Fixed Broadband Take-Up in Europe

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Abstract

In this article the value of "*Fixed Broadband Take Up*" in Europe is investigated. Data are collected from the DESI-Digital Economy and Society Index for 28 countries in the period 2016-2021. Data are analyzed with Panel Data with Fixed Effects and Random Effects. The Fixed Broadband Take-Up value is positively associated with the value of "*Connectivity*", "*Human Capital*", "*Desi Index*", "*Fast BB NGA Coverage", "Fixed Very High-Capacity Network VHCN coverage*". Fixed Broadband Take-Up value is negatively associated with "*Digital Public Services for Businesses*", "*e-Government*", "*At least Basic Digital Skills*", "*At Least Basic Software Skills*", "*Above Basic Digital Skills*", "*Advanced Skills and Development*", "*Integration of Digital Technology*", "*Broadband Price Index*", "*Mobile Broadband*", "*Fixed Broadband Coverage*". Subsequently the k-Means algorithm optimized by the Silhouette coefficient was used to identify the number of clusters. The analysis shows the presence of the two clusters. Eight different machine learning algorithms were then used to predict the future value of the "*Fixed Broadband Take-Up in Europe*". The analysis shows that the most efficient algorithm for the prediction is "*ANN-Artificial Neural Network*" with an estimated value of the prediction equal to 26.39%.

Keywords: Innovation, and Invention: Processes and Incentives; Management of Technological Innovation and R&D; Diffusion Processes; Open Innovation.

JEL Classification: O30; O31, O32; O33; O36.

1. Introduction

In the following article the determinants of "*Fixed Broadband Take Up*" in Europe have been analyzed. The data were acquired through the analysis of the DESI-Digital, Economy and Society Index database for 28 countries between 2016 and 2021. The data were analyzed through panel econometric techniques, by clustering with the k-Means algorithm and using machine learning algorithms applied to prediction. Broadband is an essential element of digitization in Europe. Indeed the adoption of broadband is essential for developing the projects of smart industries and the creation of smart cities together with the possibility of using digital products and services for families.
There is a positive relationship between the value of adopting the fixed internet network and company performance, employment impact, and investment in venture capital [1]. Using fast internet has positive effects in terms of student performance. In fact, students who have access to the internet have better

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results. However, access to the Internet is also likely to have increased social inequality in academic performance in the sense that richer students having access to the Internet also tend to perform better on equal terms [2]. [3] stresses the role of the fixed internet network in Australia and criticizes the government about the inefficiency shown in the transition from the telecommunications system of the 1980s to the internet network system. It highlights the role of 5G as opposed to the fixed internet network. In fact, in the evolution of network technologies, mobile technologies and technologies connected to 5G tend to overcome the spread of the fixed internet network [4]. [5] consider the driving role of the fixed internet in the development of the digital sector in Australia and North Korea especially for customers. Consider the role of broadband as a tool for economic growth in Brazil. The analysis shows that the more backward regions benefit more from the presence of broadband [6].

[7] analyze the role of broadband penetration in Malaysia in relation to the academic achievement of students. The analysis shows that the impact of broadband on student achievement is greater for secondary school students than for primary school students. [8] show the relationship between the spread of the internet and the performance results of private companies and public administrations in Australia, North Korea, and Denmark. [9] analyze the solutions needed to reduce the digital divide in Europe. The authors underline that the use of satellite communication is the only tool capable of allowing a reduction in the technological gap between the various European countries. [10] refers to the evaluation of the effectiveness of economic policies aimed at reducing the digital divide in Bavaria between 2010 and 2011. The rural Bavarian municipalities that have obtained subsidies for digitization show a reduction in depopulation. However, state intervention in the creation of digital infrastructures fails to increase the municipal employment rate. [11] highlight the relationship that exists between the development of internet networks and the presence of relevant digital content. The authors argue that in countries where there is more digital content, the spread of the internet is facilitated with a positive economic impact.

[12] analyze the role of geographic differences in determining the digital divide in the UK. The authors experience that in the Northeast areas of the United Kingdom and in Wales the use of the internet is less relevant than in London and the Southeast part of England. The authors also consider the role of the demographic component as an essential factor for the digital divide in the UK. [13] consider the relationship between the spread of the internet and financial development in six countries belonging to the Gulf Cooperation Council-GCC between 2010 and 2016. The data show that the spread of the internet has increased both the supply of credit to the private sector and the money supply in relation to GDP. [14] refers to the economic policies implemented in Scotland to increase the use of the internet. Scotland has a lower level of internet access than the rest of the UK despite the government's efforts to fight the digital divide. [15] consider the difficulties of the European Union in achieving the objectives of the European Digital Agenda in terms of spreading high-speed broadband infrastructures. [16] analyze the relationship between women's participation in work and the degree of digitalization in 48 African countries in the period 1990-2014. The data show that the spread of the internet and fixed broadband subscriptions have a positive impact in increasing the participation rate of women in the labor market in the countries considered.

[17] refer to the use of internet networks, mobile phones and broadband in determining trade flows in the period between 2004 and 2013. The results show that the effect of internet broadband is less than the spread of mobile phones for international trading. [18] analyze the relationship existing between the diffusion of broadband and the gross domestic product in Europe 27 in the period between 2003 and 2015. The authors verify the existence of a macro-economic impact of broadband. In fact, a 1% increase in broadband leads to GDP growth of an amount equal to 0.002-0.005%. [19] show that there is a positive relationship between the value of investing in broadband infrastructure and the increase in corporate revenue productivity. However, the analysis conducted by the authors referring to rural areas does not show the presence of a positive relationship between investment in internet networks and the employment

rate or on the growth in the number of companies operating at local level. Broadband is an important development factor especially in the interior of rural, territorial, or underdeveloped economic areas [20]. This is the case, for example, of Wales which has lower levels of economic and technological development than London levels. However, the implementation of broadband also requires an economic policy project that is aimed at increasing the endowment to ensure that the economy grows. Broadband penetration in Europe is associated with economic systems that produce more intellectual property, companies that train their employees with ICT skills and an institutional environment generally conducive to technological innovation [21].
On the technological point of view the internet infrastructure is classified in different operation scale such as Local Area Network (LAN), Metropolitan Area Network (MAN), Wide Area Network (WAN) [22]. Different typologies characterize the network infrastructure such point-to-point connection, bus line, ring layout, star connection, tree layout; and node meshing [23]. Landline technology tends to be developed in the sense of totally optical devices such as WDM wavelength Division Multiplexer [24]. The speed of the Internet network is guaranteed for fully optical networks, i.e. with integrated optical devices. Therefore, adding optical devices to the fiber increases the speed [25]. The improvement of Internet broadband can be further made more efficient using fully optical networks [26] capable of offering adequate support for digitalization processes.
The article continues as follows: in the second paragraph the econometric model for broadband estimation is presented, in the third paragraph clustering is presented using the k-Means algorithm optimized with the Silhouette coefficient, the fourth paragraph contains an analysis of machine learning algorithms for prediction, the fifth paragraph concludes. The appendix contains the set of econometric results, clustering, and machine learning outputs for prediction.

2. The Econometric Model

The data that were analyzed were acquired through the data acquisition of the European Union's DESI-Digital Economy and Society Index dataset. The data is made up of three different levels of variables, that is, there are macro-variables, subdimensions and base levels. The data were analyzed for 28 different countries of the European Union in the period between 2016 and 2021[5].The following econometric model was created below, namely:

$$
\begin{aligned}
\boldsymbol{FixedBroadbandTakeUp_{it}} &= \boldsymbol{a_1 + b_1(FixedBroadbandCoverage)_{it} + b_2(MobileBroadband)_{it}} \\
&\boldsymbol{+ b_3(BroadbandPriceIndex)_{it} + b_4(e - Government)_{it}} \\
&\boldsymbol{+ b_5(Advanced\ Skills\ and\ Development)_{it} + b_6(HumanCapital)_{it}} \\
&\boldsymbol{+ b_7(Connectivity)_{it} + b_8(Integration\ of\ Digital\ Technology)_{it}} \\
&\boldsymbol{+ b_9(Aggregate\ score)_{it} + b_{10}(DigitalPublicServicesForBusinesses)_{it}} \\
&\boldsymbol{+ b_{11}(FastBBNGACoverage)_{it}} \\
&\boldsymbol{+ b_{12}(FixedVeryHighCapacityNetworkVHCNCoverage)_{it}} \\
&\boldsymbol{+ b_{13}(AtLeastBasicDigitalSkills)_{it} + b_{14}(AboveBasicDigitalSkills)_{it}} \\
&\boldsymbol{+ b_{15}(AtLeastBasicSoftwareSkills)_{it}}
\end{aligned}
$$

[5] Countries are: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, European Union, Finland, France Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden.

Where $\boldsymbol{i} = \mathbf{28}$ and $\boldsymbol{t} = \mathbf{2016 - 2021.}$
The "*Fixed Broadband Take-Up*" variable is indicated as follows: "*Number of fixed broadband subscriptions (lines) per 100 people. Penetration of fixed broadband.*"
The value of "*Fixed Broadband Take-Up*" is negatively associated with the following variables:

- *Fixed Broadband Coverage:* It is a variable defined within the Desi as the percentage of the total / rural population living in areas served by fixed broadband: DSL networks or cable modems. As shown by the analysis, the existence of a negative relationship between the value of "*Fixed Broadband Take-Up*" and "*Fixed Broadband Coverage*" appears. In other words, it appears that the percentage number of households subscribing to an abundance of fixed bandwidth tends to decrease with the increase in coverage of fixed broadband. Such a relationship might seem counterfactual. However, it should be considered that the most digitized areas in Europe, i.e. those that use mobile connection levels compared to fixed broadband, obviously have higher fixed broadband levels. This negative relationship results from the fact that generally, especially in urban areas, generally fixed broadband coverage precedes the extensive application of mobile connection models. Mobile connections are generally preferred over fixed band connections. Therefore, fixed bandwidth connection tends to be increasing in rural or less developed areas which generally have a low broadband coverage value.
- *Mobile Broadband:* it is a composite variable made up of four different elements namely "*4G Coverage", "5G readiness*", "*5G coverage*", "*Mobile Broadband Take-Up*". There is a negative relationship between the value of "Fixed Broadband Take-Up in Europe" and "Mobile Broadband". This relationship derives from the fact that the use of internet services connected to the Mobile dimension tends to be placed in opposition to the use of fixed internet network services. Especially in urban areas where there are very efficient mobile internet connection services, consumers tend to structurally prefer mobile services rather than fixed network services. Obviously, this trade off exists above all in high-income countries which also have substantially high levels of digitization. It therefore follows that there is a negative relationship between the value of Mobile Broadband and the value of "*Fixed Broadband Take-Up*" since it can be much cheaper for consumers to purchase mobile internet services than fixed network services, especially in the most digitally evolved and innovative markets.
- *Broadband Price Index:* It is the broadband price index which measures the prices of representative baskets of fixed, mobile, and convergent broadband offers. The Broadband Price Index is a score that measures the prices of over 30 broadband consumer baskets representing different speeds and different products (standalone internet, double play, triple play and quadruple play). There is a negative relationship between the "*Fixed Broadband Take-Up*" value and the "*Broadband Price Index*" value. This relationship can be understood considering the role of price in the choice by consumers to purchase a fiber subscription. In fact, consistently with standard economic theory, price growth is associated with a reduction in the quantities requested by consumers. However, the fact that the price of the network is negatively associated with the spread of "*Fixed Broadband Take-Up*" also depends on market structuring. In fact, the markets of internet service providers tend to be oriented towards forms of monopoly and oligopoly with an increase in the prices administered which tends to be higher than the value of the competitive markets.
- *Integration of Digital Technology:* the value of the "*Integration of Digital Technology*" consists of a set of three different components namely "*Digital Intensity*", "*Digital Technologies for*

Business", "*e-Commerce*". There is a negative relationship between the "Integration of Digital Technology" value and the "*Fixed Broadband Take-Up*" value. This negative relationship can be understood since in European countries where the value of the "*Integration of Digital Technology*" is high there is also a scarce presence of a fixed internet network. In fact, the most digitally developed urban areas are generally characterized by the presence of a mobile network, with elements connected to 5G. In fact, the new digital technologies tend to be more and more aimed at mobile and less and less aimed at fixed networks. Therefore, the growth in the value of the digitization of economies is paradoxically negatively associated with the value of the "*Fixed Broadband Take-Up*".

