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Trade spillover effects of transport infrastructure investments: a structural gravity analysis for EU regions

Yevgeniya Shevtsova[a], Jorge Díaz-Lanchas[b], Damiaan Persyn[c,d] and Giovanni Mandras[e]

ABSTRACT

A structural gravity model is used to estimate the regional trade and welfare effects of the reduction in transport costs between and within European Union regions induced by European Union Cohesion Policy road infrastructure investment. The results imply that, in targeted regions, the policy increases interregional real exports by 0.03% and real gross domestic product (GDP) by 0.15% on average. The gains in real GDP are the highest in the regions receiving most funds. Although the policy always leads to more goods being shipped, for some regions it implies less trade external to the region and more trade within.

KEYWORDS

structural gravity; trade policy; general equilibrium analysis

JEL F13, F14, F15, R13

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1. INTRODUCTION

Transport infrastructure investment programmes produce tangible trade and growth effects due to the reduction in transport costs (Banerjee et al., 2020; Duranton et al., 2014; Morten & Oliveira, 2024). Moreover, in barrier-free markets such as the European Union, a reduction in transport costs might be one of the main trade-promotion channels (Asturias et al., 2019; Blouri & Ehrlich, 2020). Nevertheless, improvements in transport infrastructure might trigger uneven spatial and local effects, which are difficult to analyse (Persyn et al., 2023). Whereas some regions could benefit from such programmes, others might be penalised due to spatial spillover effects. Hence, a complete assessment of a transport infrastructure investment programme should consider a combination of both direct and indirect effects on regional trade and welfare.

In this context, an important policy question is whether countries and supra-national institutions should keep investing in improving transport infrastructure. In the case of the EU, the previous EU Cohesion Policy programme 2014–20 invested over €30 billion in road transport infrastructure, while the 2021–27 programming period has committed more than €36 billion.[1] These programmes have the double objective of improving trade accessibility in less-developed regions while enhancing regional cohesion within the EU internal market.

Assessing the attainability of these objectives becomes key for informing future policy decisions. This paper seeks to contribute to a deeper understanding of this important policy debate by performing a series of ex-ante counterfactual analyses that shed light on the regional effects of investment in transport infrastructure.

In particular, we focus on the road transport infrastructure investment implemented under the framework of the EU Cohesion Policy programme 2014–20 and examine the sole impact of such investment on trade integration and welfare of EU regions. The core objective of this analysis is to provide an estimate of the potential effects of an improved road infrastructure on trade and welfare of the EU regions, devoid of any spillover effects of alternative infrastructure investments such as improvements in rail network and short sea shipping.

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A number of studies explored the impact of transport infrastructure improvement on regional economic growth using a wide range of empirical methods, including spatial econometrics techniques, spatial computable general equilibrium (GE) models, network analysis and accessibility indicators (Álvarez-Ayuso et al., 2016; Crescenzi & Rodríguez-Pose, 2008; De Almeida et al., 2010; López et al., 2008; Persyn et al., 2023). However, most of the previous studies directly estimate the effect of transport infrastructure improvement on regional gross domestic product (GDP) growth.

On the contrary, the structural gravity approach implemented in this study explicitly models the reduction in inter- and intra-regional transportation costs and, consequently, the cost of trade due to road infrastructure improvements. These changes lead to creation of new trade linkages due to *trade creation* and *trade diversion* effects. The first arises when firms in unaffected regions increase trade with policy-affected ones, as the latter become more competitive suppliers. At the same time, the trade diversion effect arises when some regions, not benefiting from the road infrastructure investment, suffer from some decrease in exports, as some trade would be redirected to the policy-affected areas. As a result of these changes, trade and welfare effects can be expected not only in targeted regions, but also in regions farther from targeted ones. Moreover, unlike spatial econometrics models, our set-up explicitly models transmission of lower transport costs into the lower cost of production that trigger lower prices at gate and result in further increases in exports for the benefiting regions (Anderson et al., 2018; Yotov et al., 2016).

The main contribution of this study is to provide an *ex-ante* evaluation of the impact of the road infrastructure investments of the EU Cohesion Policy programme 2014–20 on trade and welfare at the regional level using the structural gravity approach (Anderson et al., 2018). The analysis is implemented using the Poisson pseudo-maximum-likelihood estimator (PPML) in a structural gravity set-up. The use of this approach allows us not only to account for the missing trade values (i.e., pairs of regions that do not trade with each other), but also to disentangle trade creation and trade diversion effects. In particular, by directly including the multilateral resistance (MR) terms into the model, we are able to estimate the effects of policy on producer and consumer prices not only in targeted, but also in non-targeted regions ('spillover' effects), and to estimate its long-run welfare implications.

Furthermore, the study employs several novel methods and regional EU datasets to calibrate the model. The first dataset comes from Thissen et al. (2019) and contains the matrix of interregional trade flows between 267 NUTS-2 EU regions for 2013. The second dataset is the matrix of interregional generalised transport costs (GTC). We calculate this GTC matrix following the methodology of Persyn et al. (2022), considering road freight transport costs for the 267 NUTS-2 EU regions. A novelty of this dataset is that it considers transport costs between, but also within, regions. Lastly, to carry out the counterfactual evaluation of EU Cohesion Policy, we calculate transport costs for both the baseline and the counterfactual scenarios. To this end, we perform a cost–benefit analysis based on Persyn et al. (2022) to determine which roads are likely to be upgraded.

Our results indicate that the effects of the reduction in transport costs due to the infrastructure investments differ significantly among regions. In particular, they reveal the largest gains for Central and Eastern European regions, where the majority of investment is taking place. Real GDP gains in this area vary between 0.1% and 0.5%. At the same time, regions that are located close to those where investment is taking place seem to benefit from limited trade spillover effects and experience small positive effects on real GDP. Regions that are farther from the investment, and countries outside the EU, experience small negative effects as a result of the policy.

The effects of the policy on trade are particularly interesting in that we do not find an unambiguous increase in trade between EU regions. Some regions experience a relatively large decrease in local transport costs, within the region, leading to a relatively large increase in local consumption, and a modest decrease in goods that are shipped across regional borders. For example, the Lower Silesian region in south-east Poland exhibits one of the largest reductions in GTC. As a result, the region shows a negligible decrease in total exports (−0.004%) accompanied by a relatively large increase in regional GDP (0.264%). Such a strong positive effect on local GDP is caused mostly by an increase in internal consumption driven by lower trade costs due to improvements in local transport infrastructure.

The rest of the paper is structured as follows. Section 2 reviews the literature on EU trade integration. Section 3 explains the theoretical framework and use of a structural gravity model within a GE set-up for the EU regions. Section 4 explains the empirical strategies for counterfactual analyses. Section 5 describes the data. Section 6 presents the results and robustness checks. Section 7 concludes.

2. LITERATURE REVIEW

Our work builds on several strands of literature. The first strand includes trade studies that employ gravity models to quantify counterfactual trade and welfare effects of trade liberalisation episodes (Krugman, 1995; Leamer & Levinsohn, 1995; Trefler, 1995). Later studies in this growing body of literature include those that solve the issues of missing trade and the 'border puzzle', and introduce MR terms (Anderson & Van Wincoop, 2003; Bernard et al., 2007; Chaney, 2008; Eaton & Kortum, 2002; Mayer & Ottaviano, 2007; Redding & Venables, 2004). Finally, the most recent papers closely related to our study include Anderson and Yotov (2016), who develop an Armington-style gravity model to estimate the welfare effects of free trade agreements implemented since 1990s; Ricardian-type models by Costinot et al. (2012) and Chor (2010); an input–output linkages gravity model by Caliendo and

Parro (2015); and a dynamic framework with asset accumulation (Anderson et al., 2015; Eaton et al., 2016; Olivero & Yotov, 2012). Finally, Allen et al. (2020) show the universal power of gravity by providing sufficient conditions for the existence and uniqueness of the trade equilibrium for a wide class of GE trade models.

