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Causal analysis of the interinfluence of workforce productivity and rail freight intensity in the regions of the Ural Federal District

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ABSTRACT
Relevance. The development of the railway industry has a significant positive impact on socio-economic dynamics at both the state and regional levels, which has been confirmed by numerous domestic and foreign studies. However, the issue of mutual influence of such categories as regional labour productivity and rail freight intensity has been little studied. At the same time, the most important task today is to find effective incentives for the growth of regional labour productivity.
Research Objective. This study aims to econometric analysis of the relationship between rail freight intensity and workforce productivity in the Ural Federal District (UFD).
Data and Methods. The study uses official statistical data on Russian regions provided by the Federal State Statistics Service. The methods of Vector Error Correction Models (VECM) and pooled mean group estimates (PMG method) formed the methodological basis of the study.
Results. The study has shown that there is a relationship between workforce productivity and rail freight intensity. At that point, in a short-term period growth of rail freight intensity leads to an increase in workforce productivity, which in a long-term period itself becomes an incentive to increase the shipped commodity mass and rail freight intensity.
Conclusions. The findings can be of interest to public authorities at the national and regional levels, for heads of industrial structures and functional institutions, representatives of business and scientific communities interested in the development and modernization of transport infrastructure, being a basic condition for the increased intensity of cargo transportation in the region.

KEYWORDS
regional development, regional transportation system, workforce productivity, rail freight intensity, vector error correction models (VECM), method of pooled mean group estimates (PMG method)

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Причинно-следственный анализ взаимовлияния производительности труда и интенсивности железнодорожных грузоперевозок в регионах Уральского федерального округа

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АННОТАЦИЯ
Актуальность. Развитие железнодорожной отрасли оказывает существенное положительное влияние на социально-экономическую динамику как на уровне государства, так и на уровне регионов, что подтверждено многочисленными отечественными и зарубежными исследованиями. Однако мало изучен вопрос взаимовлияния таких категорий как региональная производительность труда и интенсивность грузовых перевозок. Вместе с тем сегодня в условиях необходимости наращивать производственно-технологический суверенитет важнейшей задачей является поиск эффективных стимулов для роста региональной производительности труда.
Цель исследования. Цель данного исследования – эконометрический анализ взаимосвязи между интенсивностью транспортных железнодорожных грузоперевозок и производительностью труда в Уральском федеральном округе (УрФО).

КЛЮЧЕВЫЕ СЛОВА
развитие региона, транспортная система региона, производительность труда, интенсивность железнодорожных грузоперевозок, векторные модели коррекции ошибок (VECM), метод объединенных средних групповых оценок (метод PMG)

Данные и методы. В исследовании используются официальные статистические данные по российским регионам, предоставленные Федеральной службой государственной статистики. Методологическую основу исследования составили методы векторных моделей коррекции ошибок (VECM) и объединенных средних групповых оценок (метод PMG).
Результаты. Исследование показало наличие взаимосвязи между производительностью труда и интенсивностью грузоперевозок. Причем в краткосрочном периоде рост интенсивности грузоперевозок приводит к росту производительности труда, которая в долгосрочном периоде сама становится стимулом к наращиванию отгружаемой товарной массы и увеличению интенсивности грузоперевозок.
Выводы. Полученные результаты могут представлять интерес для органов государственной власти на национальном и региональном уровне, для руководителей отраслевых и функциональных органов, представителей бизнеса и научных сообществ, заинтересованных в развитии и модернизации транспортной инфраструктуры, как базовому условию наращивания интенсивности грузоперевозок в регионе.

ДЛЯ ЦИТИРОВАНИЯ
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乌拉尔联邦区劳动生产率与铁路货运强度相互影响的因果分析

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摘要
现实性：铁路行业的发展对国家和地区层面的社会经济动态有着显著的积极影响，这一点已被国内外众多研究证实。然而，学界对于地区劳动生产率和货运强度等因素之间的相互影响问题却研究甚少。同时考虑到当今增加生产和技术主权的需要，找到区域劳动生产率增长的有效激励措施是最重要的任务。
研究目标：本研究的目的是对乌拉尔联邦区铁路货运强度与劳动生产率之间的关系进行计量分析。
数据与方法：研究使用了联邦国家统计局提供的俄罗斯各地区官方统计数据。研究使用了联邦国家统计局提供的俄罗斯各地区官方统计数据。研究的方法论基础是向量误差修正模型（VECM）和合并组均值法（PMG）。
研究结果：研究表明，劳动生产率与货运强度之间存在着某种关系。此外，在短期内，货运强度的增长会导致劳动生产率的提高，而在长期内，劳动生产率的提高本身又会成为增加货运强度的动力。
结论：研究结果可能会引起国家和地区各级政府、行业和职能机构负责人，以及对交通基础设施发展和现代化感兴趣的企业界和科学界代表的兴趣。研究可作为提高区域内货物运输强度的方法之一。

关键词
区域发展、区域交通系统、劳动生产率、铁路货运强度、向量误差修正模型（VECM）、合并组均值法 (PMG)

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Introduction

Transport freight contributes significantly to economic growth and thus to overall national and socio-economic development objectives. Transport freight can contribute to economic growth both directly and indirectly: they increase overall productivity; encourage technology diffusion between industries; and increase the profitability of transport-related businesses, either by increasing their sales volumes or by reducing production and delivery costs.

Transport freight has been the subject of detailed academic analysis, especially since the seminal works (Aschauer, 1989; Eisner, 1991). The central questions are whether the intensity of freight transport contributes to economic growth, whether economic growth increases the intensity of transport use, whether they reinforce each other, and whether they jointly influence other related processes.

