Inzinerine Ekonomika-Engineering Economics, **2026, 37(1), 73–83**

Determinants of the Laser Industry Export Development: The Case of Lithuania

Asta Baliute, Jokubas Kuliesius

Kaunas University of Technology
K. Donelaicio st. 73, LT-44029, Kaunas, Lithuania
E-mail. asta.baliute@ktu.lt; jokubas.kuliesius@ktu.edu

https://doi.org/10.5755/j01.ee.37.1.41035

The Lithuanian laser industry is considered one of the country's most appreciated manufacturing sectors due to its high value-added output, growing potential significance, and the wide range of future applications of laser technologies. Despite considerable global potential and increasing export volumes, the laser industry faces challenges such as intensifying global competition, short product life cycles, high production costs, demand for highly skilled employees, dependence on global supply chains, standards, and regulations. The core aim of the research is to identify the main economic and non-economic determinants of laser export development in Lithuania in the context of rapid technological progress and geopolitical uncertainty. To empirically assess the impact of selected factors on the export results of the Lithuanian laser industry, correlation analysis, the Granger causality test, regression model, and the autoregressive distributed lag (ARDL) model were used. The results indicate that the export performance of the Lithuanian laser industry is positively affected by investment in patents and licenses. However, after controlling for other selected factors, interest rates, the number of military conflicts, and R&D expenditure were found to have a negative effect. Strategic support for intellectual property acquisition and mitigation of external economic risks are key insights for policymakers and stakeholders.

Keywords: *Laser Industry; Exports, Exogenous Factors; Endogenous Factors; Investment in Patents and Licenses.*

Introduction

The laser industry is among the most advanced and fastest growing manufacturing sectors of the modern sophisticated industrial landscape, with a constantly expanding demand and production's enlargement potential. Lasers are widely used across various sectors, including aeronautics, medicine, telecommunications, military, automotive, computer, and electronic industries, production, and measurement systems, as well as scientific research (Niu *et al.*, 2024; Hecht, 2010). The global laser technology market is expected to grow rapidly from USD 19.3 billion in 2023 to USD 32.7 billion by 2030 (Grand View Research, 2024). This growth signals an increasing demand for laser technologies and opens new opportunities for manufacturers and exporters. Manufacturing Technology Insights (2024) notes that lasers act as catalysts for innovation and offer significant efficiency gains in their applications, demonstrating the sector's spillover effects on technological advancement, innovation activity in related industries, value-added growth and customer benefits.

Lithuania exports around 80 percent of its laser production, and 95 of the top 100 ranked universities globally use Lithuanian-made laser solutions (Raciukaitis, 2023). Primary export markets are high-tech industrial and scientific centres. The US, China, Germany, Japan, and South Korea are among the main destinations for Lithuanian laser products. Lithuanian manufacturers exported lasers to 34 countries in 2013, increasing to 43 countries by 2023. During the 2013–2023 period, the highest export growth was recorded in 2021, driven by the increased demand for medical laser technologies during the pandemic. The authors' calculations of the RCA (Revealed Comparative Advantage) index (Balassa, 1965) for Lithuanian laser exports confirm the strong and growing specialisation of Lithuanian producers in this field. The RCA index measures the percentage share of a given product in total exports of a country relative to its share in global trade. Lithuania's RCA index for lasers increased from 13.2 in 2013 to 30.2 in 2023.

Considering that the laser sector creates high added value and is a significant part of the high-tech industry in any country, the analysis of the drivers affecting the growth of laser production and export is a significant scientific problem, which requires in-depth investigation. Analysis of the export problems of the laser industry and identification of factors that promote the development of laser exports is also necessary for the improvement of industrial and scientific strategies in Lithuania in support of sectoral growth.

Scientists and practitioners place a strong emphasis on the development of high-tech industries. There is great interest in how innovations, research and applied activities, and cutting-edge technologies stimulate exports in high-tech sectors, such as the laser industry. Scholars examine both exogenous and endogenous factors that encourage the development of high-tech industries and the creation of technological innovations in the sector and related sectors (Zhang & Sun, 2019), inward and outward foreign direct investment (Ilmi, 2017; Wang *et al.*, 2022, Zapata *et al.*, 2024; Wei *et al.*, 2024), public R&D investment and policies (Aflaki, Basher & Masini, 2021; Epicoco, 2021), highly skilled labour and knowledge of technology graduates (Wang *et al.*, 2022; Twining *et al.*, 2021), R&D expenditures and research staff in the business sector (Habenko, 2023), trade policy implications (Benguria, 2023), historical or geopolitical events (Epicoco, 2021).).

However, most research focusses on general analysis of high-tech export development, with insufficient scientific studies specifically addressing the laser industry. This stresses the lack of studies, directly related to investigation of laser industry export drivers.

The export performance of the laser industry faces significant challenges stemming from technological, market, political, and economic factors. First, the laser industry is highly competitive, with major global technology giants, including corporates from Germany, the US, Japan and China. This makes it particularly difficult for smaller or new entrants to compete. Although the Lithuanian laser industry is considered highly advanced, it faces strong competition from larger companies with greater production resources and capacities.

A key challenge is the technological complexity and short product life cycle of lasers. Lasers are constantly and rapidly evolving, which leads to a shorter life cycle. This creates intense pressure on manufacturers to continuously invest in R&D and innovations to remain competitive in the global market. Such investments are expensive and require highly qualified employees and advanced scientific laboratories.

Highly skilled employees may seek better opportunities abroad to increase their earnings and potentially better career prospects. Such a brain drain can also limit the industry's growth potential and innovation capacity. Since the adoption of new technologies often takes time and requires additional resources, it can be difficult for small and medium-sized companies to compete with market leaders.

Another important issue is high production costs and the need for substantial funding, because laser production involves expensive materials and specialised components. The production of laser products requires highly precise equipment, advanced technological processes, and highly skilled employees, which also increase production costs. High costs can make it difficult for smaller producers to remain competitive, as larger companies have greater production capacities and can benefit from economies of scale. Gu (2021) highlights that the main challenge in a high-power ultrafast laser industry is the cost of ownership, as the market is highly elastic to price changes.

However, high operating costs and R&D investment can be an obstacle for smaller companies, thus ensuring sufficient R&D funding is a critical issue. The uncertainty of funding can hinder long-term planning and risk taking in larger-scale projects.

The laser industry, like many other high-tech sectors, is highly dependent on global supply chains. From a historical perspective, geopolitical events, economic crises, or even global pandemics significantly affected supply flows. Supply chains can be vulnerable when conflicts, trade restrictions, or logistical disruptions arise. Smaller producers may face problems in meeting the needs of raw materials and components which affect production expansion and efficiency; therefore, to mitigate supply chain vulnerabilities, companies must diversify their suppliers and explore regional sourcing options to reduce logistics costs and reduce risks.