The next strand of literature relevant for the current study is related to the spatial dimension of trade, and, in particular, interregional EU trade. Indeed, as mentioned above, most trade literature is centred around evaluating trade effects at the national level, while, as shown by McCallum (1995) and Wei (1996), the amount of trade within national borders is much larger than across countries.

Nevertheless, despite the clear importance of assessing welfare effects of trade at regional level, the literature on this topic remains scarce. The main reason for such scarcity of empirical studies is the lack of reliable regional trade data. In fact, even in the case of the EU only a few studies estimate regional trade flows. Whereas some authors focus on regional- and country-specific trade flows for the EU (Alamá-Sabater et al., 2015; Díaz-Lanchas et al., 2022; Gallego & Llano, 2014, 2015; Llano et al., 2010; Márquez-Ramos, 2016), more recent work by Thissen et al. (2019) estimates interregional trade flows for 267 European regions. The advantage of these databases lies in estimating regional trade frictions and border effects within the EU single market (Capello et al., 2018; Santamaría et al., 2023).

Moreover, a number of theoretical and empirical studies have considered the economic effects of the reduction in transport costs. Recent studies include complex spatial GE frameworks (Allen & Arkolakis, 2022; Fajgelbaum & Schaal, 2020; Redding & Turner, 2015) as well as more traditional empirical ex-post impact assessments (Duranton et al., 2014; Koster et al., 2022). At the same time, studies that explore the impact of reduction in trade costs across EU regions are still scarce (Blouri & Ehrlich, 2020; Fajgelbaum & Schaal, 2020; Persyn et al., 2022, 2023).

Finally, the studies most closely related to our analysis, by Dhingra et al. (2017), Mayer et al. (2019) and Felbermayr et al. (2018), explore trade-related welfare effects of the EU integration. Dhingra et al. (2017) use a standard quantitative GE trade model with many countries and sectors to calculate medium- to long-run losses arising from Brexit. At the same time, Mayer et al. (2019) quantify the effects of a much broader set of policy scenarios of EU disintegration. These authors also disentangle the effects of various EU agreements and regional trade deals and estimate the changes in trade flows arising due to the specific steps of the EU integration process (the single market, Schengen area and euro). Last, Felbermayr et al. (2018) estimate industry-level gravity regressions and find that most of the EU trade effects come from factors other than tariffs. Overall, the studies discussed above are complementary and, taken together, provide estimates for a wide set of scenarios on the aggregate and sector level.

Our study builds upon this work and estimates the intra-EU trade effects of EU Cohesion Policy. Its main novelty lies in estimating such trade effects using the reductions in regional trade cost that occur due to the investment in road transport infrastructure. Differently from these recent works, trade cost reductions in our study do not come from changes in trade barriers but directly from the reductions in iceberg transport costs internal to the EU. These reductions induce a series of trade creation and trade diversion effects that affect not only trade between EU regions, but also their trade links with non-EU countries. To the best of our knowledge, such a design has not been previously explored in the literature, and it helps one to understand the role of EU policies in market integration and the reduction of regional disparities.

3. THEORETICAL FRAMEWORK

This section presents the theoretical framework and outlines its main advantages for trade policy analysis in a multi-regional environment. Our empirical strategy is based on the theoretical foundations presented by, *inter alia*, Anderson and Van Wincoop (2003), Anderson and Yotov (2016) and Yotov et al. (2016). In particular, the model follows the Anderson (1979) structural gravity model and assumes a world with N regions, with each region producing one variety of a good that is traded with the rest of the word. The factory-gate price of each variety is fixed at p_i and the supply for each good is Q_i. Consequently, the value of domestic production is defined as $Y_i = p_i Q_i$, where Y_i also stands for the nominal income of the region i. The region's i aggregate expenditure is defined as $E_i = \phi_i Y_i$, where $\phi > 1$ shows that a region runs a trade deficit, and $0 < \phi < 1$ indicates that a region i runs a trade surplus. All trade imbalances are treated as exogenous as in Dekle et al. (2007).

The demand side assumes that consumer preferences are homothetic and identical across regions, and the constant elasticity of substitution (CES) consumer utility function for region j takes the form:

$$\left\{ \sum_i \beta_i^{\frac{1-\sigma}{\sigma}} c_{ij}^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where $\sigma > 1$ is the constant elasticity of substitution across varieties produced by different regions, with products being differentiated by the place of origin (Armington, 1969), $\beta_i > 0$ is the CES preference parameter, and c_{ij} is the consumption of a variety from region i in region j.

World consumers solve a standard utility maximisation problem to maximise (1) under the budget constraint $\sum_i p_{ij} c_{ij} = E_j$. This ensures that total expenditure in region j, E_j, is equal to total spending on varieties from all regions, including j itself, at final prices $p_{ij} = p_i t_{ij}$. The final prices are defined as a function of factory-gate prices at the origin p_i adjusted by the bilateral trade or transport costs $t_{ij} >= 1$.[2]

Solving the consumer's optimisation problem results in the expenditure on goods shipped from origin i to destination j as:

$$X_{ij} = \left(\frac{\beta_i p_i t_{ij}}{P_j}\right)^{1-\sigma} E_j \tag{2}$$

with the CES consumer price index expressed as:

$$P_j = \left[\sum_i (\beta_i p_i t_{ij})^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{3}$$

There are several important intuitive relationships that come out of equations (2) and (3). First, expenditure of region j on a good from region i, X_{ij}, is directly proportional to the total expenditure of the destination j, E_j. The intuition behind this is that larger markets tend to consume more of all varieties, including the ones from i. Second, equation (2) outlines an inverse relationship between X_{ij} and the prices of varieties $p_{ij} = p_i t_{ij}$. This relationship directly reflects the law of demand and highlights the role of both, prices of varieties at factory gates, p_i, and the trade costs t_{ij}. Finally, the expenditure on varieties from i in region j is incorporated in CES price aggregator (3), which reflects the substitution effects across varieties from different countries. Intuitively, higher prices on varieties from the rest of the world lead consumers in j to substitute away from them in favour of the varieties from i. Finally, the magnitude of the response of the expenditure X_{ij} to price changes is directly related to the elasticity of substitution σ. A higher value of σ will magnify trade diversion effect away from more expensive towards cheaper varieties.

To arrive at the final version of the structural gravity model, as presented in Anderson and Van Wincoop (2003), we impose a market clearing condition for a good from each origin:

$$Y_i = \sum_j (\frac{\beta_i p_i t_{ij}}{P_j})^{(1-\sigma)} E_j \tag{4}$$

Equation (4) asserts that the value of output in region i is equal to the total expenditure on this region's variety in all locations in the world, including the region i itself. Indeed, the right-hand side of equation (4) can be replaced with the sum of all bilateral expenditures X_{ij} defined in (2) to get $Y_i = \sum_j X_{ij}$.

Next, we define $Y = \sum_i Y_i$, divide both sides of (4) by Y and rearrange the terms to get:

$$(\beta_i p_i)^{1-\sigma} = \frac{Y_i/Y}{\sum_j (t_{ij}/P_j)^{1-\sigma}(E_j/Y)} \tag{5}$$

Next, we define the term in the denominator of (5) as $\Pi_i^{1-\sigma} = \sum_j (t_{ij}/P_j)^{1-\sigma(E_j/Y)}$ and substitute it into (5) to get:

$$(\beta_i p_i)^{1-\sigma} = \frac{Y_i/Y}{\Pi_i^{1-\sigma}} \tag{6}$$

Finally, we use (6) to substitute the power transformation $(\beta_i p_i)^{1-\sigma}$ in the bilateral expenditure (2) and CES price aggregator (3) and combine the definition of $\Pi_i^{1-\sigma}$ with the updated expressions for (2) and (3) to obtain final version of the structural gravity system:

$$X_{ij} = \frac{Y_i E_j}{Y}\left(\frac{t_{ij}}{\Pi_i P_j}\right)^{1-\sigma} \tag{7}$$

$$P_j^{1-\sigma} = \sum_i \left(\frac{t_{ij}}{\Pi_i}\right)^{1-\sigma} \frac{Y_i}{Y} \tag{8}$$

$$\Pi_i^{1-\sigma} = \sum_j \left(\frac{t_{ij}}{P_j}\right)^{1-\sigma} \frac{E_j}{Y} \tag{9}$$

$$p_i = \left(\frac{Y_i}{Y}\right)^{\frac{1}{1-\sigma}} \frac{1}{\gamma_i \Pi_i} \tag{10}$$

$$E_i = \phi_i Y_i = \phi_i p_i Q_i \tag{11}$$

The system of equations (7) to (9) corresponds to the structural gravity system of Anderson and Van Wincoop (2003) or the Wilson doubly constrained gravity model (Wilson, 1971). In this setting, total production, imports and exports in every region are fixed. Yotov et al. (2016) and Anderson et al. (2018) supplemented this system with equations (10) and (11), to allow changes in transport costs to affect prices and the total level of exports and imports within the gravity framework.

