Journal of Infrastructure, Policy and Development 2024, 8(2), 2942.
https://doi.org/10.24294/jipd.v8i2.2942

Article

Railroad infrastructure investment and economic performance in Portugal: An industry-specific analysis

Pedro G. Rodrigues[1,*], **Alfredo M. Pereira**[2], **Rui M. Pereira**[2]

[1] Centre for Public Administration and Public Policies, Institute of Social and Political Sciences, Universidade de Lisboa, Rua Almerindo Lessa, 1300-663 Lisbon, Portugal
[2] Department of Economics, William and Mary, Williamsburg VA 23187, USA
*** Corresponding author:** Pedro G. Rodrigues, pedro.g.rodrigues@edu.ulisboa.pt

CITATION

Rodrigues PG, Pereira AM, Pereira RM. (2024). Railroad infrastructure investment and economic performance in Portugal: An industry-specific analysis. Journal of Infrastructure, Policy and Development. 8(2): 2942. https://doi.org/10.24294/jipd.v8i2.2942

ARTICLE INFO

Received: 27 September 2023
Accepted: 30 October 2023
Available online: 19 December 2023

Abstract: This study addresses the crucial question of the macroeconomic impact of investing in railroad infrastructure in Portugal. The aim is to shed light on the immediate and long-term effects of such investments on economic output, employment, and private investment, specifically focusing on interindustry variations. We employ a Vector Autoregressive (VAR) model and utilize industry-level data to estimate elasticities and marginal products on these three economic indicators. Our findings reveal a compelling positive long-term spillover effect of these investments. Specifically, every €1 million in capital spending results in a €20.84 million increase in GDP, a €17.78 million boost in private investment, and 72 new net permanent jobs. However, these gains are not immediate, as only 14.5% of the output increase and 38.8% of the investment surge occur in the first year. In contrast, job creation is nearly instantaneous, with 93% of new jobs materializing within the first year. A short-term negative impact on the trade balance is expected as new capital goods are imported. Upon industry-level analysis, the most pronounced output increases are witnessed in the real estate, construction, and wholesale and retail trade industries. The most substantial net job creation occurs in the construction, professional services, and hospitality industries. This study enriches the empirical literature by uncovering industry-specific impacts and temporal macroeconomic effects of railroad infrastructure investments. This underscores their dual advantage in bolstering long-term economic performance and counteracting job losses during downturns, thus offering valuable public policy implications. Notably, these benefits are not evenly distributed across all industries, necessitating strategic sectoral planning and awareness of employment agencies to optimize spending programs and adapt to industry shifts.

Keywords: infrastructure investment; railroad; economic performance; industry level; Portugal

1. Introduction

Infrastructure investment is crucial for achieving sustainable development goals and improving the quality of life (Thacker et al., 2019). It plays a role in international competition, a cleaner environment, and economic opportunities for the disadvantaged (Aschauer, 1990; Kessides, 1996; World Bank, 1994). The UN Secretary-General António Guterres recently emphasized the importance of sustainability in infrastructure investment, aiming to increase societal resilience and reduce climate risk (United Nations Environment Programme, 2022). To ensure sustainable infrastructure, it must be planned, designed, delivered, and managed to reduce negative impacts and increase positive impacts (The Economist Intelligence Unit, 2019; The World Bank and International Growth Centre, 2022).

Infrastructure is a multilevel system of facilities and structures consisting of tangible and intangible assets that are essential for the efficient functioning of an economy and for meeting a population's social needs (Baskakova and Malafeev, 2017). It is characterized by technological, economic, and institutional attributes and functions that vary with the demands of households, enterprises (Jochimsen, 1966; Rosenstein-Rodan, 1943), and the economy as a whole (Buhr, 2003). The concept of infrastructure is dynamic and constantly expanding and renewing (Baskakova and Malafeev, 2017). Intangible infrastructure includes the rule of law, stable governance, legal frameworks, the regulatory environment, urban planning, access to financing and capital markets, the educational system, research and development (R&D) capability, and high-speed Internet connectivity (Haskel and Westlake, 2018; Hazan et al., 2021; Kersley et al., 2008). The tangible type comprises economic and social infrastructure (Démurger, 2014; Fourie, 2006). The first promotes economic activity through services to households and firms, and includes transportation systems, telecommunications networks, power plants, electricity grids, and dams, as well as other water and sewage facilities. Social infrastructure, such as health facilities, educational buildings, public housing, and cultural structures, enhances population health and education. From a human capital perspective, this infrastructure directly or indirectly impacts economic growth and development (Arrow et al., 1995; Becker, 2007; Brock and Taylor, 2005).

Transportation is one of the largest categories of infrastructure investment (World Bank, 2007) with complex and expensive projects (OECD, 2023). In Portugal, between 1980 and 2018, transportation infrastructure investment amounted to 1.3% of GDP and 29.5% of the overall infrastructure investment spending (GEE–Gabinete de Estratégia e Estudos, Portuguese Ministry of the Economy and the Sea). This ranked transportation above social infrastructure (24.6%), and below utilities (46%). The corresponding figures for 2010–18 were 0.51% and 12.8%, respectively. In 2015, transport infrastructure investment and maintenance spending as a share of GDP was around 0.5% in the US, Canada, Germany, Italy, and Spain; 1%–1.5% in Turkey, India, and Korea; and almost 5% in China (Rodrigue, 2020). Between 2010 and 2020, China, Japan, Germany, Great Britain, Scandinavian, and Eastern European countries increased investment in inland transport infrastructure, whereas Spain registered a compound annual growth rate of −9.5% during the same period (International Transport Forum, 2022).

From 1980 to 2018, railroad infrastructure investment in Portugal accounted for 0.25% of GDP and 5.4% of the overall infrastructure investment (GEE–Gabinete de Estratégia e Estudos, Portuguese Ministry of the Economy and the Sea). Between 2010 and 2018, 0.1% of GDP was allocated to this type of transport, similar to US spending that year (International Transport Forum, 2022). In 2018, the average rail infrastructure investment in 42 International Transport Forum (ITF) member countries was 0.3% of their GDP, a decrease from 0.5% in 2010. China topped the list at 0.9% of GDP. Between 2010 and 2020, Greece, Spain, and Portugal experienced compound annual growth rates of investment in rail infrastructure of approximately −20%, −12%, and −6%, respectively. Between 1980 and 2018, Portugal devoted 19.2% of its transportation infrastructure investment to rail, an equivalent 20.5% of the total investment in rail and road infrastructure (see **Table 1**). At the end of 2019, the five countries that invested more in rail than road infrastructure were Austria (79%), Great Britain (58%), Belgium (55%), France (54%), and Luxembourg (52%) (International Transport Forum, 2022).

Table 1. Infrastructure investment by type of asset.

	1980–2018	**1980–89**	**1990–99**	**2000–09**	**2010–18**
Percent of GDP					
Infrastructure investment	4.30	3.24	4.65	5.39	3.85
Road transportation	**0.97**	**0.75**	**1.31**	**1.40**	**0.36**
National roads	0.40	0.35	0.60	0.53	0.08
Municipal roads	0.33	0.34	0.41	0.37	0.20
Highways	0.24	0.07	0.30	0.49	0.08
Other transportation	**0.33**	**0.22**	**0.47**	**0.47**	**0.15**
Railroads	0.25	0.15	0.37	0.35	0.10
Ports	0.04	0.03	0.06	0.05	0.03
Airports	0.04	0.03	0.03	0.06	0.03
Utilities	**1.97**	**1.46**	**1.86**	**2.40**	**2.19**
Water and waste facilities	0.44	0.34	0.45	0.52	0.43
Petroleum refining	0.14	0.09	0.18	0.15	0.13
Electricity and gas	0.62	0.46	0.36	0.82	0.87
Telecommunications	0.78	0.56	0.86	0.92	0.74
Social infrastructures	**1.02**	**0.81**	**1.01**	**1.13**	**1.14**
Health facilities	0.44	0.28	0.45	0.53	0.52
Educational buildings	0.58	0.53	0.57	0.60	0.62
Percentage of total infrastructure investment					
Infrastructure investment	100.00	100.00	100.00	100.00	100.00
Road transportation	**22.09**	**23.42**	**28.45**	**26.07**	**9.10**
National roads	9.08	10.69	13.07	9.85	1.98
Municipal roads	7.95	10.45	8.93	6.93	5.19
Highways	5.06	2.28	6.45	9.29	1.93
Other transportation	**7.36**	**6.73**	**9.96**	**8.69**	**3.70**
Railroads	5.41	4.61	7.87	6.53	2.31
Ports	1.01	1.06	1.33	0.99	0.64
Airports	0.94	1.05	0.76	1.17	0.76
Utilities	**45.99**	**44.67**	**39.71**	**44.18**	**56.44**
Water and waste facilities	10.19	10.28	9.88	9.72	10.97
Petroleum refining	3.06	2.86	3.80	2.60	2.98
Electricity and gas	14.75	14.17	7.63	15.35	22.66
Telecommunications	17.98	17.36	18.41	16.51	19.83
Social infrastructures	**24.56**	**25.18**	**21.87**	**21.06**	**30.76**
Health facilities	10.50	8.79	9.57	9.89	14.11
Educational buildings	14.06	16.40	12.30	11.17	16.65

Source—Calculations by the authors, based on information from the Gabinete de Estratégia e Estudos, Portuguese Ministry of the Economy and the Sea (GEE, 2022).

Railroad infrastructure investments in Portugal are being planned and occurring slowly against a backdrop of decades of underinvestment, an almost obsolete system, and recurring budget cuts. The Ferrovia 2020 plan launched in 2016 aimed to modernize Portugal's railroad network by improving international connections, boosting freight transport competitiveness, and promoting interoperability (Infraestruturas de Portugal, 2016). The Portuguese Rail Network Investment Plan for 2030, which allocates more than €10 billion to rail infrastructure, indicates a strong political commitment to transforming Portugal's rail system. However, its execution has faced a series of delays that are often highlighted by financial news outlets. Several challenges must be addressed to ensure the successful implementation of this plan. These include speeding up project timelines, constraining the impact on national debt, securing the necessary fiscal provisions for the national co-financing portion, and ensuring that Portugal's rail network stays connected as neighboring countries advance towards high-speed rail systems. This multifaceted task, propelled by economic, environmental, and social imperatives, requires a robust political will. However, political commitment, while crucial, is insufficient. The synergy among a well-defined strategy, adequate resources, and timely execution is vital for building a competitive rail system. With the threat of losing key EU funding, namely the Connecting Europe Facility mechanism, due to delays, it becomes imperative to complement political will with effective project management, fiscal prudence, and strategic foresight. Only a holistic political and financial approach can realize Portugal's vision for a modern, competitive rail network, boosting long-term national competitiveness and offering a sustainable transport alternative to an already extensive network of highways.

Our study aims to quantify the economic performance effects of investing in railroad infrastructure in Portugal using a multivariate dynamic time-series approach following Pereira and De Frutos (1999), Pereira (2000), Pereira (2001), and Pereira and Andraz (2003). This approach estimates industry- and infrastructure-specific vector autoregressive (VAR) models (Blanchard and Perotti, 2002), considering how investments affect output, employment, and private investment in 22 industries. The study also identifies the importance of demand and supply–side channels and their timings. The approach, related to fiscal multipliers (Mineshima et al., 2014; Ramey, 2011), highlights the dynamic relationship between infrastructure investments and the rest of the economy, accounting for dynamic interactions in all relevant timeframes. Railroad investment affects the private sector variables over time, and the evolution of these variables also affects railroad investment. This dynamic feedback allows for possible endogeneity of railroad investments and the possibility of reverse (Granger) causality.

The approach we follow is empirical but not a-theoretical, as it uses a dynamic model of the economy based on capital, labor, and railroad infrastructure to generate private output. Firms determine input demands, whereas the public sector uses economic performance-based policy rules to evolve railroad investments. Consistent with Pereira and de Frutos (1999), the estimated VAR model is a reduced form of production, input demand, and policy functions.

Our main contribution to the empirical literature is the identification of industry-by-industry incidence of the economic performance effects of railroad infrastructure investment in Portugal. Similar to Lee et al. (2018), this provides a more nuanced and granular view than previous efforts, such as Pereira and Andraz (2012; 2005), which have a marked aggregate or regional focus. Industries differ in their transportation needs (Tioga Group, 2014) and railroad infrastructure investments can have significant industry-specific economic and social effects (Melo et al., 2013). Knowing these effects helps policymakers make informed decisions about resource allocation, prioritize projects, and target investments in geographical areas with the most positive impact.

This study is timely and relevant. As Portugal continues to lag its EU peers in terms of real convergence, promoting long-term economic growth through public investments remains a key challenge. In addition, with the vast majority of the Portuguese population living in metropolitan areas, families currently spend a lion's share of their income on housing. This presents an opportunity to encourage life on the periphery, thus improving inter–regional cohesion. However, reliable, efficient, and economical interurban modes of transport are urgently required. From a structural perspective, railway projects appear to be a particularly good option in Portugal for two reasons. First, the consensus is that road investments (especially highways) have run into diminishing returns. Second, because of the potentially even lower energy consumption, investing in railroad infrastructure can also help reduce greenhouse gas (GHG) emissions and thus help meet Portugal's environmental targets.

The remainder of this paper is organized as follows. Section 2 presents an overview of the economic benefits of transportation in general and railroad infrastructure in particular, followed by a sketch of the most salient factors in choosing between investing in road or railroad infrastructure. Section 3 presents data on railroad infrastructure investments, as well as on output, employment, and investment for each of the 22 industries. Section 4 sketches the steps in data analysis involving nonstationarity, identification, and measurement issues. Section 5 focuses on the empirical results, namely the long-term economy-wide and industry-specific economic performance effects of railroad infrastructure investments, as well as their effects on impact, intertemporally, and, ultimately, their changes to the industry mix. Finally, Section 6 summarizes the major findings of this study and discusses their policy implications.

2. Economic benefits of transportation and railroad infrastructure: An overview

This section overviews the economic benefits of transportation infrastructure and then drills down, comparing road to railroad infrastructure, which is the focus of this paper.

2.1. Transportation infrastructure

Transportation infrastructure is crucial for social development and sustainability (Banerjee et al., 2020; Rodrigue, 2016, 2020; Wang et al., 2018) and targets economic efficiency, equity, health, and environmental integrity. However, innovative thinking, planning, and management are necessary for obtaining reliable solutions (Jeon and Amekudzi, 2005; Litman and Burwell, 2006). Policymakers and stakeholders must be aware of the economic effects of transportation infrastructure investments on informed decisions (Cohen, 2010; Lakshmanan, 2011; Oosterhaven and Knaap, 2003).

