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The relationship among railway networks, energy consumption, and real added value in Italy. Evidence form ARDL and Wavelet analysis

Cosimo Magazzino [a,*], Lorenzo Giolli [b]

[a] Department of Political Sciences, Roma Tre University, Italy
[b] European School of Economics, Italy

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ABSTRACT

Existing studies reveal opposing results regarding the economic growth and infrastructure nexus, which emanates from the differences in scale, timing and stage of development. In this paper, we explore the relationship between railway networks and real GDP controlling for energy consumption, over the period 1861–1970 in Italy. The empirical strategy uses both AutoRegressive Distributed Lags (ARDL) model and the Wavelet Analysis (WA), which is able to adopt to scale and time support, thereby enabling one to escape the Heisenberg's curse. Our applied findings show that the two series are generally positive correlated (being in phase), but also that railway networks cause real value added in the long-run. Thus, through an innovative approach, we can confirm previous results in literature: in fact, railway networks represent a determinant of economic growth in the Italian case.

1. Introduction

This study aims to analyze the relation among railway networks, energy consumption, and real value added in the transport and communications sectors for Italy in the long-term (1861–1970). With the fast social and economic development in the world, railway transportation plays an increasingly important role. As more railway industry expands, reduction in energy consumption and pollutant emissions in railway systems constitutes a key factor for further deployment of railway transportation (Gu et al., 2010). The evolution of the variables is crucial to understand the causal links, and determine the contribution (if any) that the infrastructure gave to the development process of the country. Infrastructure contributes to economic growth in two ways: (1) provides services in residential consumption bundles, which increases the quality of life and (2) provides inputs, which augments other factors of production in the private sector (Ayogu, 2007; Kessides, 1993, p. 213). Moreover, Bougheas et al. (2000) assert that infrastructural investment promote specialisation, which leads to economic growth. The link between infrastructural development (mostly public funded) and economic development/output has been a longstanding issue in the development economics literature, albeit both the theoretical and empirical literature remain inconclusive as to whether infrastructure contributes to economic growth/output or not. Theoretically, the capital hypothesis emphasizes the positive contributions of infrastructure to private sector output, productivity and capital formation (Rosenstein-Rodan, 1943). According to this view, public infrastructure provides direct inputs into private sector output and enhances the productivity of other inputs (i.e., labor and capital). Thus, the capital hypothesis argues that public infrastructure complements private capital formation, leading to economic growth/output (Ayogu, 2007). On the contrary, the 'crowding out' hypothesis argues that some services that are provided by private capital are substitutes to those from public capital (Aschauer, 1985). Therefore, by increasing public capital infrastructure, it lowers the return on private capital and thereby 'crowds out' private capital formation and hence lower output. In other words, according to the 'crowding out' hypothesis, there is a resource cost of infrastructural investment.

The above suggests that the approach to analyze the transportation infrastructure – economic growth nexus should be capable to capture simultaneously the scale, frequency, and potential nonlinearity associated with the relationship. However, current methodological approaches adopted in the literature, at best, are capable of addressing either one of these issues or a combination of any of them in an independent way. This study attempts to fill this gap in the literature by

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* Corresponding author.
E-mail address: cosimo.magazzino@uniroma3.it (C. Magazzino).

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using the wavelets method to study the economic growth–infrastructure nexus in Italy, in a secular perspective. Not with standing, we complement the wavelet analyses (WA) with a novel time-series estimator, the Dynamic AutoRegressive Distributed Lag (DYNARDL), as well as with the ARDL bound test. Moreover, we used the recently reconstructed data provided by ISTAT.

The ability of wavelet methods to adopt to scale and time support enables one to escape the Heisenberg's curse. To the best of our knowledge, this is the first paper that applies the wavelet analysis to the Italian railway data.

Besides this Introduction, the rest of the paper proceeds as follows. Section 2 gives the theoretical context and the survey of the literature. Section 3 describes the applied methodologies and the data used. Section 4 presents the empirical results and comments, while Section 5 concludes and gives some policy indications.

2. Review of past studies

The seminal work by Aschauer (1989), which found significant role of infrastructure in US productivity growth, paved the way for empirical investigation into the nexus between economic development and infrastructure. However, the evidence preceding the study by Aschauer has been mixed. Canning and Fay (1993), and Easterly and Rebelo (1993) confirmed the positive effects of infrastructure on economic development. However, studies by Khan and Reinhart (1990), and Easterly and Levine (1994) failed to find a significant role for infrastructure in economic development. The prior studies focused largely on the US economy, which made the evidence limited in terms of generalising for the global economy.

Nonetheless, similar to the earlier studies, posterior studies (focusing on other economies in Europe, Latin and South America, Africa and Asia) continue to reveal evidence of mixed results on the impact of infrastructure on economic development. A part of the applied literature found support to the traditional notion that, increasing the aggregate productivity, transport infrastructure investment can stimulate economic growth (Aschauer, 1990; Moomaw and Williams, 1991; Garcia-Millà & McGuire, 1992; Munnell, 1992; Bajo-Rubio & Sosvilla-Rivero, 1993; Fernald, 1999; Pereira, 2000; Démurger, 2001; Ozbay et al., 2007, 2003 and; Cohen & Paul, 2004; Cantos et al., 2005; Berechman et al., 2006; Jacoby & Minten, 2009; Jiwattanakulpaisarn et al., 2010; Hong et al., 2011; Pereira and Andraz, 2012; Pradhan and Bagchi, 2013; Agbelie, 2014; Blonigen & Cristea, 2015; Wang and Yu, 2015; Yoshino and Abidhanjaev, 2017; Cigu et al., 2019). Pradhan and Bagchi (2013) applied the Vector Error Correction Model (VECM) to examine the effect of transportation on economic growth in India. Their result showed a unidirectional causality from railway transportation to economic growth and capital formation. Cigu et al. (2019) analyzed the effect of transport infrastructure on economic development for a cross-section of EU-28 countries. In support of the capital hypothesis, they found a significant positive effect of transport infrastructure on economic development. Wang and Yu (2015) and Yoshino and Abidhanjaev (2017) rather applied the difference-in-difference method to analyze the impact of railway infrastructure on economic development in China and Uzbekistan, respectively. Both found evidence in support of the view that railway infrastructure impacts positively on economic performances. In the case of China, it increases GDP per capita by 30 percent or more and causes increases in regional economic performance in the medium- and long-run in Uzbekistan.