- *Advanced Skills and Development:* it is a variable that considers the workforce and its potential to work in and develop the digital economy. This variable considers the percentage of people in the workforce with ICT specialist skills, with a breakdown for female ICT specialists. At the same time, it looks at the share of ICT graduates. There is therefore a negative relationship between the "*Advanced Skills and Development*" value and the "*Fixed Broadband Take-Up*" value. This negative relationship can be better understood because in European countries where experts have advanced IT skills, it also occurs that subscriptions to mobile internet connection networks tend to be higher than subscriptions to fixed internet connection networks. It follows therefore that where human capital is significantly oriented to IT specialization and more generally to STEM disciplines, subscriptions to mobile internet connection networks will be required rather than subscription to fixed internet networks.
- *Above Basic Digital Skills:* is a variable that considers the number of people with above basic digital skills in each of the following four dimensions: information, communication, problem solving, software for content creation. There is a negative relationship between the value of "*Fixed Broadband Take-Up*" and the value of "*Above Basic Digital Skills*". This relationship can be better understood because generally in countries where there is a very high digital culture, operators tend to prefer mobile internet subscriptions rather than fixed internet subscriptions. This condition appears to be since operators who have advanced technological skills require advanced internet services that are generally not offered by fixed internet networks. It therefore follows that the most advanced areas in IT terms require investment in the creation of mobile internet networks.
- *At Least Basic Software Skills:* it is a variable that considers the degree of software knowledge and skills. In particular, the following activities are considered: create and modify new contents of texts, images, and videos; integrate and rework previous knowledge and contents; produce creative expressions, multimedia outputs and programming; treat and enforce intellectual property rights. The indicator refers to the activities carried out by users in the last 3 months. There are three classifications: "*basic*", "*above basic*" and "*none*". Individuals who do not use the internet are considered to have no digital skills. There is therefore a negative relationship between the number of people who have basic software skills and the presence of "*Fixed Broadband Take-Up*". This negative relationship is since generally people with basic software skills tend to request mobile internet services rather than fixed network internet services. It follows, as we have already verified for the previous indicators, that where the content of IT knowledge tends to be increasing, there is a reduction in subscriptions to the fixed internet network.
- *At Least Basic Digital Skills:* is an indicator that considers the ability to process information such as the ability to identify, locate, retrieve, archive, organize and analyze digital information. The indicator takes into consideration the activities that internet users have carried out online in the last 3 months from the survey. There are three different types of criteria for assessing digital skills: "*basic*", "*above the base*" and "*none*". Individuals who do not use the internet are

considered to have no digital skills. There is therefore a negative relationship between the value of people who have basic digital skills and the presence of subscriptions to the fixed internet network. This circumstance depends on the fact that the even marginal growth of digital skills is generally associated with the demand for advanced internet services such as those connected to the mobile internet network. It follows therefore that users with basic digital skills may be more interested in mobile network services rather than fixed internet services.

Econometric results for the estimate of the value of "Fixed Broadband Take-Up".						
Variable		Fixed Effects		Random Effects		
		Coefficient	p-Value	Coefficient	p-Value	Mean
	Coefficient	-0,0003333	***	-0,000190465	**	-0,00026189
A2	*Fixed broadband coverage*	-1,00001	***	-1,00001	***	-1,00001
A3	*Mobile broadband*	-0,999998	***	-0,999999	***	-0,9999985
A4	*Broadband price index*	-0,999981	***	-0,999986	***	-0,9999835
A5	*e-Government*	-0,084749	***	-0,0800088	***	-0,0823789
A11	*Advanced Skills and Development*	-0,266667	***	-0,253599	***	-0,260133
A15	*Human Capital*	0,727666	**	0,694357	**	0,7110115
A16	*Connectivity*	3,66097	***	3,67995	***	3,67046
A17	*Integration of Digital Technology*	-0,339033	***	-0,32005	***	-0,3295415
A19	*Aggregate score*	0,339013	***	0,320042	***	0,3295275
A33	*Digital public services for businesses*	-2,83E-06	**	-2,75E-06	**	-2,7934E-06
A35	*Fast BB (NGA) coverage*	5,18E-06	**	5,72E-06	**	5,44579E-06
A36	*Fixed Very High Capacity Network (VHCN) coverage*	4,60E-06	*	4,36E-06	**	4,47919E-06
A44	*At least Basic Digital Skills*	-0,133326	***	-0,126797	***	-0,1300615
A45	*Above basic digital skills*	-0,133341	***	-0,126806	***	-0,1300735
A46	*At least basic software skills*	-0,133335	***	-0,126795	***	-0,130065

Figure 1. Econometric results for the estimate of the value of "Fixed Broadband Take-Up"

- *e-Government:* It is a variable made up of the sum of five sub-variables: "*e-Government users*", "*Pre-filled forms*", "*Digital Public Services for Citizens*", "*Digital Public Services for Business*", "*Open Data*". E-government is usually negatively associated with the "*Fixed Broadband Take-Up*" variable. This negative relationship can be better understood considering that generally the public administrations that choose to use digital services require the use of mobile network internet services or internet services connected for example to 5G which require to overcome the dynamics of the "*Fixed Broadband Take -Up* ". The European countries that have greater capacity to implement e-government services also have a greater need to use more advanced internet services than the fixed band. Therefore, if the policy makers believe they must invest in the creation of a set of network infrastructures capable of supporting e-government, they should also design networks that exceed the size of the fixed network to reach the most advanced forms required in the field of dynamics of mobile and 5G.

The "*Fixed Broadband Take-Up*" value is positively associated with the following variables:

- *Fixed Very High-Capacity Network VHCN Coverage:* is a variable that considers the percentage of households covered by any fixed VHCN. The technologies considered are FTTH and FTTB for 2015-2018 and FTTH, FTTB and Cable Docsis 3.1 for 2019 onwards. By rural areas we mean those with less than 100 inhabitants per sq. Km. In summary, the indicator measures the share of households with very high-capacity fixed network connections. There is a positive relationship between the presence of a very high-capacity network and the value of the "*Fixed Broadband Take Up*". This positive relationship is since the very high-capacity network is often the prerequisite required by users to be able to access the services connected to fixed network subscriptions. In fact, using the very high-capacity network, it is possible to use the Internet both for the typical purposes of digital businesses and for all the consumer and entertainment activities required by families. It therefore follows that a growth in the very high-capacity fixed network tends to be associated with a growth in subscriptions within the fixed internet network.

- *Fast BB NGA Coverage:* it is a variable that considers the percentage of households residing in the areas served by NGA. Next Generation Access includes the following technologies: FTTH, FTTB, Cable Docsis 3.0, VDSL and another super-fast broadband (minimum download 30 Mbps). There is therefore a positive relationship between the spread of super-fast broadband and the value of "*Fixed Broadband*" subscriptions in Europe. This positive relationship is since the growth in the value of super-fast broadband tends to increase the incentives that families have in subscribing to fixed network internet subscriptions. It is therefore obvious that the greater the efficiency of the fixed network services offered to families, the greater the participation of the population towards fixed network subscriptions. In fact, many services that have been introduced for consumer households can only be effectively maximized through advanced services such as super-fast broadband which therefore increases the demand for fixed network subscriptions.
- *Aggregate Score:* constitutes the aggregate and synthetic indicator of the DESI or the Digital Economy and Society Index consisting of the set of Human Capital, Connectivity, Integration of Digital Technology and Digital Public Services. There is a positive relationship between the DESI value and the "*Fixed Broadband Take-Up*" value. This positive relationship is determined by the fact that generally the growth of subscriptions to the fixed internet network are considered as a tool capable of increasing the value of digitization capacity within the European economies. Although the most developed areas of the European Union are certainly oriented towards the use of mobile internet connection tools, it occurs that on average and overall, for all the countries considered, the growth in the degree of DESI is positively associated with the distribution of the network fixed internet especially if at high capacity and speed. Therefore, overall, it is certainly true that the growth of fixed internet connections is positively associated with digital, economic, and social development within the countries concerned.
- *Human Capital:* It is a composite indicator consisting of two different sub-indicators namely "*Internet User Skills*" and "*Advanced Skills and Development*". This indicator therefore measures the IT, software and digital skills that are present within the population of the countries considered. There is a positive relationship between the value of "Human Capital" and the value of "*Fixed Broadband Take-Up*" in Europe. This positive relationship means that where general technical-computer skills grow, subscriptions to the fixed internet network also increase. From which circumstance it is evident that on average the development of the fixed internet network has some positive impact on the growth of digital, IT and software skills of human capital within the European countries considered. The suggestion for policy makers is therefore to increase investments in the internet, even fixed, perhaps at high speed and capacity, precisely to generate positive impacts in terms of human capital.
- *Connectivity:* it is a composite indicator consisting of four sub-dimensions namely "*Fixed Broadband Take-Up*", "*Fixed Broadband Coverage*", "*Mobile Broadband*", and "*Broadband Prices*". As evident from the econometric analysis, it appears that there is a positive relationship between the "*Fixed Broadband Take-Up*" value and the "*Connectivity*" value. This positive relationship is since obviously the increase in internet availability within the fixed network is an essential element of the growth of overall connectivity within a certain country. It follows therefore that if policy makers want to increase the overall value of connectivity, they must also increase the value of "*Fixed Broadband*". Obviously, this relationship is very relevant from a quantitative point of view and certainly can be very useful for increasing the value of connectivity in countries that are digitally backward. However, from a qualitative point of view it is also

necessary to aim for new forms of connectivity that allow the development of technologies related to mobile and 5G and subsequent evolutions.

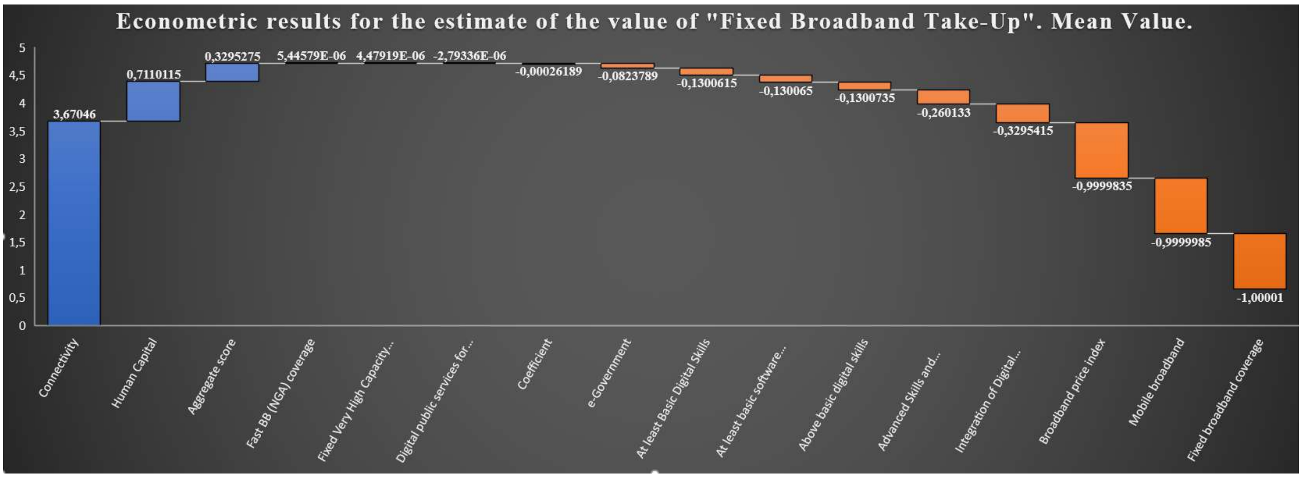


Figure 2. Econometric Results for the Estimate of the Value of "Fixed Broadband Take-Up".