Among freight transport, rail freight is particularly noteworthy as it is an important and integral part of the national economy and has a significant impact on society as a whole. At the same time, the share of rail transport in the total freight turnover of the Russian Federation (RF) is about 46-47%[1]. By comparison, the share of road transport in total freight turnover is about 5%. As noted in the paper (Petrov, et al, 2021) "the work of railway transport

[1] Transport in Russia. 2022: Statistical collection / Rosstat. - Moscow, 2022. - 101 c. - URL: https://rosstat.gov.ru/folder/210/document/13229.

and the quality of transport services depends, firstly, on the investment attractiveness of territories and the transport mobility of the population. Secondly, railway transport stimulates other sectors of the economy through direct, indirect and induced effects. Thirdly, railway transport contributes to the formation of employment and income growth. Fourthly, rail transport generates positive economies of scale, helping to increase competitiveness, and finally, rail transport is an important factor for the dissemination of technical knowledge".

For a vast country such as Russia, the lack of mobility of critical production resources can be a major challenge and an obstacle to economic growth. Therefore, it is important to identify both short-term and long-term causes of freight demand response, depending on economic and technological determinants at the national level. The most important such determinant is the workforce productivity, which affects the growth of the commodity mass shipped.

The aim of this study is an econometric analysis of the relationship between railway freight transport intensity and workforce productivity in the Urals Federal District (UFD). In order to achieve the set goal, it is necessary to analyze the cause-and-effect relationships between labour productivity and intensity of transport railway freight traffic in the Urals Federal District. This is the research objective and scientific novelty of the work.

The choice of railway freight transportation in the Urals Federal District as an object of study is interesting because part of the territory of the Urals Federal District belongs to Siberia and the Arctic and the Northern Sea Route passes through this territory. The main objective of developing the transport system of the UFD is to form a unified transport space, the main tasks of which include, among others, forming a unified year-round accessible road network; renewing the rolling stock fleet with new, modern vehicles; increasing transport development of the Far North regions. The relevance of analyzing freight traffic intensity in the Urals Federal District is due to the fact that, according to the most pessimistic scenarios of minimum 2% annual economic growth in Russia, by 2030 the deficit of railway capacity on the Siberia-Ural route will amount to about 70 million tons (Kolomak, 2020).

Among all the regions of the Urals Federal District, two regions stand out – the Khanty-Mansi Autonomous Area (KhMAO) and the Yamal-Nenets Autonomous Area (YaNAO) - whose economies are based on oil and gas extraction. These regions are among Russia's leaders in terms of hydrocarbon reserves. In addition, for example, the Khanty-Mansi Autonomous Area ranks third in the "rating of the socio-economic situation of Russia's regions" and second in terms of economic size in Russia (second only to Moscow).

It should be noted that there are practically no publications on the direct impact of workforce productivity on the intensity of rail freight transport.[2] The bulk of publications are devoted to the analysis of the impact of railway transport infrastructure on regional economic performance. For example, A.N. Rahmangulov and O.A. Kopylova (Rakhmangulov, Kopylova, 2014) proposed an econometric model to assess the impact of these factors on the logistics infrastructure facilities in the regions. An interesting publication (Macheret, 2016) analyzes the dynamics of the main indicators of the railway network of different countries over a century period. The publication notes the positive results of economic reforms in railway transport. It concludes that the development of market mechanisms and their institutional framework (in particular, the removal of restrictions on attracting private capital into the development of the existing railway infrastructure) is necessary to successfully meet the challenges of developing the Russian railway industry and the country's entire economy.

A number of works are devoted to the application of a vector error correction model to analyses the causal relationship between transport performance and economic growth. Pradhan, et al (2013) found a bi-directional causal relationship between road transport intensity and economic growth. A unidirectional causal relationship was found between economic growth and rail transport. The authors believe that policies conducive to transport infrastructure development in India will contribute to sustainable economic growth in this country. In terms of the reciprocal impact of transport and economic growth, researchers from China in VECM (Liu, et al, 2006) found a one-way causal relationship between transport logistics and economic growth in China. It should be noted that there are very few studies related to the application of VECM for causal analysis in the transport industry. Meanwhile, this toolkit seems to be the most effective for analyzing this type of problems.

The paper (Mak, et al., 2015) uses an autoregressive model and establishes a causal relation-

[2] Bibliometric analysis using the VOSviewer software product was used in this paper.

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Table 1

Indicators used in modelling

Indicator	Designations (logarithms)	Unit of measure
Rail freight intensity	lintens	tons/(km*person)
Real gross regional product (GRP) per capita employed (workforce productivity)	lvrp	Million rubles/person

Source: the authors' developed.

ship between the following four variables: transport intensity, urbanization scale, emissions and economic growth in both the short and long term. The main conclusion is that passenger transport intensity in the G-20 countries should be increased in order to stimulate economic growth.

It should be noted that the method based on the estimation of Vector Error Correction Models (VECM) is also applied in other areas of analysis. For example, to study the financial sustainability of a number of countries (Canagarajah, et al, 2012; Afonso, et al, 2015; Quintos, et al, 1995; Payne, et al, 1997). Articles (Afonso, et al, 2016; Paniagua et al, 2017; Feld, et al, 2020; Seo, et al, 2016) have analyzed the fiscal sustainability of regions.