Investing in transportation infrastructure improves quality of life by reducing congestion (Fageda, 2021; Low and Odgers, 2012) and enhancing safety, making it essential for a flourishing economy (Lin and Wei, 2019; Truong and Currie, 2019).

Modern transportation infrastructure enhances local economies by being fast, flexible, reliable, and cost-effective (Bent and Singa, 2009; Sahin et al., 2014). This competitiveness (Agrawal et al., 2017; Pradhan, 2019) attracts new businesses and industries (Gibbons et al., 2019; Zheltenkov et al., 2017), such as tourism (Doerr et al., 2020; Khadaroo and Seetanah, 2008), which benefits from cost savings for businesses and consumers (Donaldson, 2018).

Improved transport modes facilitate interregional and international trade by reducing costs (Donaldson, 2018; Limão and Venables, 2001; Rehman et al., 2020), enabling remote locations to trade with the rest.

Improved connectivity (OECD, 2020) and market access for final goods (Donaldson, 2018; Zheltenkov et al., 2017), labor (Sobieralski, 2021; Zhang et al., 2017), and essential social services such as health and education (Fay et al., 2005; McMinn et al., 2014; OECD, 2020) lead to market expansion (Limão and Venables, 2001). Fair access to transport opportunities can bridge the economic and social divide, creating long-lasting employment opportunities and bridging the economic and social divide (Bastiaanssen et al., 2020; Martincus et al., 2017; Sobieralski, 2021).

Boosts in activity promote regional development and accelerate economic growth (Chi, 2015; Chi and Baek, 2016; Pradhan, 2019) through direct and indirect pathways, enhancing economic performance through investments and job creation in relevant industries (Dash, 2016; Lin, 2020).

Transportation infrastructure investments in the short run support output and employment in industries such as construction and material production (Melo et al., 2013; OECD, 2020). Over time, productivity increases (Deichmann et al., 2004; Millemaci and Ofria, 2016; Wachs, 2011), and economic growth materializes (Ansar et al., 2016; Cigu et al., 2018; International Transport Forum, 2020). Despite evidence that infrastructure investments may divert economic activity (Gibbons et al., 2019; Haughwout, 1999; Wachs, 2011), the economic performance effects of these investments are overwhelmingly positive. Studies have shown that the UK (Young et al., 2020), Netherlands (Sturm et al., 1999), Central and Eastern European countries (Chi, 2015; Vlahinić Lenz et al., 2018), Belgium (Meersman and Nazemzadeh, 2017), India (Mohanty et al., 2022; Rudra Pradhan and Bagchi, 2013), China (Chen, 2019; Ren and Ding, 2019), Japan (Yoshino and Abidhadjaev, 2017), and Asia (Sawada, 2019) all exhibit positive economic performance effects. Three key takeaways from this literature are that overall economic performance effects tell us nothing about their constituent parts; we need to look under the aggregate hood and examine industry-specific effects as we do in this study, much like the construction of transportation infrastructure creates jobs, so does its maintenance; and finally, the full economic impact may not be known until years after a project is completed, making a dynamic long-run analysis of these effects paramount for a comprehensive appraisal.

2.2. Railroad vs road infrastructure

In this subsection, we highlight the most salient factors that should be considered when choosing between investing in two types of transportation infrastructure: rail and road. The two modes of transport serve different markets. A good decision is made not only in the context of geography, population density, and existing infrastructure, but also by the available budget (Berechman et al., 2006; Worsley, 2020). A systematic appraisal that fully compares the merits of investing in new rail and road requires a cost-benefit analysis that considers environmental, safety, and time savings (International Transport Forum, 2020). For further guidance, see, for instance, Affuso et al. (2003), who presented a comprehensive methodology.

Investing in new roads can improve economic performance, especially in vehicle-intensive industries (Achour and Belloumi, 2016; Fernald, 1999; Zhang et al., 2020), but may not be evenly distributed across locations (Elburz and Cubukcu, 2021) and may affect air quality depending on road design, traffic, and vehicle characteristics in terms of emissions (Wang and Zhang, 2009).

In developing and transitioning countries, maintaining and rehabilitating existing roads can yield more economic benefits than building new roads (Kerali, 2003). Roads are preferred for short-distance travel (International Transport Forum, 2020), providing better accessibility for local businesses given the door-to-door service that comes with expanded coverage and connectivity (Litman, 2023). Road infrastructure is less expensive, involves fewer rights of way (Affuso et al., 2003), and is more readily implemented than rail investment. Known for their lumpiness, rail infrastructure is relatively more expensive per km because of its higher initial cost (Biondini and Frangopol, 2019; Grimes and Barkan, 2006; Teodorovic and Janic, 2022). Nevertheless, railroads have lower maintenance costs and are easier to integrate with other forms of transportation (Bergqvist and Behrends, 2011; Levinson and Krizek, 2018; Rodrigue, 2020), making them better suited for point-to-point journeys (Macharis and Bontekoning, 2004). As a matter of physics, railroad steel wheels rolling on steel rails have a resistance coefficient of 6 to 20 times smaller than that of a truck or car tire rolling on tar or asphalt (The Engineering Toolbox, 2008).

Railways offer long-distance transportation services with lower carbon footprints than roads, thereby reducing congestion and pollution (Berechman et al., 2006; Bilgili et al., 2019; Fageda, 2021). According to a 2018 survey carried out by the UK Department for Business, Energy and Industrial Strategy (OWID, 2020), international rail (Eurostar) and national rail produce between 6 and 41 g of carbon dioxide equivalent per passenger kilometer, respectively, compared to medium cars that produce between 171 (diesel) and 192 (petrol) grams of carbon. Investing in rail infrastructure can provide economic benefits, increased interconnectivity between regions (Vickerman, 1997), job market accessibility (Yen, 2020), and improved energy efficiency (Chen, 2021; Erdogan, 2020; González et al., 2008), especially for freight transport, as it can haul much larger cargo volumes at higher speeds than roads. With lower emissions per ton of cargo transported, railroads are more environmentally friendly than roads (Dimoula et al., 2016; Gao, 2019; International Energy Agency, 2011), making them the preferred choice for sustainable transport during the energy transition. Notwithstanding, railroads also impact the environment during construction and if they pass through environmentally sensitive areas (Carpenter, 1994).

Rail transport is more economical (Fageda, 2021; Litman, 2005), less risky in terms of damaged goods or theft (Ekwall and Lantz, 2017), healthier (Fageda, 2021; Wrótny and Bohatkiewicz, 2021) less congested (Bhattacharjee and Goetz, 2012; Fageda, 2021), safer because of lower traffic death rates (Bhattacharjee and Goetz, 2012; Johner, 1983; Liu and Moini, 2015; Tavakoli Kashani and Sartibi, 2022; Whitehouse, 2001) more reliable in the sense that it's less affected by external factors that cause delays (Litman, 2005; Pinto et al., 2018), and more comfortable than road transport (International Transport Forum, 2020), especially for long-distance inter-urban travel (Affuso et al., 2003; González et al, 2008). Environmental pollution from road noise often exceeds environmental pollution from railway noise by a factor of 10 (Gu et al., 2019; Sun et al., 2019). Shifting from cars to trains can also significantly improve air quality (Chen and Whalley, 2012; Chester and Horvath, 2010; Wang et al., 2010). Nonetheless, Krüger (2012) disputes that rail transport is safer because of lower traffic death rates.

Railways have higher capacity and benefit from economies of density, whereby longer trains on the same infrastructure lower the cost per ton-km, in the case of freight, or per passenger-km, in the case of people (Growitsch and Wetzel, 2009), and also from economies of scope, where the same infrastructure can be used to transport various types of cargo or passengers, leading to lower overall costs (Bitzan and Keeler, 2007; Keaton, 1990). This reduces the costs per ton-km for freight and per passenger-km for people. Rail supports certain industries by compressing shipping costs, promoting trade, reducing productivity shocks, and increasing real estate value (Donaldson, 2018).

2.3. Railroad infrastructure

The literature provides substantial evidence that investment in railroad infrastructure can yield a positive macroeconomic impact, although the magnitude and channels through which these effects occur depend on contextual factors.

Investing in rail infrastructure has a proven positive multiplier effect on GDP. Although most studies focus on the level of output, there are studies such as Liu et al. (2023) that report a 0.048 percentage point acceleration in economic growth for every 1% increase in the railway infrastructure. The positive effect on GDP occurs through various mechanisms such as construction activities in the short run and changes in residents' preferences for leisure tourism consumption over time (Wu et al, 2021). In the long term, enhanced railroad infrastructure reduces transportation costs and improves connectivity between regions and economic hubs, thereby incentivizing firms to invest and enabling productivity gains across sectors (Yii et al, 2018; Bangaraju et al., 2022).

This connectivity effect leads to indirect GDP gains stemming from increased private investment, industrial agglomeration, and trade facilitation (Chen and Li, 2021; Alotaibi et al., 2022). However, the relationship between rail infrastructure and GDP is not always linear. Acheampong et al. (2022) found that it could even be negative in some contexts, particularly because of poor project selection or inefficiencies in outdated rail systems (Lenz et al., 2018; Maciulyte-Sniukiene and Butkus, 2022). Hence, careful project evaluation and targeting are essential to ensure that these macroeconomic benefits are fully realized in any given context.

Railroad infrastructure investments have also been shown to increase employment through both the direct and indirect channels. During project construction, these investments directly generate employment in several fields such as materials, construction, and engineering (Gnap et al., 2021; Sobieralski, 2021; Wu et al., 2021). Indirect employment effects stem largely from the connectivity benefits of an expanded rail network. By improving accessibility and reducing transportation costs, railroads incentivize private investment and commercial activity in proximal areas (Pokharel et al., 2023; Yii et al., 2018), thereby increasing employment (Sobieralski, 2021; Chi, 2015).

However, Sobieralski (2021) cautioned that railway investments may not increase employment in an automobile-centric environment. Moreover, overinvestment without adequate returns can displace jobs in other sectors (Lenz et al., 2018; Yii et al., 2018). Therefore, the net impact on employment remains context specific.

Investments in railroad infrastructure have significant ripple effects on broader investment activities. Bangaraju et al. (2022) pointed out that improved transport infrastructure can make a region more attractive to businesses, leading to increased investment. As Pokharel et al. (2023) demonstrated in their study on the Indian subcontinent, transport infrastructure projects stimulating local accessibility and connectivity incentivized firms to establish operations in newly connected areas.

At the regional level, rail infrastructure investments act as catalysts for growth and development by strengthening urban-rural linkages and facilitating market integration (Alotaibi et al., 2022). However, as Cascetta et al. (2020) discuss, for rail investments to fully catalyze regional development, complementary institutions and capacities related to innovation and human capital should be in place. Factor mobility also plays an important role in determining the economic benefits of infrastructure development (Banerjee et al., 2020). Overinvestment risks the unproductive allocation of resources in areas that lack such foundational conditions (Yii et al., 2018).

In summary, although rail infrastructure investments can stimulate broader capital accumulation through direct, indirect, and induced channels, realizing this potential depends on well-targeted projects attuned to the local context.

Railroad infrastructure investments have significant macroeconomic impacts on output (Berechman et al., 2006; Berger, 2019; Donaldson, 2018), employment (Berechman et al, 2006; Johansson et al., 2020; Li et al., 2020), productivity (Deichmann et al., 2004; Johansson et al., 2020; Litman, 2005), and private investment (Berechman et al., 2006; Bom and Ligthart, 2014; Pereira and Pereira, 2018a). However, Fageda and Gonzalez-Aregall (2017) find no significant impact on industrial employment. Some studies (Donaldson, 2018b) suggest that neighboring regions without railroad access are harmed, whereas others (Shabani and Safaie, 2018) find significant spatial spillovers. Knowledge-based centers benefit from urban rail access because of their viability and cultural attraction (Newman et al., 2013).

For Portugal in particular, the available literature on the economic performance effects of railroad infrastructure investments is limited to Pereira and Andraz (2012, 2005). Compared to our study, their research has a more aggregate and regional focus, and does not explicitly model industry-specific effects. They find that railroad investments have strong effects on output and crowds in both employment and private investments. While all regions in Portugal benefit from increased private investment flows, employment gains are concentrated in the north and around Lisbon, while output fails to increase in the Alentejo region.

3. Data sources and description

3.1. The railroad infrastructure investment dataset

The industry-specific empirical analysis we carry out in this study was only recently made possible by the availability of a rather comprehensive dataset on infrastructure investments in Portugal between 1978 and 2011 (Pereira and Pereira, 2016), which includes information on 12 types of infrastructure investments.

The rights to this dataset have since been acquired by the Portuguese Ministry of the Economy and the Sea with the responsibility of regular updates (GEE–Gabinete de Estratégia e Estudos, 2022). Although this dataset has been partially updated through 2021, the results of this study were obtained using data from 1978 to 2011. This horizon is necessary for two reasons. First, regarding data on infrastructure investment, the most sensitive component in our analysis, several important methodological questions remain surrounding the internal consistency of these updates with the earlier dataset. Obtaining a comprehensive dataset for infrastructure investment for any economy for a reasonably long period is a challenging undertaking. The second reason relates to the circumstances of the Portuguese economy in the 2010s. Following the Great Financial Crisis and the European sovereign debt turbulence in Portugal, since 2011 there has been extraordinary public budgetary restraint coupled with persistently disappointing structural macroeconomic performance. In this setting, infrastructure investment flows almost came to a screeching halt. As this period breaks with ongoing long-term economic trends, it is hardly typical in any meaningful structural manner. In addition, adequate treatment of this structural break would require a much longer time series than currently available.

Table 1 highlights the evolution of Portugal's infrastructure investments as a percentage of GDP and total infrastructure investment. Overall, infrastructure investment spending grew substantially over the 39 years from 1980 to 2018, averaging 4.3% of GDP (see **Table 1**). Starting from 3.2% in the 1980s, it climbed to 4.7% in the 1990s and 5.4% of GDP in the 2000s—its apex—before leveling off to 3.9% in the 2010s. In 1986, Portugal joined the EU (then termed the European Economic Community), and in the 1990s, Portugal benefited from EU Structural and Cohesion funds in the context of the first (1989–1993) and second (1994–1999) Community Support Frameworks (CSF). Infrastructure investment decelerated during the third CSF (2000–2006), and then much more markedly with Quadro de Referência Estratégico Nacional (QREN) (2007–2013), the National Strategic Reference Framework.

