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# Railway Infrastructure as a Factor of Economic Development: An Empirical Analysis of Central European Countries (2010-2021)

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**ABSTRACT**

This paper investigates the impact of investments in railway infrastructure on economic growth across six Central European countries (Croatia, Slovenia, Poland, Czech Republic, Slovakia, and Hungary) between 2010 and 2021. The study applies a panel regression model to test both the direct effects of these investments and their indirect effects through passenger and freight rail transport. Contrary to theoretical expectations, the findings reveal no statistically significant correlation between railway infrastructure investment and GDP growth in the observed countries. These results highlight the importance of institutional efficiency, intermodal integration, and alignment of transport policy as preconditions for unlocking the growth potential associated with railway investments.

## 1. Introduction

The transport infrastructure is crucial for economic development, facilitating the mobility of individuals, the distribution of goods, and the interconnection of markets. Historically, railways have been a significant element in both industrial and regional growth, particularly during the 19th and early 20th centuries, as they greatly aided in market integration and the acceleration of economic activities [1, 2]. Despite the decline in the significance of rail transport following World War II, attributed to the rise of road and air transport [3], railways are once again becoming vital in light of climate objectives, energy efficiency, and the robustness of transport systems.

The European Green Deal and the Sustainable and Smart Mobility Strategy strongly advocate for the transition of transportation from road to rail, aiming to decrease emissions, alleviate the burden on road infrastructure, and enhance the cohesion of the European area [4]. Beyond climate objectives, energy instability and interruptions in global supply chains further underscore the necessity of a contemporary, dependable, and efficient rail system [5]. In this context, investments in rail infrastructure are anticipated to yield significant economic impacts.

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Nevertheless, empirical evidence from Central European nations – including Croatia, Slovenia, Poland, the Czech Republic, Slovakia, and Hungary – presents varied outcomes. In spite of heightened investments, the railway systems in these nations encounter transitional difficulties, aging infrastructure, prolonged investment cycles, and significant competition from road transport [6, 7]. Consequently, the theoretical premise that infrastructure positively influences economic growth [8, 9] is not consistently validated in practice, indicating the presence of critical transmission factors.

Most prior studies concentrate solely on the direct correlation between investment and economic growth, treating these variables as two distinct aggregates without examining the mechanisms that connect them. This approach overlooks the reality that infrastructure investments influence the economy indirectly, for instance, through heightened freight transport volumes, enhanced passenger mobility, decreased logistics costs, or improved market integration. There is a notable lack of research in the literature concerning Central Europe that concurrently investigates both the direct and indirect impacts of railway investments, representing a considerable research gap.

This paper addresses the existing gap by presenting a panel regression model that incorporates mediation effects. Such an approach enables the differentiation of the direct impact of investments on gross domestic product from the indirect impacts that arise through the transportation of goods and passengers via rail. This approach enhances the understanding of the transmission mechanism: it investigates whether investments independently influence economic growth or only do so when they lead to an improvement in transport performance.

The objective of this paper is to analyze the role of investments in railway infrastructure in fostering economic growth within Central European nations during the period from 2010 to 2021, making a clear distinction between direct and indirect effects. This offers a novel empirical viewpoint on the circumstances under which investments in the railway sector can yield macroeconomic advantages.

The structure of the paper is as follows: following the introduction, there is a review of both theoretical and empirical literature, succeeded by the methodology and an explanation of the panel model employed the empirical findings, and ultimately a discussion and conclusions.

## 2. Literature Review

Theoretical models concerning economic growth highlight the significance of capital investment, technological advancement, and infrastructure as key elements that enhance productivity, lower transaction costs, and promote market integration [10-12]. In the context of transport economics, investment in infrastructure is regarded as a crucial development input that can boost the mobility of individuals and goods, decrease logistics expenses, and enhance economic efficiency [8; 13]. The OECD [14] points out that the beneficial economic impacts of infrastructure projects are realized only when there is suitable institutional quality, effective management, and ongoing maintenance. Furthermore, strategic documents underscore the necessity of modernizing the railway network to enhance safety, accessibility, and sustainability [13].

