high-tech products in the world. High-tech exports (current US$) is chosen as the indicator variable as in the previous study. The reason for this is that when the countries are ranked according to the second variable, it is seen that Cayman Islands (60.4%), Palau (40.2%) and Kazakhstan (32.5%) are in the first place with high rates. However, the exports of high-tech products of these countries are quite low. Since this is not suitable for the purpose of the study, the use of this variable will cause the results to be biased. Therefore, High-tech exports (current US$) variable is used as a proxy.

Topcu (2024), which suggest that free market environments create more favorable conditions for exporters and enhance competitiveness in technology-intensive sectors, thereby supporting the expected positive impact of economic freedom.

Table 2. The Impact of Economic Freedom on HTE

	(1)	(2)	(3)	(4)	(5)
FORGDP	1.021***	0.900***	0.873***	1.034***	0.916***
	(0.165)	(0.143)	(0.138)	(0.158)	(0.168)
GFCF	0.068	0.050	0.139**	0.070	0.131**
	(0.067)	(0.059)	(0.062)	(0.064)	(0.068)
FDI	-0.057	-0.031	-0.024	-0.028	-0.058
	(0.035)	(0.032)	(0.030)	0.032)	(0.036)
R&D	0.334***	0.288***	0.368***	0.305***	0.377***
	(0.060)	(0.059)	(0.073)	(0.059)	(0.070)
EDUC	0.647***	0.545***	0.647***	0.697***	0.633***
	(0.120)	(0.125)	(0.128)	(0.118)	(0.120)
EFI	1.212***				
	(0.330)				
ROL		0.613***			
		(0.080)			
GS			-0.207***		
			(0.048)		
REG				1.191***	
				(0.218)	
MO					0.560***
					(0.189)
Constant	-14.499***	-9.550***	-7.335***	-15.316***	-10.706***
	(2.398)	(1.674)	(1.683)	(2.291)	(2.080)
Observations	420	420	420	420	420
F-test	22.876	23.916	23.633	26.258	22.963
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
LM-test	975.894	843.483	792.879	969.176	799.793
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Hausman	27.891	25.803	28.377	22.408	27.891
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
LMp_stat (AC test)	256.040	255.455	254.129	254.922	253.711
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
LMh_stat (HET test)	3364.491	3366.651	3337.647	3331.760	3383.165
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Model	FE	FE	FE	FE	FE

Notes. Numbers in parentheses are Panel Cross-section SUR (PCSE) robust standard errors. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. FEM refers to the Fixed Effects Model. FORGDP: Foreign Gross Domestic Product, R&D: Research and Development, EDUC: Education, EFI: Economic Freedom Index, ROL: Rule of Law, GS: Government Size, REG: Regulations, MO: Market Openness.

The results of the other models that consider the effects of the subcomponents of economic freedom show that their individual effects (with the exception of government size) are positive and significant. Among the subcomponents, the regulatory efficiency index yields the largest positive impact. A 1% improvement in regulations can increase high-technology exports by approximately 1.19%. Studies in the relevant literature (e.g., Seyoum, 2005; Manzetti, 2024) indicate that the relationship between high-technology exports and regulations is naturally mediated by infrastructure. For instance, in the simplest terms, the spread of the internet is associated with national regulatory regimes. In addition, national innovation strategies that can influence competition, incentives, taxes, and tariffs are also considered among the factors that determine the effectiveness of regulations. Furthermore, market openness and the rule of law also exert a positive effect on high-technology exports.

Another noteworthy result is that government size has a negative impact on high-technology exports. According to Model 3, a 1% increase in government size reduces high-technology exports by approximately 0.21%. Previous studies have noted that government size can have either positive or negative effects on exports. While similar studies have reported a positive effect of government size on export diversification (see Öztürk and Topcu, 2024), Bournakis and Tsoukis (2016) argue that this effect is nonlinear and that after a certain point, the effect of government size turns negative. In contrast to Öztürk and Topcu (2024), our results are similar to those of Bournakis and Tsoukis (2016), suggesting that the size of the public sector may exert potential pressure on the private sector dynamics in the context of high-technology exports.