A taxonomy of 12 types of infrastructure assets was considered and categorized into four groups: road transportation, other transportation, utilities, and social infrastructure. In the first group, the road transportation category included national roads, municipal roads, and highways, which together accounted for 22.1% of the total infrastructure investment (just under 1% of GDP) between 1980 and 2018. In the second group, the other transportation category includes railroads, ports, and airports, accounting for 7.4% of the total infrastructure investment and averaging 0.33% of GDP during the same period.

In the other transportation infrastructure category, railroads represent the bulk (76%) of investment spending between 1980 and 2018, averaging 0.25% of GDP during this period. The apex (0.37% of GDP) was reached in the 1990s.

In the 1990s, the railway system was greatly modernized and reconverted (CP-Comboios de Portugal, EPE, n.d.), with a series of landmark achievements such as the Alfa train connecting Lisboa and Porto, electric quad and triple units for use in urban and suburban lines (Sintra, Coimbra, and Figueira da Foz), a complete overhaul of the Western Line, the intercity service connecting Barreiro, Beja, and Évora, the interregional service in the Algarve, the preparatory work for the railway crossing on the Tejo Bridge, and the expansion of the North Line between Lisboa and Azambuja.

From 2000 to 2005, the railway sector began its reconfiguration process, shrinking its mainland network to 2800 km, from a height of 3627 km in 1950 (República Portuguesa, 2022). This was mainly due to the partial closing of narrow and low-density lines in regions, such as Alentejo. At the same time, other nodes (such as Braga, Sete Rios-Roma/Areeiro, and Benfica-Agualva/Cacém) were intensively modernized with doubling and, in some cases, quadrupling the capacity to meet the most severe bottlenecks that emerged in the network.

From 2005 onwards, in line with the modernization efforts directed at passengers and building on the contract signed in 2002 between CP-Comboios de Portugal, EPE, and Sociedade Mineira de Neves Corvo (SOMINCOR) for the transport of ore from Neves Corvo, several vital connections for freight transport were established or upgraded. This is the case for the Aveiro Port, the Alcácer do Sal variant, and the connection between Coina and the Siderurgia Nacional (steel industry). In 2021, the Beira Baixa line connecting Covilhã and Guarda reopened.

As a result of all these modernization, reconversion, and reconfiguration efforts, between 1990 and 2019, the railway system lost 600 km in use (down to 2526 km), while the highway network expanded 2800 km over the same period (Cruz et al., 2021).

Since the 1980s, with enhanced purchasing power and free access to consumer credit, there has been a strong shift in the preferred transportation mode from public alternatives to cars (Cruz et al., 2021). This trend accelerated between 1990 and 2005 and leveled off. During this period, the collective transport quota (buses and trains) in overall land transport fell from over 30% to approximately 10% (República Portuguesa, 2022). To meet this shift in demand from the supply side, investment in road infrastructure was prioritized over that in railways.

As a result, in terms of accessibility, while the road system has experienced continuous improvements throughout the country, many regions are still more than 15’ away from a rail station, with some more than 60’ away (República Portuguesa, 2022). Such disparities are obviously a reason for concern regarding territorial cohesion.

3.2. The industry data set

The data on industry-specific output, employment, and private investment used in our analysis come from different annual issues in the National Accounts published by the Instituto Nacional de Estatística (National Institute of Statistics—Statistics Portugal, 2016). Employment is measured in thousands of employees.

Spanning the spectrum of all economic activities, we consider 22 industries grouped into four sectors. The different industries were grouped into two primary industries (agriculture and mining), seven manufacturing industries (food, textiles, paper, chemicals and pharmaceuticals, non-metallic minerals, basic metals, and machinery and equipment), ten private service industries (electricity and gas, water, construction, wholesale and retail trade, transportation, hospitality, telecommunications, finance, real estate, and professional services), and three public service industries (public administration, health, and education). **Table 2** provides details for each of the different industries.

Table 2. Industry classification of economic activity.

Primary sector—Agriculture	
Agriculture (S1)	Agriculture, crop and animal production, hunting, forestry, and fishing
Mining (S2)	Mining and quarrying
Secondary sector—Manufacturing	
Food (S3)	Manufacture of food products, beverages, and tobacco products
Textiles (S4)	Manufacture of textiles, wearing apparel and leather products
Paper (S5)	Manufacture of wood and paper products, and printing
Chemical and Pharmaceutical (S6)	Manufacture of chemicals and chemical products. Manufacturing of basic pharmaceutical products and pharmaceutical preparations.
Non-metallic minerals (S7)	Manufacture of rubber and plastics products, and other non-metallic mineral products
Basic metals (S8)	Manufacture of basic metals and fabricated metal products, except machinery and equipment
Machinery and equipment (S9)	Manufacture of computer, electronic and optical products; Manufacture of electrical equipment; Manufacture of machinery and equipment; Manufacture of transport equipment; Manufacture of furniture; other manufacturing; repair and installation of machinery and equipment
Electricity and gas (S10)	Electricity, gas, steam, and air-conditioning supply
Water (S11)	Water, sewerage, waste management and remediation activities
Construction (S12)	Construction
Wholesale and retail trade (S13)	Wholesale and retail trade, repair of motor vehicles and motorcycles
Tertiary sector—Private services	
Transportation and storage (S14)	Transportation, warehousing and storage, and postal and courier activities
Hospitality (S15)	Accommodation, and food and beverage service activities
Telecommunications (S16)	Telecommunications

Table 2. (*Continued*).

Tertiary sector—Private services	
Finance (S17)	Financial and insurance activities
Real estate (S18)	Real estate activities
Professional services (S19)	Publishing, audiovisual and broadcasting activities; Computer programming, consultancy and related activities; Information service activities; Legal and accounting activities; activities of head offices; Management consultancy activities; Architecture and engineering activities; Technical testing and analysis; Scientific research and development; Advertising and market research; Other professional, scientific and technical activities; Veterinary activities; Administrative and support service activities; Arts, entertainment and recreation; Rental and leasing activities; Security and investigation; Other services activities
Tertiary sector—Public services	
Public administration (S20)	Public administration and defense; Compulsory social security
Education (S21)	Education
Health (S22)	Human health activities; Residential care; Social work activities

Source—Instituto Nacional de Estatística.

4. Methodological considerations and preliminary data analysis

4.1. The methodological approach

Using industry-level data, our ultimate goal was to estimate the economic performance effects of railroad infrastructure investments, namely industry-specific private investment, employment, and output. With this goal, we use a dynamic multivariate methodology based on a vector autoregressive (VAR) approach. In this context, a VAR model can be conceptualized as a reduced form of a system consisting of a production function, two-factor demand functions, and a policy function for infrastructure investment, which operates as an externality for private production. This VAR approach has multiple advantages, as it incorporates the simultaneous endogeneity of different variables and fully captures the dynamic interactions among such variables. The process allows for the identification of contemporaneous and dynamic effects over time and how the two lead to the estimation of the long-term effects of railroad infrastructure investments.

The centerpiece of this approach naturally lies in the VAR estimates. We estimate 22 industry-specific VAR models related to industry-specific output, employment, private investment, and railroad infrastructure investments at the national level.

To achieve this, preliminary steps were required. First, we must analyze the stationarity of each data series and test for the possible existence of long-term relationships among the four relevant variables for each VAR model. This guarantees that the VAR estimation is performed with variables of the same order of integration, and that cointegration is incorporated as appropriate. Second, we need to determine the proper VAR specification, which includes the order of the VAR model, deterministic components to use, and possible structural breaks that should be considered.

Given the industry-specific VAR estimates, the next step is to generate industry-specific accumulated impulse-response functions for all private sector variables–investment, employment, and output–with respect to exogenous shocks in investments in railroad infrastructure. This process required several preliminary steps. First, we must identify exogenous railroad infrastructure investment shocks and the issue of contemporaneous correlations among shocks. Second, we must define exactly how we measured the effects and interpreted the results of the accumulated response functions. It is critical to recognize that the effects are the total effects that capture the interactions among the different variables over time. These are relevant measurements from a policy perspective that transcend traditional measurements based on ceteris paribus assumptions.

The remainder of this section presents an abbreviated version of these steps. For more detailed presentations, see Pereira (2000) and Pereira and Pereira (2018a). For brevity, we provide only a sketch of the different steps in the preliminary data analysis. The full documentation is available from the authors upon request.

4.2. Unit roots, cointegration, and the VAR specification

The unit root and cointegration analyses are the first steps. Unit root tests suggest stationarity in first differences, whereas cointegration tests suggest the absence of cointegration. We follow the standard procedure in the literature and determine the specifications of the VAR models using the growth rates of the original variables.

We estimate the VAR models for each of the 22 industries. Each VAR model includes industry-specific output, employment, private investment, and railroad infrastructure investments. We use the Bayesian information criterion (BIC) to determine the structural breaks and deterministic components to be included. Our test results suggest a VAR specification of first order with a constant and a trend, as well as structural breaks in 1989, 1994, and 2000, the years of inception of the first three Community Support Frameworks. This is the preferred choice in most cases. Our test results suggest a VAR specification of first order with a constant and a trend, as well as structural breaks in 1989, 1994, and 2000, the years of the inception of the first three Community Support Frameworks. In most cases, this is the preferred choice.

4.3. Identifying exogenous innovations in railroad infrastructure investment

The key to correctly determining the impact of infrastructure investment is identifying exogenous shocks representing innovations in infrastructure investments that are not contaminated by other contemporaneous innovations and avoiding reverse causation. To address this issue, we draw upon the approach of handling the effects of monetary policy (Christiano et al., 1996, 1999; Rudebusch, 1998) adopted by Pereira (2000) in the context of the analysis of the effects of infrastructure investments. The identification of exogenous shocks to infrastructure investment would, in general, result from knowing what fraction of government appropriations in each period is purely for non-economic reasons. The econometric counterpart is to consider a policy function that relates the growth rate of infrastructure investment to the relevant information set. The residuals from these policy functions reflect the unexpected component of the evolution of infrastructure investment and, by definition, are uncorrelated with innovations in other variables.

We assume that the relevant information set for the policy function includes the past, but not the current, values of the economic variables. In the context of the standard Cholesky decomposition, this is equivalent to assuming that innovations in investments lead innovations in economic variables; that is, while innovations in infrastructure investments affect the economic variables contemporaneously, the reverse is not true. This also means that the estimated effects of infrastructure investments are invariant to the order of the three economic variables.

There are two conceptual reasons for this assumption. First, it seems reasonable to assume that the economy reacts to innovations in infrastructure investments within a year. Second, it seems reasonable to assume that the public sector is unable to adjust infrastructure investment decisions to innovations in economic variables within the same year. This is because of the time lags involved in information gathering and public decision-making.

Furthermore, this assumption is reasonable from a statistical perspective. Invariably, the policy functions point to the exogeneity of innovations in infrastructure investments; that is, the evolution of the different infrastructure investments does not seem to be affected by the lagged evolution of the remaining variables. This is to be expected because infrastructure investments were linked to EU support programs and, therefore, not responsive to the ongoing economic conditions. Moreover, we would not expect any single economic sector to have an impact on decision-making regarding infrastructure investments at the national level.

4.4. Measuring the effects of innovations in railroad infrastructure investment

To measure the industry-specific effects of a one-percentage-point one-time shock on the growth rate of infrastructure investment in railroads on output, employment, and investment, we estimate the accumulated impulse-response functions for each VAR model. The accumulated impulse response functions typically converge within a relatively short period. The error bands surrounding the point estimates for the accumulated impulse responses were computed using bootstrapping. We consider 90% intervals, although bands that correspond to a 68% posterior probability are standard in the literature (Sims and Zha, 1999). From a practical perspective, when the 90% error bands for the accumulated impulse response functions include zero, we consider that the effects are not significantly different from zero[1].

To measure the effects of shocks on railroad infrastructure investment, we calculated the total long-term accumulated elasticities and the total long-term accumulated marginal products of the different industries' output, employment, and investment with respect to each type of infrastructure investment. These concepts depart from conventional understanding because they are not based on ceteris paribus assumptions; instead, they include all dynamic feedback effects among the different variables.

The total long-term accumulated elasticities are interpreted as the total accumulated percentage point long-term change in output, employment, and investment per percentage point accumulated long-term change in railroad infrastructure investment. The total long-term accumulated marginal products measure the change in output, employment, and investment for each additional euro of infrastructure investment in railroads. The respective marginal products are obtained by multiplying the ratio of the average output, employment, and investment to railroad infrastructure investment by the corresponding elasticity. We use the average ratio over the last ten years of the sample. Using a recent time period allows the marginal products to reflect the relative scarcity of the different infrastructures at the margin of the sample period, while the choice of ten years prevents these ratios from being overly affected by business cycle considerations.

5. On the economic effects of railroad infrastructure investments

In this section, we first consider the aggregate effects of railroad infrastructure to frame industry-specific results. We then present the results at the industry level, both the accumulated (total) long-term effects and the outcomes on impact, followed by an identification of what these results imply in terms of the various channels through which such investments affect economic performance. This is followed by the effects of railroad infrastructure investments on the industry mix.

5.1. On the aggregate effects of railroad infrastructure investments

For the economy as a whole, we estimate that, in the long term, for every €1m invested in railroad infrastructure, aggregate private investment increases by €17.78, and output increases by €20.84. Furthermore, we estimate that approximately 72 new permanent jobs will be created (see **Table 3**). These results imply that railroad infrastructure investments are effective in promoting long-term economic performance.

It is difficult to make meaningful international comparisons. This is because different studies adopt different econometric methodologies, sample periods, and data definitions, making the estimates difficult to interpret and compare with our set of results. As such, we limit the comparison of our results to strictly equivalent evidence on the output multiplier of investments in railroad infrastructure. Focusing on Ontario, Canada, and using data that span 1976 through 2011, (Pereira and Pereira, 2018b) estimate an output multiplier of 29.19 and a corresponding 107 net jobs created for each CDN$ 1m in transit infrastructure investments (Deloitte, 2013). Focusing on railroad infrastructure investments in Portugal, Pereira and Andraz (2005) estimate corresponding multipliers of 18.5 and 18.8, for output and investment, respectively, accompanied by an additional 204 net permanent jobs. Our estimates, 20.84 and 72, for output and employment, respectively, are around the same order of magnitude. These comparisons allow us to move forward and address the disaggregated details with great confidence, as the aggregate results presented here are well within the realm of the most directly comparable results.

With respect to the relationship between short- and long-term effects for the different economic variables, none of the impacts differed in sign. In terms of employment, most new net permanent jobs are frontloaded, as 92.6% of the total accumulated increase occurs in the short run within one year. Regarding private investment and output for the economy as a whole, the corresponding figures are 38.8

and 14.5%, respectively. With private investment outpacing output in the short run, in the context of job creation where private consumption and public spending are also set to rise, the fundamental identity in macroeconomics implies that net exports will fall in the first year following railroad infrastructure investment. This is not surprising, as a significant share of induced capital spending is likely to be related to imported goods and services. Over time, the trade balance is estimated to reverse.