In particular, equation (10) is derived from the market clearing condition (4):

$$\begin{aligned} Y_i &= \sum_j X_{ij} = \sum_j \left(\frac{\gamma_i p_i t_{ij}}{P_j}\right)^{(1-\sigma)} E_j \\ &= (\gamma_i p_i)^{(1-\sigma)} \sum_j \left(\frac{t_{ij}}{P_j}\right)^{(1-\sigma)} E_j \quad \text{for all } j \end{aligned}$$

Substituting the above into (8) yields (10), where $\gamma_i > 0$ is the CES preference parameter:

$$\begin{aligned} \frac{Y_i}{Y} &= (\gamma_i p_i \Pi_i)^{(1-\sigma)} \\ p_i^{(1-\sigma)} &= \frac{Y_i}{Y} \frac{1}{(\gamma_i \Pi_i)^{(1-\sigma)}} \\ p_i &= \left(\frac{Y_i}{Y}\right)^{\frac{1}{1-\sigma}} \frac{1}{\gamma_i \Pi_i} \end{aligned} \tag{12}$$

Moreover, in the model of Yotov et al. (2016) and Anderson et al. (2018) the regional value of output Y_i does not need to equal the aggregate expenditure E_i as shown in equation (11), where $\phi_i > 1$ shows that region i runs a trade deficit, while $0 < \phi_i \leq 1$ reflects that region i runs a trade surplus. Especially in a regional context, it is important to allow for the possibility of regions to run structural trade deficits.

3.1. The role of multilateral resistance (MR) terms

It is important to highlight the role of (8) and (9) in the system above. In particular, P_j in (8) stands for the inward multilateral resistance (IMR) term that aggregates the incidence of trade costs on consumers in each region; while Π_i in (9) is the outward multilateral resistance (OMR) term that aggregates origin i outward costs relative to the destination price indexes and can be used to evaluate the incidence of trade costs on producers in each region.

First defined by Anderson and Van Wincoop (2003) in the context of trade, MR terms are at the centre of the GE trade policy analysis. The intuitive interpretation of the MR indices is that the more remote the two trading partners are from the rest of the world the more they trade with each other. Based on this intuition, MR terms are often referred to as *remoteness indexes*. Defined formally in equations (8) and (9), the MR indexes are theory-consistent aggregates of the total trade costs to regional level (Anderson et al., 2018). The main advantage of the MR terms is their ability to transform a $N \times N$ system of bilateral links in the gravity model into a $2 \times N$ dimensional series of region-specific indexes. This property of MRs makes them particularly appealing for structural estimation and policy analysis.

In the framework of GE structural gravity analysis the MR terms represent the GE trade cost terms. In other words, the MRs will capture the fact that a change in trade cost will not only entail a change in bilateral trade flows between regions (i.e., direct partial effects) but will also result in: (1) additional (i.e., GE) effects for the involved regions (treated group); and (2) will also affect other non-treated regions; with (3) possible feedback effects for the affected regions. In fact, Anderson and Van Wincoop (2003) highlight the importance of GE effects of the MR terms to fully account for the impact of a change in trade costs on trade between any two trading partners. The main point being that, as mentioned above, the trade between two regions depends not only on their direct bilateral trade costs, but also on the trade costs between them and the rest of the world. In other words, in the case of a reduction in trade costs between two regions, the GE effect will result in the lower MRs between the affected regions and higher MRs between the affected regions and the rest of the world. As a result, the treated regions become more integrated while becoming more isolated from the rest of the world.

From a policy perspective, the MR terms are informative indices that summarise the GE effect of changes in trade costs. They can be used to aggregate and decompose the effects of said changes on consumers and producers not only in affected regions, but also in the rest of the world (Larch & Yotov, 2016). For example, an increase in the inward MR terms due to a policy shock represents an increase in trade resistance for consumers, whereas the same occurs for producers when the outward MR terms increase. On the contrary, a fall in inward and outward MR terms implies the opposite effect for consumers and producers, respectively.

In the context of our policy analysis, the fall in trade costs induced by the investment in road infrastructure leads to trade creation and trade diversion effects that can affect targeted as well as non-targeted EU regions via spillover effects. Practically, these effects can be computed using the changes in the MR terms produced by the model.

3.2. GE effects of road infrastructure investment

Given the absence of trade barriers such as tariffs and quotas among the EU country members, the trade costs captured by t_{ij} are the key parameter in the system of equations (equation 7–11).

In particular, in our policy scenario, the additional investment in road infrastructure results in lower t_{ij} between regions, where the magnitude of the fall in bilateral t_{ij} depends on how the infrastructure investments affect the lowest cost path between the two regions. This fall in t_{ij} would translate into new levels of trade (equation 7), leading to a new partial equilibrium. At the same time, the MR terms (IMR and OMR) would adapt to the new levels of trade flows and transport costs (equations 8 and 9) conditionally on given prices p_i and expenditureE_i, leading to conditional GE effects (i.e., conditional on constant prices and expenditure).

Anderson and Van Wincoop (2003) substitute MR terms in (7) for their expressions in (8) and (9) and use non-linear least squares to estimate (7). French (2016) employs a structural approach by defining the PPML objective as a non-linear function of the parameters and searches for the ones that maximise it. The solution by Head and Mayer (2014), which is the most relevant for our approach, uses an iterative procedure with an embedded linear estimator (structurally iterated least squares – SILS). The procedure begins with an estimation of (1) using guessed values for the MR terms. These terms are then updated using the results of the estimation of the equations (7) to (9). The procedure then continues by performing a new estimation of (7) and updating the MR terms. These re-estimations and updates are repeated until full convergence is reached. Egger and Staub (2016) implement similar iterative procedure using various non-linear estimators. They provide a comparison of the iterative estimator to similar estimators that use fixed effects to control for the MR terms and the quasi-differencing techniques that completely exclude MR terms from the regression.

In this study we solve the structural gravity model and estimate full endowment GE effects using the iterative procedure developed by Anderson et al. (2018) that builds upon Head and Mayer (2014). Specifically, the market clearing condition (10) is used to translate conditional GE effects of MRs into the changes in factory-gate prices. These price changes modify income and expenditure (equation 11), which again affects trade flows equation

(7). This iterative process continues until the difference between the new price levels and those in the previous iteration tends to zero.

In summary, a change in any of the equations gives rise to a new partial equilibrium that, using the market clearing condition, converges to a full endowment GE based on new levels of trade, prices, income and expenditure.[3]

The literature discussed above is applied to cross-sectional data. At the same time, in a panel set-up the MR terms are usually controlled for with the use of the importer-year and exporter-year fixed effects (Baldwin & Taglioni, 2007; Feenstra, 2015). These fixed effects effectively proxy for the MR terms only when the gravity model is estimated in its multiplicative form using the PPML estimator as per Silva and Tenreyro (2006) and Fally (2015). Indeed, due to its simplicity, the PPML estimator became the standard in the modern trade literature (Anderson et al., 2018; Larch et al., 2019), with several recent studies proposing new estimation procedures to account for missing trade flows (Poissonnier, 2019).