3. Clusterization

A cluster-type analysis was then carried out using the unsupervised k-Means algorithm through the Silhouette coefficient. By applying the Silhouette coefficient, the optimal number of clusters equal to a value of two was identified.

- *Cluster 1*: Austria, Greece, Croatia, Poland, Finland, Lithuania, Slovakia, Bulgaria, Italy, Ciprus, France, Latvia, Ireland, Czechia, European Union, Estonia, Romania;
- *Cluster 2*: Belgium, Sweden, Denmark, Luxembourg, Germany, Hungary, Netherlands, Malta, Portugal, Spain, Slovenia.

In the cluster analysis it appears that the median value of "*Fixed Broadband Take Up*" of cluster 1 was equal to a value of 6.20 units while the median value of cluster 2 was equal to a value of 10.28.

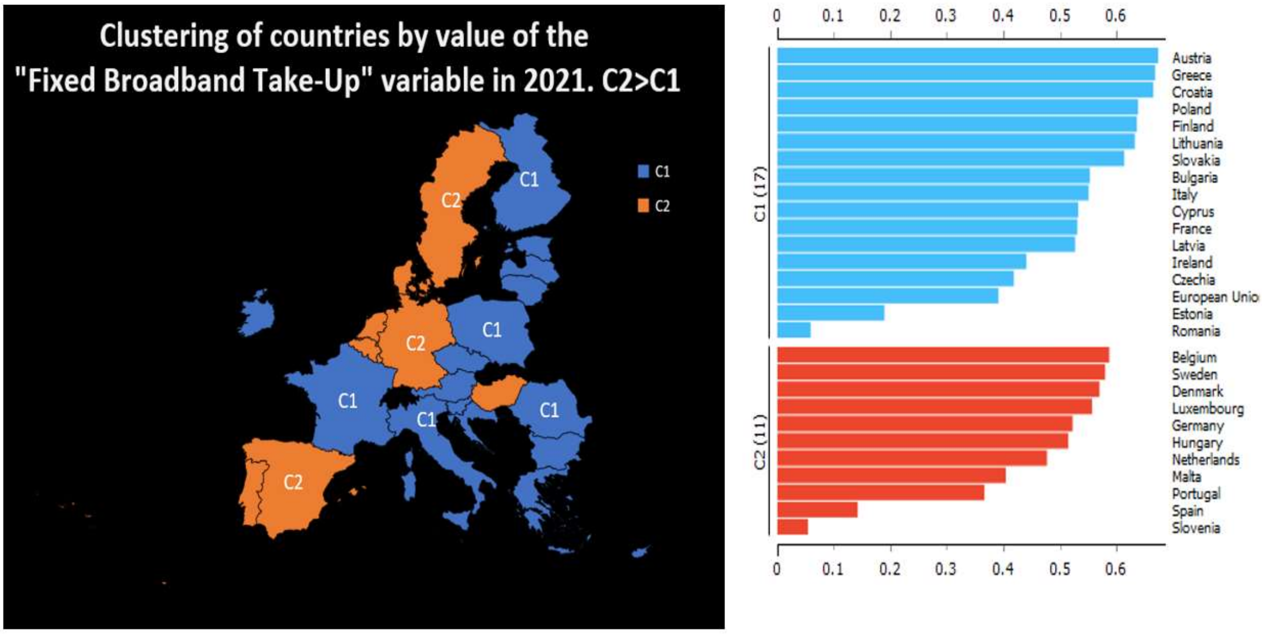


Figure 3. Clustering of countries by value of the "Fixed Broadband Take-Up" variable in 2021.

Therefore, the following ordering of the clusters derives, namely: C2> C1. As is evident from clustering, the presence of a contrast between the countries of South-Eastern Europe and the countries of Central-Northern Europe is evident. Specifically, the countries of South-Eastern Europe tend to have a lower value than the manifest value of the countries of Central-Northern Europe. This condition manifests the presence of a sort of digital divide between the North and the South of Europe which acts in the creation of differentiated conditions for economic growth. Since the digital economy and technological innovation necessarily requires investment in networks, the need on the part of the European Union to invest in the creation of networks in the various European countries is evident, above all to increase the development opportunities of the most backward countries. In this sense, it is necessary to underline that Europe should increase its investment in networks also to increase competitiveness vis-à-vis the Asian countries and the USA.

4. Machine Learning and Prediction

Below is a prediction of the value of the observed variable or "*Fixed Broadband Take-Up*" by comparing eight different machine learning algorithms. The machine learning algorithms used were compared through a set of statistical indicators. In particular, the algorithms have been selected through the ability to achieve the maximization of "*R^2*" and the minimization of the following statistical errors, namely "*Mean Absolute Error*", "*Mean Squared Error*", "*Root Mean Squared Error*", "*Mean Signed Difference*". 70% of the data was used for algorithm training while the remaining 30% was used for actual prediction. Therefore, by applying the algorithm selection criteria, the following ordering was determined, that is:

- *ANN-Artificial Neural Network* with a payoff of 7;
- *Polynomial Regression* with a payoff value of 10;
- *Linear Regression* with a payoff value of 13;
- *Tree Ensemble* with a payoff value of 22;
- *Gradient Boosted Tree* with a payoff value of 24;

- *Simple Regression Tree* with a payoff value of 31;
- *PNN-Probabilistic Neural Network* with a payoff value of 34;
- *Random Forest* with a payoff value of 39.

Therefore, based on the application of the analyzed criteria, the most relevant algorithm is the ANN-Artificial Neural Network Multilayer Perceptron. It therefore follows that using this algorithm the following predictions are made, namely:

- *Bulgaria* with an increase from an amount equal to 2.88 units up to a value of 7.65 units or equal to a variation of 4.77 units equivalent to a percentage change of 165.42%;
- *Czechia* with an increase from an amount equal to 7.55 units up to a value of 8.96 units or equal to a value of 1.42 units equal to a variation of 18.79%;
- *Germany* with an increase from an amount equal to 9.43 units up to a value of 9.49 units or equal to a value of 0.07 units equal to a variation of 0.74%;
- *Greece* with an increase from an amount equal to 4.79 units up to a value of 8.19 units or equal to a value of 3.39 units equal to a value of 70.83%;
- *Hungary* with a value of the increase from a value of 12.08 units up to a value of 10.24 units or equal to a value of -1.83 units equal to a variation of -15.19%;
- *Italy* with an increase from an amount of 4.76 to 8.18 units or equal to a change of 3.42 units equal to a value of 71.74%;
- *Latvia* with an increase from an amount equal to a value of 5.19 up to a value of 8.30 units equal to a value of 3.11 units equal to a value of 59.87%;
- *Malta* with a decrease from an amount equal to 9.78 units up to a value of 9.59 units or equal to a value of -0.18 units equal to a value of -1.88%;
- *Poland* with an increase from an amount of 6.20 up to a value of 8.58 units equal to a change of 2.38 units equal to a value of 38.45%.

On average, the value of the "*Fixed Broadband Take-Up in Europe*" is expected to grow on average from an amount of 6,96 to 8,80 units or equal to a variation of 1.84 units equal to a value of 26,39%.

Prediction realized through the ANN-Artificial Neural Network algorithm.				
Country	2021	Predizione	Var Ass	Var Perc
Bulgaria	2,88	7,65	4,77	165,42
Czechia	7,55	8,96	1,42	18,79
Germany	9,43	9,49	0,07	0,74
Greece	4,79	8,19	3,39	70,83
Hungary	12,08	10,24	-1,83	-15,19
Italy	4,76	8,18	3,42	71,74
Latvia	5,19	8,30	3,11	59,87
Malta	9,78	9,59	-0,18	-1,88
Poland	6,20	8,58	2,38	38,45
Mean	6,96	8,80	1,84	26,39

Metric results deriving from the application of machine learning algorithms for prediction					
Algorithm	R^2	Mean absolute error	Mean squared error	Root mean squared error	Mean signed difference
ANN	0,88015829	0,084827972	0,011087744	0,105298356	0,052255303
PNN	0,22866447	0,136925626	0,027256387	0,165095086	0,099426896
Gradient Boosted Tree	0,68724516	0,114747533	0,024120584	0,155308031	0,069714644
Random Forest	0,574422	0,156736028	0,031885516	0,17856516	0,111307205
Tree Ensemble	0,76634139	0,106375174	0,016251494	0,127481346	0,075187638
Simple Regression Tree	0,62869845	0,132050127	0,02759532	0,166118392	0,070133074
Linear Regression	0,80968226	0,089588227	0,011734267	0,108324822	0,039121802
Polynomial Regression	0,83558713	0,094772093	0,01179839	0,108620394	0,050488137

Figure 4. Prediction Realized Through the ANN-Artificial Neural Network Algorithm.

5. Conclusions

In this article the value of "*Fixed Broadband Take Up*" in Europe is investigated. Data are collected from the DESI-Digital Economy and Society Index for 28 countries in the period 2016-2021. Data are analyzed with Panel Data with Fixed Effects and Random Effects. The analysis of the distribution of broadband is essential for the realization of the digitization project at European level. The possibility of carrying out the projects of industry 4.0, smart cities, telemedicine, is strictly connected to the creation of large broadband networks.

The application of econometric models showed that the Fixed Broadband Take-Up value is positively associated with the value of "*Connectivity*", "*Human Capital*", "*Desi Index*", "*Fast BB NGA Coverage",* "*Fixed Very High-Capacity Network VHCN coverage*". Fixed Broadband Take-Up value is negatively associated with "*Digital Public Services for Businesses*", "*e-Government*", "*At least Basic Digital Skills*", "*At Least Basic Software Skills*", "*Above Basic Digital Skills*", "*Advanced Skills and Development*", "*Integration of Digital Technology*", "*Broadband Price Index*", "*Mobile Broadband*", "*Fixed Broadband Coverage*".

However, to better understand and investigate the presence of digital gaps determined on a regional basis, a cluster analysis was carried out. Clustering allows you to check if there are any groupings in the data that may be such as to make scars of the classifications for different levels of value of "*Fixed Broadband Take Up".* In this regard, the k-Means clustering algorithm was used. However, since this algorithm is unsupervised, it was necessary to integrate the Silhouette coefficient to choose the optimal number of clusters. The analysis shows the presence of the two clusters. The cluster analysis highlights the existence of a clear contrast between Central-Northern Europe which has higher levels of "*Fixed Broadband Take Up*" and South-Eastern Europe which has low values. This difference reverberates a wider technological

and digital divide that splits Europe in two between North and South and which would require significant economic policy interventions.
In the end eight different machine learning algorithms were then used to predict the future value of the "*Fixed Broadband Take-Up in Europe*". In particular, the algorithms have been selected through the ability to achieve the maximization of "*R^2*" and the minimization of the following statistical errors, namely "*Mean Absolute Error*", "*Mean Squared Error*", "*Root Mean Squared Error*", "*Mean Signed Difference*". The analysis shows that the most efficient algorithm for the prediction is "*ANN-Artificial Neural Network*" with an estimated value of the prediction equal to 26.39%.
In summary, it is possible to state that, as highlighted by the literature reported in the first paragraph, broadband is an essential element for economic growth and the digital and technological development of the territories. Certainly, the new optical technologies can allow to further speed up the broadband. However, economic policy interventions are also needed with plans that are defined at European level to ensure that the broadband network is more widespread among the various European countries in reducing the economic and technological gap. The creation of broadband is therefore an important work that falls both within the policies of equal opportunities and within the policies for local economic growth.