Table 3. Total long-term industry-specific effects of infrastructure investment in railroads.

	Output		**Employment**		**Investment**	
	Elasticity	**Marginal product**	**Elasticity**	**Marginal product**	**Elasticity**	**Marginal product**
Agriculture and mining						
Agriculture (S1)	−0.0428*	*	0.0207*	*	0.2385	0.38
Mining (S2)	0.0148*	*	0.1125	3.42	−1.3357	−0.36
Manufacturing						
Food (S3)	0.0083*	*	−0.0272	−5.60	0.3703	0.37
Textiles (S4)	− 0.0394*	*	−0.0119	−5.67	0.1694	0.08
Paper (S5)	−0.0962	−0.39	0.0147*	*	0.4446	0.41
Pharmaceuticals (S6)	−0.0681	−0.14	0.0050*	*	0.6409	0.28
Non-metallic minerals (S7)	−0.0598	−0.27	−0.0279	−4.48	−0.0077*	*
Basic metals (S8)	−0.0582	−0.24	−0.0359	−6.55	−0.0162*	*
Machinery and equipment (S9)	−0.1894	−1.62	−0.0685	−23.50	0.1142*	*
Private services						
Electricity and gas (S10)	0.1829	0.95	−0.0592	−1.27	1.0583	2.54
Water (S11)	0.2035	0.41	−0.0225*	*	0.2004*	*
Construction (S12)	0.1518	2.72	0.0564	56.07	0.3676	0.95
Wholesale and retail trade (S13)	0.0517	1.70	−0.0039*	*	0.2748	1.08
Transportation and storage (S14)	−0.0532	−0.57	−0.0056*	*	0.9944	4.88
Hospitality (S15)	0.0399	0.44	0.0280	13.13	0.7561	1.05
Telecommunications (S16)	−0.0078*	*	−0.0294	−0.85	0.0771*	*
Finance (S17)	−0.0283*	*	−0.0779	−14.26	−0.5444	−1.25
Real estate (S18)	0.8968	16.69	0.1018	6.31	0.1763	3.00
Professional services (S19)	−0.0367	−0.78	0.0553	55.73	0.5354	3.25
Public services						
Public administration (S20)	0.0482	0.98	−0.0007*	*	0.1715	1.12
Education (S21)	0.0500	0.80	−0.0009*	*	−0.0556*	*
Health (S22)	0.0149	0.16	−0.0163*	*	−0.0473*	*
Total economy		**20.84**		**72.48**		**17.78**

Note—values marked with * are not statistically significant as implied by the standard deviation bands around the impulse response functions. Totals may not add up due to rounding errors. Total economy marginal products are the sum of the statistically-significant constituent industry-specific effects.

5.2. On the long-term accumulated industry-level effects[2]

When we examine the economic effects of railroad infrastructure investments at the industry level, we find that real estate (S18), construction (S12), and wholesale and retail trade (S13) have the largest impacts in terms of output, with marginal products of €16.69, €2.72, and €1.70, respectively (see **Table 4**). Together, these three industries saw a boost that represented approximately 101.3% of the induced increase in GDP. Public administration (S20) and electricity and gas (S10) come next, with marginal products of €0.98 and €0.95, respectively. Positive effects were observed for water (S11), hospitality (S15), education (S21), and health (S22). On the other hand, on account of the overall change in the industry mix, for every euro invested in railroad infrastructures, output is estimated to drop by €1.62 in the machinery and equipment (S9) industry, 78 cents in professional services (S19), 57 cents in transportation and storage (S14), 39 cents in paper (S5), 27 cents in non-metallic minerals (S7), 24 cents in basic metals (S8), and 14 cents in pharmaceuticals (S6).

Table 4. A ranking of output effects of infrastructure investment in railroads.

On impact		**Intertemporal**		**Long term**	
Industry	**Marginal product**	**Industry**	**Marginal product**	**Industry**	**Marginal product**
S18	3.40	S18	13.3	S18	16.69
S12	1.60	S10	1.16	S12	2.72
S13	0.56	S13	1.14	S13	1.70
S22	0.20	S12	1.12	S20	0.98
S21	0.15	S20	1.07	S10	0.95
S15	0.04	S21	0.65	S21	0.80
		S11	0.48	S15	0.44
S19	−0.95	S15	0.40	S11	0.41
S9	−0.61	S19	0.17	S22	0.16
S5	−0.49	S5	0.10		
S10	−0.21	S6	0.06	S9	−1.62
S6	−0.20			S19	−0.78
S14	−0.19	S9	−1.01	S14	−0.57
S7	−0.11	S14	−0.38	S5	−0.39
S20	−0.09	S8	−0.24	S7	−0.27
S11	−0.07	S7	−0.16	S8	−0.24
		S22	−0.04	S6	−0.14
TOTAL	**3.03**		**17.81**		**20.84**

Key—Agriculture (S1), Mining (S2), Food (S3), Textiles (S4), Paper (S5), Pharmaceuticals (S6), Non-metallic minerals (S7), Basic metals (S8), Machinery and equipment (S9), Electricity and gas (S10), Water (S11), Construction (S12), Wholesale & retail trade (S13), Transportation & storage (S14), Hospitality (S15), Telecommunications (S16), Finance (S17), Real estate (S18), Professional services (S19), Public administration (S20), Education (S21), and Health (S22).

With respect to the industry-by-industry effect on employment, the largest gains are expected in construction (S12), professional services (S19), and hospitality (S15), with estimated marginal products of approximately 56, 56, and 13 jobs, respectively (see **Table 5**). Together, these three industries create 125 jobs, almost 74% more permanent jobs than the aggregate net change in employment induced by the railroad infrastructure itself, around 72. Thus, we estimate a non-negligible reallocation of labor input between industries, with workers moving out of machinery and equipment

(S9), finance (S17), and, to a lesser extent, basic metals (S8), food (S3), and textiles (S4), and taking up employment in professional services (S19), construction (S12), hospitality (S15), and other less significant industries, such as real estate (S18) and mining (S2).

Table 5. A ranking of employment effects of infrastructure investment in railroads.

On impact		Intertemporal		Long term	
Industry	**Marginal product**	**Industry**	**Marginal product**	**Industry**	**Marginal product**
S19	72.13	S12	49.75	S12	56.07
S15	16.42	S2	0.52	S19	55.73
S18	12.00	S16	0.32	S15	13.13
S12	6.32			S18	6.31
S2	2.90	S19	−16.4	S2	3.42
		S17	−6.45		
S9	−17.43	S9	−6.07	S9	−23.50
S17	−7.81	S18	−5.69	S17	−14.26
S4	−5.27	S8	−3.71	S8	−6.55
S3	−4.84	S15	−3.29	S4	−5.67
S8	−2.84	S7	−1.99	S3	−5.60
S7	−2.49	S3	−0.76	S7	−4.48
S16	−1.17	S10	−0.47	S10	−1.27
S10	−0.80	S4	−0.4	S16	−0.85
TOTAL	**67.12**		**5.36**		**72.48**

Key—Agriculture (S1), Mining (S2), Food (S3), Textiles (S4), Paper (S5), Pharmaceuticals (S6), Non-metallic minerals (S7), Basic metals (S8), Machinery and equipment (S9), Electricity and gas (S10), Water (S11), Construction (S12), Wholesale & retail trade (S13), Transportation & storage (S14), Hospitality (S15), Telecommunications (S16), Finance (S17), Real estate (S18), Professional services (S19), Public administration (S20), Education (S21), and Health (S22).

Regarding the industry-by-industry impact of railroad infrastructure investments on private investment, we estimate that the four industries with the highest marginal products are transportation and storage (S14), professional services (S19), real estate (S18), and electricity and gas (S10) with €4.88, €3.25, €3, and €2.54, respectively (see **Table 6**). Together, these effects accounted for 76.9% of the overall investment boost. The next tier of industries that benefit includes public administration (S20), wholesale and retail trade (S13), hospitality (S15), and construction (S12). Interestingly, finance (S17) and mining (S2) both have negative estimated marginal products of -€1.25 and 36 cents, respectively.

Table 6. A ranking of investment effects of infrastructure investment in railroads.

On impact		Intertemporal		Long term	
Industry	**Marginal product**	**Industry**	**Marginal product**	**Industry**	**Marginal product**
S14	1.93	S10	3.86	S14	4.88
S19	1.78	S14	2.95	S19	3.25
S18	1.71	S19	1.47	S18	3.00
S20	1.54	S18	1.29	S10	2.54
S15	0.68	S12	0.69	S20	1.12
S13	0.57	S13	0.51	S13	1.08
S3	0.36	S15	0.37	S15	1.05
S5	0.29	S1	0.13	S12	0.95
S12	0.26	S5	0.12	S5	0.41
S1	0.25	S6	0.10	S1	0.38
S6	0.18	S3	0.01	S3	0.37
S4	0.10			S6	0.28
		S20	−0.42	S4	0.08
S10	−1.32	S17	−0.11		
S17	−1.14	S2	−0.07	S17	−1.25
S2	−0.29	S4	−0.02	S2	−0.36
TOTAL	**6.90**		**10.88**		**17.78**

Key—Agriculture (S1), Mining (S2), Food (S3), Textiles (S4), Paper (S5), Pharmaceuticals (S6), Non-metallic minerals (S7), Basic metals (S8), Machinery and equipment (S9), Electricity and gas (S10), Water (S11), Construction (S12), Wholesale & retail trade (S13), Transportation & storage (S14), Hospitality (S15), Telecommunications (S16), Finance (S17), Real estate (S18), Professional services (S19), Public administration (S20), Education (S21), and Health (S22).

5.3. Long-term accumulated effects vs effects on impact

Next, we consider the relationship between the short- and long-term effects for the three economic variables in different industries (see **Table 7**).

With respect to output, positive long-term effects dominate short-run impacts in eight industries. By decreasing order of significance, we find this outcome in real estate (S18), electricity and gas (S10), wholesale and retail trade (S13), construction (S12), and public administration (S20), with estimated longer-term marginal products (that ignore the effects on impact) of €13.29, €1.16, €1.14, €1.12, and €1.07, respectively, and, in a second tier, to a smaller extent, in education (S21), water (S11), and hospitality (S15), with corresponding marginal products of 65 cents, 48 cents, and 40 cents, respectively. Together, the five industries that make up the first tier of effects correspond to 99.8% of economy-wide long-term output effects. In addition, by decreasing order of significance, we find negative long-term effects on output that dominate the corresponding short-run impacts in four industries, namely machinery and equipment (S9), transportation and storage (S14), basic metals (S8), and non-metallic minerals (S7). In general terms, the top three industries with the largest positive short-term impacts are, in decreasing order of significance, real estate (S18), construction (S12), and wholesale and retail trade (S13) with €3.40, €1.60, and 56 cents, respectively. Together, these three industries capture 183.5% of short-term output effects. Conversely, the top three industries with the biggest negative short-term impacts are, also in decreasing order of significance: professional services (S19), machinery and equipment (S9), and paper (S5). We find that positive long-term output effects reverse (without dominating) the initial negative short-term impacts in six industries: paper (S5), pharmaceuticals (S6), electricity and gas (S10), water (S11), professional services (S19), and public administration (S20). Conversely, we find that negative long-term output effects reverse (without dominating) initial positive short-term impacts only in the health (S22) industry.

Table 7. Total long-term marginal products vs short-term effects on impact of infrastructure investment in railroads.

		Output	**Employment**	**Investment**
Agriculture (S1)	Total	*	*	0.38
	Short-term	*	*	0.25
Mining (S2)	Total	*	3.42	−0.36
	Short-term	*	2.90	−0.29
Food (S3)	Total	*	−5.60	0.37
	Short-term	*	−4.84	0.36
Textiles (S4)	Total	*	−5.67	0.08
	Short-term	*	−5.27	0.10
Paper (S5)	Total	−0.39	*	0.41
	Short-term	−0.49	*	0.29
Pharmaceuticals (S6)	Total	−0.14	*	0.28
	Short-term	−0.20	*	0.18
Non-metallic minerals (S7)	Total	−0.27	−4.48	*
	Short-term	−0.11	−2.49	*
Basic metals (S8)	Total	−0.24	−6.55	*
	Short-term	0.00	−2.84	*
Machinery and equip. (S9)	Total	−1.62	−23.50	*
	Short-term	−0.61	−17.43	*
Electricity and gas (S10)	Total	0.95	−1.27	2.54
	Short-term	−0.21	−0.80	−1.32
Water (S11)	Total	0.41	*	*
	Short-term	−0.07	*	*
Construction (S12)	Total	2.72	56.07	0.95
	Short-term	1.60	6.32	0.26
Whole. & retail trade (S13)	Total	1.70	*	1.08
	Short-term	0.56	*	0.57
Transp. & storage (S14)	Total	−0.57	*	4.88
	Short-term	−0.19	*	1.93
Hospitality (S15)	Total	0.44	13.13	1.05
	Short-term	0.04	16.42	0.68
Telecommunications (S16)	Total	*	−0.85	*
	Short-term	*	−1.17	*
Finance (S17)	Total	*	−14.26	−1.25
	Short-term	*	−7.81	−1.14

Table 7. (*Continued*).

		Output	Employment	Investment
Real estate (S18)	Total	16.69	6.31	3.00
	Short-term	3.40	12.00	1.71
Professional services (S19)	Total	−0.78	55.73	3.25
	Short-term	−0.95	72.13	1.78
Public administration (S20)	Total	0.98	*	1.12
	Short-term	−0.09	*	1.54
Education (S21)	Total	0.80	*	*
	Short-term	0.15	*	*
Health (S22)	Total	0.16	*	*
	Short-term	0.20	*	*
Total economy	**Total**	**20.84**	**72.48**	**17.78**
	Short-term	**3.03**	**67.12**	**6.90**

Note—values marked with * are not statistically significant as implied by the standard deviation bands around the impulse response functions. Total economy short- and long-term marginal products are the sum of the respective statistically-significant industry-specific effects.