4. EMPIRICAL STRATEGY

Our empirical strategy is based on estimating two scenarios. In the baseline scenario, we estimate transport costs between and within regions.[4] Our counterfactual scenario assumes that, as a result of the Transport Infrastructure Investment (TII) programme, the transport costs t_{ij} between and within many EU regions decline. The magnitude of the fall depends on the regional level of investment, when the road network is improved in some regions and between them. Nevertheless, the geography of the road network implies that the transport cost between two regions may decline even if these regions do not receive any funds. We further supplement our data with the information on the bilateral trade and transport costs between the EU regions and extra-EU Organisation for Economic Co-operation and Development (OECD) countries, where no changes in t_{ij} occur. This additional information allows us to assess the impact of the TII investment on non-EU countries.

After obtaining estimates of transport costs before and after the policy implementation, we follow the recent literature and estimate a gravity equation with importer and exporter fixed effects and dyadic trade frictions (Feenstra, 2015) to estimate the impact on the regional economies.

Our empirical set-up follows Silva and Tenreyro (2006) and uses the PPML estimator that accounts for potential heteroskedasticity issues and takes advantage of the information conveyed by zero trade flows. In particular, from the gravity trade equation (7), we derive the following expression:

$$X_{ij} = exp[\ln E_j + \ln Y_i - \ln Y + (1-\sigma)\ln t_{ij} - (1-\sigma)\ln P_i - (1-\sigma)\ln \Pi_j] + \epsilon_{ij}, \quad (13)$$

where ϵ_{ij} is an i.i.d. error term with $E(\epsilon|x) = 0$. Equation (13) is used to obtain the estimates of bilateral trade costs and MR terms. In particular, the terms reflecting OMR and output can be captured by means of exporter fixed effects (π_j), whereas those related to IMR and the expenditure are controlled by importer fixed effects (χ_j).[5]

The vector of iceberg trade costs t_{ij} is affected by factors including contiguity, language, common currency, border controls and transport costs. In the baseline scenario trade costs (t_{ij}^{BLN}) are assumed to equal:

$$(\hat{t}_{ij}^{BLN}) = exp[\hat{\beta}_1 Cont_{ij} + \hat{\beta}_2 Language_{ij} + \hat{\beta}_3 Currency_{ij} + \hat{\beta}_4 National\_border_{ij} + \hat{\beta}_5 \ln \tau_{ij}^{BLN}], \quad (14)$$

where τ_{ij}^{BLN} is the iceberg transport cost in the baseline estimated from Persyn et al. (2022), $Cont_{ij}$ is a contiguity dummy, $Language_{ij}$ and $Currency_{it}$ are dummy variables for common language and common currency respectively, and $National\_border_{ij}$ is a dummy variable that differentiates trade flows crossing the national border between any pair of trading partners ij.

In our counterfactual scenario, once the road investment is implemented, t_{ij} changes such that equation (14) becomes:

$$(\hat{t}_{ij}^{CFL}) = exp[\hat{\beta}_1 Cont_{ij} + \hat{\beta}_2 Language_{ij} + \hat{\beta}_3 Currency_{ij} + \hat{\beta}_4 National\_border_{ij} + \hat{\beta}_5 \ln \tau_{ij}^{CFL}] \quad (15)$$

Therefore, our final version of the gravity model in both scenarios takes the form:

$$X_{ij} = exp[(1-\sigma)\beta_1 \ln Cont_{ij} + (1-\sigma)\beta_2 Language_{ij} + (1-\sigma)\beta_3 Currency_{ij} + (1-\sigma)\beta_4 National\_border_{ij} + (1-\sigma)\beta_5 \tau_{ij}^{s} + \pi_i + \chi_j] + \epsilon_{ij} \quad (16)$$

where τ_{ij}^{s} changes between the baseline and counterfactual scenario (s = BSL, CFL), while π_i and χ_j represent exporter and importer fixed effects, respectively. These fixed effects capture all the exporter- and importer-specific characteristics not explicitly included in the model, such as culture, legal systems and technological capacity, among others. Moreover, in the structural gravity set-up fixed effects account for output Y_i and expenditure E_j and are used to recover the MR terms (equations 8 and 9). We also note that equation (16) is estimated with the PPML estimator, where X_{ij} enters in levels. To avoid perfect co-linearity issues, we follow Anderson et al. (2018) and drop one importer fixed effect. Furthermore, as discussed by Anderson et al. (2018), solving the system equations (7) to (9) requires normalisation with respect to one reference country/region for which, in our case, we choose the United States. This country is external to the EU and most trade between the US and EU happens via sea or air. This means that road infrastructure investment should not affect the transportation cost in this case. Hence, we normalise the IMR that corresponds to the dropped importer fixed effect (USA), $P_0^{\tilde{U}SA} = 1$.

Under such normalisation, the theoretical interpretation of the importer fixed effect χ_0 is E_0 (i.e., importer's expenditure in the baseline scenario); while the interpretation of all other fixed effects is computed relative to χ_0. Finally, following Anas (1983), Davies and Guy (1987), and Fally (2015), the OMRs and IMRs can be recovered from the fixed effects when estimating equation (16).

We note that τ_{ij}^{c} is the main variable of interest in equation (16) as it is the variable affected by the policy shock, whereas the other variables are added as additional controls for trade costs. In the data section, we provide further details on the variables that define the transport part (τ_{ij}) of the trade costs (t_{ij}). While here, we provide more details on additional controls.

First, it has been shown in previous literature that contiguous countries/regions exhibit significantly lower trade cost and, consequently, larger bilateral trade flows. To account for this, we add a contiguity $Cont_{ij}$ variable that equals 1 if two regions share a common border to the factors that affect τ_{ij}^{BLN} in (14). Next, numerous studies have shown that an important factor that reduces the cost of international trade is common language (Melitz, 2008). Hence, we include a dummy variable $Language_{ij}$ that equals 1 if two regions share at least one official language. Another important factor that can facilitate international trade is a common currency. Indeed, it has been shown that currency unions, in general, have a positive and significant effect on trade among their members (Glick & Rose, 2016; Rose, 2000). To account for this, we add a dummy variable that equals 1 if two regions in our dataset share a common currency to equation (14). Last, as shown by previous research, international borders can have a significant negative effect on trade (McCallum, 1995; Obstfeld & Rogoff, 2000). To take this into account, we augment equation (14) with a dummy variable $National\_border_{ij}$ that equals 1 if the trade flows between any two pair of regions have to cross the national borders (i.e., international trade flows).

We use the PPML estimator discussed above and follow the three-step procedure developed by Anderson et al. (2018) to calculate the GE effects of the investment in road infrastructure in the framework of the EU Cohesion Policy programme 2014–20. Briefly, Anderson et al.'s procedure proceeds in the following manner. First, we use the PPML estimator to estimate the baseline gravity model (equation 16) using baseline transport cost (τ_{ij}^{BLN}). This allows us to recover the coefficients $\beta_1, \ldots, \beta_5$ and to construct the baseline MR terms using exporter and importer fixed effects, and baseline output and expenditure. Second, we re-estimate the gravity model in equation (16), using the counterfactual iceberg transport cost matrix, and holding the parameters $\beta_1, \ldots, \beta_5$ fixed at the levels estimated in the first step. The fixed effects estimates of this gravity model are used together with the baseline data on output and expenditure to construct conditional GE estimates of the MR terms. Finally, we use the second step estimates of trade flows (i.e., conditional GE trade flows) and conditional GE MR terms to estimate the full GE gravity using the iteration procedure that repeats the estimation of the model updating the endogenous variables (i.e., trade flows, MRs, prices and expenditure/output) until the change in prices converges to zero.[6]

5. DATA

The analysis presented in this study is based on three unique datasets. The first dataset contains interregional aggregate trade flows between EU regions, and between EU regions and OECD countries. The second dataset constitutes the cornerstone of our policy analysis and contains a matrix of GTC in a baseline and counterfactual scenario. Finally, the third dataset is a matrix of iceberg *ad-valorem* transport costs calculated using the matrix of the GTC described above. Below, we provide a more detailed description of each of these datasets.