In addition to those mentioned above, various econometric methods have been used to investigate the impact of various factors on transport energy efficiency (Lv, et al, 2015; Shi, et al, 2013). The impact of carbon dioxide emissions has been analyzed in (Xu, et al, 2016; Liang, et al 2017). The decomposition of various factors affecting energy consumption in the transport sector is described in (Belloumi, 2016; Liu, et al, 2015; Yuan, et al, 2015).

Methods and data

Econometric modelling is one approach to identify the interdependence and causality between different types of indicators. Since the time series of the indicators to be analyzed, as will be shown below, are non-stationary, standard classical methods such as the Ordinary Least Squares (OLS) method are not applicable for the estimation of regression parameters. Asymptotic distributions using classical model estimation methods such as OLS when dealing with non-stationary time series can lead to erroneous conclusions or false regressions. The solution to these problems is to test the time series of the variables under study for cointegration and to estimate Vector Error Correction Models (VECM) to distinguish short run and long run effects of intervening variables. The basic idea behind cointegration is that although each of two or more time series of variables may be non-stationary, their linear combination can have a stationary trend due to the mutual elimination of stochastic trends in the linear combination of variables. This linear combination between non-stationary variables is known as a cointegrating vector (cointegrating relationships). Thus, a cointegrating relationship between non-stationary series can be seen as a long-term steady state dynamic relationship, although there may be small short-term variations around long-term states. In order for the long-run relationship between the variables to be maintained, the variables must be corrected for bias, which is done in a vector error correction model.

Thus, at the first stage of the study the time series are checked for nonstationarity. At the second stage, the possibility of their cointegration is checked. At the third stage, VECM is estimated and causal relationships between the analyzed variables are established.

The peculiarity of the study is that it is carried out on panel data from six regions of the Ural Federal District for the period from 2000 to 2020. The choice of this rather compact data panel is due to the heterogeneity of empirical data describing the regions of the Ural Federal District in terms of industry.[3]

The analyzed indicators (Table 1) are obtained by calculation from the data available on the official website of Rosstat. All the regions of the Ural Federal District were studied: Kurgan and Sverdlovsk regions, the Khanty-Mansi (KhMAO) and the Yamal-Nenets (YaNAO) Autonomous Areas, Tyumen Region (without KhMAO and YaNAO) and the Chelyabinsk Region. The time series of indicators is annual data. The sample period is from 2000 to 2020[4]. Before the analysis, the time series of indicators are transformed into a natural logarithmic form (using the natural logarithm)[5].

[3] This choice is also due to the fact that in the absence of spatial autocorrelation between the variables under study, spatial econometric models cannot be applied.

[4] The use of annual data is due to the lack of official quarterly statistics for the indicators studied.

[5] Converting the data to logarithmic form is due to the fact that using them in their original form leads to heteroscedasticity in the residuals of the estimated equations.

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Rail freight intensity was calculated as the ratio of freight transported by rail per capita of the employed population to the operational length of public railway lines. Labour productivity was calculated as real gross regional product (GRP) per capita employed. Real GRP was determined in constant prices of 2000.

Results

Table 2 shows the descriptive statistics of the indicators under study. The analyzed variables have positive asymmetry coefficient values, i.e., the statistical distributions of all these variables are positively skewed compared to the normal distribution. Thus, the time series of these variables may have a stochastic trend and be non-stationary. In order to verify this statement, a visual analysis of the data should be carried out and the time series under study should be tested for the presence of a unit root.

Visual data analysis allows us to analyze the validity of combining them into a panel and preliminarily assess some relationships between the studied variables. Figures 1 and 2 show the time dependencies of rail freight intensity and workforce productivity for individual regions of the Ural Federal District. From the above figures we see a rather uniform picture. On average, there are some stationary values for each region relative to which there are temporal fluctuations for the studied variables. This means that a panel model with a regionally heterogeneous constant may turn out to be quite adequate for the empirical data.

Table 2

Descriptive statistics of the variables studied

Statistics indicators	lintens	lvrp
Average	1.171	368.108
Median	0.362	135.876
Maximum	21.218	1275.112
Minimum	0.084	41.997
Standard deviation	0.431	12.085
Asymmetry	2.180	1.141
Excess	2.483	2.475

Source: the authors' calculations are based on "Regions of Russia. Main Characteristics of the Constituent Entities of the Russian Federation. Retrieved from: https://rosstat.gov.ru/ *(accessed 26.01.2023).*

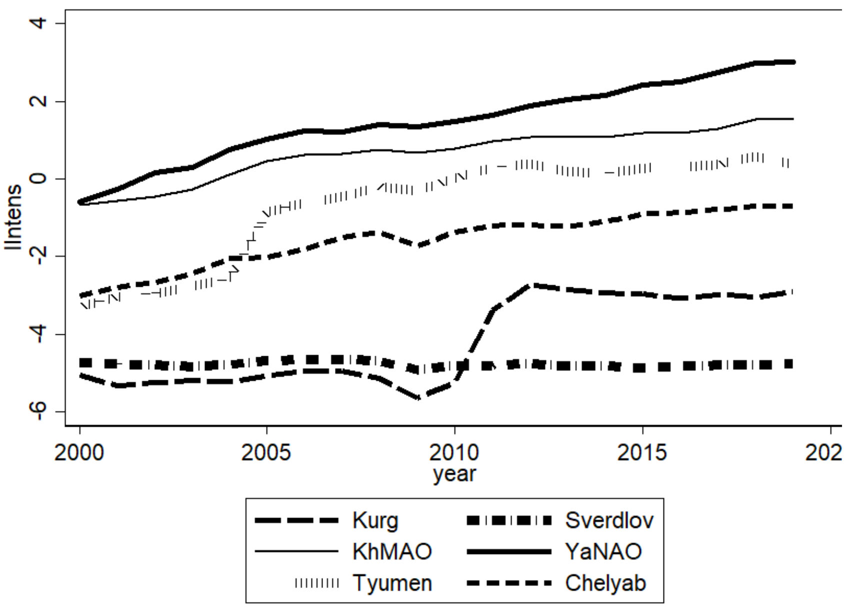

Figure 1. *Time dependence of the logarithm of the rail freight intensity for individual regions of the Ural Federal District*