Export performance is greatly influenced by different trade regulations across global markets, which can complicate or limit the possibilities of laser producers to export laser products. In addition, the export success of the laser industry may be hampered by market saturation and the challenges in maintaining a balance between price and quality. While industries in Lithuania have quite favourable environment for the development of technology-based industries, laser producers face specific regulatory challenges that also affect the laser export performance. Laser manufacturing often involves hazardous components, thus, compliance with waste management regulations, including proper disposal and recycling, can be complex and expensive. The laser manufacturing process is energy-intensive, and compliance with energy efficiency standards and potential carbon taxes can affect costs.

As an EU member state, Lithuania must ensure CE certification for most products, including lasers. Compliance with strict safety standards and documentation can be time-consuming. Depending on the laser product specifics (e.g. medical, industrial), additional certifications are usually required.

The core aim of the article is to conduct an empirical analysis for the Lithuanian laser industry to assess the main export development determinants in the context of rapid technological advancement and geopolitical uncertainty seeking investigate possibilities to maintain export growth trends.

The contribution to the issue is based on performing in-depth analysis investigating impact of different types of exogenous and endogenous factors on laser exports and on providing deeper insight on effects in the context of rapid technological progress and unstable geopolitical environment. The originality of this research is based on the lack of empirical studies specifically focused on the Lithuanian laser industry. This case study analyses the performance of the sector during the period 2013–2023.

The article is organised as follows: The first section of the article covers the review of the relevant scientific literature. The second part outlines the method and data of the empirics. The third section of the article presents the results and findings analysis. The article ends with a discussion of the results obtained and the conclusion of the research.

Literature Review

The large number of scientific publications on the development and challenges of the laser industry highlight the strategic importance of the laser sector and wide range of applications of laser products and technologies (Niu *et al*., 2024; Guo *et al*., 2024; Latz *et al*., 2021; Zhang *et al*., 2022). The potential use of advanced laser propulsion technology in aerospace applications was discussed by Sinko (2024). Abbas & Jamil (2024) investigated how emerging laser propulsion techniques can be applied in aerospace for purposes such as centimetre-scale debris removal, pointing micro and nanosatellites, and laser micro-thrusters for spacecraft attitude and orbit control.

The application of lasers in the electronics, telecommunications, and automative industries, and the huge number of other fields, contributes to increased efficiency and quality, and to reduced energy consumption and material waste (Angeloni *et al*., 2023; Jones *et al*., 2022). The integration of laser technology into medicine has led to remarkable advancements in diagnostic, therapeutic, and surgical procedures, offering enhanced precision and efficiency (Reyes, 2023; Sroka & Lilge, 2016; Niu *et al*., 2024; Biswas, Sikander & Kulkarni, 2023). The extensive use of lasers in military operations encourages a rapidly growing demand for laser production in the context of the current geopolitical situation (Epicoco, 2021; Lazov *et al*., 2021).

When assessing the factors that determine the export performance of high-tech industries, various aspects are taken into account. However, particular attention is first paid to R&D expenditure, the creation of innovations, especially technological ones, the availability of highly educated employees, and the relationship between industry and scientific institutions. These factors can stimulate high-tech performance both endogenously and exogenously. An empirical study of Zapata *et al*. (2024) provides evidence of the relevance of variables such as the percentage of university graduates in the population, R&D expenditure as a share of GDP, the stock of inward foreign direct investment, imports of high-tech manufactures as a share of GDP, and the quality of national governance and regulation in the EU as key determinants of technology-intensive exports.

Public expenditure on R&D is considered an important exogenous factor. However, scholars emphasise the significant role of R&D and technological innovations carried out within companies, providing evidence that this endogenous factor encourages export growth, particularly in high-tech sectors (Zhang & Sun, 2019; Aflaki *et al*., 2021; Bayraktutan *et al*., 2018).). The findings of Yang (2024), who investigated the multifaceted impacts of R&D activities on exporting behaviour, confirm that companies engaged in R&D are more likely to self-select in exporting, achieve higher export volumes, charge lower prices, export a broader range of products, and access more export markets. An empirical study by Sandu & Ciocanel (2014) found that the effect of private R&D expenditure on high-tech exports is stronger than that of public R&D expenditure. Endogenous investment in R&D is a key mechanism that contributes to long-term performance divergence between companies with differing levels of export market exposure (Peters *et al*., 2022).

However, the relationship between higher education and the manufacturing industry is close and reciprocal, as the development of high-tech sectors significantly influences the advancement of academic disciplines in universities. Rapid economic, environmental, and social transformations in the technological era have increased the demand for advanced skills, competencies, and knowledge (Twining *et al*., 2021). Slimi (2023) discusses the importance of artificial intelligence literacy training for technology graduates, with the aim of meeting the growing demand for AI-related competencies. Buenstorf & Heinisch (2020) analysed the performance of German laser companies and found that academic start-ups became increasingly competitive following substantial changes in the governance of university–industry relationships. The education system of a country plays a critical role in preparing highly educated specialists for the labour market and exerts an exogenous impact on industry performance.

However, researchers (Wang *et al*., 2022; Tebaldi, 2011) emphasise the endogenous role of improving employees' skills and knowledge within companies. Company funds allocated to various training programmes aimed at acquiring advanced expertise – particularly in the context of rapid digital technological progress – have become an important determinant, especially in high tech sectors. The availability of qualified labour, particularly in the fields of science, technology, and engineering, is also a key driver of the development of the high-tech industry. A study conducted by Wang et al. (2022) demonstrated that flows of highly qualified labour between cities have a significant impact on the development of high-tech industrial regions, which are often closely interconnected.

Bayraktutan *et al*. (2018) investigated the impact of R&D expenditure, the number of researchers, and other determinants on the exports of high-tech and medium-high-technology industries. They found that the elasticity of R&D expenditure with respect to high-tech exports is higher in developing countries than in developed ones. According to the results of the panel vector error correction model, there is long-term causality from R&D expenditure and the number of researchers and short-term causality from gross fixed capital formation and foreign direct investment to high-tech export volumes. Tung (2024) argues that countries, especially emerging economies, should employ more intellectual capital to improve industry competitiveness on the global market.

The impact of patents, as intellectual assets, on export performance has been widely discussed by scholars (Palangkaraya *et al*., 2017; Xu & Chiang, 2005). The direction of this effect is often explained by the assumption that firms export to foreign markets if they possess a quality or cost advantage due to patented solutions. According to Brunel & Zylkin (2022), the positive effects of patents on exports vary between industry groups. Patents tend to promote significantly more export growth in industries with high demand elasticity and in those that are relatively further downstream in the supply chain. An empirical study by Tebaldi (2011), which examined the determinants of high-technology exports, demonstrated that human capital, inward foreign direct investment, and openness to international trade are major drivers of high-tech industry performance in the global market. However, gross capital formation, national savings, and macroeconomic volatility had no significant effect on high-tech exports.