6. Figure Index

7. Bibliography

[1] D. Andrews, G. Nicoletti e C. Timiliotis, «Digital technology diffusion: A matter of capabilities, incentives or both?,» 2018.

[2] L. J. Dettling, S. Goodman e J. Smith, «Every little bit counts: The impact of high-speed internet on the transition to college,» *Review of Economics and Statistics,* vol. 100, n. 2, pp. 260-273, 2018.

[3] G. McLaren, «What now for Australia's NBN?: How Australia's politics, insular policies and preference for monopolies have made Australia a broadband backwater,» *Journal of Telecommunications and the Digital Economy,* vol. 6, n. 4, pp. 31-62., 2018.

[4] M. Condoluci, S. H. Johnson, V. Ayadurai, M. A. C. M. A. Lema, M. Dohler e T. Mahmoodi, «Fixed-mobile convergence in the 5G era: From hybrid access to converged core,» *IEEE Network,* vol. 33, n. 2, pp. 138-145, 2019.

[5] T. Dwyer, Y. Shim, H. Lee e J. Hutchinson, «Comparing digital media industries in South Korea and Australia: The case of Netflix take-up,» *International Journal of Communication,* vol. 12, n. 20, 2018.

[6] J. Jung e E. López-Bazo, «On the regional impact of broadband on productivity: The case of Brazil,» *Telecommunications Policy,* vol. 1, n. 101826, p. 44, 2020.

[7] M. Z. M. Tajuddin e I. Rohman, «The Impact of Broadband Penetration on the Student Performance in Primary and Secondary School in Malaysia,» *Proceedings of the 11th International Conference on Theory and Practice of Electronic Governance,* pp. 111-117, 2018.

[8] M. Meyerhoff Nielsen e Z. Jordanoski, «Digital transformation, governance and coordination models: A comparative study of Australia, Denmark and the Republic of Korea,» *The 21st Annual International Conference on Digital Government Research,* pp. 285-293, 2020.

[9] A. Chiha, M. Van der Wee, D. Colle e S. Verbrugge, «Techno-economic viability of integrating satellite communication in 4G networks to bridge the broadband digital divide,» *Telecommunications Policy,* vol. 3, n. 101874, p. 44, 2020.

[10] T. Sudtasan, «Adoption and diffusion of optical fiber broadband in Thailand,» *Doctoral dissertation,* 2018.

[11] H. S. Na, J. Hwang e H. Kim, «Digital content as a fast Internet diffusion factor: Focusing on the fixed broadband Internet,» *Information Development,,* vol. 36 , n. 1, pp. 97-111, 2020.

[12] G. Blank, M. Graham e C. Calvino, «Local geographies of digital inequality,» *Social Science Computer Review,* vol. 36, n. 1, pp. 82-102, 2018.

[13] F. Alshubiri, S. A. Jamil e M. Elheddad, «The impact of ICT on financial development: Empirical evidence from the Gulf Cooperation Council countries,» *International Journal of engineering business management,* vol. 11, n. 1847979019870670, 2019.

[14] E. Sutherland, «A Short Note on Broadband Internet Access in Scotland,» *SSRN ,* n. 3106248, 2018.

[15] C. Feijóo, S. Ramos, C. Armuña, A. Arenal e J. L. Gómez-Barroso, «A study on the deployment of high-speed broadband networks in NUTS3 regions within the framework of digital agenda for Europe,» *Telecommunications Policy,* vol. 42, n. 9, pp. 682-699, 2018.

[16] U. R. Efobi, B. V. Tanankem e S. A. Asongu, «Female economic participation with information and communication technology advancement: Evidence from Sub-Saharan Africa,» *South African Journal of Economics,* vol. 86, n. 2, pp. 231-246., 2018.

[17] E. Rodriguez-Crespo, R. Marco e M. Billon, « ICTs impacts on trade: a comparative dynamic analysis for internet, mobile phones and broadband,» *Asia-Pacific Journal of Accounting & Economics,* vol. 28, n. 5, pp. 577-591, 2021.

[18] W. Briglauer e K. Gugler, «Go for Gigabit? First Evidence on Economic Benefits of High-speed Broadband Technologies in Europe,» *JCMS: Journal of Common Market Studies,* vol. 57, n. 5, pp. 1071-1090, 2019.

[19] G. Canzian, S. Poy e S. Schüller, «Broadband upgrade and firm performance in rural areas: Quasi-experimental evidence,» *Regional Science and Urban Economics,* vol. 77, pp. 87-103, 2019.

[20] C. Jones e D. Henderson, «Broadband and uneven spatial development: The case of Cardiff City-Region,» *Local Economy,* vol. 34, n. 3, pp. 228-247, 2019.

[21] A. Leogrande, A. Costantiello e L. Laureti, «The Broadband Penetration in Europe,» *Journal of Applied Economic Sciences,* vol. 16, n. 3, 2021.

[22] A. Massaro, «Electronic in Advanced Research Industry: From Industry 4.0 to Industry 5.0 Advances,» *Wiley/IEEE,* vol. 9781119716877, n. 10.1002/9781119716907, 2022.

[23] A. Massaro, «State of the Art and Technology Innovation,» in *Electronics in Advanced Research Industries: Industry 4.0 to Industry 5.0 Advances*, doi: 10.1002/9781119716907.ch1., IEEE, 2022, pp. 1-49.

[24] A. Massaro, R. Cingolani, M. De Vittorio e A. Passaseo, «Design and Optimisation of WDM Circular Photonic Crystals Characterised by Induced Anisotropy,» *Journal of Computational and Theoretical Nanoscience,* vol. 7, n. 9, pp. 1848-1854, 2010.

[25] A. Massaro, R. Cingolani, M. De Vittorio e A. Passaseo, «Novel grating design approach by radiation modes coupling in nonlinear optical waveguides,» *Optics Express,* vol. 17, n. 9, pp. 6982-6995, 2009.

[26] A. Massaro, V. Tasco, M. T. Todaro, R. Cingolani, M. De Vittorio e A. Passaseo, «Scalar time domain modeling and coupling of second harmonic generation process in GaAs discontinuous optical waveguide,» *Optics Express,* vol. 16, n. 19, pp. 14496-14511, 2008.

8. Appendix

The following software have been used: Gretl, Orange and KNIME.

Modello 33: Effetti fissi, usando 168 osservazioni
Incluse 28 unità cross section
Lunghezza serie storiche = 6
Variabile dipendente: A1

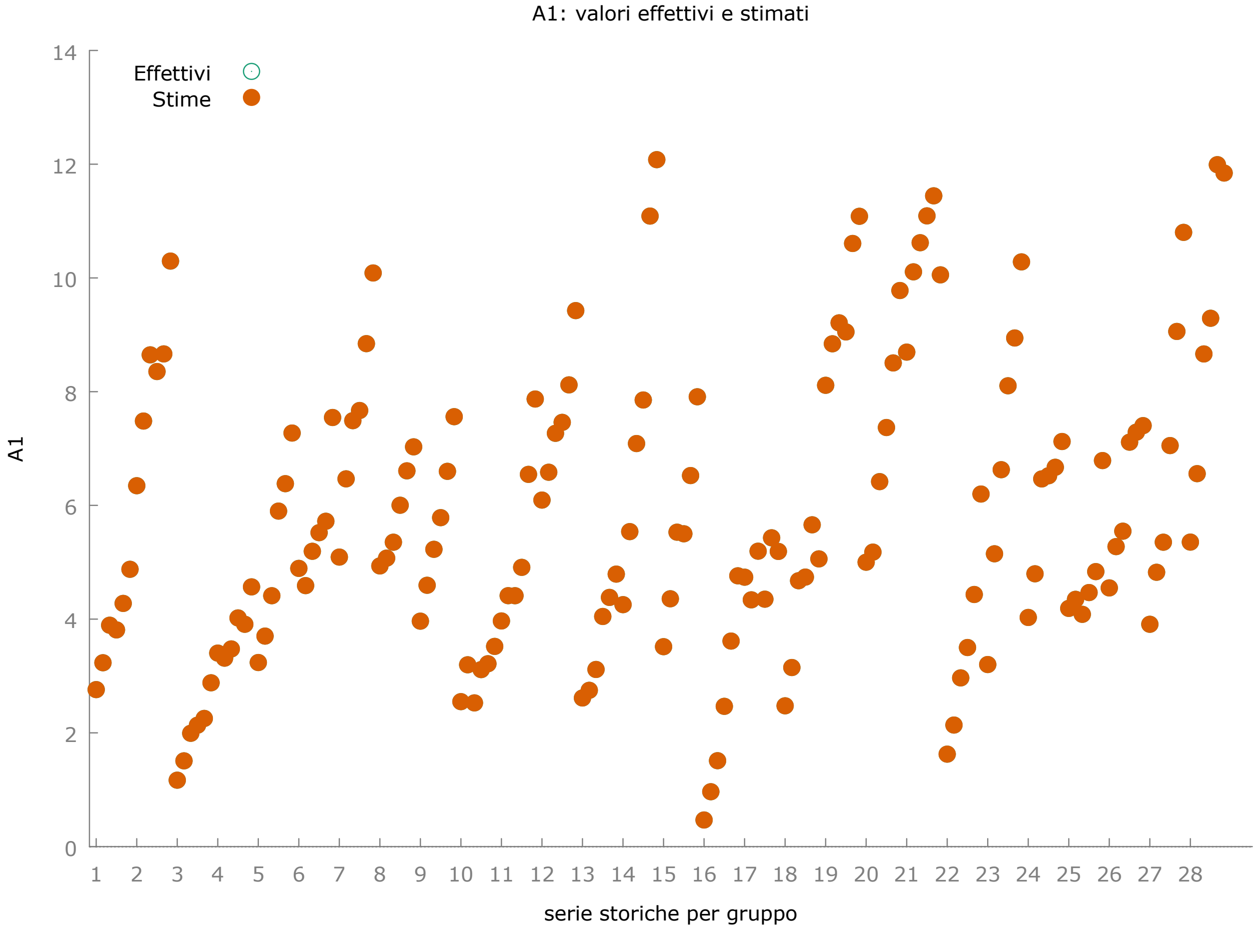
	Coefficiente	*Errore Std.*	*rapporto t*	*p-value*	
const	−0,000333315	0,000111742	−2,983	0,0034	***
A2	−1,00001	1,07248e-05	−9,324e+004	<0,0001	***
A3	−0,999998	4,42007e-06	−2,262e+005	<0,0001	***
A4	−0,999981	1,21560e-05	−8,226e+004	<0,0001	***

A5	−0,0847490	0,0275077	−3,081	0,0025	***
A11	−0,266667	0,0834419	−3,196	0,0018	***
A15	0,727666	0,329206	2,210	0,0289	**
A16	3,66097	0,110030	33,27	<0,0001	***
A17	−0,339033	0,110033	−3,081	0,0025	***
A19	0,339013	0,110031	3,081	0,0025	***
A33	−2,83288e-06	1,32191e-06	−2,143	0,0340	**
A35	5,17638e-06	2,55798e-06	2,024	0,0451	**
A36	4,60091e-06	2,37671e-06	1,936	0,0551	*
A44	−0,133326	0,0417197	−3,196	0,0018	***
A45	−0,133341	0,0417216	−3,196	0,0018	***
A46	−0,133335	0,0417231	−3,196	0,0018	***