Regarding employment, only in the construction (S12) industry does the positive long-term effect dominate the short-run impact, with an estimated long-term marginal product of around 50 jobs. The impact in this industry alone is almost 9.3 times the economy-wide long-term employment effect. We find negative long-term effects on employment that dominate the corresponding short-run impacts in the basic metals (S8) industry with a long-term marginal loss of almost four jobs. In general terms, the top three industries with the largest positive short-term impacts on employment are, in decreasing order of significance, professional services (S19), hospitality (S15), and real estate (S18), with marginal products of approximately 72, 16, and 12 jobs, respectively. Together, these three industries capture almost 150% of economy-wide short-term employment effects. Conversely, the top three industries with the largest negative short-term employment impacts are also in decreasing order of significance: machinery and equipment (S9), finance (S17), and textiles (S4). We find that positive long-term employment effects reverse (without dominating) the initial negative short-term impacts only in the telecommunications (S16) industry. Conversely, we find that negative long-term employment effects reverse (without dominating) the initial positive short-term impacts in three industries: professional services (S19), real estate (S18), and hospitality (S15).

With respect to private investment, positive long-term effects dominate short-run impacts in three industries: electricity and gas (S10), transportation and storage (S14), and construction (S12), with long-term marginal products to investment of €3.86, €2.95, and 69 cents, respectively. Together, these three industries capture 69% of economy-wide long-term investment effects. We find no industries in which the negative long-term effects on investment dominate the corresponding short-run impacts. Generally, the top three industries with the largest positive short-term impacts on investment are, in decreasing order of significance, transportation and storage (S14), professional services (S19), and real estate (S18), with marginal products/investments of €1.93, €1.78, and €1.71, respectively. Together, these three industries capture 79%

of the economy-wide, short-term impact on investment. Conversely, the top three industries with the largest negative short-term impacts on investment are also in decreasing order of significance: electricity and gas (S10), finance (S17), and mining (S2). We find positive long-term effects on investment reverse (without dominating) initial negative short-term impacts only in the electricity and gas industry (S10). Conversely, we find negative long-term effects on investment reverse (without dominating) initial positive short-term impacts in two industries: textiles (S4) and public administration (S20).

Examining the case of the transportation and storage (S14) industry, most of the effects on private investment occur over time, indicating that capital spending in this industry is self-reinforcing. As we find no changes in employment in this industry, we can conclude that, as a result of railroad infrastructure investments, it will become more capital intensive.

5.4. What we can learn about the nature of the effects of railroad infrastructure investments

Next, we identify the channels through which investment in railroad infrastructure affects economic performance. To decompose economy-wide long-term marginal products, we consider the dichotomies between short-term and intertemporal effects as well as between demand-side and supply-side impacts (see **Table 8**).

Table 8. Decomposition of total long-term effects of infrastructure investment in railroads.

	Output		**Employment**		**Investment**	
	Marginal product	**As a % of total**	**Marginal product**	**As a % of total**	**Marginal product**	**As a % of total**
Demand-side effects	4.15	19.91	116.87	161.24	7.59	42.69
Site-location effects	13.29	63.77	−5.69	−7.85	1.29	7.26
Functional effects	3.40	16.32	−38.76	−53.39	8.90	50.06
Traded	−1.63	−7.82	−12.47	−17.12	3.22	18.11
Nontraded	5.03	24.14	−26.29	−36.27	5.68	31.95
Total economy	**20.84**	**100.00**	**72.48**	**100.00**	**17.78**	**100.00**

Note—values marked with * are not statistically significant as implied by the standard deviation bands around the impulse response functions. Demand-side effects include the sum of short-term effects on impact in all sectors plus intertemporal effects over time in industry S12 (construction). Site-location effects correspond to intertemporal effects of industry S18 (real estate). Functional effects of the traded variety include the sum of intertemporal effects in industries S1–S9 (agriculture and mining, and manufacturing) and in S14 (transportation and storage). Functional effects of the nontraded kind include the sum of intertemporal effects in industries S10−S22 (private and public services), except for S12, S14 and S18 (construction, transportation and storage, and real estate, respectively).

In terms of output, demand-side effects account for 19.91% of the economy-wide long-term marginal product in terms of output, €20.84, which adds together the on-impact and intertemporal effects. Demand-side effects include the sum of short-term effects on the impact in all industries and intertemporal effects over time in construction. Of these, in the case of output, the bulk is in real estate (S18) and construction (S12). Site-location effects are induced by the presence of the railroad infrastructure itself, corresponding to the intertemporal effects of the construction (S12) industry, and represent 63.77% of the total economy's long-term effect. Having considered the demand-side and site-location effects, we turn to the supply-side channel and examine the functional effects that come in two types: traded and non-traded. The functional effects of the traded variety account for −7.82% of the economy-wide long-term marginal product in terms of output and include the sum of the intertemporal effects in industries S1 through S9, comprising agriculture and mining, as well as manufacturing, plus those in the transportation and storage (S14) industry. These effects can be further split into two groups: one with positive marginal products in the paper (S5) and pharmaceutical (S6) industries, and the other with negative marginal products in each of the following industries: machinery and equipment (S9), transportation and storage (S14), basic metals (S8), and non-metallic minerals (S7). On the other hand, the functional effects of the non-traded variety represent 24.14% of the total economy's marginal product in terms of output and include the sum of the intertemporal effects in industries S10–S22, with the exception of construction (S12), transportation and storage (S14), and real estate (S18). These functional effects of the non-traded variety are strongest in electricity and gas (S10), wholesale and retail trade (S13), and public administration (S20) and marginally negative in the health (S22) industry.

In terms of employment, demand-side effects represent 161.24% of the economy-wide long-term marginal product, estimated at approximately 72 net permanent jobs. The bulk of demand-side effects are concentrated in professional services (S19) and construction (S12). Site-location effects represent −7.85% of the total economy's long-term employment effect. The functional effects of the traded variety correspond to −17.12% of the economy-wide long-term marginal product in terms of jobs. In most industries, the marginal products are negative, with the exception of mining (S2). The basic metals (S8) and machinery and equipment (S9) industries have the most significant negative marginal products. The functional effects of the non-traded kind represent −36.27% of the total economy's employment impact, with the strongest negative marginal products in professional services (S19), finance (S17), and hospitality (S15). Telecommunications (S16) is estimated to be the exception here, with a positive marginal product.

Finally, in terms of private investment, demand-side effects represent 42.69% of the economy-wide long-term marginal product, estimated at approximately €17.78. The bulk of demand-side effects are concentrated in transportation and storage (S14), professional services (S19), and real estate (S18). It is worth highlighting that the construction (S12) industry does not have one of the most significant marginal products. Site-location effects represent 7.26% of the total economy's long-term effects in terms of investment. The functional effects of the traded variety correspond to 18.11% of the economy-wide long-term marginal products in terms of investment. Transportation and storage take the lead as the industry with the largest marginal product. Generally, marginal products are positive, except for mining (S2) and textiles (S4) with marginal losses. The functional effects of the non-traded type represent 31.95% of the total economy's impact on investment, with the strongest positive marginal products being electricity and gas (S10) and professional services (S19). Conversely, public administration (S20) and finance (S17) are estimated to be the exceptions, with negative marginal products.

6. Summary and policy implications

This study aimed to assess the impact of railroad infrastructure investments on Portugal's economic performance with a distinct focus on industry-level effects. By leveraging a vector autoregressive model and a unique dataset, we calculated both the elasticity and marginal product of capital expenditures on railways with regard to output, employment, and private investment.

Our primary contribution lies in deriving industry-specific economic outcomes from such investments in transport infrastructure. Our model intentionally eschews an aggregate approach as we explore how railway investments propagate through the economy over time, triggering industry-specific adjustments in output, employment, and private investment. Thus, the total economic performance impacts we determine are a compilation of statistically significant industry-specific effects.

The main findings of our research are summarized as follows: For the overall economy, we estimate that a €1m investment in railway infrastructure has substantial positive spillover effects, amplifying GDP by €20.84m, creating approximately 72 new permanent jobs, and stimulating an additional €17.78m in private investment.

The short-term impact (within the first year) accounted for only 14.5% and 38.8% of the total accumulated increase in output and private investment, respectively. Conversely, most of the permanent job creation is immediate, with approximately 93% of the 72 new long-term jobs being established within one year of a €1m railway infrastructure investment. With a rise in fixed capital investment that exceeds that of GDP and with private consumption and public expenditure also set to increase, a transient dip in net exports is expected. Over time, this deterioration is more than compensated for as long-term net exports are positive.

At the disaggregated level, our analysis suggests that the real estate, construction, wholesale, and retail trade industries jointly account for 101.3% of the total accumulated increase in GDP, closely trailed by public administration, electricity and gas, and education, with an additional 13.1 percentage points. The industries that generate the greatest number of permanent jobs per €1m of railway investment, in decreasing order of significance, are construction, professional services, and hospitality.

Examining the total industry-specific accumulated marginal products of investment, industries such as transportation and storage, professional services, real estate, and electricity and gas jointly account for nearly 77% of the overall increase in gross fixed capital formation. This is followed by public administration, wholesale and retail trade, hospitality, and construction, contributing approximately 23%. These shifts significantly transformed the industry composition of output, employment, and private investment. The only industries benefiting in relative terms across all three dimensions are real estate, construction, and hospitality, whereas professional services, wholesale and retail trade, electricity and gas, and public administration benefit in two of these three areas. Meanwhile, industries such as nonmetallic minerals, basic metals, machinery and equipment, and finance experience relative losses in two dimensions.

Regarding the traded/non-traded divide, non-traded service industries such as real estate, construction, and wholesale and retail trade have emerged as the primary beneficiaries of railway investments in terms of total accumulated output. By contrast, machinery, equipment, and professional services experience significant losses. With respect to employment, the divide is not clear. All traded industries, barring mining, experience total job losses, while non-traded industries, such as professional services and hospitality, report gains, albeit with labor reallocation within the non-traded group from finance, electricity, and gas. Regarding total accumulated changes in private investment, all non-traded industries, except finance, benefit more than their traded counterparts, which also register increased gross fixed capital formation, although on a smaller scale. Of note is the profound induced effect (nearly 27.5% of the total) in the transportation and storage industry, and the net reduction in mining.

The economic effects of investment in railroad infrastructure are essential for policymakers in Portugal and beyond. While projects such as Ferrovia 2020 (Infraestruturas de Portugal, 2016) aim to modernize and revitalize Portugal's rail network, delays in implementation risk not only losing access to key EU funding sources but also forgoing potential economic benefits. Research shows that infrastructure investments can stimulate economic growth in the short term through increased employment and demand and, in the long run, by improving productivity and competitiveness. Furthermore, the countercyclical nature of infrastructure spending can dampen economic downturns. Thus, as Portugal plans significant new investments in its rail network, policymakers should be informed of the magnitude of its expected economic impact. With evidence-based knowledge of economic outcomes, policymakers can not only make better decisions on project timelines, budgetary allocations, and funding sources but can also strategically employ railroad investments to bolster Portugal's competitiveness and long-term prosperity.

A few policy implications can be extracted from our results. First, with large positive effects on GDP, employment, and private investment, railroad infrastructure investments are effective in promoting long-term economic performance. For this reason, this type of capital spending ought to be part of Portugal's medium- to long-term growth strategies. Second, although very significant effects materialize over time, the bulk of the gains occur within the first year only in the case of employment. This clearly suggests that railroad infrastructure investments should be a part of the countercyclical policy toolbox, and, mindful of this, public officials need to schedule the start of such projects during periods of weak economic activity. Nevertheless, our results suggest that they also need to be prepared to worsen their trade balance during this short period. Third, when examining the channels through which economic performance is impacted, we find that demand-side effects, obtained by the sum of short-term effects across all industries as well as long-term construction effects, are especially important for employment and private investment. The long-term location effects are particularly significant in the case of output. Functional effects, especially those of the non-traded variety, are also meaningful in the case of output and private investment. Finally, policymakers at various levels need to keep in mind that railroad infrastructure investments will likely substantially alter the industry mix. While real estate, construction, and hospitality are all set to gain across the three dimensions, we consider output, employment, and private investment, followed by professional services, wholesale and retail trade, electricity and gas, and public administration, as industries that stand to benefit in most dimensions. These gains come at the expense of comparatively slower economic activity in other industries, such as non-metallic minerals, basic metals, machinery and equipment, and finance. Indeed, the implications in terms of the traded/non-traded industry divide are clear: non-traded industries, such as real estate, construction, hospitality, wholesale and retail trade, and professional services, will likely be the big winners.

This study contributes to empirical literature in several ways. First, the dynamic and reverberating total accumulated results of railroad infrastructure investments on economic performance are decomposed into effects registered in the first year and those that take longer to occur as well as into their constituent demand- and supply-side channels. Second, by estimating industry-specific effects, sectoral planning and employment agencies can set and adjust their spending programs and their respective compositions. Furthermore, more accurate aggregate estimates are obtained as the sum of statistically significant impacts, thus lending even more convincing support to the idea that, for Portugal, which remains one of the least developed Member States of the EU, well-timed investments in railroad infrastructure can not only serve countercyclical policy objectives but are also worthy of consideration to improve its long-term economic growth potential and thus accelerate its real convergence.

Next, we highlight a promising avenue for future research. In achieving the much-needed global energy transition, it is useful to keep in mind that the transport sector is responsible for more than half of the global oil demand and approximately ¼ of the global CO_2 emissions from fuel combustion (International Energy Agency, 2019). Notwithstanding the substantial industry-specific detail that characterizes the dataset we used, an add-on that could further enhance our analysis would be information on the CO2 emissions related to the construction and operation of each of the six types of transportation infrastructure assets for each of the 22 industries that span economic activity in Portugal. This would add an environmental dimension to the other three that we consider—output, employment, and private investment—and would potentially allow us to answer the following research question: Which kind of transportation infrastructure would best assist Portugal both in terms of economic performance and in reducing greenhouse gas (GHG) emissions? Although railways have been in operation in Portugal since 1856 (CP-Comboios de Portugal; EPE, n.d.), there is a growing perception that it is a mode of transport that functions much below its full capability. Globally, less than 20% of the total road and rail infrastructure is devoted to rail (International Transport Forum, 2022), lending support to the enormous potential, in Portugal, to not only reduce traffic congestion on roads but also to alleviate the housing shortage problem if new transport corridors are made available that improve accessibility, shorten the distance to work, and effectively open up accommodation options on the periphery of cities.

In addition to all the economic results presented above and the possible extension just mentioned, it is important to conclude by acknowledging that investments in railroad infrastructure also lead to an array of indirect effects that transcend the macroeconomic dimension we consider in this study and, as such, are not considered in our analysis. This must be the subject of future research.

Such indirect gains are multifaceted and interconnected, spanning enhanced safety, reduced congestion, decreased pollution, reduced vehicle disposal, reduced greenhouse gas emissions, improved energy efficiency, equitable access, urban planning benefits, and technological advancements. Policymakers should judiciously consider these diverse benefits when making transportation investment decisions to ensure a comprehensive and sustainable development approach.