Considering the influence of the real exchange rate on export performance, Blecker (2023) argued that the effects differ by the type of goods exported, while the negative effects of overvaluation on export growth may be stronger than the positive effects of undervaluation. If the effects of the real exchange rate on export growth rates are found only for medium-term transitions, scholars argue that these may imply a long-term impact on levels of output.

Research by Kim *et al*. (2022) investigated factors that affect the technological transition of companies toward Industry 4.0 technologies, focussing on firm capabilities and policy impact using related and complexity measures. The ability of a company to effectively manage an innovation process, adapt to technological changes, integrate new knowledge, and the role of organisational capabilities in technological transition was emphasised. However, the authors state that the companies with greater government support are more likely to integrate intelligent digital technologies into production processes, such as a set of technologies that include industrial equipment, artificial intelligence, big data, robotics, etc. The creation and dissemination of knowledge, their diffusion within a company and between companies is the driver for promotion of innovations (Carlsson, 2013). In high-tech clusters, mechanisms such as collaboration and informal networks facilitate knowledge diffusion, increase collective learning and innovation capacity. Zapata *et al*. (2024) identified the role of technological complexity and innovation capacity as endogenous factors determining high-tech exports. Their empirical study confirmed that corporate policies directed to promote knowledge creation and diffusion by organising training programmes and seminars for qualification improvement have significant impact enlarging high-tech export volumes. Daszkiewicz & Wach (2023) consider high-tech industries as highly innovative, whose inherent feature lies in innovations. Feng (2020) emphasises the importance of technological infrastructure in companies as a foundation for high-tech industries and regional economic growth. Advanced infrastructure, such as research laboratories, IT networks, and knowledge-sharing systems, drives innovation activity and productivity growth in companies. The strategic role of investment in tangible and intangible assets in export performance was highlighted in various studies (Shahabadi *et al*., 2023; Resta *et al*., 2024; Leogrande *et al*., 2022). Investment in tangibles such as advanced digital or robotic technologies and modern machinery increases production capacity and product quality and allows high-tech companies to compete more effectively in global markets. It is valuable to distinguish intellectual property, patents, proprietary technologies, and skilled human capital as intangible assets considering them drivers for operating in foreign markets.

Epicoco (2021) states that exogenous factors impacting technological development and innovations may include random historical events (e.g., wars, crises, Covid-19), technical factors, public policies, and socio-institutional determinants. Military and political conflicts can accelerate technological innovation in the military industry due to faster demand for advanced solutions (Kaushal & Kaddoum, 2017), the participation of the company in the military business acts on substantive innovation outputs and further affects their technological innovation through the intensity of R&D (Yang & Liu, 2022).). On the other hand, political conflicts increase the risk, instability and lower expectations in the market, disrupting supply chains. The increase in economic policy uncertainty has a negative impact on manufacturing value-added trade flows primarily through the cost to export (Zhao, 2022). Financial crises can limit investment in R&D, slowing technological progress. Public policies shape an innovative environment, set industry standards, encourage the relationship between industry and scientific institutions, and influence consumer behaviour. Aflaki *et al*. (2021) also stress the positive effect of public investment in R&D investment and public policies on innovation creation and diffusion in high tech. Scholars highlight the importance of policies for environmental protection and ecological transition in high-tech performance (Roussilhe *et al*., 2022). The impact of interest rate incentives that encourage industry companies to gain a strategic advantage was disclosed by Liu *et al*. (2019). The trade policy implications are discussed as exogenous factor, specifically the imposition of higher import tariffs, and cases of trade conflict determine to negative shifts in global supply chains, forcing companies to adapt to changed competitive environment and new trade barriers (Benguria, 2023; Wang & Xie, 2025). These highlights how the geopolitical events and regulatory policies may have a significant impact on the performance and strategic decisions of companies around the world.

In conclusion, scientists analysed the determinants of high-tech industries development but there are very few studies that specifically examine the factors of the laser industry; thus, there is a research gap in the scientific literature on the factors impacting the laser export, that encourage to perform an empirical study on the case of Lithuanian laser industry.

Method

The empirical study analyses data for the period 2013 – 2023, which was collected using a database provided by the State Data Agency and the Central Bank of Lithuania. The sources were chosen because of their high reliability and the possibility of obtaining data for a longer period.

In the first stage, an econometric estimation of the impact of selected factors on the export performance of the Lithuanian laser industry is performed. As a dependent variable in this analysis, the Lithuanian laser export volume (thousand euros) is assigned. Following the analysis of the scientific literature, these factors were selected as independent variables: the number of R&D employees in the sector, total sectoral operating profit of enterprises (euros), sectoral gross investment in new buildings and structures (euros), sectoral investment in technology and equipment (euros), sectoral gross investment in patents and licenses (euros), the number of employees in the sector, sectoral employee costs (euros), sectoral R&D expenditure (million euros), public funding for R&D (million euros), total sectoral inward FDI (million euros), the number of companies in the sector, the number of military conflicts in the world, the number of electrical car models produced in Europe, average annual interest rates for companies (%), exchange rate (EUR/USD).

To comprehensively understand the complex relations between various economic and non-economic factors and laser industry export performance, a suite of econometric models has been employed. Stationarity test, correlation analysis, regression model, the Granger causality test and the autoregressive distributed lag (ARDL) model have been specifically chosen for their ability to analyse time series data and reveal the strength, direction, and effect of these interdependencies. Econometric estimations have been carried out using EViews 12 software.

The empirical evaluation firstly includes an assessment of the stationarity of the time series. The unit root method is used to test the stationarity of the time series of the variables. In the case of non-stationarity, dependent and independent variables are differenced once (if the process is I(1)) or twice (if the process is I(2)):

$$\Delta y_t = y_t - y_{t-1} \quad (1)$$

$$\Delta\Delta y_t = \Delta y_t - \Delta y_{t-1} = (y_t - y_{t-1}) - (y_{t-1} - y_{t-2}) = y_t - 2y_{t-1} + y_{t-2} \quad (2)$$

This step is followed by tests using two different methods. The first is correlation analysis with stationary variables. The correlation between the dependent and independent variables is determined by Pearson's correlation coefficient and the significance is estimated by the T-statistics probability. Obtained results show what kind of correlation exists (strong, moderate, or weak correlation), and the test shows if the correlation is significant. With the obtained significant correlations, regression models with stationary variables are created. The results of the model are evaluated in terms of the significance of the model and the significance of the variables. If the model and the variables in the model are significant and the error conditions are met, the model results are used to determine the impact of selected factors on the export performance of the Lithuanian laser industry.