Media var. dipendente	5,794404	SQM var. dipendente	2,534831
Somma quadr. residui	2,09e-07	E.S. della regressione	0,000041
R-quadro LSDV	1,000000	R-quadro intra-gruppi	1,000000
LSDV F(42, 125)	1,53e+10	P-value(F)	0,000000
Log-verosimiglianza	1483,934	Criterio di Akaike	−2881,868
Criterio di Schwarz	−2747,538	Hannan-Quinn	−2827,351
rho	−0,232265	Durbin-Watson	2,070377

Test congiunto sui regressori -
Statistica test: F(15, 125) = 1,3298e+010
con p-value = P(F(15, 125) > 1,3298e+010) = 0

Test per la differenza delle intercette di gruppo -
Ipotesi nulla: i gruppi hanno un'intercetta comune
Statistica test: F(27, 125) = 1,79182
con p-value = P(F(27, 125) > 1,79182) = 0,0170595

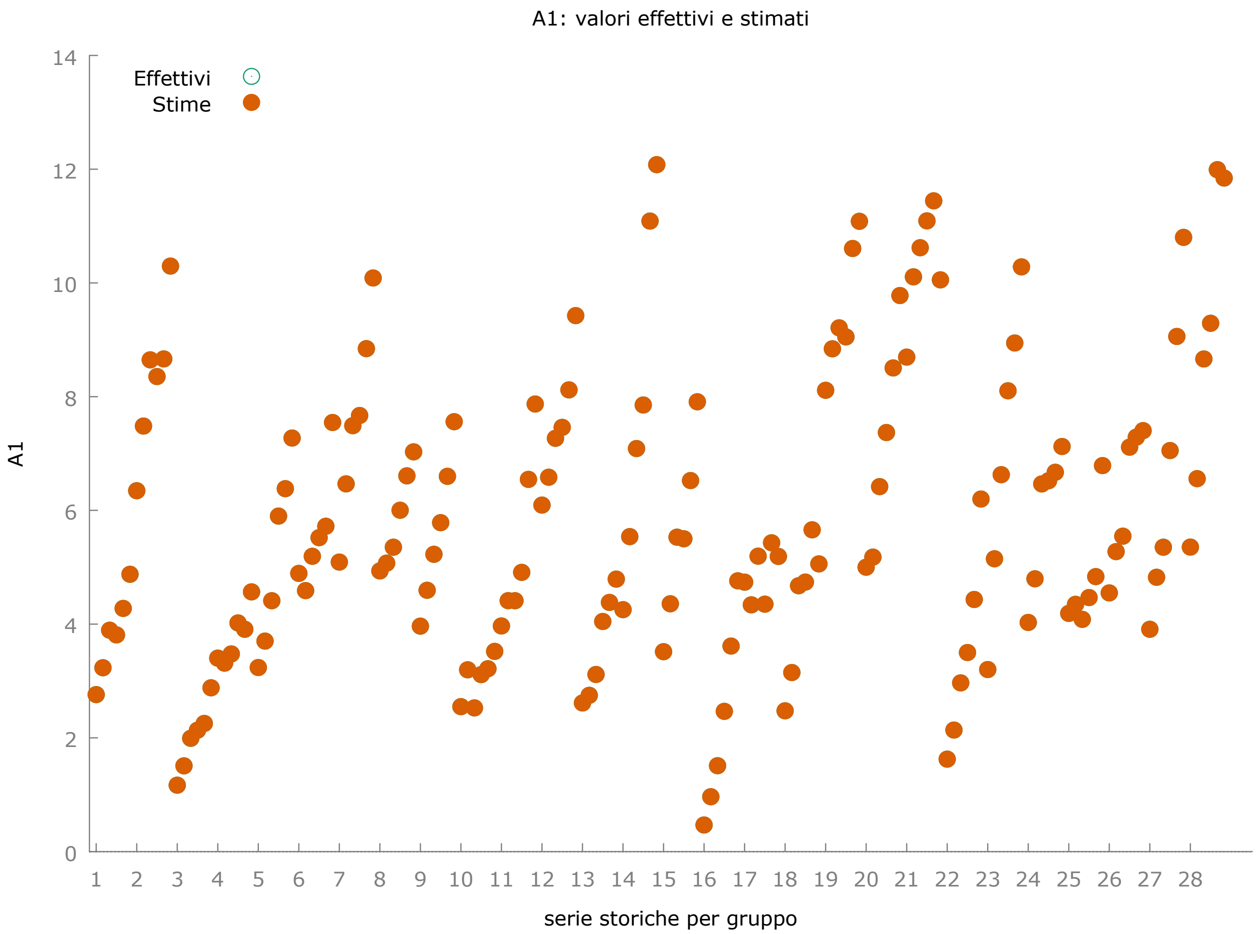


Modello 35: Effetti casuali (GLS), usando 168 osservazioni					
Con trasformazione di Nerlove					
Incluse 28 unità cross section					
Lunghezza serie storiche = 6					
Variabile dipendente: A1					
	Coefficiente	*Errore Std.*	*z*	*p-value*	
const	−0,00019046 5	7,63759e-05	−2,494	0,0126	**
A2	−1,00001	9,87597e-06	−1,013e+005	<0,0001	***
A3	−0,999999	3,77516e-06	−2,649e+005	<0,0001	***
A4	−0,999986	7,97318e-06	−1,254e+005	<0,0001	***
A5	−0,0800088	0,0256025	−3,125	0,0018	***
A11	−0,253599	0,0773479	−3,279	0,0010	***

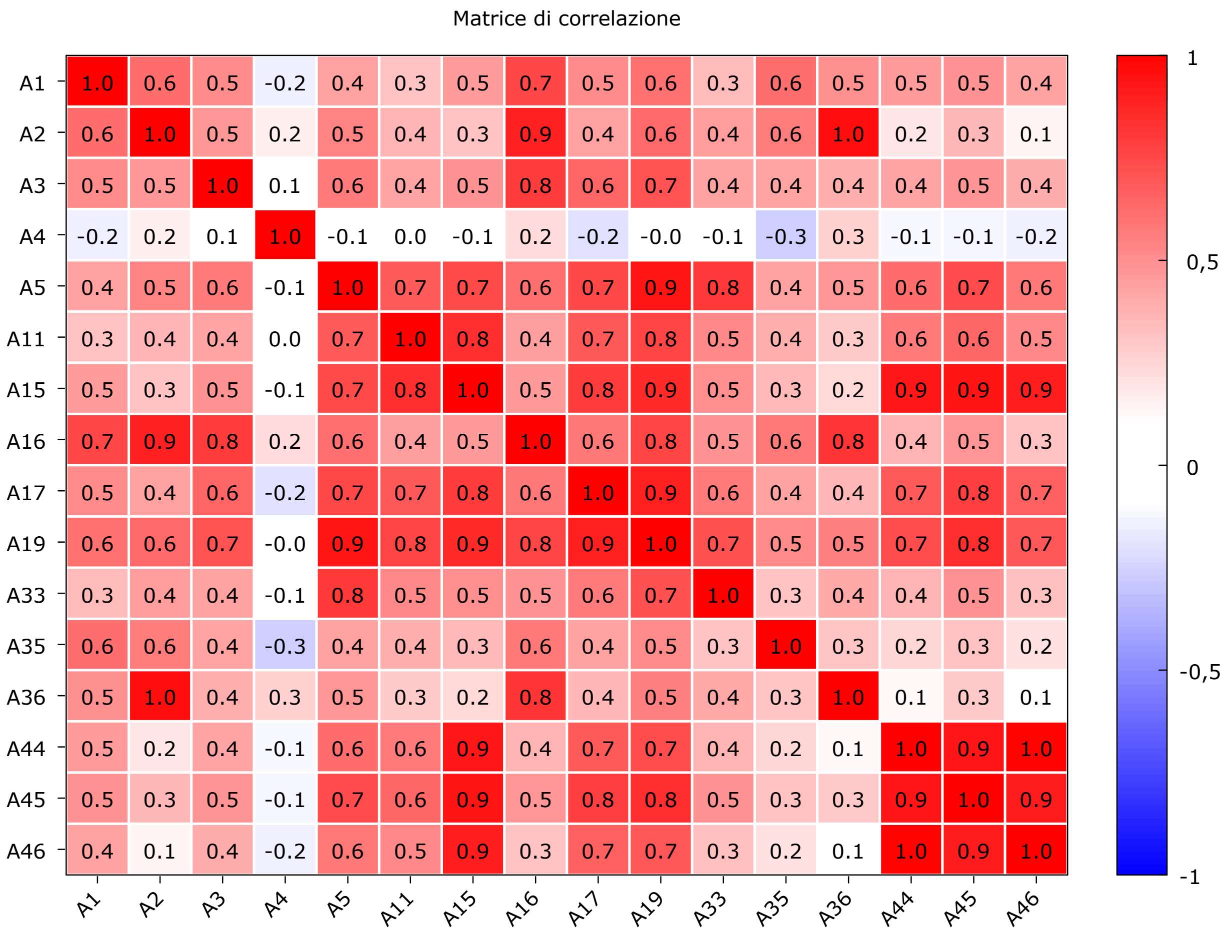
A15	0,694357	0,304846	2,278	0,0227	**
A16	3,67995	0,102409	35,93	<0,0001	***
A17	−0,320050	0,102411	−3,125	0,0018	***
A19	0,320042	0,102410	3,125	0,0018	***
A33	−2,75383e-06	1,20813e-06	−2,279	0,0226	**
A35	5,71519e-06	2,36773e-06	2,414	0,0158	**
A36	4,35747e-06	2,21033e-06	1,971	0,0487	**
A44	−0,126797	0,0386734	−3,279	0,0010	***
A45	−0,126806	0,0386744	−3,279	0,0010	***
A46	−0,126795	0,0386750	−3,278	0,0010	***

Media var. dipendente	5,794404	SQM var. dipendente	2,534831
Somma quadr. residui	4,08e-07	E.S. della regressione	0,000052
Log-verosimiglianza	1427,779	Criterio di Akaike	−2823,557
Criterio di Schwarz	−2773,574	Hannan-Quinn	−2803,271
rho	−0,232265	Durbin-Watson	2,070377