Conversely, a different group of papers suggest evidence against the significance of the effect of transportation infrastructure on economic growth (Chandra & Thompson, 2000; Evans & Karras, 1994; Garcia-Millà et al., 1996; Holtz-Eakin, 1994; Padeiro, 2013). Chi and Baek (2016) analyzed the dynamic relationships among transport infrastructure, non-transport public infrastructure (e.g., schools, hospital, and other public buildings), private capital, labor hours, GDP, and exports using an Autoregressive Distributed Lag (ARDL) approach. The results showed that, in the long-run, a bidirectional relationship exist between transport infrastructure and GDP. Nevertheless, the magnitude of the impact of transport infrastructure on GDP is smaller than that of non-transport public infrastructure. While, Canning and Pedroni (2008) and Crafts (2009) explained that there are associated costs for governments investing in transport infrastructure. Lenz et al. (2018) applied panel time series to analyze the effect of transportation on economic performance in Central and Eastern Europe. While they found road infrastructure to have positive impact on economic growth, the impact of railway infrastructure on economic growth is negative. A more recent study by Wang et al. (2020) revealed evidence of mixed results for Belt and Road Initiative countries based on econometric technique. The authors found that road and railway infrastructure positively affect economic growth of Central and Eastern Europe countries (contrasting somehow the evidence provided by Lenz et al., 2018) but negatively affects economic growth in East, South, and Central Asia and the Commonwealth of Independent States (CIS).

The controversy in the results emanate from the differences in scale, timing and stage of development. Others have raised concerns about the complexity of the nature of the relationship. Furtherance to this, numerous researchers have presented theoretical arguments and empirical evidence, suggesting that there should exist a non-linear relationship between transport infrastructure provision and economic growth (Agénor, 2010; Banister, 2012; Bougheas et al., 2000; Canning & Pedroni, 2008; Crafts, 2009; Fernald, 1999). According to Bougheas et al. (2000), albeit infrastructure stimulates economic growth by promoting specialisation, the resource costs of infrastructure dampens economic activity. Thus, the relationship between economic activity and infrastructure is one that is non-monotonic in nature.

In addition, several studies inspected the linkage among transportation intensity, urbanization, economic growth, and CO_2 emissions. Arvin et al. (2015) studying the G-20 countries and using a Panel Vector Auto-Regressive (PVAR) model, revealed a causal flow among these four variables in the short-run. At the same time, some researchers highlighted the relationship between urbanization or CO_2 emissions with transportation development or economic growth (Abbasi, 2021; Abdallah et al., 2013; Hossain, 2011; Liddle & Lung, 2013; Magazzino, 2016a, 2019; Magazzino, 2012a; Salim and Shafiei, 2014). On the other hand, a different strand of literature focused on the interactions amongst transportation infrastructure, financial penetration, and economic growth (Pradhan, 2019). While the analysis of the nexus between urbanization or innovation with transportation development or economic growth is provided by Magazzino (Magazzino, 2012a, 2021c), Pradhan et al. (2021). Finally, the nexus between energy consumption and economic growth for Italy has been investigated by Brady and Magazzino (2018), Magazzino (2018, 2017, 2016b, 2015, 2012b), Magazzino and Giolli (2014).

3. Methodology and data

Wavelets can be compared to a wide-point camera lens that permits one to take expansive scene pictures just as focus in on tiny detail that is regularly covered up to the natural eye. In mathematical terms, wavelets are local orthonormal bases comprising of small waves that analyze a function into layers of various scale. Wavelet theory has its underlying foundations in Fourier analysis, yet there are significant contrasts. The Fourier transformation utilizes a sum of sine and cosine functions at various wavelengths to address a given function. Sine and cosine functions, in any case, are periodic functions that are innately nonlocal, that is, they go on to plus or minus infinity on both ends of the real line.

Subsequently, any change at a specific point of the time domain has an impact that is felt over the entire real line. Wavelets, om the other hand, are characterized over a finite domain and they give an advantageous and effective way of addressing complex signs. All the more critically, wavelets can cut data up into various frequency components for singular analysis. This scale decay opens a totally different way of processing data so wavelets empower us to see both the forest and the trees.

Like Fourier analysis, wavelet analysis manages expansion of functions regarding a bunch of basis functions. Not at all like Fourier analysis, wavelet analysis expands functions not in terms of trigonometric polynomials however regarding wavelets, which are created as translations and dilatations of a fixed function called the mother wavelet. The wavelets acquired in this manner special scaling properties. They are localized in time and frequency, allowing a nearer association between the function being addressed and their coefficients. Therefore, more prominent numerical stability in reconstruction and control is guaranteed.

Wavelet analysis has pulled in much consideration as of late in signal processing. It has been effectively applied in numerous applications, for example, transient signal analysis, image analysis, communication systems, and other signal processing applications. It is not a new theory in the feeling that a considerable lot of the ideas and strategies associated with wavelets were grown autonomously in different signal processing applications also, have been known for quite a while. What is going on is the improvement of late outcomes on the mathematical foundations of wavelets that give a bound together structure to the subject.

Inside this structure a typical connection is set up between the many differentiated problems that are important to various fields, including electrical engineering (signal processing, data compression), mathematical analysis (harmonic analysis, operator theory), and physics (fractals, quantum field theory). Wavelet theory has become an active area of research in these fields. There are openings for additional advancement of both the mathematical comprehension of wavelets and a wide scope of utilizations in science and engineering.

The goal of wavelet analysis is to characterize these amazing wavelet basis function and discover efficient methods for their calculation. It tends to be shown that each application utilizing the fast Fourier change can be defined utilizing wavelets to give more localized temporal (or spatial) and frequency information. In this manner, rather than a frequency spectrum, for instance, one gets a wavelet spectrum. In signal processing, wavelets are extremely helpful for preparing non stationary signals.

Wavelet analysis uncovers the spectral characteristics of a time series (finding patterns and in any case covered up information), specifically, the manner by which different periodic components of the data on Italian transport infrastructures develop over the long run. The wavelet investigation permits recognizing, within a time series, the short and long-run periodic components, addressing a substantial option in contrast to the ARIMA X-11 and ARIMA X-12 for the identification of the long-run component, and to the frequency analysis for the identification of the cyclical components (Magazzino, 2012a).

The wavelet transform is an instrument that permits us to partition functions, operators or data into components of different frequencies, allowing us to examine them independently. The wavelet investigation can be considered as a generalization of the analysis with the Hilbert space method, where the equations in this space can be solved in terms of bases (Magazzino et al., 2020).

In the wavelet analysis, it is feasible to express a given function as a linear combination of elementary functions (on various scales and positions) called wavelets. Wavelets are functions obtained by translation and dilation of a single function called a mother wavelet, with zero mean, compact support and oscillatory behaviour (Magazzino and Mutascu, 2019).

The period or scale parameter is defined as 1/frequency and naturally it tends to be compared to the scale of the maps, as in this case, a high scale parameter corresponds to a global and not detailed vision of the signal, while a low scale parameter corresponds to a detailed view. Similarly, in terms of frequency, low frequencies (high scale) correspond to a global signal information (which usually lasts for the whole signal), while high frequencies (low scale) correspond to detailed information on hidden signal pieces (which usually have a relatively short duration) (Lo Cascio, 2015).