The second method is the Granger causality test with stationary variables. The Granger causality test is used to examine the direction of the relationship between the variables. The causal relationship between variables is established by the Granger causality test. The equations for this test are:

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \cdots + \alpha_i y_{t-1} + \beta_1 x_{t-1} + \cdots + \beta_i x_{t-1} + \varepsilon_t \quad (3)$$

$$x_t = \alpha_0 + \alpha_1 x_{t-1} + \cdots + \alpha_i y_{t-1} + \beta_1 y_{t-1} + \cdots + \beta_i y_{t-1} + \varepsilon_t \quad (4)$$

The equations are used to test hypothesis:

$$\boldsymbol{H_0}: \beta_1 = \beta_2 = \cdots = \beta_i = 0 \quad (5)$$

Acceptance of the H_0 hypothesis implies that x has no effect on the variation of y in the first equation and the opposite variation in the second equation.

If significance is found, a Schwarz (SC) test is performed, and the most appropriate model is identified. If the appropriate ARDL model is identified, an ARDL model with stationary variables is developed. Once the model is created, the obtained results are evaluated in terms of model significance, stability, and significance of the values. If the value obtained is not significant, the model is modified by removing the most insignificant parameter from the model. The initial or new model must satisfy the error conditions.

After the empirical study, the results are summarised and compared with the outcomes of other estimations, discussed in the literature review.

Results

The empirical analysis started by establishing the stationarity of each variable, which is a prerequisite for many statistical and econometric methods. Stationarity will assess whether the meaning and variance of the variables remain constant over time. It was found that stationary times series are investment in patents and licenses and exchange rate; the first order integrated I(1) time series are FDI, the number of enterprises, investment in buildings and structures, personnel costs, investment in technology and equipment assets, R&D expenditure in the sector, operating profits, the number of employees, the number of military conflicts. The second order integrated I(2) time series are laser export, the number of electric car models produced in Europe, average annual interest rates, public investment in R&D, the number of R&D employees in the sector.

In order to determine the relationship between the dependent variable and the independent variables, a correlation matrix and the Granger causality test are developed. Correlation is assessed by Pearson's correlation coefficient, which indicates the strength of the relationship, and the probability which indicates whether there is a significant linear relationship between the dependent and independent variables.

Table 1

Correlation Matrix

Variable	Pearson's correlation coefficient	Probabilities
	Δexport	
ΔFDI	0.2675	0.4865
Δnumber of military conflicts	0.6775	0.0510
Δnumber of enterprises	0.4456	0.2293
ΔΔnumber of electric car models produced in Europe	0.1057	0.7867
ΔΔinterest rates	-0.7699	0.0429
Δpublic investment in R&D	-0.8021	0.0093
Δinvestment in buildings and structures	0.5807	0.1011
Investment in patents and licenses	0.1302	0.7385
Δpersonnel costs	0.3784	0.3153
Δinvestment in technology and equipment assets	0.0364	0.9259
ΔΔnumber of R&D employees in the sector	-0.4941	0.1764
ΔR&D expenditure in the sector	-0.7575	0.0181
Δoperating profits	0.6458	0.0603
Exchange rate	0.3275	0.3896
Δnumber of employees	0.3584	0.3436

The results of the correlation matrix show that interest rates, public investment in R&D and R&D expenditure in the sector do not exceed the value of 0.05, indicating a correlation with these variables. The probability values for the other selected variables are above 0.05, indicating that the correlation is not significant. The correlations between interest rates (-0.7699), public investment in R&D (-0.8021) and R&D expenditure in the sector (-0.7575) and the laser exports show a strong negative relationship. These variables will be used in a further study to develop regression models to assess the short-term impact of the variables.

Table 2

Estimates of the Regression between the Laser Industry Export and the Interest Rate

Independent variable	Estimates	Probabilities
C	27233.16	0.2404
ΔΔinterest rates	-55900.20	0.0429
Adjusted R^2	0.5113	
Probability of F-statistic	0.04299	
Mean of the errors	4.68e-12	
Normality of errors: Jargue-Bera probability	0.4930	
Breusch-Pagan test probability	0.6427	
LM test probability with lag=1	0.6301	

The independent variable – interest rate – is a significant parameter because its probability is less than alpha meaning (0.05), the model is significant (F-statistic is less than 0.05) and the accuracy of the model is 51.3 %, which indicates a moderate relationship between variables. The model errors satisfy zero means. The results of the regression model show that the increase in the interest rate had a negative impact on export performance. The model shows that the one percentage point increase in the interest rate leads to an average decrease in export performance of EUR 55.9 million within one year.

The short-term effect of interest rates on the export performance of the Lithuanian laser industry under the regression model is given by the equation:

$$\Delta\Delta export_t = 27233.16 - 55900.20 * \Delta\Delta interest\ rates_t \quad (6)$$

This equation can be rewritten using (2) formula:

$$export_t = 27233.16 + 2export_{t-1} - export_{t-2} - 55900.20 * interest\ rates_t + 111800.40 * interest\ rates_{t-1} - 55900.20 * interest\ rates_{t-2} \quad (7)$$

The regression model between laser industry exports and public investment in R&D is being developed further.

Table 3

Estimates of the Regression between the Laser Industry Export and Public Investment in R&D

Independent variable	Estimates	Probabilities
C	10607.46	0.7469
Δpublic investment in R&D	0.1382	0.86611
Adjusted R^2	-0.1379	
Probability of F-statistic	0.8661	
Mean of the errors	-4.04e-12	
Normality of errors: Jargue-Bera probability	0.5357	
Breusch-Pagan test probability	0.6224	
LM test probability with lag=1	0.0688	

The results of the regression model are not significant. Public investment in R&D is a non-significant parameter and the obtained F-statistic is greater than 0.05 which indicates that the model itself is also not significant. Although the model errors satisfy zero means, the model does not show a significant relationship between the export performance of the laser industry and public investment in R&D. The regression model between Lithuanian laser industry exports and the R&D expenditure in the sector will be developed.

Table 4

Estimates of the Regression between the Laser Industry Export and R&D Expenditure in the Sector

Independent variable	Estimates	Probabilities
C	533472.50	0.0407
ΔR&D expenditure in the sector	-2.1775	0.0181
Adjusted R^2	0.5129	
Probability of F-statistic	0.0181	
Mean of the errors	7.07e-12	
Normality of errors: Jargue-Bera probability	0.7269	
Breusch-Pagan test probability	0.1786	
LM test probability with lag=1	0.7674	

The regression model showed that R&D expenditure in the sector is significant, and the F-statistic of the model is greater than 0.05 which indicates that the model is significant. The accuracy of the model is obtained at 51.29%, indicating that the model is moderately accurate. The results of the regression model satisfy all four error criteria. The results show a negative impact of R&D expenditure in the sector on the export performance of the laser industry – an increase in R&D expenditure of EUR 1 million results in an average decrease in export of EUR 2.18 million in the current year. Although R&D investment is generally expected to have a positive impact on export performance, the model shows the opposite trend. This result may indicate that R&D expenditure has a negative effect in the current year.