The empirical research regarding the impact of transport infrastructure on economic growth presents varied outcomes. Rodrigue and Notteboom [15] along with Välilä [16] assert that transport infrastructure has the potential to enhance economic growth by improving market connectivity and lowering transport expenses. Jiwattanakulpaisarn et al. [17] demonstrates that investments in infrastructure positively influence regional employment, whereas Li et al. [18] cautions that the impacts of transport initiatives differ from one region to another. Global studies

on railway infrastructure indicate that the modernization of railways can enhance trade flows, mobility, and development: Li & Su, [19] for Myanmar and Hassan et al. [20] for Lebanon identify favorable economic and environmental outcomes resulting from railway revitalization, while Wu, et al. [21] emphasize the long-term advantages of railway investments through heightened consumption and mobility.

Simultaneously, numerous authors caution that investments in infrastructure do not inherently ensure economic growth. The World Bank [22] highlights that the beneficial impacts of railway initiatives depend on the quality of institutions, financial viability, and intermodal connectivity. Additionally, Wangai et al. [23] note that the potential benefits of infrastructure investments are frequently unfulfilled due to outdated networks, incompatible capacities, and inadequate integration of transport systems in transitioning economies.

In the European context, historical research [2] indicates that the establishment of railways served as the cornerstone of industrialization and regional integration. Current studies reveal that transport infrastructure can play a role in regional development; however, the impact is heavily influenced by the initial state and quality of the transport network [24]. In the countries of Central and Eastern Europe, various structural issues within the railway sector are prominent, such as aging infrastructure, slow modernization efforts, and significant competition from road transport [25]. Wiśnicki and Dyrda [26] point out that inadequate intermodal connectivity greatly restricts the growth potential of railways, while recent findings indicate that rail transport in this region is less adaptable to economic fluctuations compared to road transport [6].

Despite the extensive body of work on transport systems, there remains a notable absence of quantitative macroeconomic research that systematically investigates the impact of railway infrastructure investments on economic growth in Central European countries. The majority of existing studies focus on the technical, operational, and institutional dimensions of the railway sector, while empirical analyses with a macroeconomic perspective are exceedingly scarce. One of the few quantitative investigations carried out in this area highlights significant challenges related to the availability and comparability of data, a limited observation period, the diversity of the infrastructure systems across different countries, and variations in statistical standards. The authors point out that the differing levels of investment, quality of networks, and unique characteristics of national railway systems complicate the ability to draw definitive and clear conclusions regarding the economic impacts of railway investments [27].

It is evident from the existing literature that a considerable research gap exists in Central European countries, primarily due to the absence of systematic quantitative studies and analytical frameworks that can elucidate the processes by which infrastructure investments translate into economic outcomes. This paper aims to address this gap by utilizing a panel regression methodology, which facilitates a deeper comprehension of the interplay between rail infrastructure investments, traffic patterns, and economic growth within the regional framework of Central Europe.

## 3. Methodology

The empirical study was carried out utilizing multiple panel regression analysis on a sample comprising six Central European nations (Croatia, Slovenia, Poland, Czech Republic, Slovakia, and Hungary) during the timeframe from 2010 to 2021. The data were sourced from the Eurostat database and encompass annual statistics on investments in railway infrastructure, rail freight transport, rail passenger transport, and gross domestic product.

Total investments in railway infrastructure and gross domestic product were further adjusted using the implicit deflator price index (2010 = 100), which was also sourced from Eurostat. This adjustment transformed variables that were initially stated in current prices into constant prices, thereby neutralizing the impact of inflation on their fluctuations and enabling the analysis of real effects among the variables. All variables utilized were converted into natural logarithms, endowing the models with the characteristic of constant elasticity, consistent with the assumptions of the majority of macroeconomic theoretical frameworks. Log-log models also enhance interpretation, as the estimated coefficients represent partial elasticity coefficients, indicating relative rather than absolute changes in the variables.

The application of panel regression analysis is methodologically sound as it facilitates more robust and accurate estimations in comparison to individual (cross-sectional or time) regressions. Panel data consolidates variations across different countries and over time, thus enhancing the informational richness of the sample. According to Udović [27], panel data regression produces superior outcomes because the panel structure permits increased variability, reduced mutual collinearity, additional degrees of freedom, and improved efficiency of estimates. Moreover, the panel methodology enables the control of invariant characteristics of individual countries, such as institutional traits, the historical evolution of the transport network, or geographical features, thereby mitigating bias resulting from omitted variables.