We enter the discussion on infrastructures-income nexus by moving toward it in a novel way. Our examination isn't established in the time domain. We are keen on distinguishing and measuring the time-frequency dependence of railway networks and value added in the transport and communications sector at constant prices. For that reason, we utilize some wavelet investigation tools by isolating the univariate features of the series through the Continuous Wavelet Transform (CWT) (Grossmann & Morlet, 1984; Mallat, 2008), and the wavelet power spectrum, which give information simultaneously on time and frequency features of the data.

The wavelet transform uses a set of local basis functions that are dilated, or compressed, through a scale or dilation factor and shifted along with the signal through a translation or location parameter. This property is particularly useful when dealing with complex, non-stationary signals, such as historical time series, since their secular movements are likely to exhibit structural changes due to shocks such as wars and crisis periods (Crowley, 2007; Fratianni et al., 2021).

Following Aguiar-Conraria and Soares (2011) the minimum requirement imposed on a function $\psi(t) \in L^2(R)$ to qualify for being a mother wavelet is that it satisfies a condition, usually referred to as the admissibility condition:

$$0 < C_\psi := \int_{-\infty}^{\infty} \frac{|\Psi(\omega)|}{|\omega|} d\omega < \infty \tag{1}$$

where the constant C_ψ above is called the admissibility constant. For functions with sufficient decay, it turns out that the admissibility condition above is equivalent to requiring that:

$$\Psi(0) = \int_{-\infty}^{\infty} \psi(t) dt = 0 \tag{2}$$

so it must behave like a wave. Following Aguiar-Conraria and Soares (2011), starting with a mother wavelet ψ, a family $\psi_{\tau,s}$ of wavelet daughters can be obtained by simply scaling and translating ψ:

$$\psi_{\tau,s}(t) := \frac{1}{\sqrt{|s|}} \psi\left(\frac{t-\tau}{s}\right), \quad s, \tau \in \mathbb{R}, s \neq 0 \tag{3}$$

where s is a scaling or dilation factor that controls the width of the wavelet and τ is a translation parameter controlling the location of the wavelet. Furthermore, given a time series $x(t) \in L^2(R)$, its CWT with respect to the wavelet ψ is a function of two variables, $W_{x,\psi}(\tau,s)$:

$$W_{x;\psi}(\tau, s) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{|s|}} \psi^* \left(\frac{t-\tau}{s}\right) dt \tag{4}$$

the position of the wavelet in the time domain is given by τ; while its position in the frequency domain is given by s. Using the well-known properties of the Fourier transform, one immediately can see that the CWT may also be represented in the frequency, as:

$$W_x(\tau, s) = \frac{\sqrt{|s|}}{2\pi} \int_{-\infty}^{\infty} \Psi^*(s\omega) X(\omega) e^{i\omega\tau} d\omega \tag{5}$$

In analogy with the terminology used in the Fourier case, the (local) wavelet power spectrum (sometimes called scalogram or wavelet periodogram) is defined as:

$$(WPS)_x(\tau, s) = |\mathrm{W}_a(\tau, s)|^2 . \tag{6}$$

Following Aguiar-Conraria and Soares (2011), in analogy with the concept of coherency used in Fourier analysis, given two time series $x(t)$ and $y(t)$ one can define their complex wavelet coherency ρ_{xy} by:

$$\rho_{xy} = \frac{S(W_{xy})}{\left[S\left(|W_x|^2\right) S\left(|W_y|^2\right)\right]^{1/2}} \tag{7}$$

where S denotes a smoothing operator in both time and scale. The complex wavelet coherency can be written in polar form, as $\rho_{xy} = |\rho_{xy}| e^{i\phi_{xy}}$. The absolute value of the complex wavelet coherency is called the wavelet coherency and is denoted by *Rxy*:

$$R_{xy} = \frac{|S(W_{xy})|}{\left[S\left(|W_x|^2\right)S\left(|W_y|^2\right)\right]^{1/2}} \tag{8}$$

with $0 \leq R_{xy}(\tau,s) \leq 1$. The angle ϕ_{xy} of the complex coherency is called the phase-difference (phase lead of x over y):

$$\varphi_{xy} = \text{Arctan}\left(\frac{\Im(S(W_{xy}))}{\Re(S(W_{xy}))}\right) \tag{9}$$

A phase difference of 0 indicates that the time series move together at the specified time-frequency; if $\phi_{xy} \in (0; \pi/2)$, then the series move in phase, but the time series x leads y; if $\phi_{xy} \in (-\pi/2; 0)$, then it is y that is leading. A phase difference of π (or -π) indicates an anti-phase relation; if $\phi_{xy} \in (\pi/2; \pi)$, then y is leading; while time series x is leading if $\phi_{xy} \in (-\pi; -\pi/2)$ (Fig. 1).

To complete the empirical investigation, we utilize an extra wavelet device, the Partial Wavelet Coherence (PWC), which empowers to represent the link with other control factors while evaluating the relationship between two series. The PWC is a straightforward speculation of the relating ideas of (Fourier) multiple partial coherency to the time-frequency plane and details can be found in Aguiar-Conraria and Soares (2014).

To inspect the stationarity properties of our series, we perform the Phillips (2007) Modified Log Periodogram Regression (MLPR) estimator, which is a modified form of the Geweke and Porter-Hudak (1983) estimate of the long memory (fractional integration) parameter d of a time-series. Here, the dependent variable is modified to reflect the distribution of d under the null hypothesis that $d = 1$. By default, a linear trend is extracted from the series. Moreover, to inspect the long-run relationship among the three selected variables, we run the Gregory and Hansen (1996) test for cointegration with regime shifts, and the Pesaran et al. (2001) bounds test for cointegration. Both tests are able to take into account the (eventual) presence of structural breaks in the series.