The short-term effect of R&D expenditure in the sector on the export performance of the Lithuanian laser industry is captured by the regression model in the following equation:

$$\Delta\Delta export_t = 53472.50 - 2.1775 * \Delta R\&D\ \ business\ sector_t \quad (8)$$

After elimination of the differences, the model's expression is given as follows:

$$export_t = 53472.50 + 2export_{t-1} - export_{t-2} - 2.1775 * R\&D\ \ business\ sector_t + 2.1775 * R\&D\ business\ sector_{t-1} \quad (9)$$

The Granger causality test shows whether changes in the independent variable affect changes in the dependent variable.

Table 5

Granger Causality Test Results

Hypothesis	I=1	I=2
Δ(FDI) → ΔΔexport	0.1871	0.6780
Δnumber of military conflicts → ΔΔexport	0.1327	0.0301
Δnumber of enterprises → ΔΔexport	0.3280	0.1995
ΔΔnumber of electric car models produced in Europe → ΔΔexport	0.9326	0.6282
ΔΔinterest rates → ΔΔexport	0.1719	0.1369
ΔΔpublic investment in R&D → ΔΔexport	0.6304	0.1049
Δinvestment in buildings and structures → ΔΔexport	0.2982	0.2624
Investment in patents and licenses → ΔΔexport	0.3498	0.0381
Δpersonnel costs → ΔΔexport	0.4486	0.2911
Δinvestment in technology and equipment assets → ΔΔexport	0.2716	0.5253

Hypothesis	I=1	I=2
ΔΔnumber of R&D employees in the sector → ΔΔexport	0.9920	0.5833
ΔR&D expenditure in the sector → ΔΔexport	0.2307	0.4780
Δoperating profits → ΔΔexport	0.1684	0.4108
Exchange rate → ΔΔexport	0.3864	0.8918
Δnumber of employees → ΔΔexport	0.2648	0.1511

After the Granger causality test, the results are as followed – the number of military conflicts and investment in patents and licenses are influencing the change in Lithuanian laser exports. The influence of both independent variables is evident after including 2-year lags. As the empirical analysis examines the impact of selected factors on the export performance, based on the results of the causality test, ARDL models are developed between the export performance of the laser industry and the number of military conflicts and the investment in patents and licenses.

In order to determine the most appropriate model for the number of military conflicts and exports of Lithuanian laser industry, the values of the Schwarz (SC) were used. Results indicate that the most appropriate ARDL model is ARDL(2,2), since both variables – the number of military conflicts and the export performance – were non-stationary, variables are differentiated.

Table 6

ARDL(2,2) Model Results for the Number of Military Conflicts and the Laser Industry Export

Variable	ARDL (2,2) estimates	Probabilities
C	54562.28	0.0341
ΔΔ(export (-1))	1.1207	0.0723
ΔΔ(export (-2))	1.4472	0.0284
Δ(number of military conflicts (-1))	-25973.72	0.0179
Δ(number of military conflicts (-2))	-3319.07	0.3491
Adjusted R^2	0.9401	
Probability of F-statistic	0.0396	
Mean of the errors	5.16e-12	
Normality of errors: Jargue-Bera probability	0.9833	
Breusch-Pagan test probability	0.1384	
LM test probability with lag=1	0.882	

The results of the ARDL(2,2) model demonstrate that the model is not stable, but significant variables are obtained. The probability of the F-statistic indicates that the model is significant, and its accuracy makes 94 %. The model results also satisfy all four error criteria. The results of the model show that the significant impact of the number of military conflicts on export volumes is felt after one year. The results show that the additional occurrence of the military conflict after one year reduces export volumes by EUR 25.97 million. Considering the results obtained, the further impact is not significant.

Estimating equation for the impact of the number of military conflicts on Lithuanian laser industry exports:

$$\Delta\Delta export_t = 54562.28 + 1.1207 * \Delta\Delta export_{t-1} + 1.4472 * \Delta\Delta export_{t-2} - 25973.72 * \Delta military\ conflicts_t - 3319.07 * \Delta military\ conflicts_{t-1} \quad (10)$$

The expression of the transformed model is:

$$export_t = 54562.28 + 0.8793 * export_{t-1} - 0.2058 * export_{t-2} + 1.7737 * export_{t-3} - 1.4472 * export_{t-4} - 25973.72 * military\ conflicts_t + 22654.65 * military\ conflicts_{t-1} + 3319.07 * military\ conflicts_{t-2} \quad (11)$$

The ARDL model for the export of the Lithuanian laser industry and investment in patents and licenses is being further developed. To determine the most appropriate model, the values of the Schwarz criterion (SC) are estimated. The results indicate that the most appropriate ARDL model is ARDL(1,2), since only one variable – the export performance – was non-stationary, variable is differentiated.

Table 7

ARDL(1,2) Model Results for the Investment in Patents and Licenses and the Laser Industry Export

Variable	ARDL (2,2) estimates	Probabilities
C	-49460.87	0.0502
ΔΔ(export (-1))	-0.0937875	0.0058
Investment in patents and licenses	-0.0157	0.4120
Investment in patents and licenses (-1)	0.0588	0.0289
Investment in patents and licenses (-2)	0.0923	0.0084
Adjusted R^2	0.9155	
Probability of F-statistic	0.0169	
Mean of the errors	1.159e-12	
Normality of errors: Jargue-Bera probability	0.7753	
Breusch-Pagan test probability	0.1422	
LM test probability with lag=1	0.132	

The F-statistic probability is less than 0.05 indicating that the model is significant and has a high accuracy – 91.55 %. The zero mean conditions are satisfied. The model variables are significant when including lags 1 and 2, indicating the impact of investment in patents and licenses on the export performance of the Lithuanian laser industry. The results for the current year (without lags) have no impact on export performance, as the obtained possibility is above 0.05 and the indicator is not significant. The model demonstrates that investment in patents and licenses has a positive impact after one and two years. The results show that investing one euro in patents and licenses increases in Lithuanian laser industry exports by EUR 58.8 and after two years the positive impact is even stronger – investing one euro in patents and licenses increases export volumes by EUR 92.3.