In contrast to conducting individual regressions for each country, the panel model facilitates the recognition of shared patterns and leads to more reliable conclusions regarding the connection between investment, transportation, and economic growth. Furthermore, in cases where the time series data is relatively brief, panel regression enhances the statistical strength of the model and provides more consistent parameter estimates.

The research's conceptual framework incorporates two intermediary variables – rail freight transport and rail passenger transport – which serve as channels for analyzing the indirect impact of investment. The mathematical representation of the model can be expressed through the following system of equations:

$$\text{Freight\_transport} = i_1 + a_1\,\text{Investmentse} + e_1 \quad (1)$$

$$\text{Passenger\_transport} = i_2 + a_2\,\text{Investments} + e_2 \quad (2)$$

$$\text{BDP} = i_3 + c'\text{Investments} + b_1\text{Freight\_transport} + b_2\,\text{Passenger\_transport} + e_3 \quad (3)$$

Where $i_i$ denotes constants and $e_i$ signifies statistic regression errors.

The effect of rail infrastructure investments on freight transport is indicated by the coefficient $a_1$, whereas the effect of these investments on passenger transport is represented by the coefficient $a_2$. The overall effect of investments on GDP is computed as the aggregate of both direct and indirect impacts:

$$c = c' + a_1 b_1 + a_2 b_2 \quad (4)$$

Where $c$ represents the overall effect of investment on GDP, $c'$ signifies the direct effect of investment on GDP, $a_1b_1$ indicates the indirect effect via goods traffic, and $a_2b_2$ denotes the indirect effect via passenger traffic.

The standard errors associated with the product of estimators can be derived by:

$$sd(a_i b_i) = \sqrt{a_i^2 sd(b_i)^2 + b_i^2 sd(a_i)^2 + sd(a_i)^2 sd(b_i)^2}, \text{for } i = 1,2 \quad (5)$$

Panel regression analysis is conducted with the understanding that the data is organized as longitudinal indicators spanning twelve years (2010-2021) across six countries, aiming to uncover common trends while also considering the unique characteristics of each nation. In the final model specification, the Hausman test [28] was executed to determine the appropriateness of either the

fixed effects model (FEM) or the random effects model (REM). The findings from the Hausman test [28] indicated that the fixed effects model is more suitable (p less than 5%), supporting the premise that specific characteristics of each country (such as institutional traits, historical evolution of the transport network, etc.) are linked to the explanatory variables.

## 4. Research Results

The initial segment of the analysis concentrated on assessing the effects of investments in railway infrastructure on both freight and passenger traffic. The findings indicate that these investments do not have a statistically significant effect on either freight or passenger rail traffic. The estimated coefficient for freight traffic is 0.012, with $t = 1.36$ and $p > 0.05$, while for passenger traffic, a negative yet statistically insignificant result was recorded ($-0.002$, $t = -0.21$, $p > 0.05$). Consequently, the investments made during the observed period did not lead to a notable increase in railway traffic volume. These results are shown in Table 1.

The second segment of the analysis focuses on assessing the influence of investments, freight transport, and passenger transport on GDP. The findings reveal that investments in railway infrastructure alone do not exert a statistically significant effect on GDP (0.0039; t=0.47, p>0.05). Conversely, freight transport via rail demonstrates a positive and statistically significant contribution to economic growth (0.119; $t = 2.14$, $p < 0.05$), while an even more substantial impact is observed for passenger transport by rail (0.087; $t = 4.58$, $p < 0.001$).

**Table 1**
Results of panel regression analysis (2010–2021)

| Dependent variable | Independent variable | Partial elasticity coefficient | t-value | p-value |
|---|---|---|---|---|
| Freight transport | Investments in railway infrastructure | 0.012 | 1.36 | > 0.05 |
| Passenger transport | Investments in railway infrastructure | -0.002 | -0.21 | > 0.05 |
| BDP | Investments in railway infrastructure | 0.004 | 0.47 | > 0.05 |
| BDP | Transport of goods by rail | 0.119 | 2.14 | < 0.05 |
| BDP | Transport of passengers by rail | 0.087 | 4.58 | < 0.001 |

The interpretation of the partial elasticity coefficients indicates that a 1% rise in rail freight traffic would result in a 0.119% increase in GDP, whereas a 1% rise in rail passenger traffic would lead to a 0.087% increase in GDP. These results affirm that economic growth is more influenced by the efficiency and intensity of railway system usage than by the level of investment itself.