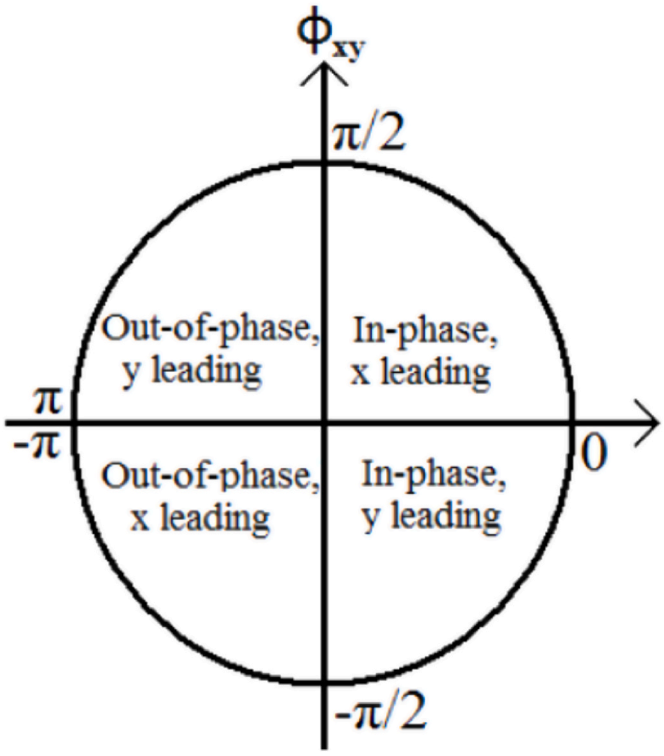

Fig. 1. Phase-difference circle.
Source: Aguiar-Conraria and Soares (2011).

However, we complement our analyses applying a new time-series DYNARDL simulation model, introduced by Jordan and Philips (2018). DYNARDL model has the potential to auto-generate the graphs of positive and negative 10% shock of each independent variable to dependent variable. It is also compulsory that all the variables should be stationary at the level or at the first difference, and the cointegration nexus should exist in the variables. Authors widely use DYNARDL because it is convenient to show substantive results for time-series models, whose coefficient is always hidden interpretation or non-intuitive.

ARDL bound testing procedure has several advantages as compared to traditional cointegration methods. In contrast to the conventional cointegration tests, which require the same lag length for all dependent and independent variables, the ARDL cointegration can be estimated using different lag lengths. The ARDL cointegration model is suitable in the case of level-stationary or first difference-stationary variables as well as for small sample size, and it is also applicable for the analysis of the ARDL model.

The empirical analysis uses the time series data of railway networks (km, *LRN*), primary energy consumption (millions of equivalent tons of oil, *LTE*), and added value in the transport and communications sector at 1938 prices (*LRAV*) for Italy in the 1861–1970 years. We used the data recently reconstructed by ISTAT. The analysis is conditioned by the availability of the value added and total energy data.[1] We provide in Table A in the Appendix the descriptive statistics of the three series.

4. Empirical results

Given the nature of our data – which span a very long historical period – we choose to run a kind of long memory (fractional integration) test, rather than the conventional unit root or stationarity tests. The results of Phillips MLPR test are given in Table 1.

The MLPR test, applied to these series, finds that $d = 0$ (stationarity) can be rejected for all powers tested at levels, while the same null hypothesis for the first-difference series may not be rejected at any significance level for primary energy and real value added, and at 1 percent level for powers 0.40, 0.45, and 0.50 for railway networks.

To analyze the (eventual) presence of structural breaks in the series the innovative outlier unit root test by Clemente et al. (1998) is performed, which provides tests for stationarity in the presence of a double structural break (see Table 2).

We note that the break detected by the test roughly corresponds to the timing of the World War II for all three series. Even in the structural break, we can reject the null hypothesis of a unit root in these series, both at the levels and at the first differences.

Then, the Gregory and Hansen (1996) cointegration technique, allowing for the presence of potential structural breaks in the data, is applied.

The results based on the Gregory and Hansen cointegration procedure suggests how the calculated statistic is smaller than its respective 5% Critical Value reported in Gregory and Hansen (1996) in three out of four deterministic specifications. This confirms the rejection of the null hypothesis of no cointegration in favour of the existence of at least one cointegration relationship in the presence of a structural break. As regards the structural breaks, the results indicate their occurrence around 1876 (with the general election and the robust increase of railway km) and 1916 (during the World War I) (see Table 3).

Table 4 gives the results of the ARDL bounds cointegration test; we used asymptotic critical values and approximate P-Values given by

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[1] http://seriestoriche.istat.it/.

Table 1
MLPR estimate of fractional differencing parameter.

Variable	Power	Estimated *d*	Standard Error	*t*	P-Value
LRN	0.40	1.0470	0.1244	8.4170	0.000***
	0.45	0.9688	0.1006	9.6286	0.000***
	0.50	0.9642	0.0710	13.5856	0.000***
	0.55	0.9229	0.0579	15.9327	0.000***
	0.60	0.8944	0.0519	17.2316	0.000***
ΔLRN	0.40	0.3764	0.2670	1.4095	0.202
	0.45	0.5212	0.2101	2.4804	0.035**
	0.50	0.5014	0.1712	2.9287	0.013**
	0.55	0.5095	0.1552	3.2824	0.005***
	0.60	0.4257	0.1293	3.2934	0.004***
LTE	0.40	1.2530	0.1865	6.7197	0.001***
	0.45	0.8568	0.2350	3.6465	0.008***
	0.50	0.8488	0.1805	4.7023	0.001***
	0.55	0.8263	0.1523	5.4267	0.000***
	0.60	0.7823	0.1211	6.4587	0.000***
ΔLTE	0.40	0.2577	0.4059	0.6350	0.553
	0.45	−0.1193	0.3101	−0.3845	0.712
	0.50	−0.1534	0.2209	−0.6947	0.505
	0.55	−0.1980	0.1711	−1.1575	0.272
	0.60	−0.2713	0.1306	−2.0773	0.057*
LRAV	0.40	1.4281	0.3789	3.7694	0.007***
	0.45	1.3924	0.3556	3.9157	0.004***
	0.50	1.1020	0.2782	3.9608	0.002***
	0.55	0.9419	0.2298	4.0985	0.001***
	0.60	0.8340	0.1780	4.6851	0.000***
ΔLRAV	0.40	0.3361	0.1861	1.8059	0.114
	0.45	0.2650	0.1490	1.7785	0.109
	0.50	0.2437	0.1484	1.6414	0.129
	0.55	0.0906	0.1616	0.5609	0.583
	0.60	−0.0144	0.1296	−0.1113	0.913

Notes: Δ: first differences. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Table 2
Results for innovative outlier unit root tests (two structural breaks).

Variable	Optimal break points	*k*	*t*-stat
LRN	1942, 1944	1	−15.201
ΔLRN	1894, 1944	1	−8.016
LTE	1941, 1944	3	−9.127
ΔLTE	1941, 1945	6	−6.391
LRAV	1898, 1944	2	−5.211
ΔLRAV	1942, 1944	4	−9.013

Notes: Δ: first differences. *k* denotes the lag length. 5% Critical Values: 5.490.

Table 3
Gregory and Hansen cointegration tests results.

Constant	Constant and trend	Constant and slope	Constant, slope and trend
−5.20**	−6.72***	−6.34***	−5.76* (−5.96)
(−4.92)	(−5.29)	(−5.50)	(1876)
(1916)	(1876)	(1912)	

Notes: *ADF* statistics are reported. 5% Critical Values and break date are reported in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Table 4
ARDL bounds test estimation results.