5.1. The interregional trade flows matrix

The interregional trade flows matrix is the first dataset used in our analysis. The dataset is produced by the European Commission Joint Research Centre (JRC) and PBL Netherlands and is based on the methodology of Thissen et al. (2019) that estimates a probabilistic trade flow matrix to construct the interregional trade flows for the 267 NUTS-2 EU regions. The methodology is based on the 2013 national supply and use tables (SUTs) that contain an update of the statistics presented in the Eurostat SUTs and follow NACE Rev2 classification.[8] The tables account for the distribution of re-exports over origin and destination countries and ensure the consistency of bilateral trade flows. We note that the use of the 2013 SUTs is essential to our analysis, as this year represents the starting point of the Cohesion Policy programming period. Hence, using the data of later years would already reflect the impact of some investment projects, which would bias the results.

Furthermore, we complement the Eurostat SUTs with corresponding and equivalent OECD Inter-Country Input–Output Tables for the same year.[9] This process allows estimating coherent trade flows between the EU regions and OECD countries which in our analysis become external EU countries.

5.2. The generalised transport cost (GTC) matrix

Transport costs are an essential element of spatial economic models. The assumptions on transport costs directly affect the results of any spatial economic analysis. However, since regional-level transport costs are not readily available, the distance between two regions is often approximated by the distance between corresponding regional capitals, while the within-region transport costs are approximated using ad-hoc assumptions.

To improve the precision of transport cost estimates, this study rather calculates a transport costs matrix using the methodology of Persyn et al. (2022), who in turn build on a theoretical (Hanssen et al., 2012) and empirical

(Combes & Lafourcade, 2005; Ford et al., 2015; Laurino et al., 2019; Zofío et al., 2014) literature. In particular, we compute the average cost of road freight transportation between samples of centroids within and between all EU regions. The centroids are taken from a 1 ×1 km population grid, which allows us to sample a significant number of centroids for each EU region, in proportion to the spatial population distribution. Moreover, given a large number of centroids for each region, we are able to calculate precise transport costs within and between every region. This technique allows us to identify the cost-minimising route between pairs of centroids sampled from a population density grid. In particular, the optimal route is identified as a minimum cost for a typical 40 t heavy duty vehicle. Specifically, we define the GTC as:

$$GTC_{ij} = min_{I_{ij}}(DistC_{ij} + TimeC_{ij}) + Tax_i + Vignette_{ij}, \quad (17)$$

where $DistD_{ij}$ stands for distance-related costs, $TimeC_{ij}$ stands for time-related costs, and Tax_i and $Vignette_{ij}$ account for vehicles taxes and EU road-pricing schemes (Eurovignettes) that are different from tolls.

Distance-related costs include mainly fuel costs and toll costs (in countries where tolls are levied per km driven), and also costs for tires and maintenance. Fuel costs are country specific and taken from Eurostat. Maintenance and tire costs are based on Zofío et al. (2014).

Time-related costs include mainly the wage of the driver, which we took from Eurostat for 2013, as well as insurance costs, which we again based on Zofío et al. (2014).

Given these costs, the optimal routes are calculated on a digitised road network from OpenStreetMap. We use the state of the network on 1 January 2014, which are the oldest data available from https://download.geofabrik.de/europe.html. The approach controls for properties of the road network such as the curvature and slope, maximum speeds and the presence of roundabouts or traffic lights. The estimates rely on a large set of auxiliary datasets such as OpenStreetMap, and Eurostat data on wages at the regional level, satellite observations on elevation and population distribution which are used to estimate the traffic flows between the various regions.

The final GTC is an estimate of the cost (€) of moving a truck between samples of centroids. This estimate is then aggregated to the region-to-region level. Therefore, any change in the GTC's components leads to a new level of GTC and, subsequently, a change in the overall GTC matrix for regions.

5.3. The iceberg transport cost matrix

As calculated above, the GTC matrix is easy to understand and is commonly used in the transport literature. However, the majority of economic models use so-called 'iceberg' representation of transport costs, where the transport costs are considered a wasteful tax, proportional to the value of a good.

To incorporate the nominal € measure of transport costs presented by the GTC into a spatial economic model, the GTC matrix is converted into a traditional iceberg equivalent transport cost matrix that also accounts for differences in the unit values when trading between i and j.

To calculate these iceberg transport costs we use the following formula:

$$\tau_{ij} = \frac{F_{ij}\left(\frac{1}{L}\right)GTC_{ij}}{V_{ij}}, \quad (18)$$

where F_{ij} is the flow of goods in tons between i and j; L is the average load (tonnes) of trucks; GTC_{ij} is the corresponding GTC between i and j; and V_{ij} is the value of the goods traded between i and j.

The numerator expresses the total transport costs that arise from shipping the observed trade flow between regions, by multiplying the trade flow in tonnes by the number of trucks required to ship one ton, and by the cost of the trip for one truck. Expressing the total transport cost relative to the value of the trade flow gives the trade costs expressed in *ad-valorem* terms (Hummels, 1999). Changes in the GTC trigger changes in τ. The iceberg transport cost also depends on the heterogeneous distribution of the tonnes-to-value ratio across regions and countries which are not properly captured with the GTC.[10]

5.4. Counterfactual analysis: change in the transport cost matrix

Using a cost–benefit approach (described in detail in Persyn et al., 2022), we estimate the reductions in transport costs induced by the upgrading of secondary and primary roads to highways. The number of highway-km constructed in each region is determined by the EU funds allocated to the road infrastructure investment in each region. The cost of improving a road is assumed to be €10 million/km, and this amount is adjusted for differences in the price level of civil engineering works per country, the slope of the terrain and the population density surrounding the road. The candidate roads for improvement are ranked by an estimate of the total economic gain from improving them, based on an estimate of the number of trucks that are using the road. To obtain the required estimate of the total traffic on each road segment, a simple gravity model is applied using the interregional data from Thissen et al. (2019), where the trade is assumed to take place between samples of centroids based on satellite images, taking the lowest cost route over the digitised road network. For more details, see in Appendix C in the supplemental data online.

Figure 2 shows the estimated reduction in transport costs due to the road transport investment in the context of EU Cohesion Policy, by showing the percentage difference, for each region, in the harmonic regional-gross value added (GVA) weighted average of the transport cost of each region to all destinations, comparing the situation before and after the reduction due to infrastructure investment.

The results presented below report the difference in the predicted trade flows and corresponding welfare effects based on the gravity model that employs the original baseline transport cost estimates, and the predicted trade flows using the counterfactual transport cost estimates.

6. ROAD INFRASTRUCTURE INVESTMENTS: RESULTS

This section computes the GE effects of the road infrastructure investment envisaged under EU Cohesion Policy 2014–20. The spatial structure of the investment (Figure 1) points to a distribution markedly skewed towards the regions of Central and Eastern Europe. Indeed, many EU regions located in the new EU member states are still characterised by a lack in transport infrastructure. Hence, in line with the priorities of EU Cohesion Policy, the road infrastructure investment is distributed to bring the level of infrastructure in these regions closer to the EU average. The resulting decrease in the transportation cost is hoped to foster trade and production. We use the framework presented in the previous sections to quantify these effects.

As discussed above, the impact of road infrastructure investment in our framework is modelled as a reduction in the GTCs between and within the 267 NUTS-2 EU regions, which is then translated into differences in the iceberg transport costs τ. Logically, the Central and Eastern European regions experience the highest decline in GTCs following the investment in road infrastructure (Figure 2).[11]

Next, we follow the steps described in section 4. To this end, we use the original matrix of GTCs and employ the procedure of Anderson et al. (2018) described above to compute, first, conditional and then GE effects of the road infrastructure investment envisaged under EU Cohesion Policy 2014–20.