To further elucidate the dynamics of this relationship, a decomposition of the investment effects on GDP was performed. The findings are presented in Table 2. It is clear from this table that the overall impact of investment on GDP is not statistically significant, as neither the direct nor the indirect effects surpass the significance threshold.

**Table 2**
Breakdown of both direct and indirect impacts of railway infrastructure investments on GDP

| Total impact of investments on GDP | Direct (c') | Indirect effects through freight transport (a1b1) | Indirect effects through passenger transport (a2b2) |
|---|---|---|---|
| 0.0081 | 0.0039 (0.472) | 0.0049 (1.142) | -0.0006 (-0.214) |

The overall coefficient of investment in GDP stands at 0.0081; however, it lacks statistical significance. The analysis reveals that the direct effect (0.0039; $t = 0.472$) is not significant, nor are the indirect effects related to the transport of goods (0.0049; $t = 1.142$) and passengers (-0.0006; $t = -0.214$).

In summary, the findings indicate that investments in railway infrastructure during the examined period do not directly influence the economic growth of Central European nations. Nevertheless, an increase in the transportation of goods and passengers via rail does significantly enhance GDP growth. This suggests that mere investments, without a corresponding improvement in railway transport efficiency, are insufficient to achieve the desired developmental outcomes.

## 5. Discussion

The findings obtained suggest that investments in railway infrastructure within Central European nations from 2010 to 2021 did not exhibit a statistically significant direct impact on economic growth. While theoretical growth models imply a positive correlation between infrastructure investments and economic development [8, 11, 12], the empirical results of this study support the assertion that the level of investment alone is inadequate to generate multiplier effects on the economy [5, 29]. This outcome indicates that the railway sector in the countries analyzed has not yet attained the efficiency threshold necessary for investments to directly foster growth; instead, it is essential to transform the invested capital into quantifiable operational and organizational outcomes.

It is particularly noteworthy that a positive and statistically significant effect on GDP is attained through the transportation of goods and passengers via rail, whereas the direct effect of investments remains insignificant. This indicates that investments only become pertinent when they lead to a tangible enhancement in transport performance. In other terms, the economy reacts not to the mere occurrence of investment, but to the results of these investments - such as increased capacity, throughput, reliability, and service quality. This finding aligns with the studies conducted by Alotaibi et al. [30] which demonstrated that the most substantial contribution of railways to economic growth is realized specifically through transport effects and improved accessibility. This supports the reasoning that infrastructure serves as an indirect input: its value is only realized when it is actively utilized.

The minimal direct impacts of investments discussed in this study can be attributed to various factors. Firstly, infrastructure projects typically involve a lengthy investment cycle, resulting in their effects not becoming apparent in the short to medium term. This phenomenon is particularly evident in transition countries, where the execution of projects is hindered by intricate administrative processes and inadequate coordination between national and European institutions [31]. Secondly, railways in Central European countries remain insufficiently competitive compared to road transport, which predominates in both freight and passenger services [3]. This situation leads to the dilution of investment effects within a market structure that consistently favors road transport. Thirdly, the absence of intermodal connectivity with seaports, logistics hubs, and road terminals further restricts the potential multiplicative impacts of investments [26]. Under these circumstances, even infrastructure that is technically completed fails to yield economic returns unless it is paired with heightened demand and improved integration into logistics networks.

Furthermore, it is important to emphasize a more extensive structural issue: in the examined countries, investments frequently concentrated on upgrading existing infrastructure, with less emphasis on increasing capacity or advancing technologically sophisticated systems (ERTMS, automation, digitalization). These investments mainly aim to preserve functionality, rather than to stimulate additional economic activity. This clarifies the reason behind the limited direct impact of investments - a significant portion of the funds essentially functions to "offset" losses resulting from obsolescence, instead of generating new value [27].

The results further validate the OECD's conclusions [5] that infrastructure investments yield measurable outcomes only when paired with suitable institutional and technological reforms. In contrast to the practices observed in Western European nations, where railways are consistently modernized and integrated into broader logistics frameworks [4, 7], investments in the Central European context still fail to generate adequate growth as they do not result in substantial alterations to the transport structure. These findings indicate that the current infrastructure capacities are not being utilized to their full potential and that investments will not yield significant effects without concurrent restructuring of the market, regulations, and railway operations.