Silla and Kallberg (2012) observed that passenger rail has an accident rate of approximately one-tenth that of automobiles per passenger mile traveled, implying a significant safety benefit in shifting from cars to trains. This finding was reinforced by Waycaster et al. (2018) and Litman (2022), who identified rail as one of the safest modes of transportation based on the metrics of injuries and fatalities per distance traveled. Filigrana et al. (2022) highlighted the tangible economic value of this safety improvement, resulting from saved lives and decreased healthcare costs.

Congestion mitigation is another indirect gain arising from investment in rail infrastructure. Adler et al. (2020) found that introducing a commuter rail service in major cities decreased highway congestion and provided much needed relief on crowded roads. This finding is echoed by Anderson (2014), who demonstrated that expanded urban rail networks directly reduced road congestion. Moreover, as Small and Verhoef (2019) articulated, trains, with their high passenger capacity, can transport more people than private automobiles in the same amount of space, reducing the externalities of congestion such as wasted time, stress, and lost productivity (Börjesson et al., 2015; Yang et al., 2018).

Investments in rail infrastructure have a profound impact on urban planning and land use. Cervero (1997) demonstrated how rail investments can encourage transit-oriented development, resulting in the creation of compact, mixed-use neighborhoods that promote walking and sustainable living. These urban reshaping efforts further enhance the aesthetic appeal of cities, a point that Chester and Horvath (2010) also noted by stating that a railway is often less visually intrusive than multilane highway slicing through an urban neighborhood.

From an environmental perspective, rail vehicles generally have longer usable lifespans than cars and buses, reducing the waste and pollution from discarded vehicles (Chester and Horvath, 2012; Hou et al., 2020). This benefit, coupled with the reduction in greenhouse gas emissions from shifting travelers to lower-emission electric trains (American Public Transportation Association, 2020; Beaudoin et al., 2015; Chen and Whalley, 2012; Chester and Horvath, 2010; Gu et al., 2019; Merchan et al., 2020; Sun et al., 2019; Wang et al., 2010), contributes to mitigating the impacts of climate change in the transportation sector. According to a report by the European Union Agency for Railways (2022), rail is the safest mode of land transport in the EU with a passenger fatality rate similar to that of aircraft passengers, thereby showcasing the environmental benefits of rail transportation.

Significant improvements in the energy efficiency of passenger transportation are another indirect benefit of railroad infrastructure investment. As Davis and Boundy (2022) reported—see Table 2.13 thereof—transit rail requires only 31% of the energy per passenger miles compared with private automobiles. Button (2022) further asserted that by shifting travelers from less efficient modes, such as driving, to more efficient electrified rail systems, the overall energy consumption for a given level of mobility is reduced (Merchan et al., 2020; Scheepmaker et al., 2017; Gołębiowski et al., 2021).

Equity considerations are crucial for the indirect benefits of investing in rail infrastructure (Sanchez et al., 2007). Improved rail services can enhance accessibility for lower-income and disadvantaged populations and promote social equality by offering a more equitable distribution of transportation services.

Technological innovation plays a pivotal role in rail transport (Kácik et al., 2023). Vuchic (2007) stressed the importance of advancements in technology such as high-speed trains and automated signaling systems, which can further increase the capacity, efficiency, and attractiveness of rail transport.

Author contributions: Conceptualization, funding acquisition, literature review, analysis of the results, presentation of the results, interpretation of the results, original draft preparation, writing and rewriting the manuscript, review and editing, PGR; conceptualization, research design, formulation of the article's objectives and general goals, methodology, certifying the correctness of the manuscript, proof reading and general research supervision, AMP; conceptualization, data collection, data curation, and statistical analysis, RMP. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by Portuguese national funds through FCT—Fundação para a Ciência e a Tecnologia, under project UIDB/00713/2020.

Conflict of interest: The authors declare no conflict of interest.

Notes

1. Once more, for the sake of brevity, the impulse response functions have been omitted. Full documentation is available from the authors upon request.
2. The effects estimated at the industry level reflect, by design, a mixture of long-term and short-term demand- and supply-side effects. In this sense, examining input/output tables as a measuring stick would not be particularly informative, as these capture strictly demand-side effects.

References

Acheampong AO, Dzator J, Dzator M, et al. (2022). Unveiling the effect of transport infrastructure and technological innovation on economic growth, energy consumption and CO_2 emissions. Technological Forecasting and Social Change. 182, 121843. https://doi.org/10.1016/j.techfore.2022.121843

Adler MW, Liberini F, Russo A, et al. (2020). The congestion relief benefit of public transit: evidence from Rome. Journal of Economic Geography. 21(3): 397–431. https://doi.org/10.1093/jeg/lbaa037

Affuso L, Masson J, Newbery D (2003). Comparing investments in new transport infrastructure: Roads versus railways, Fiscal Studies. 24(3): 275–315. https://doi.org/10.1111/j.1475-5890.2003.tb00085.x

Agrawal A, Galasso A, Oettl A (2017). Roads and innovation. The Review of Economics and Statistics. 99(3), 417–434. https://doi.org/10.1162/REST_a_00619

Alotaibi S, Quddus M, Morton C, et al. (2022). Transport investment, railway accessibility and their dynamic impacts on regional economic growth. Research in Transportation Business & Management. 43, 100702. https://doi.org/10.1016/j.rtbm.2021.100702

American Public Transportation Association (2020). Public transportation reduces greenhouse gases and conserves energy. https://www.apta.com/wp-content/uploads/Resources/resources/reportsandpublications/Documents/greenhouse_brochure.pdf

Anderson ML (2014). Subways, strikes, and slowdowns: the impacts of public transit on traffic congestion. American Economic Review. 104(9): 2763–2796.

Ansar A, Flyvbjerg B, Budzier A, et al. (2016). Does infrastructure investment lead to economic growth or economic fragility? Evidence from China. Oxford Review of Economic Policy. 32(3): 360–390. https://doi.org/10.1093/oxrep/grw022

Arrow K, Bolin B, Costanza R, et al. (1995). Economic growth, carrying capacity, and the environment. Science. 268(5210): 520–521. https://doi.org/10.1126/science.268.5210.520

Aschauer DA (1990). Why is infrastructure important? Proceedings of the Conference 'Is There a Shortfall in Public Capital Investment?' https://www.bostonfed.org/economic/conf/conf34/conf34b.pdf

Banerjee A, Duflo E, Qian N (2020). On the road: Access to transportation infrastructure and economic growth in China. Journal of Development Economics. 145. https://doi.org/10.1016/j.jdeveco.2020.102442

Bangaraju T, Aneja P, Mishra B (2022). Transport infrastructure investment: A comparative analysis between China, Russia and India. IOP Conference Series: Earth and Environmental Science. 1084(1): 012065. https://doi.org/10.1088/1755-1315/1084/1/012065

Baskakova IV, Malafeev NS (2017). The concept of infrastructure: Definition, classification and methodology for empirical evaluation. Journal of the Ural State University of Economics. 71(3): 29–41. https://doi.org/10.29141/2073-1019-2017-15-3-3

Bastiaanssen J, Johnson D, Lucas K (2020). Does transport help people to gain employment? A systematic review and meta-analysis of the empirical evidence. Transport Reviews. 40(5): 607–628. https://doi.org/10.1080/01441647.2020.1747569

Beaudoin J, Farzin Y H, Lawell CYCL (2015). Public transit investment and sustainable transportation: A review of studies of transit's impact on traffic congestion and air quality. Research in Transportation Economics. 52, 15–22. https://doi.org/10.1016/j.retrec.2015.10.004

Becker GS (2007). Health as human capital: synthesis and extensions. Oxford Economic Papers. 59(3): 379–410. https://doi.org/10.1093/oep/gpm020

Bent E M, and Singa K (2009). Modal choices and spending patterns of travelers to downtown San Francisco, California: Impacts of congestion pricing on retail trade. Transportation Research Record. 2115(1): 66–74. https://doi.org/10.3141/2115-09

Berechman J, Ozmen D, Ozbay K (2006). Empirical analysis of transportation investment and economic development at state, county and municipality levels. Transportation. 33(6): 537–551. https://doi.org/10.1007/s11116-006-7472-6

Berger T (2019). Railroads and rural industrialization: Evidence from a historical policy experiment. Explorations in Economic History. 74. https://doi.org/10.1016/j.eeh.2019.06.002

Bergqvist R, and Behrends S (2011). Assessing the effects of longer vehicles: The case of pre- and post-haulage in intermodal transport chains. Transport Reviews. 31(5): 591–602. https://doi.org/10.1080/01441647.2011.584980

Bhattacharjee S, and Goetz AR (2012). Impact of light rail on traffic congestion in Denver. Journal of Transport Geography. 22, 262–270. https://doi.org/10.1016/j.jtrangeo.2012.01.008

Bilgili L, Kuzu SL, Çetinkaya AY, et al. (2019). Evaluation of railway versus highway emissions using LCA approach between thetwo cities of Middle Anatolia. Sustainable Cities and Society. 49. https://doi.org/10.1016/j.scs.2019.101635

Biondini F, and Frangopol DM (2019). Life-Cycle Design, Assessment, and Maintenance of Structures and Infrastructure Systems. American Society of Civil Engineers. https://doi.org/10.1061/9780784415467

Bitzan J D, and Keeler TE (2007). Economies of density and regulatory change in the U.S. railroad freight industry. The Journal of Law & Economics. 50(1), 157–180. https://doi.org/10.1086/508308

Blanchard O, and Perotti R (2002). An empirical characterization of the dynamic effects of changes in government spending and taxes on output. The Quarterly Journal of Economics. 117(4):1329–1368. https://doi.org/10.1162/003355302320935043

Bom PRD, and Ligthart JE (2014). What have we learned from three decades of research on the productivity of public capital? Journal of Economic Surveys. 28(5):889–916. https://doi.org/10.1111/joes.12037

Börjesson M, Hamilton CJ, Näsman P, et al. (2015). Factors driving public support for road congestion reduction policies: Congestion charging, free public transport and more roads in Stockholm, Helsinki and Lyon. Transportation Research Part A: Policy and Practice. 78, 452–462. https://doi.org/10.1016/j.tra.2015.06.008

Brock WA, Taylor MS (2005). Economic growth and the environment: A review of theory and empirics. In: Aghion P, Durlauf SN (editors). Handbook of Economic Growth. Elsevier. pp. 1749–1821. https://doi.org/10.1016/S1574-0684(05)01028-2

Buhr W (2003). What is infrastructure? Volkswirtschaftliche Diskussionsbeiträge. 107(3).

Button K (2022). Transport Economics, 4th ed. Edward Elgar Publishing.

Carpenter TG (1994). The environmental impact of railways, 1st ed. Wiley.

Cascetta E, Cartenì A, Henke I, et al. (2020). Economic growth, transport accessibility and regional equity impacts of high-speed railways in Italy: ten years ex post evaluation and future perspectives. Transportation Research Part A: Policy and Practice. 139: 412–428. https://doi.org/10.1016/j.tra.2020.07.008

Cervero R (1997). Transit-oriented development's ridership bonus: a product of self-selection and public policies. Transportation Research Record. 1607(1): 1–6.

Chen J (2021). High-speed rail and energy consumption in China: The intermediary roles of industry and technology. Energy. 230. https://doi.org/10.1016/j.energy.2021.120816

Chen Y, Whalley A (2012). Green infrastructure: The effects of urban rail transit on air quality. American Economic Journal: Economic Policy. 4(1): 58–97. https://doi.org/10.1257/pol.4.1.58

Chen Z (2019). Measuring the regional economic impacts of high-speed rail using a dynamic SCGE model: The case of China. European Planning Studies. 27(3). https://doi.org/10.1080/09654313.2018.1562655

Chen Z, Li X (2021). Economic impact of transportation infrastructure investment under the Belt and Road Initiative. Asia Europe Journal. 19(Suppl 1): 131–159. https://doi.org/10.1007/s10308-021-00617-3

Chester M, Horvath A (2012). High-speed rail with emerging automobiles and aircraft can reduce environmental impacts in California's future. Environmental Research Letters. 7(3), 034012. https://doi.org/10.1088/1748-9326/7/3/034012

Chester M, Horvath A (2010). Life-cycle assessment of high-speed rail: The case of California. Environmental Research Letters: ERL. 5(1). https://doi.org/10.1088/1748-9326/5/1/014003

Chi J (2015). Transport infrastructure and macroeconomic performance in European countries. Transportation Research Record: Journal of the Transportation Research Board. 2530. https://doi.org/10.3141/2530-10

Chi J, Baek J (2016). Modeling the transport infrastructure-growth nexus in the United States. Journal of the Transportation Research Forum. 55. https://doi.org/10.5399/osu/jtrf.55.3.4394

Christiano LJ, Eichenbaum M, Evans C (1996). The effects of monetary policy shocks: Evidence from the flow of funds. The Review of Economics and Statistics. 78(1): 16–34. https://doi.org/10.2307/2109845

Christiano LJ, Eichenbaum M, Evans CL (1999). Chapter 2-Monetary policy shocks: What have we learned and to what end? In: Handbook of Macroeconomics. Elsevier. pp. 65–148. https://doi.org/10.1016/S1574-0048(99)01005-8

Cigu E, Agheorghiesei DT, Gavriluță A, et al. (2018). Transport infrastructure development, public performance and long-run economic growth: A case study for the EU-28 countries. Sustainability: Science Practice and Policy. https://doi.org/10.3390/su11010067

Cohen JP (2010). The broader effects of transportation infrastructure: Spatial econometrics and productivity approaches. Transportation Research Part E-Logistics and Transportation Review. https://doi.org/10.1016/j.tre.2009.11.003

CP-Comboios de Portugal, EPE (n.d.). Chronology of the history of railroads in Portugal (Portuguese). Available online: https://www.cp.pt/institucional/pt/cultura-ferroviaria/historia-cp/cronologia (accessed on 12 September 2023).

Cruz CO, Sarmento JM, Faria e Sousa V, et al. (2021). Transport systems in Portugal: Analysis of efficiency and regional impact. Fundação Francisco Manuel dos Santos.

Dash P (2016). The impact of public investment on private investment: Evidence from India. Vikalpa. 41(4): 288–307. https://doi.org/10.1177/0256090916676439

Davis, Stacy C, Robert Gary (2022). Transportation Energy Data Book (Edition 40). https://doi.org/10.2172/1878695

Deichmann U, Fay M, Koo J, et al. (2004). Economic structure, productivity, and infrastructure quality in Southern Mexico. The Annals of Regional Science. 38(3). https://doi.org/10.1007/s00168-003-0171-8

Deloitte (2013). Economic impact of infrastructure investments across asset categories in Ontario. Report commissioned by the Ontario Ministry of Infrastructure.