Source: Compiled by the authors are based on "Regions of Russia. Main Characteristics of the Constituent Entities of the Russian Federation. Retrieved from: https://rosstat.gov.ru/ *(accessed 26.01.2023).*

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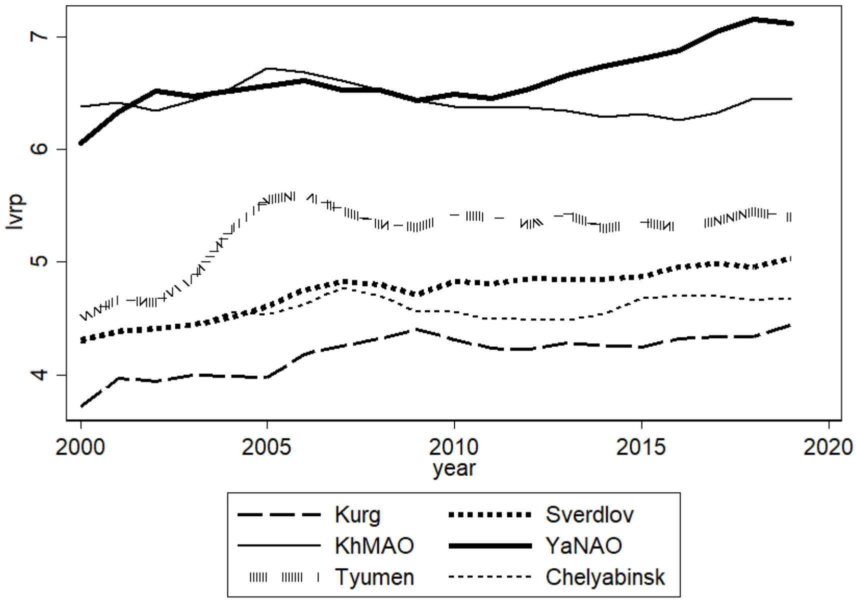

Figure 2. *Time dependence of the logarithm of workforce productivity for individual subjects of the Ural Federal District*

Source: Compiled by the authors are based on "Regions of Russia. Main Characteristics of the Constituent Entities of the Russian Federation. Retrieved from: https://rosstat.gov.ru/ (accessed 26.01.2023).

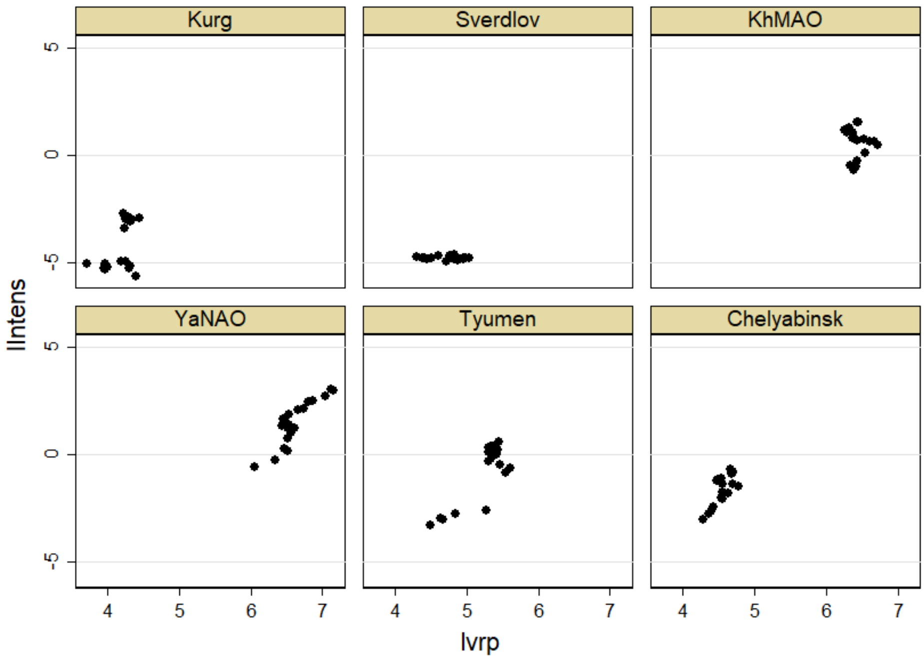

Figure 3. *Dependence of railway freight traffic intensity on workforce productivity for selected Ural Federal District subjects. Logarithmic values. Point diagrams.*

Source: Compiled by the authors are based on "Regions of Russia. Main Characteristics of the Constituent Entities of the Russian Federation. Retrieved from: https://rosstat.gov.ru/ (accessed 26.01.2023).

The test (Pesaran, 2007) confirms the cross-dependence of the studied series of panel data[6]. The CD (cross-dependence) test statistic is 2.624, the p-value is 0.0087 and the null hypothesis H_0 is no cross-dependence. The average value of the absolute correlation of the non-diagonal elements of the residual's matrix is 0.561, which confirms the specification of the fixed-effects model.

[6] A cross-dependence test for time series of individual variables showed that the time series under study are cross-dependent.