Next, Table 3 displays the regression results based on an interaction specification using an interaction term between R&D and the Economic Freedom Index (R&D*EF). In this specification, we relied on the interaction term to establish contingency. If the term is positive and significant, this would imply that the effect of R&D on high-technology exports increases with economic freedom.

The most striking result here is that when the interaction term of EFI and R&D is added to the model, the positive effect of R&D on high-technology exports has increased from 0.334 to 7.548. This indicates that the interaction term plays a significant role. It can be said that the positive effect of R&D on high-tech exports becomes more pronounced with improvements in EFI, such as better regulatory environments, protection of property rights, and support for entrepreneurship. For example, as a similar result, Bournakis and Tsoukis (2016) show that when the interaction between R&D and entrepreneurship barriers is included in the model, the impact of R&D on export performance is higher compared to other specifications.

Another interesting finding is that the coefficient of the EFI and R&D interaction is negative. Studies addressing similar interactions with FDI (e.g., Tebaldi, 2011; Özsoy, 2020) report that the interaction coefficient tends to have the same sign (positive) as the main effects. In contrast, Bournakis and Tsoukis (2016) report that the interaction between R&D and barriers to competition, entrepreneurship, and FDI can have a negative sign, even though these variables individually enhance countries' export performance. According to our results, while both EFI and R&D alone lead to an increase in high-technology exports, their interaction yields a diminishing effect. Possible explanations include the bureaucratic burden of regulations in countries with high institutional capacity (e.g., the rigidity of patent processes), which may hinder R&D efforts. Another reason could be that reforms aimed at enhancing economic freedoms or institutional capacity may generate exclusionary effects on R&D. In summary, the commercialization of R&D may become more difficult in environments with high economic freedom, increased competition pressure may reduce its impact, and R&D investments may increasingly be oriented toward the domestic market. These potential reasons are clearly visible in the interaction effects of R&D with Rule of Law, Regulatory Efficiency, and Market Openness, which appear to reduce high-technology exports.

Table 3. Interaction Specification between R&D and EF

	(1)	(2)	(3)	(4)	(5)
FORGDP	0.986***	1.047***	0.896***	1.000***	0.939***
	(0.166)	(0.158)	(0.136)	(0.157)	(0.160)
GFCF	0.066	0.027	0.136**	0.084	0.073
	(0.063)	(0.053)	(0.061)	(0.061)	(0.065)
FDI	0.000	0.011	-0.033	-0.017	-0.007
	(0.036)	(0.036)	(0.030)	(0.033)	(0.034)
R&D	7.548***	3.124***	-0.265	3.771**	5.108***
	(0.893)	(0.215)	(0.378)	(1.273)	(0.539)
EDUC	0.624***	0.408***	0.651***	0.605***	0.499***
	(0.112)	(0.110)	(0.128)	(0.109)	(0.107)
EFI	1.993***				
	(0.358)				
R&D*EFI	-1.726***				
	(0.215)				
ROL		0.640***			
		(0.071)			
R&D*ROL		-0.723***			
		(0.054)			
GS			-0.341***		
			(0.087)		
R&D*GS			0.152*		
			(0.091)		
REG				1.574***	

					(0.316)
R&D*REG					-0.816**
					(0.296)
MO					0.885***
					(0.170)
R&D*MO					-1.134***
					(0.129)
Constant	-17.728***	-11.632***	-7.040***	-16.252***	-11.761***
	(2.544)	(2.036)	(1.668)	(2.551)	(2.074
Observations	420	420	420	420	420
F-test	26.391	24.667	23.607	25.867	22.279
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
LM-test	973.982	838.344	793.160	907.571	794.914
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Hausman	22.524	25.970	27.718	23.627	25.596
	[0.002]	[0.001]	[0.002]	[0.000]	[0.000]
LMp_stat (AC test)	256.003	253.427	253.914	251.782	253.905
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
LMh_stat (HET test)	665.697	3664.006	3327.371	3118.084	3515.474
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Model	FE	FE	FE	FE	FE

Notes. Numbers in parentheses are Panel SUR (PCSE) robust standard errors. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. FEM refers to the Fixed Effects Model. FORGDP: Foreign Gross Domestic Product, R&D: Research and Development, EDUC: Education, EFI: Economic Freedom Index, ROL: Rule of Law, GS: Government Size, REG: Regulations, MO: Market Openness.