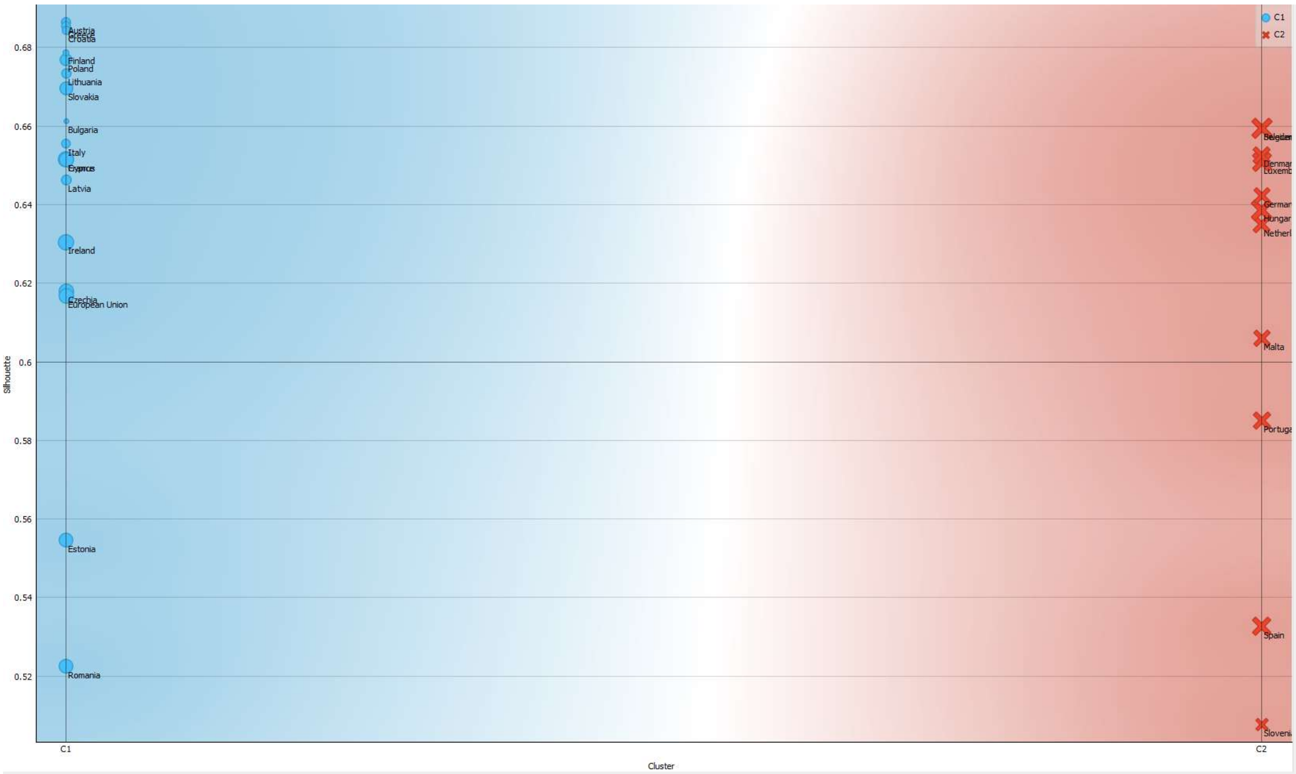
Varianza 'between' = 4,40819e-009
Varianza 'within' = 1,24546e-009
Theta usato per la trasformazione = 0,787936
Test congiunto sui regressori -
Statistica test asintotica: Chi-quadro(15) = 2,48874e+011
con p-value = 0
Test Breusch-Pagan -
Ipotesi nulla: varianza dell'errore specifico all'unità = 0
Statistica test asintotica: Chi-quadro(1) = 0,04295
con p-value = 0,835819
Test di Hausman -
Ipotesi nulla: le stime GLS sono consistenti
Statistica test asintotica: Chi-quadro(15) = 10,8525
con p-value = 0,762976



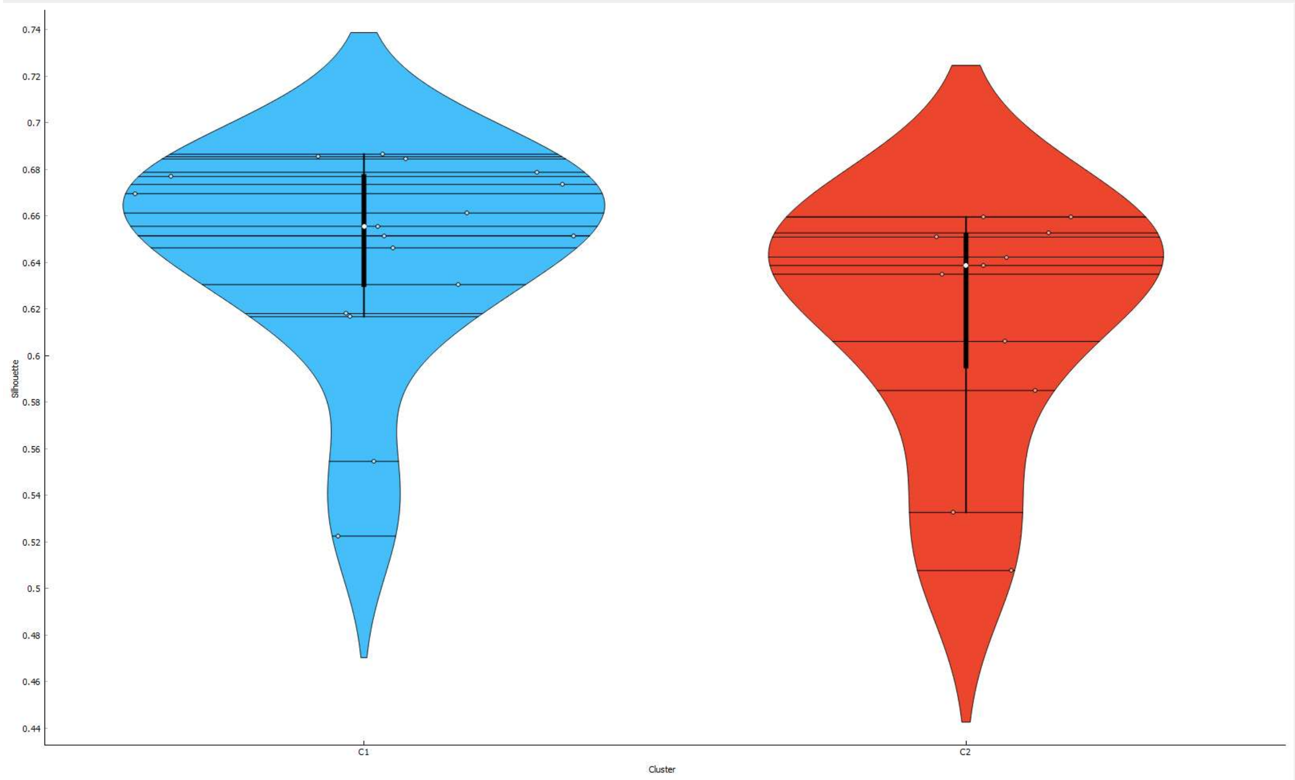
A1: valori effettivi e stimati
Effettivi
Stime
A1
0
2
4
6
8
10
12
14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
serie storiche per gruppo