Model for estimation	Lag length	Statistics		Significance level	Critical Values	
					I(0)	I(1)
$F_{LRAV}^{LRN,LTE}$	(1,1,2)	*F*	7.2588***	10%	2.63	3.35
				5%	3.10	3.87
				2.5%	3.55	4.38
				1%	4.13	5.00

Notes: Asymptotic critical values bounds are obtained from table *F*-statistic in Pesaran et al. (2001). $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Pesaran et al. (2001). The ARDL bounds test results clearly indicate that the *F*-statistic value is above the upper bound critical values [*I(1)*], at any level of statistical significance; in addition, this conclusion is reinforced by *t*-statistic, which again is smaller than bound critical values [*I (0)*].

Opposite to the intricate ARDL models designed to inspect the effect both the short- and long-run effects, Jordan and Philips (2018) presented a dynamic simulated ARDL model, which aims to estimate, simulate, and automatically plot forecasts of counterfactual variation in one regressor on the dependent variable, keeping the *ceteris paribus* condition (holding other regressors constant). However, this procedure requires the time-series in the estimated model to be *I(1)* and also cointegrated. The dynamic simulated ARDL model here adopted uses 5000 simulations of the vector of parameters from a multivariate normal distribution. Regression results are showed in Table 5. For the selection of the model, we followed the Hannan-Quinn Information Criterion (HQIC), which suggested an ARDL(1,1,2) model; while the Newey-West Heteroskedasticity and Autocorrelation Consistent (HAC) procedure has been used to calculate the coefficient covariance matrix.

The results in Table 5 show a negative and statistically significant error correction of −0.91, which means a 91% speed of correction of the previous disequilibrium over time. The coefficient of railway networks is positive in the short-run, with a 1% statistical significance. Moreover, we found a positive short-run effect of primary energy consumption on real value added, which is reinforced in the long-run.

Regarding the model validation, we run several diagnostic tests (the results are given in the lower part of Table 5 and in Fig. A in Appendix). To achieve robust Standard Errors, 5000 dynamic simulations were performed.

The stability of the model was checked by the analysis of several diagnostic tests, such as serial correlation, normality, heteroscedasticity, cumulative sum, and cumulative sum of squares (CUSUM) tests. In time-series regression analysis, a common assumption is that the coefficients are stable over time. In order to check for (eventual) structural breaks in the residuals, we applied the cumulative sum and the cumulative sum of squares tests. Results from CUSUM plots show that all the data series are within the 95% confidence band, hence, confirming the stability of the estimated models. Besides, we analyzed the stability tests to confirm the fitness of the good model (Fig. B in Appendix). The bottom part of Table 4 shows that the Breusch-Godfrey serial correlation LM test does not reject the null hypothesis, which confirms that the estimated model does not suffer from autocorrelation problem. Similarly, no

Table 5
Results of dynamic simulated ARDL model.

Variable	Coefficient
$LRAV_{t-1}$	−0.9074*** (0.0354)
ΔLRN	0.9323*** (0.2004)
LRN_{t-1}	−0.0208 (0.1401)
ΔLTE	0.0550* (0.0301)
LTE_{t-1}	0.1696*** (0.0235)
LTE_{t-2}	−0.1139*** (0.0265)
Constant	0.5696 (0.9485)
F	5080.503*** (0.0000)
Adj. R^2	0.9975
RMSE	0.0350
Log-Likelihood	152.4991
Simulations	5000
AIC	−3.7792
SBIC	−3.5661
HQIC	−3.6940
DW statistic	2.3972
Breusch-Godfrey Serial Correlation LM test	2.2610* (0.0893)
Heteroskedasticity ARCH test	0.6445 (0.4246)
Ramsey REST test	0.1564 (0.8762)

Notes: Heteroskedasticity and Autocorrelation-Consistent (HAC) Newey-West Standard Errors in parentheses (Bartlett kernel). Deterministic component: unrestricted constant and no trend. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

heteroskedasticity problem was detected by the analysis of the AutoRegressive Conditional Heteroskedasticity (ARCH) test, given the fact that again the null hypothesis is not rejected. Furthermore, the Jarque-Bera normality test confirm that the model's residuals follow a Gaussian distribution. Finally, the Ramsey Regression Equation Specification Error Test (RESET) results show that the model is properly specified. To sum up, results evidence that the estimated model is appropriate. In the dearth of literature, many researchers used the same stability tests to check the stability of the model (Abbasi et al., 2021; Sharif et al., 2020).

Fig. 2 reports the Impulse-Response Functions (IRFs) graphs of railway networks-real value added nexus and primary energy consumption-real value added nexus. As it is clear from Fig. 2a, a positive shock in railway networks produces a small decrease in the economic activity, which fades over time, eventually disappearing in about 20 years. On the contrary, a -1 shock produces a negative effect in the short-run, which declines towards 0 over time in the long-run. Thus, a shock in railway networks affects the economic growth in the long-run. Fig. 2b shows the change in predicted value, starting when the shock in energy consumption occurs; a $+1$ shock produces a small increase, which is slightly statistically significant in the short-run, but which eventually increases to a predicted value of about 5.5 over the long-run, when the change is statistically significant at the 95% level of confidence. This increase is statistically significant. Instead, a negative shock in energy consumption triggers a negative response in real value added, but it amplifies in the long-run to a predicted value of around -5.0, and it is statistically significant at the 95% level of confidence. Therefore, a positive shock in primary energy consumption increases real value added, while a negative shock negatively affects the economic process, meaning that energy consumption is strictly linked to the aggregate income.

In brief, the overall results of the Dynamic ARDL simulation model confirm that primary energy consumption have a long-run impact on real value added.

In Fig. 3, we have, on the left, the railway network and real value added in the transport and communications sector (both measured in logarithms) observed over the 1861–1970 period. On the right side of the figure, we have the Wavelet Power Spectrum (WPS) of the series. The analysis has been carried out by using the ASToolbox provided, and freely available through their website, by Aguiar-Conraria and Joanna Soares.[2] The colour code for power ranges from blue (low power) to red (high power).

Looking at railway networks, we are able to isolate five major events, which in chronological order are due to the Historical Right governments (1861–1876, with the robust increase of railway km), World War I and Fascist Era (1916–1942, with an almost static endowments), World War II (1942–1945, with a fall of railway networks due to damages caused by the war), and the first Republican years (1947–1970, again with a constant railway endowments). Regarding the series of value added, we observe two negative peaks in correspondence with the two war events (1921 and 1945). Finally, looking at the evolution of primary energy consumption series, there are two sudden falls, the first as an effect of the Great Crisis of 1929, and the second as a direct consequence of the World War II.