It is noteworthy that rail freight intensity in the Sverdlovsk Region remained virtually unchanged over the study period (Figure 1), while the time dependencies for the Kurgan and Tyumen Regions are characterized by some positive jumps in intensity (especially for the Kurgan Region). It is precisely during these spikes that relatively strong productivity growth occurred for these regions (Figure 2).

Figure 3 shows the dependence of railway freight traffic intensity on workforce productivity for individual Ural Federal District subjects in the form of point diagrams. The diagrams show that a pronounced positive dependence of intensity on workforce productivity is observed for the KhMAO, YaNAO, Tyumen and Chelyabinsk regions. There is no such dependence for the Sverdlovsk Region. Finally, a rather contradictory picture is observed for the Kurgan Region, characterized by a jump and a negative dependence.

Panel data were tested for unit root using the Hadri and Pesaran tests (). The essence of the Hadri test (Hadri, 2000) is to test the statistical significance of model coefficients on time differences of the original time series data:

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{t-1} + \gamma_i t + \varepsilon_{it}\ , \qquad (1)$$

The test involves testing the null hypothesis that the process is stationary against the alternative hypothesis that it is non-stationary (the presence of unit roots). If for any number of cross sections is satisfied $\gamma_i \neq 0$ and $\beta_i < 0$, then the series of first-order differences is stationary, and hence the process is integrable of order I (1).

For the Hadri test, an estimated value of the Z-statistic

$$Z = \frac{\sqrt{N(LM-\mu)}}{\zeta} \to N(0,1)\,,$$

is calculated using Lagrange multipliers:

$$LM = \frac{1}{N}\left\{\frac{\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\left(\hat{Y}_{it} - Y_{it}\right)^2\right)}{T^2 \bar{f}_0}\right\}, \qquad (2)$$

where $\bar{f}_0 = \frac{\sum_{i=1}^{N} f_{i0}}{N}$ – average estimation of spectral density of residuals of estimated model, N – the number of observations, T – the number of time periods, $\mu = 1/15, \sigma^2 = 11/6300$ if there is a trend and $\mu = 1/6,\ \sigma^2 = 1/45$ otherwise. The statistics are counted in Neuve-West estimates.

The results of the Hadri test are presented in Table 3. The Z-statistic and its corresponding significance level for rejecting the null hypothesis that the panel process is stationary are calculated for the test. In addition to the conventional Hadri statistic, statistics with possible heteroscedasticity, performed in Neuve-West estimates, are estimated.

The Pesaran test (Pesaran, 2007) is based on the assumption of cross-sectional dependence of series in a panel. In this case, a cross-sectional dependence statistic (CD-statistic) is calculated. Two model specifications were considered: with constant; with constant and trend. The test results are shown in Table 4.

Table 3

Hadri panel test results for a single root

Model specification	lintens	lvrp
With a constant		
Z - statistics	6.293***	4.772***
Z - statistics including possible heteroscedasticity	5.272***	4.342***
With constant and trend		
Z - statistics	3.834***	4.192***
Z - statistics including possible heteroscedasticity	3.542***	3.793***

*Note. H0 - the series is stationary (does not contain a unit root). * – the null hypothesis is rejected at 10%-level of significance; ** – the null hypothesis is rejected at 5%-level of significance; *** – the null hypothesis is rejected at 1%-level of significance.*

Source: the authors' calculations.

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Table 4

Pesaran panel test results for a single root

Model specification	lintens	lvrp
Testing variables in levels		
With a constant	-1.342	-1.876
With constant and trend	-2.232	-2.765**
Testing variables in first differences		
With a constant	-4.121***	-4.654**
With constant and trend	-4.523***	-4.854***

*Note. H0 - the series contains a unit root. Selection of lag length for each individual test regression was performed automatically based on the "general-to-specific" approach using the pooled F-test with maximum lag length equal to 3; * – null hypothesis rejected at 10%-level of significance; ** – null hypothesis rejected at 5%-level of significance; *** – null hypothesis rejected at 1%-level of significance.*

Source: the authors' calculations.

Table 5

Results of Pedroni panel tests for cointegration

Alternative hypothesis: overall autoregressive coefficients (within-group significance)		
	Statistic	p-value
Panel v-Statistic	1.694***	0.001
Panel rho-Statistic	0.456	0.618
Panel PP-Statistic	-3.216***	0.005
Panel ADF-Statistic	-3.714***	0.003
Alternative hypothesis: individual autoregressive coefficients (intergroup significance)		
	Statistic	p-value
Group rho-Statistic	1.760	0.355
Group PP-Statistic	-7. 393***	0.001
Group ADF-Statistic	-8.513***	0.001

*Note. H0 – no cointegration; The lag length is selected automatically using AIC criterion with maximum lag length equal to 3. Model specification includes individual constants and trends; *** – null hypothesis rejected at 1% significance level.*

Source: the authors' calculations.

Thus, based on the results of the tests performed, it is safe to conclude that all variables are first-order integrated I (1), hence a long-run relationship can exist between them.

Testing the long-run relationship between the variables under study is done for a regression equation:

$$\text{lintens}_{it} = \mu_i + b_i \text{trend}_t + \beta \text{lvrp}_{it} + \varepsilon_{it},\ \varepsilon_{it} \sim N(0,\sigma^2), \quad (3)$$

where μ_i, b_i – coefficients reflect the presence of spatial and temporal heterogeneity in the regions, respectively; index i – the number of the region; *trend* – the trend of traffic intensity; ε_{it} – error with zero mean and a finite constant variance. Equation (4) assumes that workforce productivity is the main factor affecting rail freight intensity. Since the variables under study are logarithmic, the coefficient estimate at the relevant variable can be interpreted as the elasticity of rail freight intensity at this indicator.