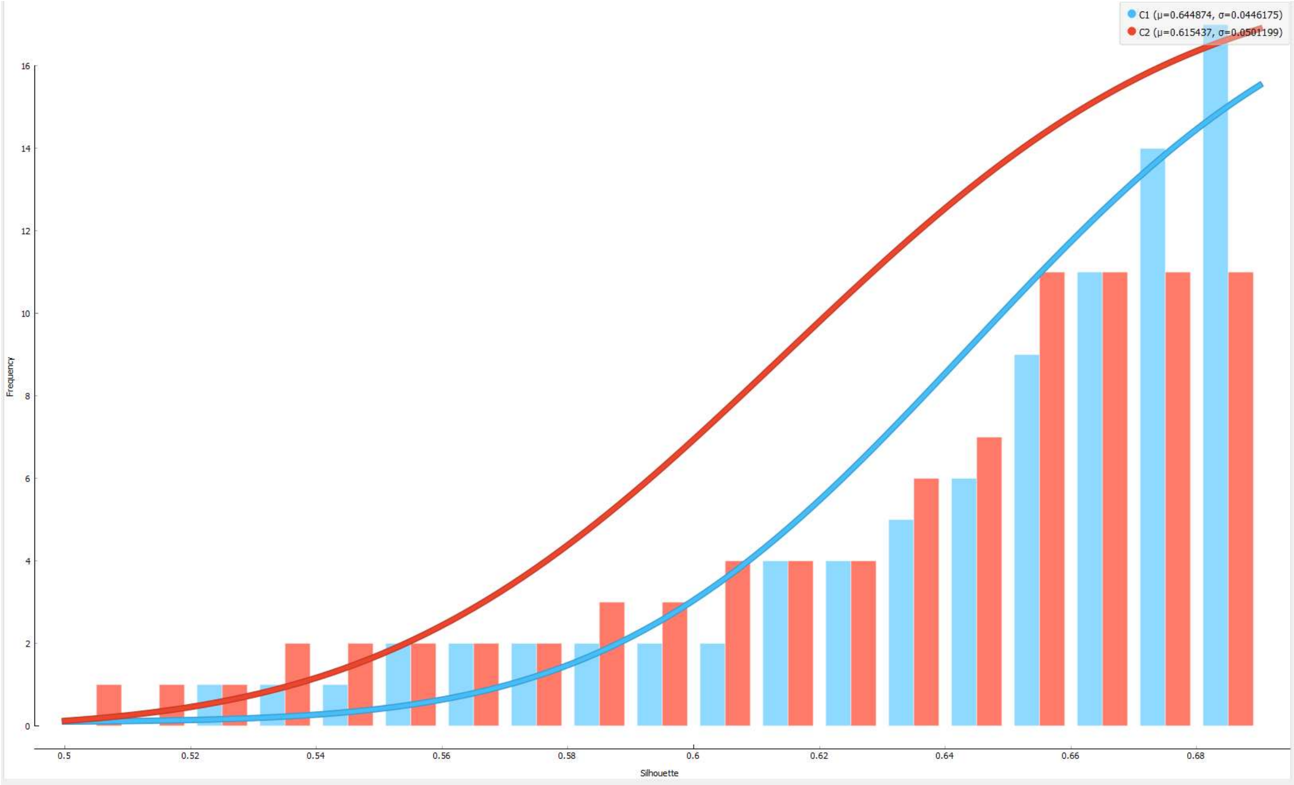
8.1 Clusterization

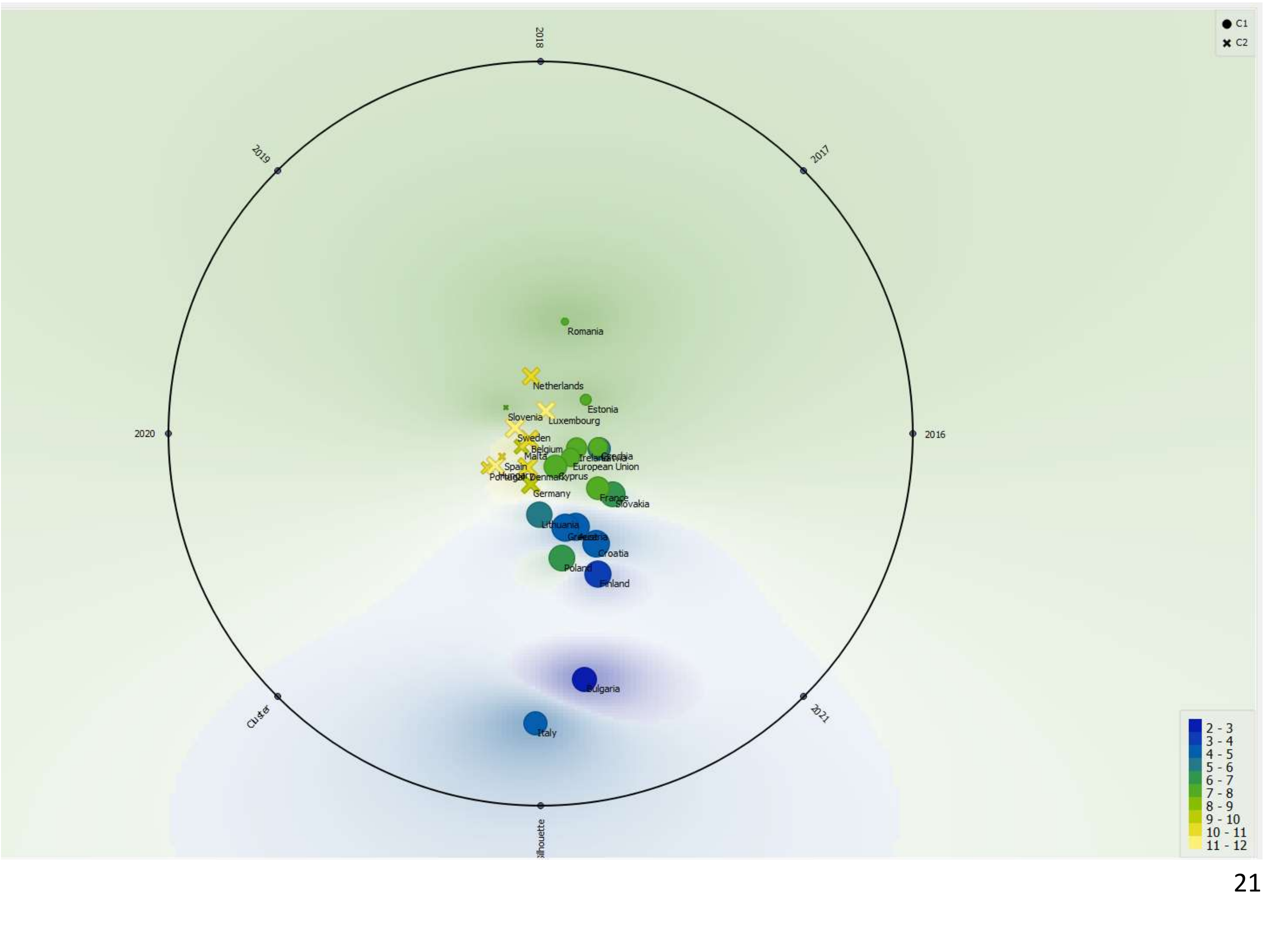


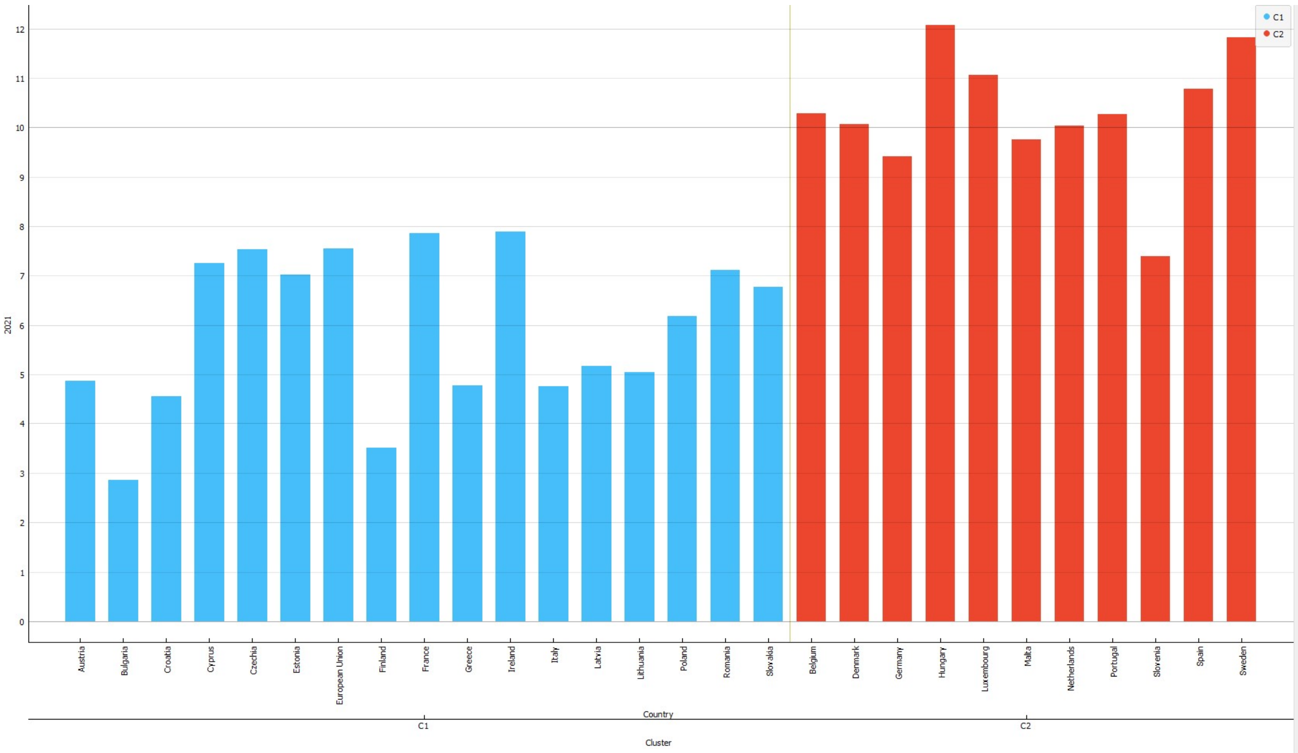
C1
C2
Austria
Croatia
Finland
Poland
Lithuania
Slovakia
Bulgaria
Italy
Latvia
Ireland
European Union
Estonia
Romania
Malta
Spain
Silhouette
Cluster
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52

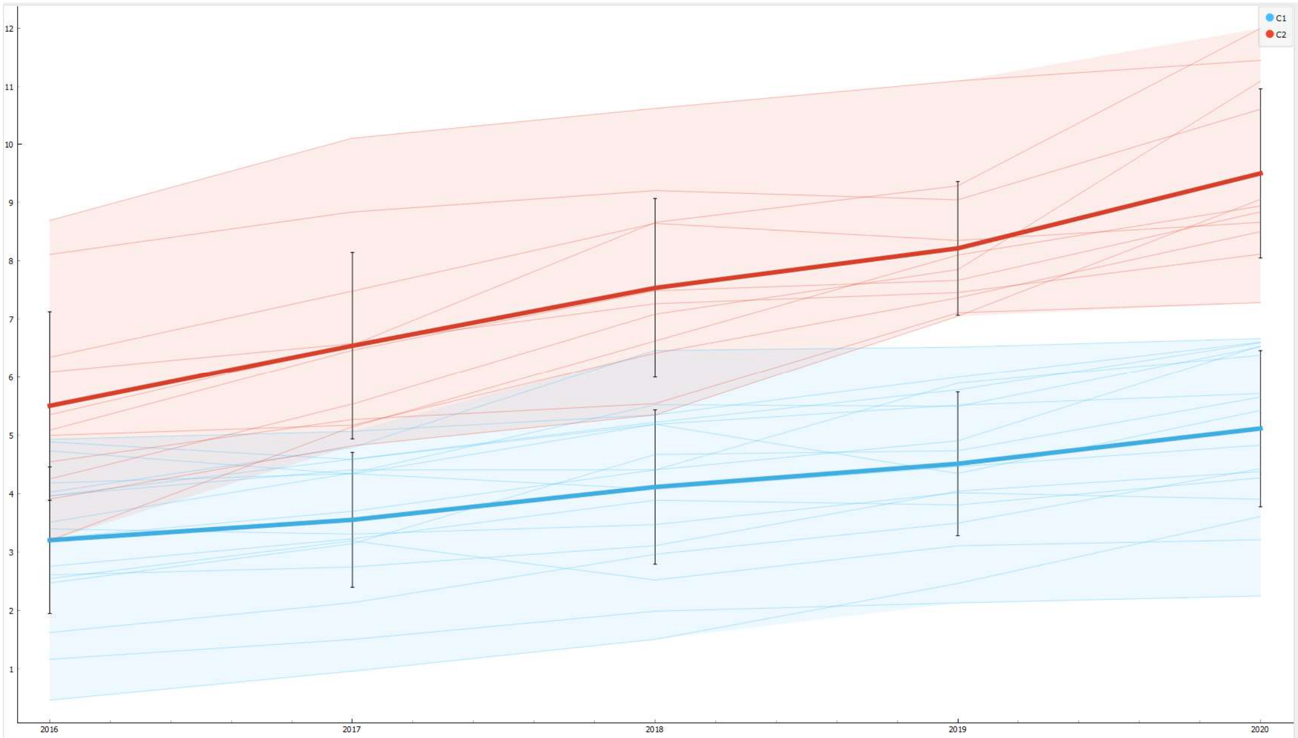


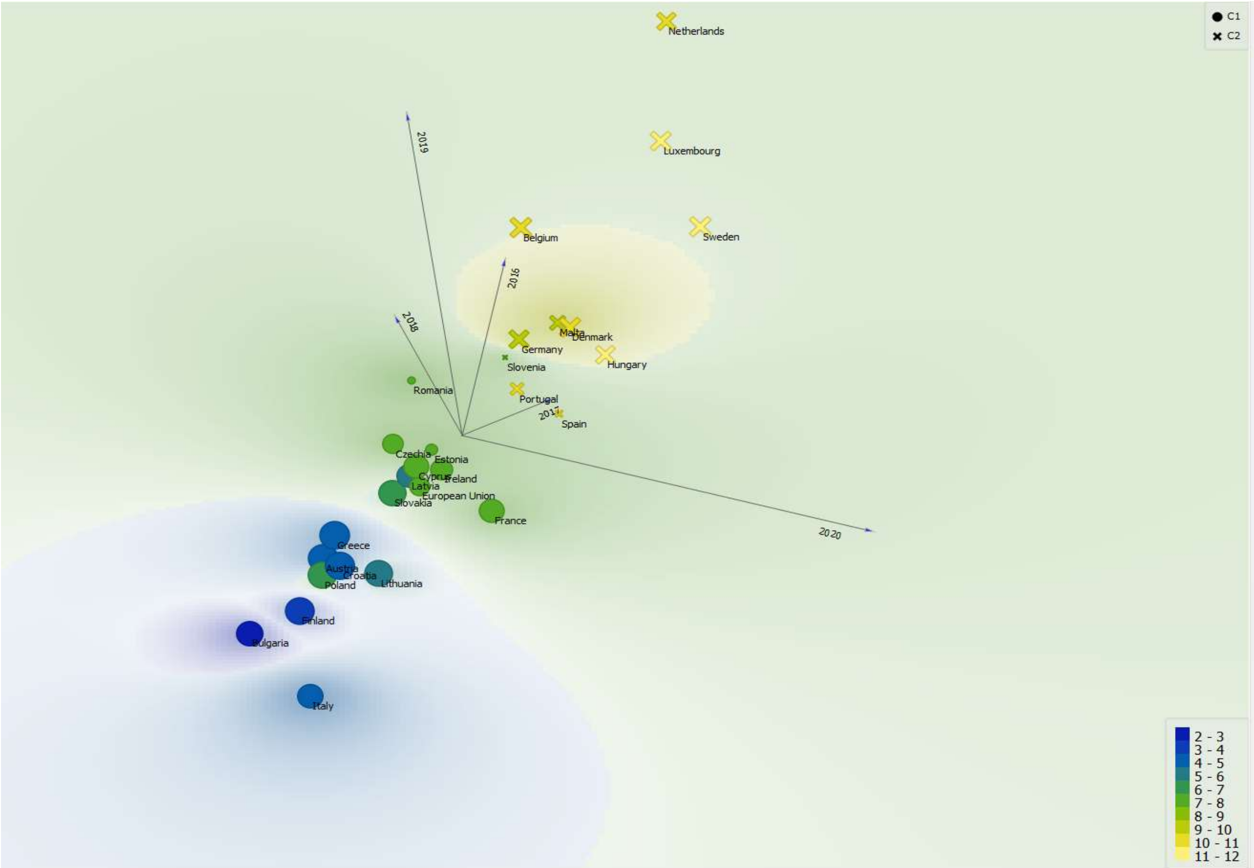
Silhouette
Cluster
C1
C2
0.74
0.72
0.7
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44


C1 (μ=0.644874, σ=0.0446175)
C2 (μ=0.615437, σ=0.0501199)
Frequency
Silhouette
0
2
4
6
8
10
12
14
16
0.5
0.52
0.54
0.56
0.58
0.6
0.62
0.64
0.66
0.68


C1
C2
2018
2017
2016
2021
Silhouette
Cluster
2020
2019
Romania
Netherlands
Estonia
Slovenia
Luxembourg
Sweden
Belgium
Malta
Spain
European Union
Cyprus
Germany
France
Slovakia
Lithuania
Croatia
Poland
Finland
Bulgaria
Italy
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
9 - 10
10 - 11
11 - 12


C1
C2
2021
Austria
Bulgaria
Croatia
Cyprus
Czechia
Estonia
European Union
Finland
France
Greece
Ireland
Italy
Latvia
Lithuania
Poland
Romania
Slovakia
Belgium
Denmark
Germany
Hungary
Luxembourg
Malta
Netherlands
Portugal
Slovenia
Spain
Sweden
Country
Cluster