Démurger S (2014). Infrastructure in China. In: Kanbur FR, Wei SJ, Zhang X (editors). The Oxford Companion to the Economics of China. Oxford University Press. pp. 348–352. https://doi.org/10.1093/acprof:oso/9780199678204.003.0057

Dimoula V, Kehagia F, Tsakalidis A (2016). A holistic approach for estimating carbon emissions of road and rail transport systems. Aerosol and Air Quality Research. 16(1): 61–68. https://doi.org/10.4209/aaqr.2015.05.0313

Doerr L, Dorn F, Gaebler S, et al. (2020). How new airport infrastructure promotes tourism: evidence from a synthetic control approach in German regions. Regional Studies. 54(10), 1402–1412. https://doi.org/10.1080/00343404.2020.1714022

Donaldson D (2018). Railroads of the Raj: Estimating the impact of transportation infrastructure. The American Economic Review. https://doi.org/10.1257/aer.20101199

Ekwall D, Lantz B (2017). Cargo theft risk and security: product and location. 29th Norforma Conference.

Erdogan S (2020). Analyzing the environmental Kuznets curve hypothesis: The role of disaggregated transport infrastructure investments. Sustainable Cities and Society, 61. https://doi.org/10.1016/j.scs.2020.102338

European Union Agency for Railways (2022). Report on railway safety and interoperability in the EU. Publications Office of the European Union.

Fageda X (2021). Do light rail systems reduce traffic externalities? Empirical evidence from mid-size European cities. Transportation Research Part D: Transport and Environment. 92. https://doi.org/10.1016/j.trd.2021.102731
Fay M, Leipziger D, Wodon Q, et al (2005). Achieving child-health-related Millennium Development Goals: The role of infrastructure. World Development. 33(8): 1267–1284. https://doi.org/10.1016/J.WORLDDEV.2005.03.001
Filigrana P, Levy JI, Gauthier J, et al. (2022). Health benefits from cleaner vehicles and increased active transportation in Seattle, Washington. Journal of Exposure Science & Environmental Epidemiology. 32(4): 538–544. https://doi.org/10.1038/s41370-022-00423-y
Fourie J (2006). Economic infrastructure: A review of definitions, theory and empirics. The South African Journal of Economics. Suid-Afrikaanse Tydskrif Vir Ekonomie. 74(3): 530–556. https://doi.org/10.1111/j.1813-6982.2006.00086.x
Gao HL (2019). Exploring the alternative modes of eco-friendly express freight transport. Applied Ecology and Environmental Research. 17(4). https://doi.org/10.15666/aeer/1704_88058816
GEE–Gabinete de Estratégia e Estudos, Portuguese Ministry of the Economy and the Sea (2022). Infrastructure database (Portuguese). Available online: https://www.gee.gov.pt/pt/publicacoes/indicadores-e-estatisticas/base-de-dados-de-infraestruturas (accessed on 12 September 2023).
Gibbons S, Lyytikäinen T, Overman, et al. (2019). New road infrastructure: The effects on firms. Journal of Urban Economics. 110, 35–50. https://doi.org/10.1016/j.jue.2019.01.002
Gnap J, Senko Š, Kostrzewski M, et al. (2021). Research on the relationship between transport infrastructure and performance in rail and road freight transport—A case study of Japan and selected European countries. Sustainability, 13(12): 6654. https://doi.org/10.3390/su13126654
Gołębiowski P, Jacyna M, et al. (2021). The assessment of energy efficiency versus planning of rail freight traffic: A case study on the example of Poland. Energies. 14(18): 5629. https://doi.org/10.3390/en14185629
González J Á, Ponce E, Mataix C, et al. (2008). The automatic generation of transhipment plans for a train–train terminal: Application to the Spanish–French border. Transportation Planning and Technology. 31(5): 545–567. https://doi.org/10.1080/03081060802364539
Grimes GA, and Barkan CPL (2006). Cost-effectiveness of railway infrastructure renewal maintenance. Journal of Transportation Engineering/American Society of Civil Engineers. 132(8): 601–608. https://doi.org/10.1061/(ASCE)0733-947X(2006)132:8(601)
Growitsch C, Wetzel H (2009). Testing for economies of scope in European railways: An efficiency analysis. Journal of Transport Economics and Policy. 43(1): 1–24. https://www.jstor.org/stable/20466766
Gu P, He D, Chen Y, et al. (2019). Transit-oriented development and air quality in Chinese cities: A city-level examination. Transportation Research Part D: Transport and Environment. 68: 10–25. https://doi.org/10.1016/j.trd.2018.03.009
Haskel J, Westlake S (2018). Capitalism without capital. In: The rise of the intangible economy. Princeton University Press. pp. 144–157. https://doi.org/10.1515/9781400888320-010
Haughwout AF (1999). State infrastructure and the geography of employment. Growth and Change. 30(4): 549–566. https://doi.org/10.1111/j.1468-2257.1999.tb00045.x
Hazan E, Smit S, Woetzel J, et al. (2021). Getting tangible about intangibles: The future of growth and productivity? McKinsey Global Institute.
Hornbeck R, Rotemberg M (2019). Railroads, reallocation, and the rise of American manufacturing. National Bureau of Economic Research Working Paper Series. 26594. https://doi.org/10.3386/w26594
Hou L, Peng Y, Sun D (2020). Dynamic analysis of railway vehicle derailment mechanism in train-to-train collision accidents. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. 235(8): 1022–1034. https://doi.org/10.1177/0954409720959870
Infraestruturas de Portugal (2016). Plano de Investimentos em Infraestruturas–Ferrovia 2020. Available online: https://shorturl.at/txJQX (accessed on 15 December 2023).
International Energy Agency (2011). The future of rail: Opportunities for energy and the environment. Available online: https://www.oecd.org/publications/the-future-of-rail-9789264312821-en.htm (accessed on 12 September 2023).
International Transport Forum (2022). Spending on transport infrastructure. OECD Statistics Brief, June.
International Transport Forum. (2020). Comparing road and rail investment in cost-benefit analysis. Available online: https://www.itf-oecd.org/comparing-road-rail-investment-cost-benefit-analysis (accessed on 12 September 2023).
Jochimsen R (1966). Theory of infrastructure (Portuguese). Grundlagen der marktwirtschaftlichen Entwicklung. Tübingen, Mohr.

Johansson E, Camporeale R, Palmqvist CW (2020). Railway network design and regional labor markets in Sweden. Research in Transportation Economics. 83. https://doi.org/10.1016/j.retrec.2020.100921
Johner J (1983). Are roads safer than railways. Modern Railways.
Kácik D, Martincek I, Goraus M, et al. (2023). Monitoring the technical conditions of railway vehicles during operation. European Workshop on Optical Fibre Sensors (EWOFS 2023), 12643. https://doi.org/10.1117/12.2678309
Keaton MH (1990). Economies of density and service levels on U.S. railroads: An experimental analysis. Transportation Research Part E: Logistics and Transportation Review. 26(3): 211–228.
Kersley R, O'Sullivan M, Rochon S (2008). Intangible infrastructure: The key to growth. Credit Suisse Research.
Kessides C (1996). A review of infrastructure's impact on economic development. pp. 213–230. https://doi.org/10.1007/978-3-642-80266-9_12
Khadaroo J, and Seetanah B (2008). The role of transport infrastructure in international tourism development: A gravity model approach. Tourism Management 29(5): 831–840. https://doi.org/10.1016/j.tourman.2007.09.005
Krüger NA (2012). To kill a real option—Incomplete contracts, real options and PPP. Transportation Research Part A: Policy and Practice. 46(8): 1359–1371. https://doi.org/10.1016/j.tra.2012.04.009
Lakshmanan TR (2011). The broader economic consequences of transport infrastructure investments. Journal of Transport Geography. 19(1): 1–12. https://doi.org/10.1016/j.jtrangeo.2010.01.001
Lee C, Ma J, Oh, K (2018). Economic impact analysis on regional industries by high-speed rail investments: Application of an input-output model. Transportation Research Record. 2672(10): 247–259.
Lenz NV, Skender HP, Mirković PA (2018). The macroeconomic effects of transport infrastructure on economic growth: the case of Central and Eastern E.U. member states. Economic Research-Ekonomska Istraživanja, 31(1): 1953–1964. https://doi.org/10.1080/1331677x.2018.1523740
Levinson DM, Krizek KJ (2018). Metropolitan transport and land use: Planning for place and plexus, 1st ed. Routledge.
Li JH, Rim GN, An CJ (2020). Relationship between transport infrastructure and employment: Evidence from the Chinese inland provinces under the "One Belt, One Road" initiative. Business Perspective Review. 2(1): 13–28. https://doi.org/10.38157/business-perspective-review.v2i1.103
Limão N, Venables AJ (2001). Infrastructure, geographical disadvantage, transport costs, and trade. The World Bank Economic Review. 15(3): 451–479. https://doi.org/10.1093/WBER/15.3.451
Lin HZ, Wei J (2019). Optimal transport network design for both traffic safety and risk equity considerations. Journal of Cleaner Production. 218: 738–745. https://doi.org/10.1016/j.jclepro.2019.02.070
Lin X (2019). Multiple pathways of transportation investment to promote economic growth in China: a structural equation modeling perspective. Transportation Letters. 12(7): 471–482. https://doi.org/10.1080/19427867.2019.1635780
Lindholm EL, Berg S (2005). Energy requirement and environmental impact in timber transport. Scandinavian Journal of Forest Research; Issued Bimonthly by the Nordic Forest Research Cooperation Committee. 20(2): 184–191. https://doi.org/10.1080/02827580510008329
Litman T (2005). Impacts of rail transit on the performance of a transportation system. Transportation Research Record. 1930(1): 23–29. https://doi.org/10.1177/0361198105193000103
Litman T (2022). Evaluating Public Transit Benefits and Costs - Best Practices Guidebook. Victoria Transport Policy Institute.
Litman T (2023). Evaluating accessibility for transport planning: Measuring people's ability to reach desired services and activities. Victoria Transport Policy Institute.
Litman T, Burwell D (2006). Issues in sustainable transportation. International Journal of Global Environmental Issues. 6(4): 331–347. https://doi.org/10.1504/IJGENVI.2006.010889
Liu R, Moini N (2015). Benchmarking transportation safety performance via shift-share approaches. Journal of Transportation Safety and Security. 7(2): 124–137. https://doi.org/10.1080/19439962.2014.940478
Liu Y, Ali A, Chen Y, et al. (2023). The effect of transport infrastructure (road, rail, and air) investments on economic growth and environmental pollution and testing the validity of EKC in China, India, Japan, and Russia. Environmental Science and Pollution Research. 30(12): 32585–32599. https://doi.org/10.1007/s11356-022-24448-w
Macharis C, Bontekoning YM (2004). Opportunities for OR in intermodal freight transport research: A review. European Journal of Operational Research. 153(2): 400–416. https://doi.org/10.1016/S0377-2217(03)00161-9
Maciulyte-Sniukiene A, Butkus M (2022). Does infrastructure development contribute to EU countries' economic growth? Sustainability. 14(9): 5610. https://doi.org/10.3390/su14095610

Martincus CV, Carballo J, Cusolito A (2017). Roads, exports and employment: Evidence from a developing country. Journal of Development Economics. 125: 21–39. https://doi.org/10.1016/j.jdeveco.2016.10.002

McMinn D, Oreskovic NM, Aitkenhead MJ, et al (2014). The physical environment and health-enhancing activity during the school commute: global positioning system, geographical information systems and accelerometry. Geospatial Health, 8(2): 569–572. https://doi.org/10.4081/gh.2014.46

Meersman H, Nazemzadeh M (2017). The contribution of transport infrastructure to economic activity: The case of Belgium. Case Studies on Transport Policy. 5(2): 316–324. https://doi.org/10.1016/j.cstp.2017.03.009

Melo PC, Graham DJ, Brage-Ardao R (2013). The productivity of transport infrastructure investment: A meta-analysis of empirical evidence. Regional Science and Urban Economics. https://doi.org/10.1016/j.regsciurbeco.2013.05.002

Merchan AL, Belboom S, Léonard A (2020). Life cycle assessment of rail freight transport in Belgium. Clean Technologies and Environmental Policy. 22(5): 1109–1131. https://doi.org/10.1007/s10098-020-01853-8

Mihyeon Jeon C, Amekudzi A (2005). Addressing sustainability in transportation systems: Definitions, indicators, and metrics. Journal of Infrastructure Systems. 11(1): 31–50. https://doi.org/10.1061/(asce)1076-0342(2005)11:1(31)

Millemaci E, Ofria F (2016). Supply and demand-side determinants of productivity growth in Italian regions. Structural Change and Economic Dynamics. 37: 138–146. https://doi.org/10.1016/j.strueco.2016.04.001

Mineshima A, Poplawski-Ribeiro M, Weber A (2014). Size of fiscal multipliers. In: Cottarelli C, Gerson P, Senhadji A (editors). Post-crisis fiscal policy. The MIT Press. pp. 315–372. https://doi.org/10.7551/mitpress/9780262027182.003.0013

Mohanty MK, Mohapatra AK, Samanta PK. (2022). Dichotomy of infrastructure projects in India: Improved performance amid persistent overhangs. Orissa Journal of Commerce. https://doi.org/10.54063/ojc.2022.v43i01.01

Murakami J, Matsui Y, Kato H (2016). Airport rail links and economic productivity: Evidence from 82 cities with the world's 100 busiest airports. Transport Policy. 52: 89–99. https://doi.org/10.1016/j.tranpol.2016.07.009

National Institute of Statistics—Statistics Portugal (2016). National Accounts SEC2010 Base 2016 (Portuguese). Available online: https://bit.ly/3o9ekHf (accessed on 12 September 2023).

Newman P, Kenworthy J, Glazebrook G (2013). Peak car use and the rise of global rail: Why this is happening and what it means for large and small cities. Journal of Transportation Technologies. 3(4): 272–287. https://doi.org/10.4236/jtts.2013.34029

OECD (2020). Transport bridging divides. OECD. https://doi.org/10.1787/55AE1FD8-EN

OECD (2023). Infrastructure investment. https://doi.org/10.1787/b06ce3ad-en

Oosterhaven J, Knaap T (2003). Spatial economic impacts of transport infrastructure investments. In: Transport projects, programmes and policies. Routledge.