In the first step, we obtain the point estimates of the effects of transport costs, contiguity, international borders, common language and common currency on international trade flows. The results (Table 1) bear expected signs and are significant at $p < 0.01$. The effect of transport costs, the main variable of interest, is also negative and highly significant with $\beta_5 = -0.537$ (0.043). The magnitude of the β_5 coefficient implies that a change in the iceberg transport costs by 10% reduces trade by an average of 4.1% in our simulation results, calculated as $(\exp[\hat{\beta}_5] - 1) \times 10$. This effect remains significant even after controlling for other potentially important factors, such as contiguity, common language and currency, the presence of national borders and region-specific characteristics. Next, we use these estimates to evaluate the conditional GE effects from the reduction in transport costs. In particular, we constrain the parameter estimates on all the regressors to their baseline values reported in column 5 of Table 1 and replace the baseline transport cost matrix with the counterfactual one:

$$X_{ij} = exp[\mathbf{0.617}\ln Cont_{ij} + \mathbf{0.436}\, Language_{ij} + \mathbf{0.449}\, Currency_{ij} - \mathbf{2.613} National\ Border_{ij} - \mathbf{0.537}\tau_{ij}^{CFL} + \pi_i + \chi_j] + \epsilon_{ij}. \quad (19)$$

This allows us to measure the effects of the reduction in transport costs on trade flows while holding output and expenditure constant (i.e., conditional GE effect). The summary of the results (Table 2) reveals significant heterogeneity in conditional GE effects. In particular, the estimated conditional GE effects on cross-border (i.e., interregional) exports by the NUTS-2 EU region range between −0.2% and +0.2%. As can be seen from Figure 3 and the detailed

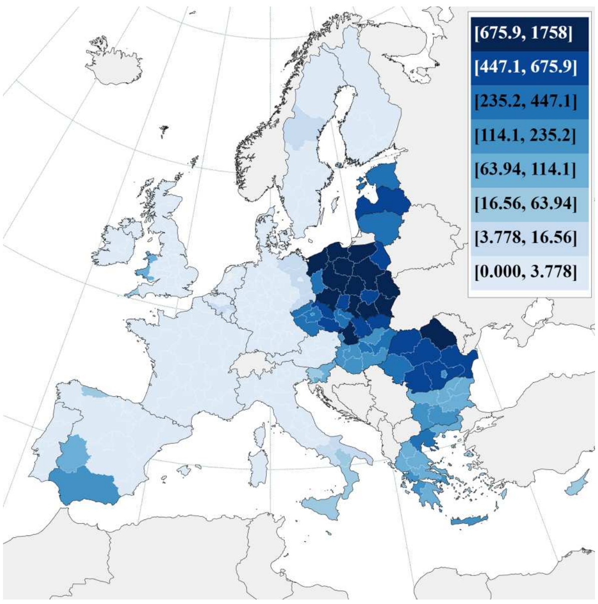

Figure 1. Investment in road infrastructure in the European Union's Cohesion Policy Programme, 2014–20 (€, millions).

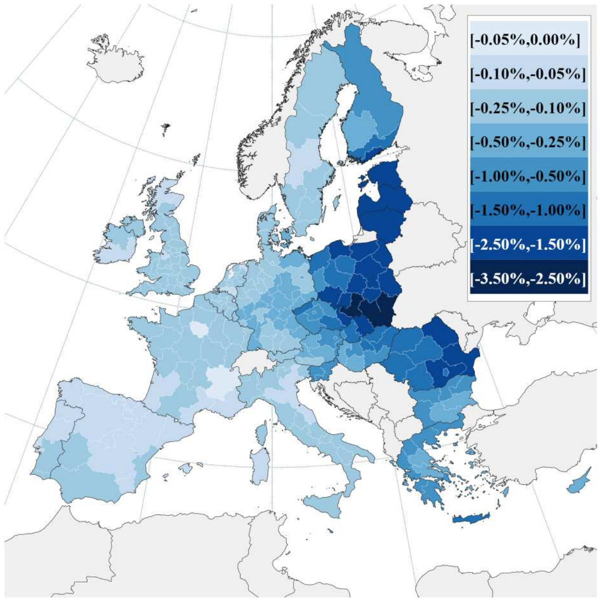

Figure 2. Average change in transport costs due to the road infrastructure investment (%).

Table 1. Baseline gravity results, Poisson pseudo-maximum-likelihood estimator (PPML).

	(1)	(2)	(3)	(4)	(5)
$\ln(\tau^{BLN})$	−1.729***	−1.711***	−1.204***	−1.027***	−0.537***
	(0.062)	(0.067)	(0.046)	(0.040)	(0.043)
Contiguous region		0.265***	1.269***	1.756***	0.617***
		(0.082)	(0.090)	(0.109)	(0.052)
Common language			1.762***	1.086***	0.436***
			(0.110)	(0.112)	(0.099)
Common currency				1.179***	0.449***
				(0.148)	(0.066)
National border					−2.613***
					(0.072)
N	88,197	88,197	88,197	88,197	88,197
R^2	0.745	0.744	0.926	0.968	0.983
Chi^2	9.79***	13.87***	29.41***	28.46***	1.26
Origin fixed effects	✓	✓	✓	✓	✓
Destination fixed effects	✓	✓	✓	✓	✓

Note: Standard errors are shown in parentheses $^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

results per region in Appendix A in the supplemental data online, regions that do not receive any funds and are quite far from the targeted regions (e.g., regions in Sweden) hardly experience any change in exports. Modest increases in exports can be seen in regions that do not receive funds, but are close to where investment is taking place. This is especially the case for regions for which improvements of the road network in Eastern Europe are relevant due to their geography. A prime example is Finland, which depends on a corridor of roads through targeted regions for road freight to and from the EU's economic core regions. More surprisingly, at first sight, is the fact that some regions in which investment is taking place (such as several Polish regions) experience a decline in cross-regional-border exports. The reason is simple: in the conditional GE, output is constant. The decline in exports to other regions is accompanied by an increase in shipments to destinations within the own region. This prediction of a decrease in cross-border shipments to the benefit of sales

Table 2. Structural gravity results, conditional and full general equilibrium (GE) effects, $\sigma = 7$.

	Mean (%)	Minimum (%)	Maximum (%)
Targeted regions			
Conditional GE Δ*Exp*	−0.003	−0.198	0.217
Full GE Δ*Exp*	0.033	−0.189	0.246
Full GE Δ*IMR*	−0.077	−0.204	−0.007
Full GE Δ*OMR*	−0.084	−0.239	−0.003
Full GE Δ*rGDP*	0.149	0.009	0.409
Full GE Δ*price*	0.072	0.003	0.205
European Union			
Conditional GE Δ*Exp*	−0.001	−0.198	0.217
Full GE Δ*Exp*	0.008	−0.189	0.246
Full GE Δ*IMR*	−0.021	−0.204	0.007
Full GE Δ*OMR*	−0.019	−0.239	0.018
Full GE Δ*rGDP*	0.037	−0.022	0.409
Full GE Δ*price*	0.016	−0.015	0.205
OECD			
Conditional GE Δ*Exp*	−0.016	−0.042	−0.001
Full GE Δ*Exp*	−0.013	−0.036	−0.000
Full GE Δ*IMR*	−0.001	−0.004	0.003
Full GE Δ*OMR*	0.005	0.001	0.009
Full GE Δ*rGDP*	−0.003	−0.010	−0.001
Full GE Δ*price*	−0.004	−0.007	−0.001

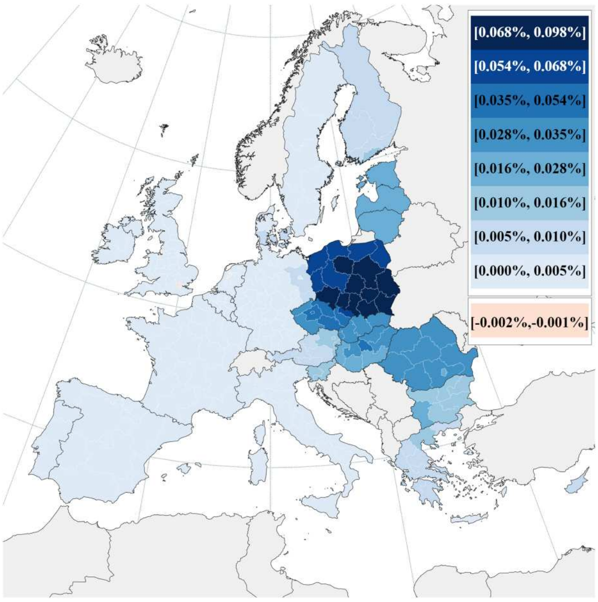

Figure 3. Percentage change in nominal shipment value: full general equilibrium (GE) results.

within the own region can only occur because we model within-region transport costs, and changes therein. This is a feature that is missing from a most models estimating the effect of economic integration.