Equation for estimating the impact of investment in patents and licenses on the export performance of the Lithuanian laser industry:

$$\Delta\Delta export_t = -49460.87 - 0.937875 * \Delta\Delta export_{t-1} - 0.0157 * investment_t + 0.0588 * investment_{t-1} + 0.0923 * investment_{t-2} \quad (12)$$

This equation can be rewritten using the (2) formula:

$$export_t = -49460.87 + 1.0621 * export_{t-1} + 0.8758 * export_{t-2} - 0.937875 * export_{t-3} - 0.0157 * investment_t + 0.0588 * investment_{t-1} + 0.0923 * investment_{t-2} \quad (13)$$

Taken together, the results suggest that interest rates have a moderate negative significant linear relationship with the export performance of the Lithuanian laser industry. One percentage point increase in the interest rate leads to an average decrease in export volumes of EUR 55.9 million. A moderate negative significant linear relationship also seen between R&D expenditure in the sector and laser exports. An increase in R&D expenditure of €1 million decreases export volumes by EUR 2.18 million on average. The Granger causality test found that both the number of military conflicts and investment in patens and licenses have an impact on the export performance of the Lithuanian laser industry. The number of military conflicts has a negative impact on export performance – an additional military conflict reduces export volumes by EUR 25.97 million, but this effect is visible only after one year, while after two years, the effect is not significant. The causality test also shows a positive impact of investment in patents and licenses on the export performance of the Lithuanian laser industry. This effect is visible after 1 and 2 years. After one year, an additional investment of one euro in patents and licenses increases the volume of exports by EUR 58.8 and after two years the export amount increases to EUR 92.3.

Discussion

Considering the results obtained, first, it is important to stress the impact of intellectual capital on the export performance of the Lithuanian laser industry. The results of the empirical analysis showed that investment in patents and licenses has a positive impact on export performance after one and two years. This goes in line with evidence of investigations, provided by Xu & Chiang (2005), stating that international trade flows and trade openness have large effects on technology spillovers and countries benefit from investment to domestic and foreign patents. The results confirm the findings of Brunel & Zylkin (2022), Palangkaraya *et al*. (2017) considering the positive effect of investment in intellectual properties on export performance in global markets, thus the investment in patents and licenses becomes vital for accessibility to innovation and maintaining competitive advantage based on quality. Investing in patents helps develop unique products, which facilitate access to foreign markets and more sustainable operation globally.

The importance of private R&D expenditures for high-tech export development is highlighted by Zhang & Sun, (2019), Aflaki *et al*. (2021), Bayraktutan *et al*. (2018). The results obtained in this study do not confirm the results got by other scholars, since they reveal a negative impact of sectoral R&D expenditure on Lithuanian laser export performance. This outcome could have been obtained due to limited data for R&D expenditure exclusively in the laser industry and the use of broader sectoral data. Another cause of the negative impact could be related to the inclusion of time series that are quite short or annual data that cannot measure the evolution of export volumes in the current year. However, the expenditure on R&D activities, aimed at advancing scientific or technological knowledge, does not always ensure that innovative decisions or technological inventions will be developed. The scientific literature provides evidence that the significant relationship between R&D intensity and export capacity has not been confirmed in part of empirical studies (Becchetti & Rossi, 2000; Wagner, 2008). The research results of Yaseen *et al.* (2025) imply that despite the increase in levels of R&D and innovation in the economies analysed, these factors have not led to improved sustainability in trading practices. Evidence of a negative relationship between the scale of innovation activity and export performance is provided by Roper & Love (2002). Ganotakis & Love (2011) noted that product innovators are more likely to export, but conditional on entering export markets successful innovation does not increase subsequent export intensity. Toker *et al*. (2017) pointed out that alone R&D expenditure in the sector does not have a direct significant impact on export performance and stressed the significance of the number of employees involved in research activity. Our analysis also implies that the investment in patents and licenses plays a more significant role for Lithuanian laser industry development than R&D expenditure and emphasises the meaningful impact of technology spillover, especially in high-tech.

The impact of interest rates on the industry was examined by Liu *et al.* (2019), who argue that rising interest rates increase the cost of borrowing, which may discourage firms from undertaking new projects or expanding existing activities. Such a scenario may stifle innovation and slow the growth of high-tech exports. Another aspect is the impact of rising interest rates on the growth of exchange rates and export competitiveness. The results in this empirical analysis go in line with studies reviewed in the Literature review section.

Our study finds that the number of military conflicts has a negative impact on laser export performance. In contrast, Teirumnieks & Ghalot (2021), Epicoco (2021), Kaushal & Kaddoum (2017) look at the increasing applicability of lasers in the military industry, which indicates that the occurrence of an additional military conflict is expected to have a positive impact on export performance. However, the results obtained confirm the findings of Zhao (2022), arguing that negative impact can occur, since the military and political conflicts, economic policy uncertainty can cause a supply chain disruption, instability and risks in markets, reduce demand, increase trade costs.

Conclusions

The motivation for research is based on the importance of the laser sector in any economy and the insufficient scientific studies on determinants of export development that specifically address the laser industry. Lithuania is among the global leaders in laser technologies, and the contribution of the research is justified on the in-depth analysis of the drivers affecting the growth of Lithuanian laser export. The empirical study selected a wide range of endogenous and exogenous independent variables that have been identified in the scientific literature as factors that affect the export performance of high-tech industries. The scope of factors which were included in the investigation depended on their availability in the databases. The results of the empirical study showed that the export performance of the Lithuanian laser industry has a strong negative correlation with interest rates and private R&D expenditure in the sector. A more detailed analysis showed that a 1 percentage point increase in the interest rate reduces Lithuanian laser export volumes EUR 55.9 million, while a EUR 1 million increase in R&D expenditure in the sector reduces export volumes by EUR 2.18 million.

The Granger causality test revealed that the number of military conflicts and the volume of investment in patents and licenses affect export performance after the inclusion of one and two lags. The results of the ARDL model between the number of military conflicts have a negative effect on export performance. One additional occurrence of military conflict has an impact on export performance after one year, which decreases by EUR 25.97 million. The ARDL model between export of Lithuanian laser industry and investment in patents and licenses shows that investment in patents and licenses has a positive impact on the export performance – an additional investment of EUR 1 in patents and licenses increases the volume of laser exports by almost EUR 59 after one year, and by just over EUR 92 after two years.

This study provides evidence and valuable insights to stakeholders and policy makers, thus contributing to a deeper understanding of the sustainable efforts needed to stimulate the growth of the laser sector in terms of production and export volumes. The magnitude of investment in the acquisition of intellectual property and the effect of the technology spillover are emphasised. This study embarks on an insightful exploration for companies and stakeholders considering endogenous investment in patents and licenses. Exogenous strategic support for the acquisition of intellectual property, accessibility to capital, and the mitigation of external economic risks are key insights for policy implications.