A key finding of this study is the indication that even a modest percentage rise in rail freight and passenger traffic can significantly influence GDP. A 1% rise in rail freight traffic results in a 0.119% increase in GDP, whereas a 1% rise in passenger traffic produces a 0.087% increase in GDP. These findings imply that even slight enhancements in rail operational usage can yield considerable economic advantages, especially in economies that are predominantly reliant on road transport. In essence, minor adjustments in modal share can lead to disproportionately substantial benefits, which serve as a crucial message for policymakers.

The implications of the research distinctly highlight the necessity to shift the emphasis of transport policies. Rather than focusing on the total amount of funds allocated, priority ought to be placed on the effectiveness of implementation, management capabilities, and intermodal integration. The outcomes suggest that investments in rail can aid in meeting climate objectives, lowering logistics expenses, and enhancing regional connectivity, but this is contingent upon the synchronized advancement of technology, regulations, and personnel training. In practical terms, this implies that investments should be channeled towards projects that possess the highest potential to enhance the operational utilization of the network - such as electrification, double-track corridors, logistics terminals, and integrated tariff systems.

In summary, the results of this research add to the existing literature by demonstrating that within the Central European context, investments in railways can foster economic growth. However, this potential is dependent on institutional capabilities, the configuration of the transport market, and the degree of integration with alternative transport modes. Furthermore, the findings reinforce the notion that infrastructure alone does not generate economic growth; instead, it is the effective utilization and incorporation of infrastructure into broader economic activities that drive growth [5; 29].

## 6. Conclusion

This study examined the correlation between investment in railway infrastructure and economic growth in Central European countries from 2010 to 2021, utilizing panel regression models with intermediary effects. The findings indicated that the direct impacts of investments on gross domestic product are not statistically significant; however, the transportation of goods and passengers via rail demonstrates a positive and quantifiable contribution to economic growth. This conclusion implies that economic advancement is not solely reliant on the amount of investment, but rather on how effectively the infrastructure translates into tangible transport and economic outcomes.

The cumulative impact of investments, assessed through both direct and indirect channels, is not statistically significant. Nevertheless, the strong positive influence of operational indicators of railway transport on GDP indicates that the railways in the countries studied possess a developmental potential that is only actualized when investments lead to enhanced utilization of

the network. This underscores the necessity of efficient project execution, intermodal integration, technical modernization, and the competitiveness of railway services.

The outcomes observed can be attributed to the structural features of Central European transport systems: prolonged investment cycles, bureaucratic hurdles, inadequate competitiveness of railways in relation to road transport, and poor integration with logistics and port systems. In this context, investments frequently aim to sustain current capacities rather than to foster new economic activity. Consequently, the economic effect is only evident when there is a tangible increase in transport performance.

The findings of this research carry significant consequences for transportation policies. Rather than concentrating solely on the total amount of investment, it is essential to focus on management capabilities, the efficiency of implementation, enhancing intermodal connectivity, and initiatives that promote a transition from road to rail. In accordance with the climate and digital goals of the European Union, rail has the potential to serve as a more robust catalyst for economic growth, provided that investment is complemented by technological advancements, service modernization, and the promotion of increased utilization of the network.

Future studies ought to encompass an extended timeframe to more effectively discern the delayed impacts of infrastructure investments, while also taking into account spatial variations within the examined countries. Furthermore, it would be beneficial to incorporate qualitative metrics, such as institutional efficiency, technological advancement, and the degree of digitalization, as well as to evaluate the potential of cutting-edge technologies, including artificial intelligence, in enhancing transport processes. Comparative analyses among various EU Member States could provide additional insights into how different governance structures, regulatory environments, and funding sources influence the economic outcomes of railway initiatives.

In summary, this study indicates that rail infrastructure has the potential to serve a significant developmental role in Central European nations, provided that investments are effectively converted into enhanced utilization of the rail system and its incorporation into broader economic activities. The essence of the economic value of rail investments is found in this transition - from mere investment to practical usage.

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Not application

**Conflicts of Interest**
The authors declare no conflicts of interest.

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