The colour contour for each of the two series shows that the wavelet power is not constant over time as well as across frequencies. The railway networks and real value added series share common features in terms of wavelet power. In fact, both series variables have high power at low frequencies. In particular, railway networks series shows a deep red (high power) at very low frequencies (12–16 years) in the pre-World War I years (1861–1915); while, at all other periodicities, volatility is low. Real value added exhibits high power in correspondence to 8–12 years of periodicity, especially in the second part of the sample (1905–1960) period. Moreover, for the two series, volatility is very low at all other (not mentioned) frequencies across time. As regards primary energy consumption, only one principal event emerges, due to World War II (1942–1945). In fact, after a slight increase during Fascism (1926–1942), we register a negative peak in the war years, and then a sharp rise between 1946 and 1970. The WPS of *LTE* shows a deep red (high power) at very high periodicity (12–16 years) from 1950.

The thick black curve in the right panel of Fig. 4 represents the cone of influence. Black and grey contours designate, respectively, the five and ten percent significance levels against an ARMA(1,1) null and the values for the significance were obtained from Monte Carlo simulations. The white lines show the maxima of the undulations of the wavelet power spectrum.

In Fig. 4, we compute the partial wavelet coherency between railway networks and real value added, after controlling for primary energy consumption. The concept of PWC is an extension of the concept of wavelet coherency just like partial correlation is an extension of the simple correlation. We show, in panels (2) and (3), the partial coherency between railway networks and real value added and the phase difference for two different frequency bands, corresponding to cycles of 3–8 and 8–16 years, respectively. The local correlation was high and statistically significant (red colour) during the periods of range 1931–1933 (around 2 years) and 1939–1943 (around 2–4 years). Moreover, it exhibits some cycles with low periodicity (essentially 2–4 years). In the shorter period cycle (3–8 year scales), the phase difference lies almost continuously between -π/2 and π/2 (except the years 1958–1962, when it goes in the interval between -π/2 and -π), indicating that the two series move in phase – so that they are positively correlated. However, sometimes railway networks are leading real value added, and *vice versa*. Occasionally, the phase difference lies outside the interval -π/2 and π/2; nevertheless, those periods are essentially of low coherency and, therefore, there is not much meaning attached to the phase-difference. In particular, during the period 1926–1944, the phase difference lies between 0 and π/2, with the series in phase and railway networks leads real value added. On the other hand, in the subsequent period 1945–1958, the phase difference is in the interval (-π/2; 0), again in phase, and suggesting that the causality flow proceeds in the opposite direction, from real value added (which leads) to railway networks.

In the longer period cycle (8–16 year scales), the phase difference lies almost continuously between -π/2 and π/2, with the series in phase and positively correlated. In particular, the phase difference is between 0 and π/2 until 1953, the series move in phase and railway networks are leading. In the years 1953–1957, the phase difference is around 0; yet, these are years of low coherency. From 1954, the phase information shows a positive correlation (phase relation, again between 0 and π/2), implying that railway networks are leading real value added. Therefore, the information related to periods of significant coherence shows a phase relation (positive correlation between railway networks and real value added, with the series that move together in phase), and the railway networks are leading. However, because railway networks change gradually, the long time scale is particular meaningful for our analysis.

Therefore, we can deduce that in the short-run each variable influences the other. In particular, during the period 1926–1944, railway networks cause real value added, so that we can consider this variable as a determinant of the country's economic growth. On the other hand, in the years 1945–1958 the direction of causality moves in the opposite direction, with real value added causing railway networks. This result is generally confirmed by the long-run analysis, which confirms the positive correlation between the two series. However, in this case railway networks cause real value added. In addition, our results are in line with recent empirical findings in Ciccarelli et al. (2020).

5. Concluding remarks and policy implications

This paper sheds light on the linkages among railway networks,

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[2] https://sites.google.com/site/aguiarconraria/joanasoares-wavelets/the-astoolbox.

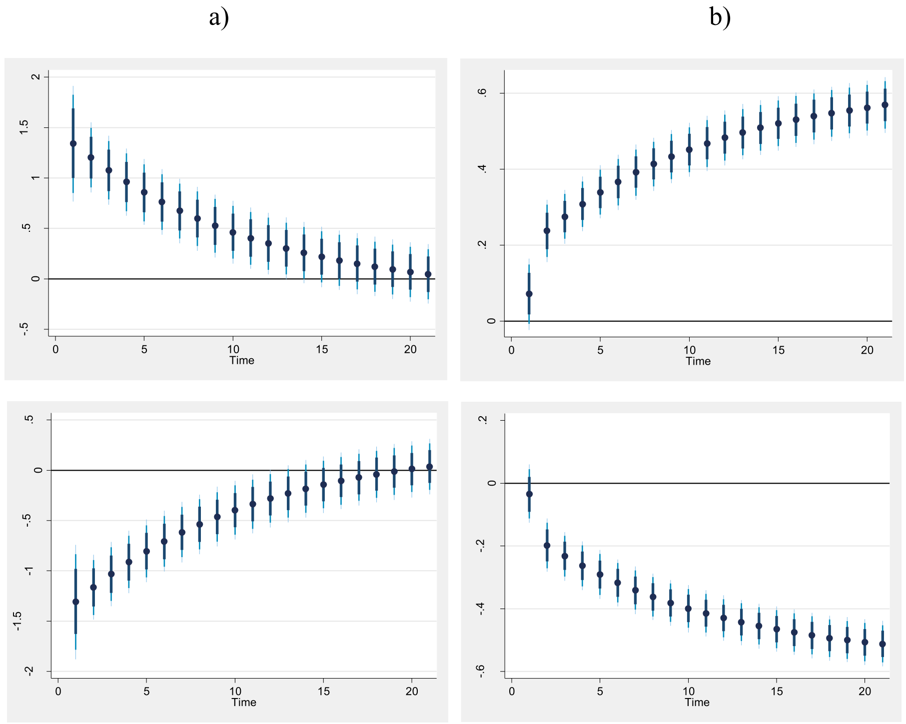

Fig. 2. (a) Change (±1%) in predicted LRN on LRAV; (b) Change (±1%) in predicted LTE on LRAV.
Notes: Dots represent average predicted value while dark blue to light blue lines denote 75, 90 and 95% confidence interval. Our elaborations in STATA.

energy consumption, and real valued added for Italy in the long-run using an innovative empirical strategy, the WA, able to analyze both long-run properties of the series at low frequencies and short-run dynamics at high frequencies.

Thus, railway infrastructure can spur the economic activity. A higher aggregate income should be used to increase railway networks. Furthermore, in order to curb the overuse of energy, Italian policymakers may implement plans based on extension of public infrastructure, reducing congestion and greenhouses emissions.