References

Abbas, A., & Jamil, Y. (2024). Ablative laser propulsion, the propellants and measuring parameters: a brief overview. *Journal of laser applications*, 36, 021201. https://doi.org/10.2351/7.0001342

Aflaki, S., Basher, S.A., & Masini, A. (2021). Technology-push, demand-pull and endogenous drivers of innovation in the renewable energy industry. *Clean Technologies and Environmental Policy*, 23, 1563–1580. https://doi.org/10.10 07/ s10098-021-02048-5

Angeloni, C., Francioso, M., Liverani, E., & Ascari, A. (2023). Laser welding in e-mobility: process characterization and monitoring. *Lasers in Manufacturing and Materials Processing*, 11(1), 1-22. https://doi.org/10.1007/s40516-023-00216-7

Balassa, B. (1965). Trade Liberalization and Revealed Comparative Advantage. *The Manchester School of Economic and Social Studies*, 33, 99-123. https://doi.org/10.1111/j.1467-9957.1965.tb00050.x

Bayraktutan, Y., Bidirdi, H., & Kutlar, A. (2018). Research and Development and High Technology Exports in Selected Countries at Different Development Stages: a Panel Co-integration and Causality Analysis. In: F. Bakirci, T. Heupel, O. Kocagoz, U. Ozen (Ed.) German-Turkish Perspectives on IT and Innovation Management. https://doi.org/10.1007 /978-3-658-16962-6_3

Becchetti, L., & Rossi, S. P. (2000). The positive effect of industrial district on the export performance of Italian firms. *Review of industrial organization*, 16(1), 53-68. https://doi.org/10.1023/A:1007783900387

Biswas, P., Sikander, S., & Kulkarni, P. (2023). Recent advances in robot-assisted surgical systems. *Biomedical Engineering Advances*, 6, 100109. https://doi.org/10.1016/j.bea.2023.100109.

Blecker, R. A. (2023). How important is the real exchange rate for exports and growth? *European Journal of Economics and Economic Policies Intervention*, 20(2), 250-265. https://doi.org/10.4337/ejeep.2023.0099

Brunel, C., & Zylkin, Th. (2022). Do cross-border patents promote trade? *Canadian Journal of Economics*, 55(1), 379-418. https://doi.org/10.1111/caje.12577

Buenstorf, G., & Heinisch, D.P. (2020). Science and industry evolution: evidence from the first 50 years of the German laser industry. *Small Business Economics*, 54, 523–538. https://doi.org/10.1007/s11187-018-0032-6

Benguria, F. (2023). The global impact of the US–China trade war: firm-level evidence. *Review of World Economics*, 159, 827–851. https://doi.org/10.1007/s10290-022-00490-1

Carlsson, B. (2013). Knowledge Flows in High-Tech Industry Clusters: Dissemination Mechanisms and Innovation Regimes. In: A. Pyka, E. Andersen (Ed.) Long Term Economic Development. Economic Complexity and Evolution. Springer. https://doi.org/10.1007/978-3-642-35125-9_9

Daszkiewicz, N., & Wach, K. (2023). Networking and Familiness as Factors Stimulating the Early Internationalization of High-Tech Firms. *Inzinerine Ekonomika-Engineering Economics*, 34(5), 554–567. https://doi.org/10.5755/ j01.ee.34. 5.33855

Epicoco, M. (2021). Technological Revolutions and Economic Development: Endogenous and Exogenous Fluctuations. *Journal of the Knowledge Economy*, 12, 1437–1461. https://doi.org/10.1007/s13132-020-00671-z

Ganotakis, P., & Love, J. H. (2011). R&D, product innovation, and exporting: evidence from UK new technology based firms. *Oxford Economic Papers*, 63(2), 279–306. https://doi.org/10.1093/oep/gpq027

Grand View Research (2024). "Global Laser Technology Market Size Analysis Report, 2030". Available from internet: https://www.grandviewresearch.com/industry-analysis/laser-technology-market-report

Gu, B. B. (2021). New lasers for industrial manufacturing. SPIE (01-05-2021). Available from internet: https://spie.org/news/photonics-focus/mayjune-2021/new-lasers-for-industrial-manufacturing

Guo, H., Xie, J., He, G., Zhu, D., Qiao, M., Yan, J., Yu, J., Li, J., Zhao, Y., Luo, M., & Han, H. (2024). A review of ultrafast laser micro/nano fabrication: Material processing, surface/interface controlling, and devices fabrication. *Nano Research*, 17, 6212–6230. https://doi.org/10.1007/s12274-024-6644-z

Habenko, M. (2023). Export of high-tech goods in the context of innovation transfer for social-economic development: factor analysis. *SocioEconomic Challenges*, 7(2), 152-160. https://doi.org/10.21272/sec.7(2).152-160.2023

Hecht, J. (2010). Short history of laser development. *Optical Engineering*, 49(9), 091002. https://doi.org/10.1117/1.3483597

Ilmi, N. (2017). The Impact of Innovation and Foreign Direct Investment (FDI) and Its Interaction to Export Value of High-Technology Products of Asian-10. *Journal of Developing Economies*, 2(1), 47–57. https://doi.org/10.20473/jde.v2i1.5095

Latz, C., Asshauer, T., Rathjen, C., & Mirshahi, A. (2021). Femtosecond-Laser Assisted Surgery of the Eye: Overview and Impact of the Low-Energy Concept. *Micromachines*, 12(2), 122. https://doi.org/10.3390/mi12020122

Lazov, L., Teirumnieks, E., & Ghalot, R. (2021). Applications of Laser Technology in the Army. *Journal of Defence Management*, 11(4), 1-8. https://doi.org/10.35248/2167-0374.21.11.210.

Leogrande, A., Costantiello, A., & Laureti, L. (2022). The Impact of Patent Applications on Technological Innovation in European Countries. MPRA Paper. http://dx.doi.org/10.2139/ssrn.4275264

Liu, E., Mian, A., & Sufi, A. (2019). Low Interest Rates, Market Power, and Productivity Growth. Available from internet: https://www.ecb.europa.eu/press/conferences/shared/pdf/20191007_mo_po_conf/Low_interest_rates_market_power_and_productivity_growth.pdf?

Jones, L. C. R., Goffin, N., Ouyang, J., Mirhossein, N., Xiong, J., Li, Y., Li, L., Tyrer, J., Liu, Z., Woolley, E., He, Y., Mi, G., & Mativenga, P. (2022). Laser specific energy consumption: How do laser systems compare to other manufacturing processes? *Journal of Laser Applications*, 1; 34 (4), 042029. https://doi.org/10.2351/7.0000790

Kaushal, H., & Kaddoum, G. (2017). Applications of Lasers for Tactical Military Operations. IEEE Access. https://doi.org/10.1109/ACCESS.2017.2755678

Kim, S.H., Jeon, J., Aridi, A., & Jun, B. (2022). Factors that affect the technological transition of firms toward the Industry 4.0 technologies. *Economics*. https://doi.org/10.48550/arXiv.2209.02239

Manufacturing Technology Insights (2024). „Laser Technology: a Catalyst for innovation in European Manufacturing“ (2024-08-13). Available from internet: https://www.manufacturingtechnologyinsights.com/news/laser-technology-a-catalyst-for-innovation-in-european-manufacturing-nwid-4163.html

Niu, S., Wang, W., Liu, P., Zhang, Y., Zhao, X., Li, J., Xiao, M., Wang, Y., Li, J., & Shao, X. (2024). Recent Advances in Applications of Ultrafast Lasers. *Photonics*, 11(9), 857. https://doi.org/10.3390/photonics11090857

Palangkaraya, A., Jensen, P.H., & Webster, E. (2017). The effect of patents on trade. *Journal of International Economics*, 105, 1-9. https://doi.org/10.1016/j.jinteco.2016.12.002.