The cointegration of the variables in question means that there is a long-run effect of workforce productivity on regional rail freight intensity and that an equilibrium trajectory exists in their dynamics. To assess the presence of cointegration we will use the Pedroni panel test.

Table 5 presents the results of Pedroni's panel tests (Pedroni, 1999; Pedroni, 2004). Five tests out of seven reject the lack of cointegration between the variables. Thus, the results of the tests indicate that the variables in question are cointegrated, hence the relationship between the variables under investigation (equation 4) is characterized by the presence of long-run equilibrium dynamics.

Further analysis was carried out within the model described by Equation 4. The parameters of this cointegration equation were estimated using the method of pooled mean group estimates (PMG method).

PMG method (Pesaran, et al, 1999) allows simultaneously testing the presence of cointegration among variables, estimating parameters of their long-run relationship as well as the impact of these variables on the dependent variable in the short-run. It also allows for panel data to take into account existing differences in long-run and short-run dynamics between individual regions.

The initial model, as applied to our task in the PMG test, is an autoregressive dynamic model with a distributed lag $ARDL(p, q_1)$:

$$\text{lintens}_{it} = \mu_i + b_i \text{trend}_t + \sum_{j=1}^{p} \varphi_{ij}^{(1)} \text{lintens}_{i,t-j} + \sum_{j=0}^{q_1} \varphi_{ij}^{(2)} \text{lvrp}_{i,t-j} + \varepsilon_{it}, \quad (4)$$

Where $\phi_{ij}^{(1)}, \phi_{ij}^{(2)}$ – the coefficients are at lag variables. This model is reparametrized into an error correction model (VECM):

$$\Delta\text{lintens}_{it} = \tilde{\mu}_i + \sum_{j=1}^{p-1} \tilde{\varphi}_{ij}^{(1)} \Delta\text{lintens}_{i,t-j} + \sum_{j=0}^{q_1-1} \tilde{\varphi}_{ij}^{(2)} \Delta\text{lvrp}_{i,t-j} + \quad (5)$$
$$\varphi_i^{ecm}(\text{lintens}_{i,t-1} - \beta_i \text{vrp}_{i,t-1} - \gamma_i \text{trend}_{t-1}) + \varepsilon_{it},$$

where Δ – the operator of the first differences of the variables; ϕ_i^{ecm} – a coefficient describing the rate at which the system returns to an equilibrium state; the expression in brackets represents the equilibrium adjustment mechanism; β_i – the coefficient of the long-run relationship between the variables; $\tilde{\phi}_{ij}^{(.)}$ – parameters characterizing the short-run dependencies of the regressors on the dependent variable, which are expressed through the coefficients $\phi_{ij}^{(1)}, \phi_{ij}^{(2)}$ of equation (4).

In equation (5), all terms are stationary. If cointegration is present, the coefficient ϕ_i^{ecm} should have a statistically significant negative value. If the parameter $\phi_i^{ecm} \approx 0$ and is insignificant, then variable under study does not adjust to long-run equilibrium.

In PMG estimation, short-term variation can vary across panels. PMG estimation constrains the long-run slope coefficient β_i, so that it remains homogeneous across panels, while the free terms, short-run coefficients $\tilde{\phi}_{ij}^{(.)}$ and error variances may vary by region. In addition, consistency and efficiency conditions are fulfilled when there is evidence of a long-run relationship between covariates. To do so, the covariates must be exogenous (i.e. they must not be consistently correlated). To satisfy these conditions, lags are included in both dependent and independent variables. Thus, the PMG method provides for uniform equilibrium long-run dynamics of the variables.

To select the length of the lag in the model, the information criteria AIC (Akaike criterion) and SIC (Schwartz criterion) were used. Testing using these criteria clearly led to the choice of the ARDL model specification (1,1).

Table 6 shows the results of the estimation of the long- and short-run relationship parameters (equation 5) using the PMG method. The parameters were estimated by the maximum likelihood method. The expression for the maximum likelihood function is the product of the similar functions for each panel.

Table 6

Estimating the parameters of equation (5) by the PMG method

D.lIntens	Coefficient	statistical error	p-value
ec			
lvrp	1.781***	0.097	0.000
trend	0.059**	0.023	0.039
SR			
ecm	**-0.213*** **	0.128	0.008
D.lvrp	0.108	0.613	0.860
const	-2.151**	0.726	0.003

*Note: The null hypothesis H0- parameter insignificance. * – the null hypothesis is rejected at 10% significance level; ** – null hypothesis rejected at 5% significance level; *** – null hypothesis rejected at 1% significance level. Model specification corresponds to ARDL (1,1)*

Source: the authors' calculations.

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For comparison, the parameters of the cointegration equation 3 were also estimated using the method of mean group estimates (MG method) (Table 3). In this method, the short-run coefficients and error variances are unweighted averages of the individual values, i.e., in particular the short-run coefficients $\bar{\phi}_j^{(.)} = \frac{1}{N}\sum_{i=1}^{N}\phi_j^{(.)}$. The validity of either PMG or MG method can be determined by using the Hausman test.

Given the strengths and weaknesses of the models compared, the Hausman test is used to examine significant differences between these models. The test assumes that there is no significant difference between PMG and MG in estimating long-run relationships. The absence of a significant difference indicates that the null hypothesis is valid and thus PMG is used. However, the alternative indicates that there is a significant difference between PMG and MG and hence the preferred use of the MG method. This process is used to test for differences between MG and PMG.