Next, conditional GE effects on trade for the non-EU OECD countries that do not receive any funds are small and negative, which is in line with most structural gravity studies (Yotov et al., 2016). Indeed, all the effects of EU Cohesion Policy road infrastructure investment on export flows of these countries arise from trade diversion: as the goods produced in these countries become more expensive in relative terms compared with the output from the regions that benefit from the investments, some countries may see their exports decline. The effects are negative but quite small, ranging between −0.001% and −0.042%.

Next, we analyse the full endowment GE effects of the transport infrastructure investment. In this case, production is no longer held constant, and we see that using this model, the predicted increase in cross-border shipments is larger than in the conditional case. On average, the effect is positive, albeit small. It should be emphasised that the effect on overall shipments, including to the own region, is unambiguously positive in all regions. Regional real GDP also increases everywhere in the targeted regions, with increases ranging from +0.01% to +0.41%, with an average of 0.15%.

Also interesting are the results for the EU as a whole. Here we see that, although on average the effect on regional real GDP is positive, some regions experience a small decrease in real GDP of up to −0.022%. Figure 4 and Appendix A in the supplemental data online show that regions experiencing negative effects are mostly located far from the regions where investment is taking place, in Spain, Portugal, France and the UK.

To shed more light on the underlying forces behind these heterogeneous effects, we include some additional results of the full endowment GE scenario. In particular, we consider changes in the IMR and OMR terms and long-run changes in producer prices. We note that both IMR and OMR are only determined in relative terms due to the normalisation of the model needed to solve the MR system. Following the mainstream structural gravity literature we choose a region largely unaffected by the policy experiment as a reference point. To this end, we have chosen the IMR of the United States as a reference. Hence, MR changes in all other regions/countries should be interpreted relative to the effects of Cohesion Policy road infrastructure investment on American consumers.

We find that, on average for the EU regions, additional road infrastructure investment leads to a similar decrease in trade costs for consumers (IMR) and for producers (OMR) of around −0.02%. As expected, in the targeted regions the decrease is much larger and is around −0.08%. This result is different from that of Anderson and Yotov (2010) who find that the incidence of trade costs on producers is much larger than the one on consumers. In our case, instead, the gains from the investment in road infrastructure are approximately equally divided between the two groups.

Furthermore, as can be seen in Figures 5 and 6, the results differ significantly across regions. In particular, regions with the strongest decrease in both IMR and OMR terms experience the strongest positive full endowment GE effects on their export and real GDP.

For the non-EU countries the OMR term increases slightly, by on average 0.005%, suggesting that the cost for the non-EU producers to sell to the EU market rises. At the same time, the IMR term for the non-EU countries on average exhibits a negligible decline, suggesting that consumers in non-EU countries still get a small gain from lower global prices. For non-EU countries, the

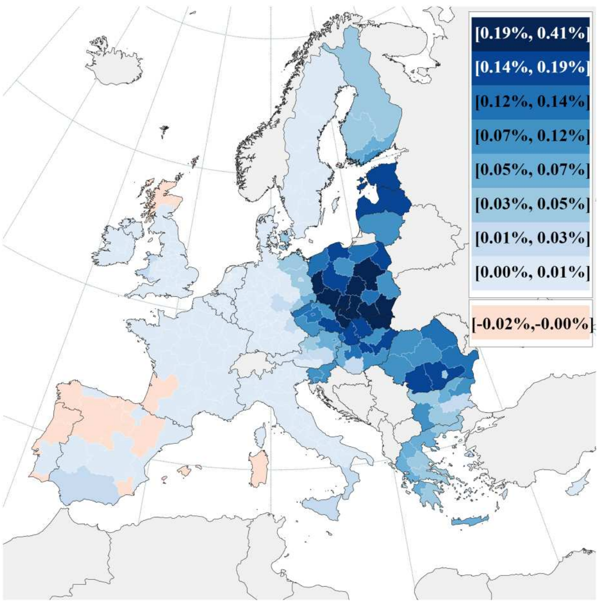

Figure 4. Percentage changes in real gross domestic product (GDP) (welfare): full general equilibrium (GE) results.

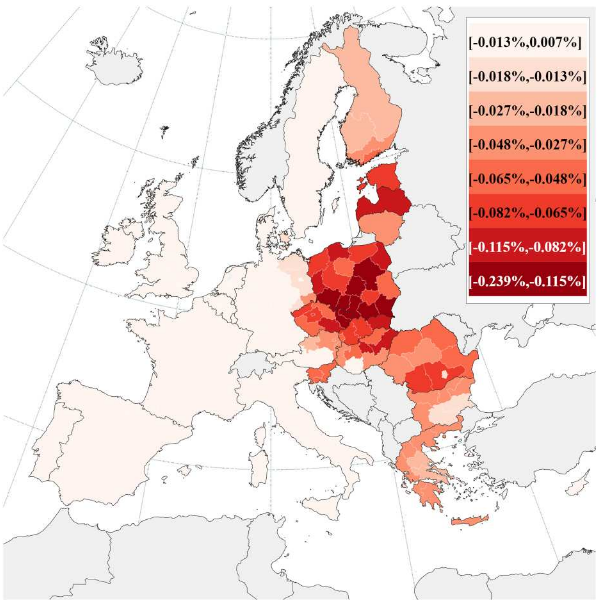

Figure 5. Changes in inward multilateral resistance (IMR): full general equilibrium (GE) results.

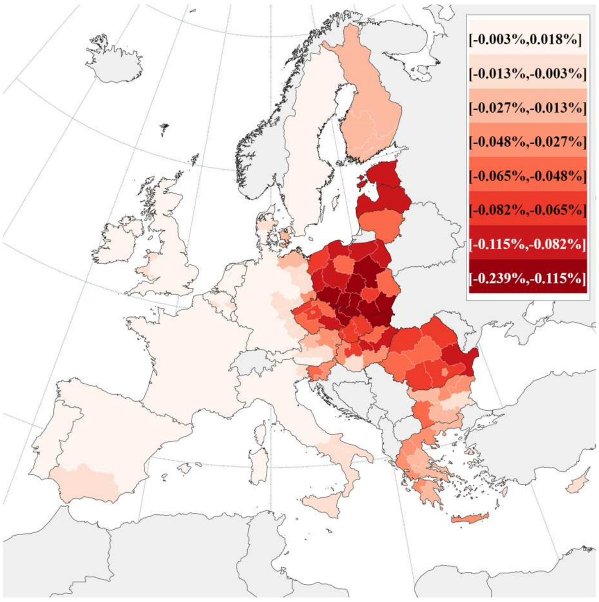

Figure 6. Changes in outward multilateral resistance (OMR): full general equilibrium (GE) results.

results are generally small and exhibit lower heterogeneity in the full endowment GE effects. Such results are in line with our expectations, as all the effects of the road infrastructure investment on export flows of the non-EU countries are attributed to spillovers and not to the direct effects of the improvement in the EU transport infrastructure.