Peters, B., Roberts, M. J. & Vuong, V. A. (2002). Firm R&D investment and export market exposure. *Research Policy* 51(10), 104601. https://doi.org/10.1016/j.respol.2022.104601

Raciukaitis, G. (2023). „Laser Lithuania: why Lithuania is punching above its weight in laser technologies“. Lithuania Co-Create (2023-06-24). Available from internet: https://lithuania.lt/news/business-and-innovations-in-lithuania/laser-lithuania-why-lithuania-is-punching-above-its-weight-in-laser-technologies/

Reyes, P. (2023). Advancements in Laser technology for Medical Applications. *Journal of Lasers, Optics & Photonics*, 10, 115. Available from internet: https://www.hilarispublisher.com/open-access/advancements-in-laser-technology-for-medical-applications.pdf

Resta, E., Costantiello, A., Anobile, F., Laureti, L., & Leogrande, A. (2024). The Impact of Patent Applications on Technological Innovation in European Countries. *International Journal of Entrepreneurship* 28(3).

Roper, S., & Love, J. H. (2002). Innovation and export performance: Evidence from the UK and German manufacturing plants. *Research Policy*, 31(7), 1087-1102. https://doi.org/10.1016/S0048-7333(01)00175-5

Roussilhe, G., Pirson, T., Xhonneux, M., & Bol, D. (2022). From Silicon Shield to Carbon Lock-in? The Environmental Footprint of Electronic Components Manufacturing in Taiwan (2015-2020). *Computers and Society*. https://doi.org/10.48550/arXiv.2209.12523

Sinko, J. E. (2024). Laser Propulsion Science and Technology. *Aerospace*, 11(10), 806. https://doi.org/10.3390/aerospace11100806

Slimi, Z. (2023). The impact of Artificial Intelligence on Higher Education: An Empirical Study. *European Journal of Educational Sciences*, 10 (1). doi: http://dx.doi.org/10.19044/ejes.v10no1a17

Sandu, S., & Ciocanel, B. (2014). Impact of R&D and Innovation on High-tech Export. *Procedia Economics and Finance*, 15, 80-90. https://doi.org/10.1016/S2212-5671(14)00450-X.

Sroka, R., & Lilge, L. (2016). Laser-Advanced new methods for diagnostics and therapeutics. *Photonics & Lasers in Medicine*, 5(1), 1-4. https://doi.org/10.1515/plm-2015-0046

Shahabadi, A., Amjadian, S., Ghasemifar, S., & Shafieian, M. (2023). The effect of the national brand on high-tech exports in selected countries. *Journal of Innovation and Entrepreneurship*, 12(1), 1-19. https://doi.org/10.1186/s13731-023-00318-8

Tebaldi, E. (2011). The Determinants of High-Technology Exports: A Panel Data Analysis. *Atlantic Economic Journal*, 39, 343–353. https://doi.org/10.1007/s11293-011-9288-9

Toker, K., Tasci, M. E., & Gorener, A. (2017). The Mediator Effect Of R&D Employment On R&D Expenditures and Export Revenues. In M. Ozsahin (Ed.), Strategic Management of Corporate Sustainability, Social Responsibility and Innovativeness. *European Proceedings of Social and Behavioural Sciences*, 34, 332–339. https://doi.org/10.15405/epsbs.2017.12.02.28

Tung, L. T. (2024). Is the Export-Led Growth Model Valid in Emerging Economies? The Role of Intellectual Capital. *Inzinerine Ekonomika-Engineering Economics*, 35(3), 285–298. https://doi.org/10.5755/j01.ee.35.3.29581

Twining, P., Butler, D., Fisser, P., Leahy, M., Shelton, C., Forget-Dubois, N., &·Lacasse, M. (2021). Developing a quality curriculum in a technological era. *Educational Technology Research and Development*, 69, 2285–2308. https://doi.org/10.1007/s11423-020-09857-3

Wagner, J. (2008). Exports and firm characteristics: first evidence from fractional probit panel estimates. University of Lyneburg Working Paper Series in Economics, 97, 1–19. Available from internet: https://www.econstor.eu/bitstream/10419/28215/1/577512366.PDF

Wang, C., Wang, L., Xue, Y., & Li, R. (2022). Revealing Spatial Spillover Effect in High-Tech Industry Agglomeration from a High-Skilled Labor Flow Network Perspective. *Journal of Systems Science and Complexity*, 35, 839–859 https://doi.org/10.1007/s11424-022-1056-1

Wang, M., & Xie, Z. (2025). International trade barriers, export and industrial resilience: An empirical study based on the EU and USA antidumping and countervailing policies on photovoltaic products. *Energy Policy*, 201, 114556. https://doi.org/10.1016/j.enpol.2025.114556

Wei, W., Li, Q., Jin, Q., & Huang, Ch. (2024). Unleashing the Impact of Outward Foreign Direct Investment on the High-Quality Development of High-Tech Manufacturing Industry: Evidence from China. *Journal of the Knowledge Economy*. https://doi.org/10.1007/s13132-024-02363-4

Xu, B., & CHiang, E. P. (2005). Trade, Patents and International Technology Diffusion. *The Journal of International Trade & Economic Development*, 14(1), 115–135. https://doi.org/10.1080/0963819042000333270

Yang, X. (2024). Multifaceted impacts of R&D activities on exporting behavior. *Applied Economics*, 1–17. https://doi.org/10.108 0/00036846.2024.2401572

Yang, J., & Liu, R. (2022). Can Private Enterprises Improve Their Technological Innovation by Joining the Military Business? Evidence from China. *Inzinerine Ekonomika-Engineering Economics*, 33(5), 540–55. http://dx.doi.org/10.5755/j01.ee.33.5.31399

Yaseen, I., Singh, S., & Banerjee, S. (2025). Bolstering critical minerals trade between India and other MSP countries: A gravity model evaluation. *Resources Policy*, 103, 105542. https://doi.org/10.1016/j.resourpol.2025.105542

Zhao, T. (2022). Economic Policy Uncertainty and Manufacturing Value-added Exports. *Inzinerine Ekonomika-Engineering Economics*, 33(1), 103–114. http://dx.doi.org/10.5755/j01.ee.33.1.27373.

Authors' Biographies

Asta Baliutė, Dr., is an Associate Professor at the School of Economics and Business at the Academic Centre of Economics, Business and Management; Kaunas University of Technology. Her research interests include industrial development, export competitiveness and labor market issues. ORCID ID 0000-0002-9373-5449.

Jokūbas Kuliešius is a master student in Economics at the School of Economics and Business at the Kaunas University of Technology.

The article has been reviewed.

Received in March 2025; accepted in December 2025.