Our World in Data (2020). Carbon footprint of select modes of transport per kilometer of travel in 2018 (in grams of carbon dioxide equivalent per passenger kilometer) [Graph]. Statista. Available online: https://www.statista.com/statistics/1185559/carbon-footprint-of-travel-per-kilometer-by-mode-of-transport/ (accessed on 12 September 2023).

Pereira A (2000). Is all public capital created equal? The Review of Economics and Statistics. 82(3): 513–518. https://doi.org/10.1162/rest.2000.82.3.513

Pereira A, and Andraz J (2012). On the economic effects of investment in railroad infrastructures in Portugal. Journal of Economic Development. 37(2): 79–107. https://doi.org/10.35866/caujed.2012.37.2.004

Pereira A, and de Frutos R (1999). Public capital accumulation and private sector performance. Journal of Urban Economics. 46(2): 300–322. https://doi.org/10.1006/juec.1998.2124

Pereira AM (2001). On the effects of public investment on private investment: What crowds in what? Public Finance Review. 29(1): 3–25. https://doi.org/10.1177/109114210102900101

Pereira AM, Andraz JM (2003). On the impact of public investment on the performance of US industries. Public Finance Review. 31(1): 66–90. https://doi.org/10.1177/1091142102239135

Pereira AM, Andraz JM (2005). Public investment in transportation infrastructure and economic performance in Portugal. Review of Development Economics. 9(2): 177–196. https://doi.org/10.1111/j.1467-9361.2005.00271.x

Pereira AM, Pereira RM (2018). Are all infrastructure investments created equal? The case of Portugal. Journal of Infrastructure Policy and Development. 2(1): 67–86. https://doi.org/10.24294/jipd.v2i1.145

Pereira AM, Pereira RM (2018). On the effects of infrastructure investment on economic performance in Ontario. Journal of Infrastructure, Policy and Development. 2(2): 1. https://doi.org/10.24294/jipd.v2i2.839

Pokharel R, Bertolini L, Brömmelstroet Mte (2023). How does transportation facilitate regional economic development? A heuristic mapping of the literature. Transportation Research Interdisciplinary Perspectives. 19: 100817. https://doi.org/10.1016/j.trip.2023.100817

Pinto JT. de M, Mistage O, Bilotta P, et al (2018). Road-rail intermodal freight transport as a strategy for climate change mitigation. Environmental Development. 25: 100–110. https://doi.org/10.1016/j.envdev.2017.07.005

Pradhan RP (2019). Investigating the causal relationship between transportation infrastructure, financial penetration and economic growth in G-20 countries. Research in Transportation Economics. 78: 100766. https://doi.org/10.1016/j.retrec.2019.100766

Pradhan RP, Bagchi TP (2013). Effect of transportation infrastructure on economic growth in India: The VECM approach. Research in Transportation Economics. 38(1): 139–148. https://doi.org/10.1016/j.retrec.2012.05.008

Qin Y (2016). China's Transport Infrastructure Investment: Past, Present, and Future. Asian Economic Policy Review. 11(2): 199–217. https://doi.org/10.1111/aepr.12135

Ramey VA (2011). Can government purchases stimulate the economy? Journal of Economic Literature. 49(3): 673–685. https://doi.org/10.1257/jel.49.3.673

Rehman FU, Noman AA, Ding Y (2020). Does infrastructure increase exports and reduce trade deficit? Evidence from selected South Asian countries using a new Global Infrastructure Index. Journal of Economic Structures. 9(1). https://doi.org/10.1186/s40008-020-0183-x

Ren X, Ding Q (2019). The effect of high-speed rail on regional economy in China using AHP. International Journal of Transportation Engineering and Technology. 5(4): 111. https://doi.org/10.11648/j.ijtet.20190504.18

República Portuguesa (2022). Plano ferroviário nacional: Diagnóstico da situação territorial. Available online: https://pfn.gov.pt/wp-content/uploads/2022/11/diagnostico-situacao-territorial-pfn-20221117.pdf (accessed on 12 September 2023).

Rietveld P (1994). Spatial economic-impacts of transport infrastructure supply. Transportation Research Part A-Policy and Practice. 28(4): 329–341. https://doi.org/10.1016/0965-8564(94)90007-8

Rodrigue JP (2016). The role of transport and communication infrastructure in realising development outcomes. The Palgrave Handbook of International Development. 595–614. https://doi.org/10.1057/978-1-137-42724-3_33

Rodrigue JP (2020). The Geography of Transport Systems. Routledge. https://doi.org/10.4324/9780429346323

Rosenstein-Rodan PN (1943). Problems of Industrialisation of Eastern and South-Eastern Europe. The Economic Journal. 53: 210, 211, 202. https://doi.org/10.2307/2226317

Rothengatter W (2017). Wider economic impacts of transport infrastructure investments: Relevant or negligible? Transport Policy. 59: 124–133. https://doi.org/10.1016/j.tranpol.2017.07.011

Rudebusch GD (1998). Do measures of monetary policy in a VAR make sense? International Economic Review. 39(4): 907. https://doi.org/10.2307/2527344

Sahin B, Yilmaz H, Ust Y, et al (2014). An approach for economic analysis of intermodal transportation. The Scientific World Journal. 2014, 1–10. https://doi.org/10.1155/2014/630320

Sanchez TW, Shen Q, Peng ZR (2004). Transit mobility, jobs access and low-income labor participation in US metropolitan areas. Urban Studies. 41(7): 1313–1331. https://doi.org/10.1080/0042098042000214815

Sawada Y (2019). Infrastructure investments, technologies and jobs in Asia. International Journal of Training Research. 17(sup1): 12–25. https://doi.org/10.1080/14480220.2019.1629724

Scheepmaker GM, Goverde RMP, Kroon LG (2017). Review of energy-efficient train control and timetabling. European Journal of Operational Research. 257(2): 355–376. https://doi.org/10.1016/j.ejor.2016.09.044

Seidu RD, Young BE, Robinson H, et al (2020). The impact of infrastructure investment on economic growth in the United Kingdom. Journal of Infrastructure, Policy and Development. 4(2): 217. https://doi.org/10.24294/jipd.v4i2.1206

Sénquiz-Díaz C (2021). The effect of transport and logistics on trade facilitation and trade: A PLS-SEM approach. Economics. 9(2): 11–24. https://doi.org/10.2478/eoik-2021-0021

Shepherd B, and Wilson JS (2009). Trade facilitation in ASEAN member countries: Measuring progress and assessing priorities. Journal of Asian Economics. 20(4): 367–383. https://doi.org/10.1016/j.asieco.2009.03.001

Shove E, Trentmann F (2018). Infrastructures in Practice. Routledge. https://doi.org/10.4324/9781351106177

Signal M (1996). Green design in rail industry—Threat or possibility? Transportation Research Record. 1531(1): 27–34. https://doi.org/10.1177/0361198196153100104

Silla A, Kallberg VP (2012). The development of railway safety in Finland. Accident Analysis & Prevention. 45: 737–744. https://doi.org/10.1016/j.aap.2011.09.043

Sims CA, Zha T (1999). Error bands for impulse responses. Econometrica. 67(5): 1113–1155. https://doi.org/10.1111/1468-0262.00071

Small KA, Verhoef ET, Lindsey R (2007). The Economics of Urban Transportation. Routledge. https://doi.org/10.4324/9780203642306

Sobieralski JB (2021). Transportation infrastructure and employment: Are all investments created equal? Research in Transportation Economics. 88, 100927. https://doi.org/10.1016/j.retrec.2020.100927

Sturm JE, Jacobs J, Groote P (1999). Output effects of infrastructure investment in the Netherlands, 1853–1913. Journal of Macroeconomics. 21(2): 355–380. https://doi.org/10.1016/s0164-0704(99)00107-x

Sun C, Zhang W, Luo Y, et al (2019). The improvement and substitution effect of transportation infrastructure on air quality: An empirical evidence from China's rail transit construction. Energy Policy 129: 949–957. https://doi.org/10.1016/j.enpol.2019.03.005

Tavakoli Kashani A, Sartibi Z (2022). Is there a relationship between rail transport and road fatalities? Iranian Journal of Science and Technology. Transactions of Civil Engineering, 46(2): 1645–1654. https://doi.org/10.1007/s40996-021-00667-y

Teodorovic D, Janic M (2022). Transportation engineering: Theory, practice, and modeling (2nd ed.). Butterworth-Heinemann.

Thacker S, Adshead D, Fay M, et al (2019). Infrastructure for sustainable development. Nature Sustainability. 2(4): 324–331. https://doi.org/10.1038/s41893-019-0256-8

The Economist Intelligence Unit (2019). The critical role of infrastructure for the Sustainable Development Goals. Available online: https://impact.economist.com/projects/towards-the-sdgs/pdfs/critical-role-of-infrastructure_EN.pdf (accessed on 12 September 2023).

The Engineering Toolbox (2008). Rolling resistance. Available online: https://www.engineeringtoolbox.com/rolling-friction-resistance-d_1303.html (accessed on 12 September 2023).

Tioga Group (2014). The role of rail infrastructure in the economic development of Michigan's Northern Lower Peninsula. Available online: https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Travel/Mobility/Rail/Freight-Economic-Development/Role-Rail-Infrastructure-Northern-Lower-MI.pdf?rev=207f83c2cf6f453389a97474a5898fbd&hash=BA6357E48C2176E4C45C48C748993779 (accessed on 12 September 2023).

Tolliver D, Lu P, Benson D (2014). Railroad energy efficiency in the United States: Analytical and statistical analysis. Journal of Transportation Engineering. 140(1): 23–30. https://doi.org/10.1061/(asce)te.1943-5436.0000620

Truong LT, Currie G (2019). Macroscopic road safety impacts of public transport: A case study of Melbourne, Australia. Accident Analysis & Prevention. 132, 105270. https://doi.org/10.1016/j.aap.2019.105270

Unesco, World Bank (2021). Cities culture creativity: Leveraging culture and creativity for sustainable urban development and inclusive growth.

United Nations Environment Programme UN (2022). International good practice principles for sustainable infrastructure. Available online: http://www.unep.org/resources/publication/international-good-practice-principles-sustainable-infrastructure (accessed on 12 September 2023).

Vanek F, and Sun Y (2008). Transportation versus perishability in life cycle energy consumption: A case study of the temperature-controlled food product supply chain. Transportation Research Part D: Transport and Environment. 13(6): 383–391. https://doi.org/10.1016/j.trd.2008.07.001

Vickerman R (1997). High-speed rail in Europe: Experience and issues for future development. The Annals of Regional Science. https://doi.org/10.1007/S001680050037

Vickerman R (2008). Recent evolution of research into the wider economic benefit of transport infrastructure investments. ITF Round Tables. 29–49. https://doi.org/10.1787/9789282101834-3-en

Vlahinić Lenz N, Pavlić Skender H, Mirković PA (2018). The macroeconomic effects of transport infrastructure on economic growth: the case of Central and Eastern E.U. member states. Economic Research-Ekonomska Istrazivanja. 31(1): 1953–1964. https://doi.org/10.1080/1331677X.2018.1523740

Vuchic VR (2007). Urban Transit Systems and Technology. John Wiley & Sons.

Wachs M (2011). Transportation jobs, and economic growth. Access, 38(Spring): 8–14. Available online: https://www.accessmagazine.org/spring-2011/transportation-jobs-economic-growth/ (accessed on 12 September 2023).

Wang L, Xue X, Zhao Z, et al (2018). The impacts of transportation infrastructure on sustainable development: emerging trends and challenges. International Journal of Environmental Research and Public Health. 15(6): 1172. https://doi.org/10.3390/ijerph15061172

Wang S, Zhao M, Xing J, et al (2010). Quantifying the air pollutants emission reduction during the 2008 olympic games in Beijing. Environmental Science & Technology. 44(7): 2490–2496. https://doi.org/10.1021/es9028167

Waycaster GC, Matsumura T, Bilotkach V, et al (2017). Review of regulatory emphasis on transportation safety in the United States, 2002–2009: public versus private modes. Risk Analysis. 38(5): 1085–1101. https://doi.org/10.1111/risa.12693

Whitehouse A (2001). One rule for road, another for rail. Rail Professional.

World Bank (1994). World Development Report 1994. Available online: https://elibrary.worldbank.org/doi/abs/10.1596/978-0-1952-0992-1 (accessed on 12 September 2023).

World Bank (2007). Evaluation of World Bank support to transportation infrastructure. World Bank Publications.

Worsley T (2020). Comparing road and rail investment in cost-benefit analysis. Discussion paper, International Transport Forum (ITF). Available online: https://www.itf-oecd.org/comparing-road-rail-investment-cost-benefit-analysis (accessed on 12 September 2023).

Wrótny M, Bohatkiewicz J (2021). Traffic noise and inhabitant health—a comparison of road and rail noise. Sustainability. 13(13): 7340. https://doi.org/10.3390/su13137340

Wu C, Zhang N, Xu L (2021). Travelers on the railway: An economic growth model of the effects of railway transportation infrastructure on consumption and sustainable economic growth. Sustainability (Switzerland). 13(12). https://doi.org/10.3390/su13126863

Yang J, Chen S, Qin P, et al. (2018). The effect of subway expansions on vehicle congestion: Evidence from Beijing. Journal of Environmental Economics and Management. 88: 114–133. https://doi.org/10.1016/j.jeem.2017.09.007

Yen M (2020). Does rapid transit and light rail infrastructure improve labor market outcomes? https://doi.org/10.2139/ssrn.3650709

Yii KJ, Bee KY, Cheam WY, et al (2018). Is transportation infrastructure important to the one belt one road (OBOR) initiative? Empirical evidence from the selected Asian countries. Sustainability. 10(11): 4131. https://doi.org/10.3390/su10114131

Yoshino N, Abidhadjaev U (2017). Impact of infrastructure on tax revenue: Case study of high-speed train in Japan. Journal of Infrastructure, Policy and Development. 1(2): 129. https://doi.org/10.24294/jipd.v1i2.69

Zenou Y (2011). Search, migration, and urban land use: The case of transportation policies. Journal of Development Economics. 96(2): 174–187. https://doi.org/10.1016/j.jdeveco.2010.11.001

Zhang X, Wan G, Wang X (2017). Road infrastructure and the share of labor income: Evidence from China's manufacturing sector. Economic Systems. 41(4): 513–523. https://doi.org/10.1016/j.ecosys.2017.08.001

Zheltenkov A, Syuzeva O, Vasilyeva E, et al (2017). Development of investment infrastructure as the factor of the increase in investment attractiveness of the region. IOP Conference Series: Earth and Environmental Science. 90(1), 012122. https://doi.org/10.1088/1755-1315/90/1/012122