The Hausmann test indicates the preferred use of the PMG method for estimating short- and long-term relationships of the model 5 (statistic value $\chi^2 = 1.166$, $\Pr ob > \chi^2 = 0.688$, the null hypothesis of no significant difference between the long-run relationship coefficients is not rejected).

Table 6 shows that the long-run relationship coefficient β is positive and statistically significant. This means that in the long run an increase in workforce productivity increases the intensity of trucking. (The intensity elasticity for this indicator is respectively 1.781). Since the coefficient $\phi_i^{ecm} = -0.213$ and is statistically significant, the railway transport intensity adjusts to long-run equilibrium, which confirms the existence of cointegration between the variables under study.

In the short run, the coefficient at the first difference of the productivity variable is statistically insignificant (Table 6) and has no effect on transport intensity.

It is of particular interest to compare the results shown in Table 6 for the Ural Federal District panel data with similar results for individual regions of the district. Table 8 shows estimation of short-run dependencies for individual regions by PMG method (the coefficient for all regions is determined by equation (3)). As can be seen from the table, the long-run equilibrium adjustment indicator for all regions is negative and statistically significant at 1% level, except for Kurgan Region, for which this indicator is statistically insignificant. This means that, in the long run, rail transport intensity in this region does not adjust to a long-term equilibrium condition in the event of any shocks. It should be noted that the rate of adjustment to the long-term equilibrium state of freight traffic intensity in the Ural Federal District is the highest for the Tyumen Region and relatively high for the YaNAO and the Chelyabinsk Region. For the Khanty-Mansi Autonomous Area and especially for the Sverdlovsk Region, the equilibrium adjustment rate is much lower. This result may indicate that the intensity of freight traffic in the Tyumen Region, Yamal-Nenets Autonomous Area and Chelyabinsk Region is closest to the long-term equilibrium value typical of the entire macro-region (the Urals Federal District). The result for the Sverdlovsk Region correlates with

Table 7

Estimation of the parameters of equation (5) by the MG method

D.lIntens	Coefficient	statistical error	p-value
ec			
lvrp	1.772**	0.111	0.001
trend	0.053**	0.019	0.036
SR			
ecm	**-0.277****	0.141	0.035
D.lvrp	0.257	0.538	0.629
const	7.14	6.126	0.287

*Note: The null hypothesis H0 – parameter insignificance. * – the null hypothesis is rejected at 10% significance level; ** – the null hypothesis is rejected at 5% significance level; *** – the null hypothesis is rejected at 1% significance level. The model specification corresponds to ARDL (1,1)*

Source: the authors' calculations.

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Table 8

Estimation of long-term and short-term dependencies for selected regions of the Ural Federal District using the PMG method

D.lIntens	Coefficient	statistical error	p-value
ec			
lvrp	1.781***	0.067	0.000
Kurgan Region			
ecm	-0.099	0.093	0.198
D.lvrp	-2.509	1.185	0.34
const	-1.560	1.391	0.262
Sverdlovsk Region			
ecm	-0.090***	0.024	0.002
D.lvrp	0.910***	0.157	0.000
const	-0.648**	0.330	0.050
KhMAO			
ecm	-0.172***	0.015	0.000
D.lvrp	1.046***	0.136	0.000
const	-0.900***	0.339	0.000
YaNAO			
ecm	-0.342***	0.054	0.000
D.lvrp	0.580**	0.254	0.023
const	-2.147**	0.985	0.023
Tyumen Region			
ecm	-0.853***	0.115	0.000
Dlvrp.	0.098	0.082	0.198
const	-5.317***	0.144	0.000
Chelyabinsk Region			
ecm	-0.297**	0.113	0.048
D.lvrp	1.231***	0.396	0.002
const	-1.715	0.995	0.121

*Note: The null hypothesis H0 – parameter insignificance; * – the null hypothesis is rejected at 10% significance level; ** – the null hypothesis is rejected at 5% significance level; *** – the null hypothesis is rejected at 1% significance level. Coefficient relationship for all regions is defined by equation (6).*

Source: the authors' calculations.

the visualization shown in Figures 1 and 3, from which it can be seen that the freight intensity and its dependence on workforce productivity remained virtually unchanged over the study period. In addition, in the period under study, the largest number of large investment projects was concentrated in the YaNAO, Chelyabinsk and Tyumen Regions, and was practically absent in the Kurgan Region

In the short run, changes in workforce productivity in all regions except Kurgan and Tyumen regions have a positive effect on changes in freight intensity in the short run (at the 5% significance level). For Kurgan and Tyumen regions, the indicator at this variable is statistically insignificant.

In equation 3 describing the long-run cointegration relationship between the variables, it is assumed that the regressor *lvrp* is exogenous and the dependent variable *lintens* is endogenous. Since the exogeneity of the variable *lvrp* is questionable, it is necessary to test the *lvrp* and *lintens* variables for long-run Granger causality (Granger,1969). The test was conducted according to the authors procedure (Dumitrescu, Hurlin, 2012), taking into account the panel data structure. The results of the Granger long-run causality test between the variables *lvrp* and *lintens* are shown in Table 9.