It is a hard task to prove how a railway connection might affect economic outcomes or capture all the perennial effects derived from such a connection. Nevertheless, this does not lessen the degree of policy relevance in understanding whether and how infrastructure provision influences regional economies within a country. Understanding the performance of infrastructure projects is important for central governments for reviewing the economic viability of future infrastructure projects arising from budgetary constraints (Yoshino and Abidhadjaev, 2017).

The empirical results show that, in general, railway networks and real value added are in phase and positively correlated, both in the short- and in the long-run. In addition, in the long-run a causal flow running from railway networks to real value added emerges. This implies that transport infrastructure sustains the economic growth process of the country, being a determinant of that process.

This research enhances our understanding of transport infrastructure impacts on economic growth in Italy and can inform national transport infrastructure policy. The results are specific to the Italian context, but they may be useful for policymakers in other advanced countries with similar development patterns and economic structures (Magazzino & Valeri, 2012).

Furthermore, good infrastructure can contribute to greater European integration. In fact, public infrastructures increase private sector revenues, and therefore can produce positive effects on supply and as multipliers (Stiglitz, 2016).

Further research, at a regional level, might explore the spatial nature of the relationship between railway networks and added value, using a method that combines wavelet analysis and non-stationary time-series, to detect short-lived spatial coherent patterns (Chavez & Cazelles, 2019) or using recent applied analysis through Artificial Intelligence experiments (Magazzino, Mele, Morelli, et al., 2021; Magazzino, Mele, & Schneider, 2021; Magazzino & Mele, 2020).

5.1. *Compliance with ethical standards*

No funds were provided for this study. The authors declare that they have no conflict of interest. The research did not involve human participants.

Availability of data and material

The data are available upon request.

Funding

Not applicable.

CRediT authorship contribution statement

Cosimo Magazzino: Conceptualization, Investigation, Methodology, Software, Writing – original draft, Validation, Supervision, Writing – review & editing. **Lorenzo Giolli:** Data curation, Visualization, Writing – original draft, Software.

Declaration of competing interest

The authors declare that they have no conflict of interest.

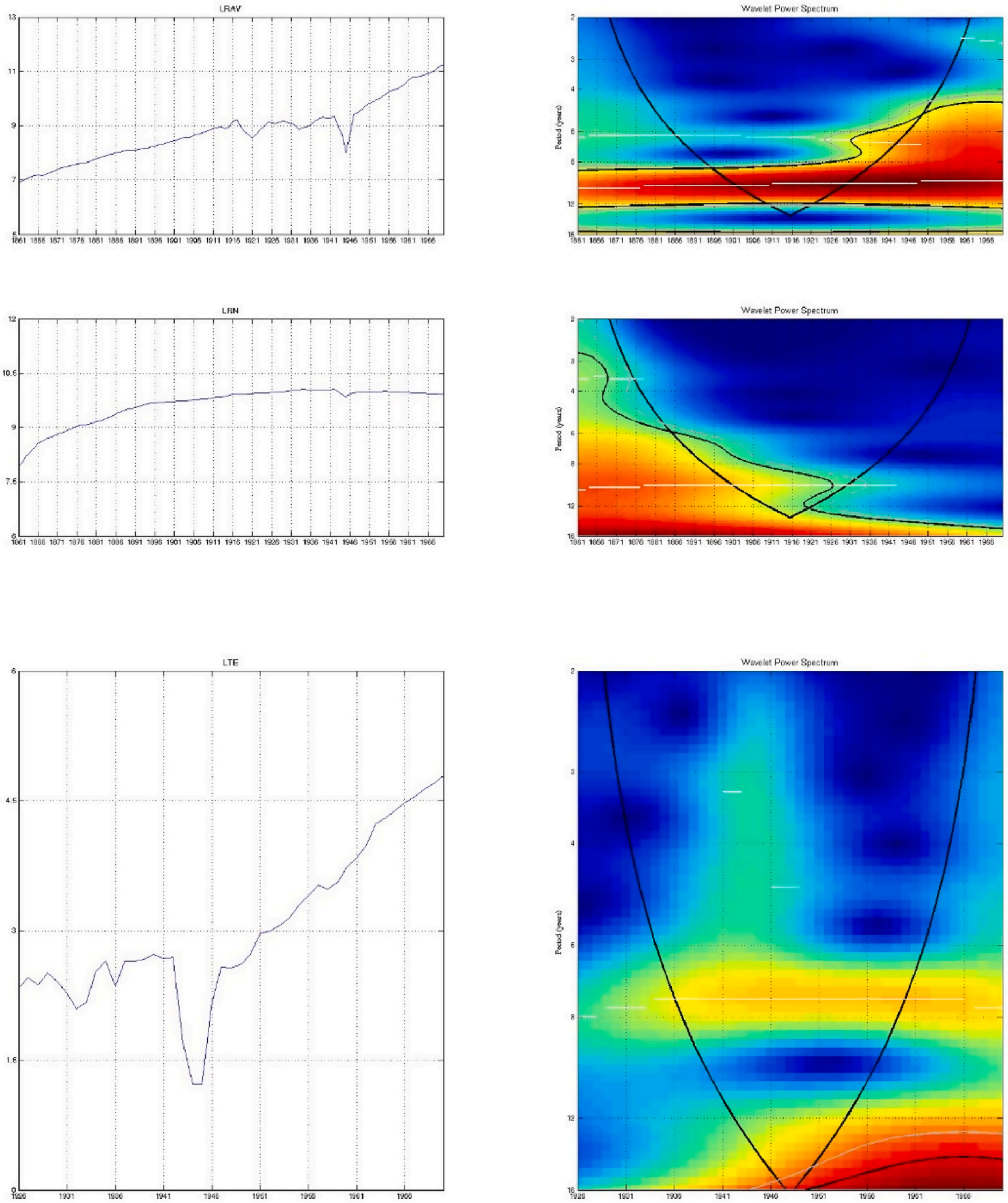

Fig. 3. Real value added in the transport and communications sector, railway networks, and primary energy consumption, and their power spectrum.
Sources: our elaborations on Ferrovie dello Stato and ISTAT data. Our elaborations in MATLAB.