In summary, our analysis indicates that the road infrastructure investment implemented under the framework of EU Cohesion Policy would lead to increasing real GDP, especially for the targeted EU regions, and for the vast majority of other EU regions. Non-EU countries and a few EU regions experience small negative real GDP effects. Because the investment lowers transport costs not only between but also within regions, it is predicted to increase overall production and shipments of goods. And, although in some cases cross-regional trade decreases, the shipments within the region increase by more. Overall, the policy stimulates EU consumers to substitute away from non-EU imports, which decline, in favour of goods produced in the EU.

Finally, to ensure the robustness of our findings, we have implemented the analysis using alternative values of σ. In particular, we followed Zofío et al. (2020), who find that regional elasticity of substitution across varieties is around 4 for interregional trade within the EU internal market. We used this alternative value of σ in our model to produce an additional set of results presented in Table 3. The results reveal that the effects are larger, but the qualitative nature of the results holds.[12]

Table 3. Structural gravity results, conditional and full general equilibrium (GE) effects, $\sigma = 4$.

	Mean (%)	Minimum (%)	Maximum (%)
Targeted regions			
Conditional GE ΔExp	−0.003	−0.198	0.217
Full GE ΔExp	0.069	−0.180	0.313
Full GE ΔIMR	−0.077	−0.204	−0.007
Full GE ΔOMR	−0.096	−0.273	−0.004
Full GE $\Delta rGDP$	0.221	0.012	0.615
Full GE $\Delta price$	0.144	0.005	0.411
European Union			
Conditional GE ΔExp	−0.001	−0.198	0.217
Full GE ΔExp	0.018	−0.180	0.313
Full GE ΔIMR	−0.021	−0.204	0.007
Full GE ΔOMR	−0.022	−0.273	0.020
Full GE $\Delta rGDP$	0.053	−0.037	0.615
Full GE $\Delta price$	0.033	−0.030	0.411
OECD			
Conditional GE ΔExp	−0.016	−0.042	−0.001
Full GE ΔExp	−0.011	−0.033	0.003
Full GE ΔIMR	−0.001	−0.004	0.003
Full GE ΔOMR	0.005	0.001	0.010
Full GE $\Delta rGDP$	−0.007	−0.017	−0.001
Full GE $\Delta price$	−0.008	−0.015	−0.001

7. DISCUSSION AND CONCLUSIONS

Most of the current European policy debate is focused on a more unified European market and on the reduction of imbalances across EU countries and regions. In this context, the Cohesion Policy funding is one of the largest and most important EU policy instruments, with an allocation of around one third of the EU budget. Hence, providing an assessment of trade and welfare effects of the Cohesion Policy programme and its components is crucial for a better understanding of its impact and limitations.

To this end, this study seeks to quantify effects of one of the main components of the EU Cohesion Policy programme, road infrastructure investment, on the interconnectedness, trade and welfare of the EU regions. To the best of our knowledge, this paper is the first in using a structural gravity model to analyse the effects of road transport infrastructure improvement on trade and GDP at the regional level. The changes in transport costs induced by the policy are estimated using sampling of many centroids based on the spatial distribution of population, and consider the geography of a digitised road network. This allows us to consider not only changes in transport costs between regions due to improvements in roads, but also within regions, and fully takes into account how trade between regions may be affected by the policy even if the regions themselves do not receive any funds, but rather regions connecting them.

Our results confirm an overall positive effect of EU Cohesion Policy on interregional trade and regional real GDP values. In particular, we find an average increase in real GDP of around 0.149% in targeted regions, with some of these regions experiencing the increase up to 0.4%. There are modest spatial spillovers with countries such as Finland benefiting from road improvements in Eastern Europe, increasing their connectivity with the EU's economic core. While the average EU GDP modestly increases, and the vast majority of regions enjoy positive effects either directly or through spillovers, small negative effects on GDP are predicted in third countries, as well as for some EU regions which are remote to the focus of investments in Central and Eastern Europe. An interesting finding of the paper is that a reduction in transport cost does not always lead to more external trade. Instead, some regions that experience a relatively large decrease in local transport costs, exhibit a relatively large increase in local consumption, accompanied by a modest decrease in goods that are shipped across regional borders.

Finally, if we compare the total cost and benefit of the programme, we find that the Cohesion Policy road infrastructure investment is predicted to increase in total EU GDP by around €2.25 billion. Compared with a cost of about €30 billion, this implies that, given the full convergence has been achieved, the benefits outweigh the costs after about 13 years. This is impressive, especially since our simulations are limited in scope and ignore dynamic growth effects, increases in welfare through smoother commuting and other factors.

Some limitations of our analysis are that it only captures the long-run static effects. Our setting does not allow us to consider any dynamic mechanism that would promote growth due to increased investments or agglomeration effects. Hence, our estimates should be interpreted as conservative. We also ignore welfare effects related to, for example, reduced commuting times, or decreased interregional economic inequality.

Another possibility to explore the full effects of the Cohesion Policy programme is to implement an ex-post impact evaluation using, for example, satellite images of the EU road network. Unfortunately, it might be too early to assess such effects for several reasons. First, most Cohesion Policy projects have a *grey* period of two to three years during which the projects can be brought to completion after the deadline and the expenses associated with those projects can still be claimed. Second, some projects expected to be terminated by the end of the programming period suffered delays due to the COVID pandemic. Therefore, it is possible, that projects are still ongoing, which precludes the possibility to obtain reliable ex-post estimates.

To conclude, our study finds that the road infrastructure investment implemented under the framework of EU Cohesion Policy leads to significant trade and welfare gains that are mostly concentrated in the Central and Eastern regions, identified as *less-developed regions* of the EU. Hence, our results provide additional supportive evidence towards the effectiveness of EU Cohesion Policy programmes in reducing disparities among EU member states and regions.

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DATA AVAILABILITY

The trade data for this study were constructed by the authors based on the methodology of Thissen et al. (2019) using 2013 national supply and use tables (SUTs) downloaded from Eurostat. It was complemented with the corresponding and equivalent OECD Inter-Country Input–Output Tables for the same year. The generalised transport cost (GTC) matrix was constructed following the methodology of Persyn et al. (2022) using a digitised road network from OpenStreetMap (https://download.geofabrik.de/europe.html).

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

NOTES

1. For more information about the Connecting Europe Facility see https://transport.ec.europa.eu/index_en; and https://ec.europa.eu/regional_policy/funding/available-budget_en/.
2. Throughout the analysis, the trade costs are treated as iceberg costs, following the standards of the trade literature.
3. Appendix B in the supplemental data online includes a complete description of the iterative procedure (Anderson et al., 2018).
4. We use the method described by Persyn et al. (2022) based on the existing (2013) OpenStreetMap road network.
5. The cross-section database used for trade flows allows us to estimate equation (13) with a PPML estimator including origin and destination fixed effects to estimate the MR terms.
6. The analysis in this study employs an elasticity of substitution of $\sigma = 7$ (Anderson et al., 2018). See Appendix B in the supplemental data online for a complete description of the iterative procedure.
8. For the description of the NACE Rev2 classification, see https://ec.europa.eu/eurostat/ramon/index.cfm?TargetUrl=DSP_PUB_WELC/.
9. For more information and access to the data, see the OECD's Inter-Country Input–Output Tables; https://www.oecd.org/en/data/datasets/inter-country-input-output-tables.html/.

10. For more information on the data used on construction of the GTC matrix and to download an example of such a matrix, see Persyn et al. (2022).
11. We calculate transport costs following the methodology of Persyn et al. (2022) only between and within EU regions. We use linear extrapolation to obtain estimates of GTC for the extra-EU OECD countries.
12. The complete set of results by region employing elasticity of substitution $\sigma = 4$ is available from the authors upon request.

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