C1
C2
2016
2017
2018
2019
2020



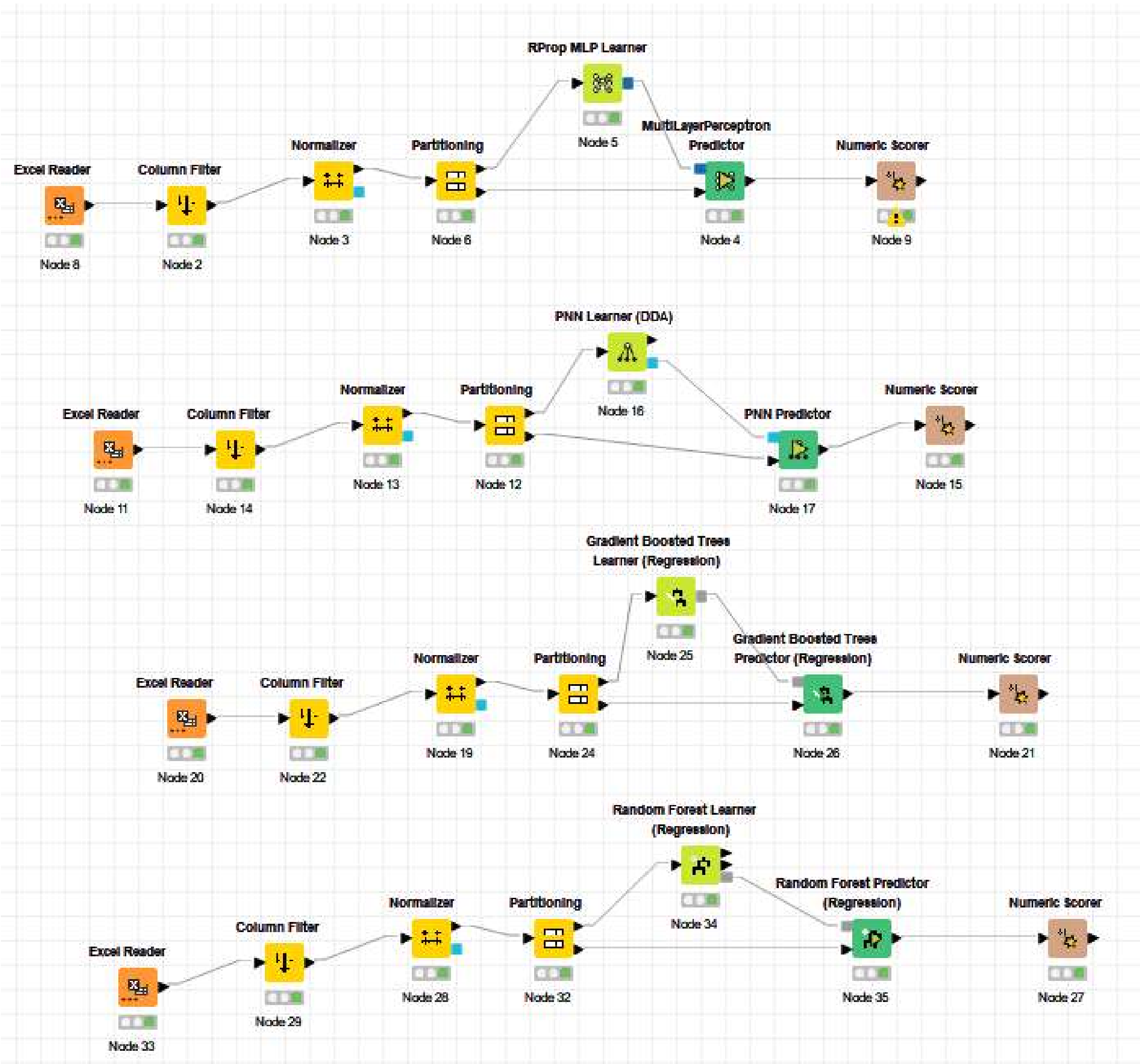
C1
C2
Netherlands
Luxembourg
Belgium
Sweden
2019
2016
2018
Malta
Denmark
Germany
Slovenia
Hungary
Romania
Portugal
2017
Spain
Czechia
Estonia
Cyprus
Ireland
Latvia
European Union
Slovakia
France
2020
Greece
Austria
Croatia
Poland
Lithuania
Finland
Bulgaria
Italy
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
9 - 10
10 - 11
11 - 12

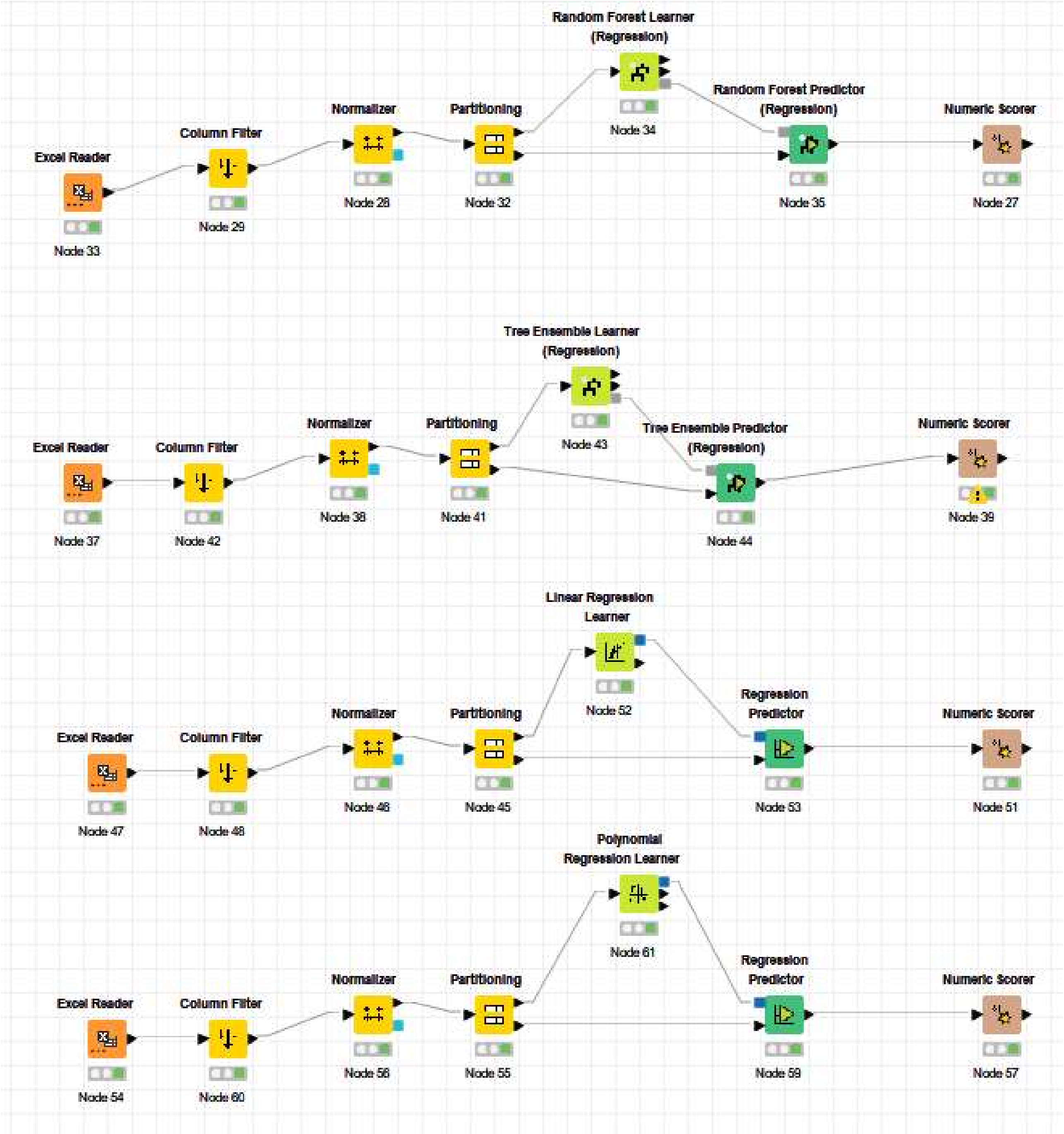
	2021	Country	Cluster
25	6.7886	Slovakia	C1
24	7.12351	Romania	C1
22	6.19958	Poland	C1
18	5.05964	Lithuania	C1
17	5.19057	Latvia	C1
16	4.76134	Italy	C1
15	7.91001	Ireland	C1
13	4.79167	Greece	C1
11	7.8708	France	C1
10	3.52097	Finland	C1
9	7.55956	European Union	C1
8	7.0298	Estonia	C1
6	7.54568	Czechia	C1
5	7.27223	Cyprus	C1
4	4.56732	Croatia	C1
3	2.88067	Bulgaria	C1
1	4.87661	Austria	C1
28	11.8443	Sweden	C2
27	10.8012	Spain	C2
26	7.40247	Slovenia	C2
23	10.2824	Portugal	C2
21	10.0538	Netherlands	C2
20	9.77871	Malta	C2
19	11.0836	Luxembourg	C2
14	12.0795	Hungary	C2
12	9.42512	Germany	C2
7	10.0868	Denmark	C2
2	10.2961	Belgium	C2

8.3 Machine Learning and Predictions

Metric results deriving from the application of machine learning algorithms for prediction					
Algorithm	**R^2**	**Mean absolute error**	**Mean squared error**	**Root mean squared error**	**Mean signed difference**
ANN	0,88015829	0,084827972	0,011087744	0,105298356	0,052255303
PNN	0,22866447	0,136925626	0,027256387	0,165095086	0,099426896
Gradient Boosted Tree	0,68724516	0,114747533	0,024120584	0,155308031	0,069714644
Random Forest	0,574422	0,156736028	0,031885516	0,17856516	0,111307205
Tree Ensemble	0,76634139	0,106375174	0,016251494	0,127481346	0,075187638
Simple Regression Tree	0,62869845	0,132050127	0,02759532	0,166118392	0,070133074
Linear Regression	0,80968226	0,089588227	0,011734267	0,108324822	0,039121802
Polynomial Regression	0,83558713	0,094772093	0,01179839	0,108620394	0,050488137

Ranking of algorithms for predictive efficiency						
Algorithm	**R^2**	**Mean absolute error**	**Mean squared error**	**Root mean squared error**	**Mean signed difference**	**Total**
ANN	1	1	1	1	3	7
Polynomial Regression	2	2	2	2	2	10
Linear Regression	3	3	3	3	1	13
Tree Ensemble	4	4	4	4	6	22
Gradient Boosted Tree	5	5	5	5	4	24
Simple Regression Tree	6	6	7	7	5	31
PNN	8	7	6	6	7	34
Random Forest	7	8	8	8	8	39




Random Forest Learner (Regression)
Node 34
Random Forest Predictor (Regression)
Numeric Scorer
Excel Reader
Column Filter
Normalizer
Partitioning
Node 33
Node 29
Node 28
Node 32
Node 35
Node 27
Tree Ensemble Learner (Regression)
Node 43
Tree Ensemble Predictor (Regression)
Numeric Scorer
Excel Reader
Column Filter
Normalizer
Partitioning
Node 37
Node 42
Node 38
Node 41
Node 44
Node 39
Linear Regression Learner
Node 52
Regression Predictor
Numeric Scorer
Excel Reader
Column Filter
Normalizer
Partitioning
Node 47
Node 48
Node 46
Node 45
Node 53
Node 51
Polynomial Regression Learner
Node 61
Regression Predictor
Numeric Scorer
Excel Reader
Column Filter
Normalizer
Partitioning
Node 54
Node 60
Node 56
Node 55
Node 59
Node 57