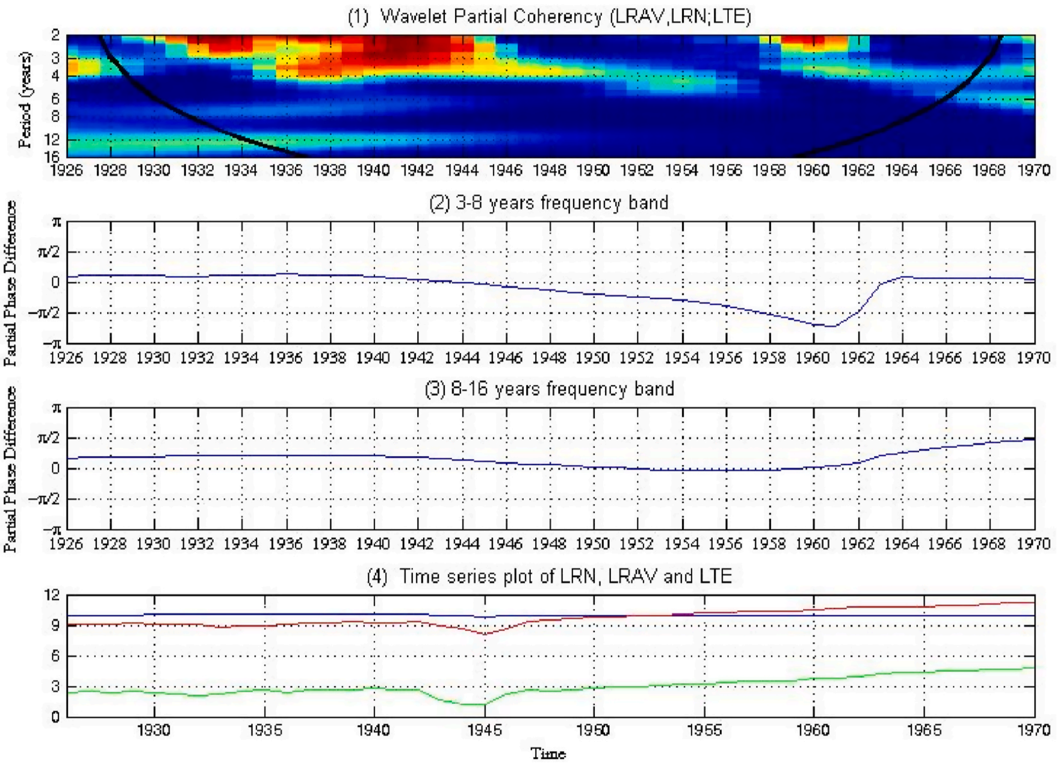

Fig. 4. Wavelet coherence (Italy, 1926–1970).

Sources: our elaborations on Ferrovie dello Stato and ISTAT data. Our elaborations in MATLAB.

Appendix

Table A

Descriptive statistics.

Variable	Mean	Median	SD	Skewness	Kurtosis	Range	IQR	10-Trim
LRN	9.6987	9.8903	0.4458	−2.0222	6.4880	2.1254	0.2507	9.797
LTE	3.9642	4.5433	1.2308	−0.4868	1.7383	4.0736	2.3892	4.064
LRAV	5.4723	5.1748	0.8421	0.6031	1.9295	2.6078	1.5412	5.407

Notes: SD: Standard Deviation; IQR: Inter-Quartile Range; 10-Trim: 10% trimmed mean.

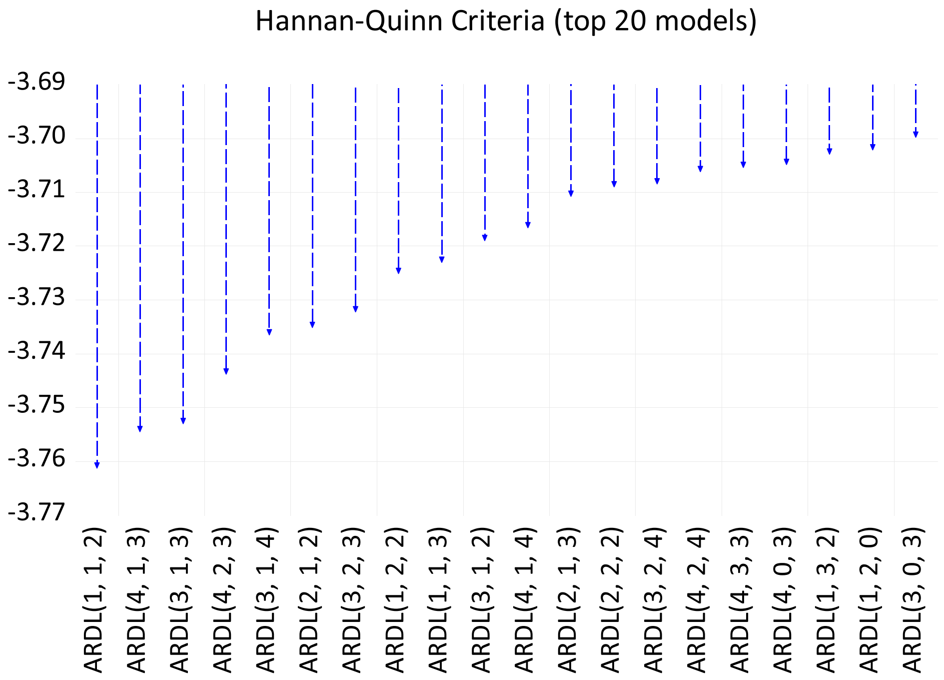

Fig A. Model selection HQ criteria graph..

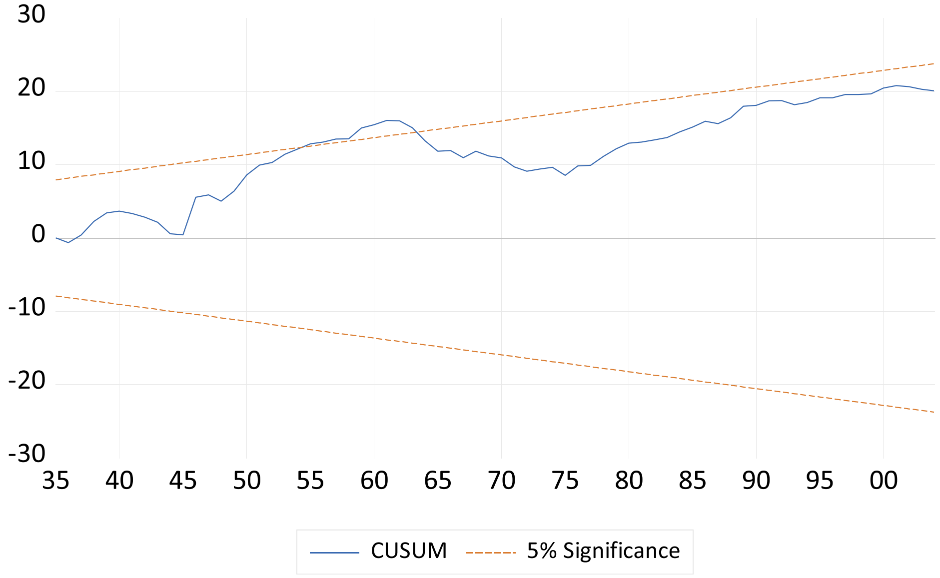

Fig. B. CUSUM test graph.

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