Table 9

Results of Granger long-term causality tests between the variables *lvrp* and *lintens*

$lvrp \to l\,\text{int}\,ens$
Optimal number of lags (BIC): 2 (tested number of lags: 1 to 4)
W-bar = 5.0287 Z-bar = 3.7094 (p-value = 0.0002) Z-bar tilde = 2.2980 (p-value = 0.0216)
H0: *lvrp* cannot be the cause of a Granger change in the variable *lIntens*. H1: *lvrp* can be the cause of a Granger change in the *lIntens* variable for at least one panel
$l\,\text{int}\,ens \to lvrp$
Optimal number of lags (BIC): 1 (tested number of lags: 1 to 4)
W-bar = 0.9705 Z-bar = -0.0511 (p-value = 0.9593) Z-bar tilde = -0.2336 (p-value = 0.8153)
H0: *lintens* cannot cause Granger variable *lvrp* to change. H1:*lintens* can cause Granger variable *lvrp* to change for at least one panel

Source: the authors' calculations.

Table 10

Results of the Granger short-term causality test

D.lvrp	Coefficient	statistical error	p-value
SR			
ecm	- 0.002	0.002	0.331
D.lintens	0.298**	0.128	0.021
const	-0.339	0.320	0.345

*The null hypothesis H0 – parameter insignificance; * – null hypothesis rejected at 10% significance level; ** – null hypothesis rejected at 5% significance level; *** – null hypothesis rejected at 1% significance level.*

Figure 4. *Granger long-term causality diagram between the indicators under study (equation 3). The one-way arrows indicate a one-way relationship.*
Source: Compiled by the authors.

The results of the tests in Table 9 clearly indicate that variable *lvrp* in the long-run cointegration relation is exogenous and *lintens* is endogenous. Figure 4 shows a diagram of the long-run causal relationship between the variables under investigation.

To analyze exogeneity and endogeneity of variables with short-run Granger causality, it is necessary to estimate VECM models with adjustment mechanism whose equations are similar to equation (5), but with variable *lvrp* as the dependent variable besides *lintens*. Thus, the following models are estimated:

$$\Delta l\,\text{int}\,ens_{it} = \tilde{\mu}_{1i} + \sum_{k=1}^{p} \gamma_{11,k} \Delta l\,\text{int}\,ens_{i,t-k} + \sum_{k=1}^{q} \gamma_{12} \Delta lvrp_{i,t-k} + \phi_1 v_{i,t-1}^{ecm} + u_{1i,t}, \quad (6)$$

$$\Delta lvrp_{it} = \tilde{\mu}_{2i} + \sum_{k=1}^{q} \gamma_{21,k} \Delta lvrp_{i,t-k} + \sum_{k=1}^{p} \gamma_{22} \Delta l\,\text{int}\,ens_{i,t-k} + \phi_2 v_{i,t-1}^{ecm} + u_{2i,t}, \quad (7)$$

where γ and ϕ – regression coefficients; u – errors with zero mean and final variance; v_{t-1}^{ecm} – long-run equilibrium correction terms.

The test results for equation (6) are shown in Table 10. The test results for equation (7) are pre-

Figure 5. *Granger short-term causality diagram between the indicators under study the one-way arrows indicate a one-way relationship.*
Source: Compiled by the authors.

sented in Table 10. The data in the table show that in the short run, a change in rail freight intensity affects the change in workforce productivity (at 5% level of significance).

The analysis of the results of Tables 6 and 10 can be presented as a Granger short-run causality diagram between the indicators under investigation (Figure 5). The diagram shows that there is a one-way causal relationship between the variables *lvrp* and *lintens*.

Conclusion

Thus, in line with the task at hand and according to the resulting estimates (Table 6), a 1% increase in workforce productivity in the UFD leads to a 1.781% increase in rail freight intensity in the long run. At the same time, there is a one-way causal relationship between rail freight intensity and workforce productivity in the UFD in the long run, as shown in Figure 4 (change in workforce productivity is the cause of change in rail freight intensity).

The error correction mechanism is as follows. If the workforce productivity at time *(t-1)* increases by 1% and the rail freight intensity increases by more than 1.781%, there will be a positive shock, which must be corrected for at time *t*. According to the two equations (6) – (7) of the error correction model, the variable rail freight intensity is subject to adjustment in the right direction at a rate characterized by the coefficient $\phi_1 = -0.213$ before the cointegration relation in the model v_{t-1}^{ecm}. The higher the value of this coefficient, the higher the speed of correction. The workforce productivity indicator does not adjust to long-run equilibrium, as the similar coefficient of the $\phi_2 = -0.002$ is statistically insignificant and negative. There is thus a one-way long-term causal relationship between these two indicators - changes in workforce productivity affect changes in rail freight intensity, but not vice versa.

In the short run, there is a one-way causality between workforce productivity and rail freight intensity (Tables 6 and 10, Figure 5), directed in the opposite direction to that in the long run (changes in rail freight intensity cause changes in workforce productivity).

Another interesting result is that the speed of adjustment to the long-term equilibrium state of freight intensity in the Ural Federal District is highest for the Tyumen region and relatively high for the YaNAO and the Chelyabinsk Region. For the KhMAO and especially for the Sverdlovsk Region, the rate of equilibrium adjustment is much lower. This result may indicate that the intensity of freight traffic in the Tyumen region, YaNAO and Chelyabinsk Region is closest to the long-term equilibrium value characteristic of the entire macroregion (UFD).

The economic sense of the obtained results in terms of their possible use for decision-making on freight traffic management, in particular by the authorities, is that it is necessary to accelerate the development of the railway transport network, which will have to absorb additional freight flows, which in the short term will lead to an increase in labour productivity (Figure 5). In turn, an increase in productivity will in the long run lead to an increase in the amount of goods shipped and the intensity of freight transport (Figure 4).

The model analyzed in this study indicates the existence of a range of effective growth rates for rail freight intensity and workforce productivity in the short and long term.

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