Moreover, long-term and high-risk investments such as R&D often require public support. In environments where economic freedom is high, such support may be limited. Therefore, public policies supporting R&D are necessary. This is also evident from Table 3, where the negative effect of government size turns positive when interacted with R&D. Moreover, in contrast to the results in Table 2, when interaction terms are included, Model 3 in Table 3 shows that the coefficient of R&D becomes negative. It is also observed that while government size continues to reduce high-tech exports, its interaction with R&D has a small but positive effect. Among the interaction terms, R&D*EFI and R&D*MO have highest magnitudes.

5. CONCLUSION

This study investigates the relationship between economic freedom and high-technology exports (HTE) by focusing on 28 countries whose average high-tech exports exceeded 10 billion USD between 2009 and 2023. Unlike the broader trade literature, this research narrows its lens to high-tech trade and seeks to understand not only the direct effects of economic freedom on HTE but also the interactional dynamics between economic freedom and other structural and technological determinants, particularly R&D expenditures.

The empirical findings derived from fixed-effects panel regressions suggest that economic freedom plays a vital role in enhancing high-tech exports. Specifically, both the aggregated Economic Freedom Index (EFI) and its sub-components—namely, regulatory efficiency, market openness, and the rule of law—are found to have positive and statistically significant effects on HTE. Among these, regulatory efficiency appears to exert the largest impact, supporting the notion that institutional arrangements surrounding entrepreneurship, market access, and business regulations significantly shape technological export capacity.

One of the most original contributions of this study is its examination of interaction effects, especially between R&D expenditures and economic freedom indicators. The results reveal that while R&D and EFI individually contribute positively to high-tech exports, their interaction often yields a counterintuitive negative effect. This suggests that the positive impact of R&D on export performance may be constrained or diluted in highly liberalized institutional settings. Possible explanations include excessive competition, rigid patent processes, or an overemphasis on market-led R&D, which may reduce long-term innovation capacity. Notably, the interaction between R&D and government size is the only one that produces a positive coefficient, indicating that R&D-intensive sectors might benefit from targeted public support even within a liberal economic framework.

These findings offer several policy implications. First, while liberal economic institutions are important for fostering high-tech exports, their effectiveness depends on complementary policies that support R&D commercialization and innovation ecosystems. Governments should therefore consider adopting hybrid approaches: ensuring economic freedom while strategically investing in public R&D, technology transfer infrastructure, and innovation incentives. Second, given the variation in interaction effects, policies aimed at enhancing high-tech exports should be institutional environment sensitive. For instance, in countries with already high economic freedom, marginal gains from further economic freedom may be limited or even counterproductive unless accompanied by mechanisms that protect arising innovations and reduce structural rigidities.

From a broader perspective, this study contributes to the literature by highlighting the multidimensional and conditional nature of the institutional determinants of trade. The role of economic freedom is not linear nor universally positive across all dimensions; instead, its effects are mediated by the interaction with other economic inputs. In conclusion, promoting high-tech exports requires more than simply improving economic freedom scores. It necessitates an integrated policy framework that balances economic freedom or institutional

quality with proactive innovation policies, thereby creating an environment where R&D efforts can be effectively translated into global technological competitiveness.

Declaration of Research and Publication Ethics

This study, which does not require ethical committee approval and/or legal/special permission, complies with research and publication ethics.

Researcher's Contribution Rate Statement

Authors contributed equally to the article.

Declaration of Researcher's Conflict of Interest

There are no potential conflicts of interest in this study.

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