Is ‘post-decline’ the next phase of the diffusion of ISO 9001 certifications? New empirical evidence from European countries

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ABSTRACT

ISO 9001 certifications for quality management and assurance are widespread worldwide. Since their introduction, more than two decades ago, their geographical diffusion has been studied and analysed by academics and practitioners in order to understand dynamics, drivers and trends.
This work enriches the state-of-art research on European countries, extending the period of observation to twenty-five consecutive years (i.e., from 1993 to 2017). Apart from confirming the already known diffusion phases – i.e. *growth*, *maturity* and *decline* – this analysis conceptualizes a new diffusion phase: *post-decline*, i.e. a period of time following the phase of decline in which the number of certifications tends to stabilize. This phase can be interpreted as a point of equilibrium between the two opposing forces of (1) incentive to certification and (2) incentive to decertification, which govern the trend of the certifications related to a certain country.

Keywords: *ISO 9001, diffusion, certification, Dynamic Time Warping, Clustering.*

1. INTRODUCTION

Since 1987 – i.e., the year of the introduction of the ISO 9001 standard for quality management and quality assurance – the number of certifications issued has grown steadily, involving an increasing number of firms/organizations. An updated picture of the ISO 9001 certification diffusion across the whole world is given by the last *ISO Survey* (ISO Survey 2018). At 31 December 2017, the number of valid certifications was around 1058500, disseminated in 201 countries (40.8% of them in Europe). These numbers reflect the importance of ISO 9001 certifications for firms/organizations worldwide. Being standards for general application, ISO 9001 certifications are an important marketing tool to develop, strengthen and ease business contract, with both national and international partners, and increase business performance (Martínez-Costa et al. 2009; Sampaio et al. 2009; Terziovski et al. 2003). In general, there are several reasons why organizations seek ISO 9001 certifications (Anderson et al. 2009; Fonseca and Domingues, 2017; Sfreddo et al., 2019; Zimon and Zimon, 2019). Simplifying, ISO 9001 certifications help organizations to define, document and follow the best practices for their key processes, resulting in a higher probability to achieve acceptable outputs (Castka & Corbett 2015). This does not mean that the certified organizations will never produce defective products/services, but that they will be able to manage and respond to them, reducing this eventuality as much as possible. Additionally, ISO 9001 certifications are *de facto* indispensable for the acquisition of certain (national and international) contracts; they are implemented to gain a real or presumed advantage over competitors, etc..

Since the late '90s, many authors focused their research on the impact of ISO 9001 certifications on the performance of organizations (Hussain et al. 2018). It was empirically documented that certifications seem to have a positive impact on quality, although the precise reason for certification is crucial to the actual improvement of quality. For example, organizations that want to be certified because they really want to enhance their quality system are more likely to improve than organizations that do so solely for reasons of image towards their customers (Withers & Ebrahimpour 2000; Castka and Corbett 2015).

ISO 9001 standards are the most successful and widespread standards by the *International Organization for Standardization* (ISO), in terms of numbers and geographical diffusion all over the world. Similarly to other past studies by the same authors (Franceschini et al. 2010), this paper aims to investigate the recent ISO 9001 diffusion trends, analysing the number certifications issued over time, for a representative sample of European countries. Specifically, a clustering of European countries will be carried out, based on the similarity of the corresponding time series of the annual numbers of certifications. Translating into research questions, "Do the recent evolutionary dynamics show any novelties compared to what had emerged in previous studies on ISO-9001 diffusion?". If so, "What are the characteristics of the new diffusion patterns" and "How can these new results be interpreted and justified?".

Important new features of this study with respect to other state-of-art are:

- Larger time window, represented by twenty-four consecutive years (i.e., from 1993 to 2017).
- Clustering method that is suitable to align/compare time series even if they have a different speed of development and are not "synchronized". The resulting clusters of (European) countries will therefore be seen as different snapshots of the same phenomenon, taken at different evolutionary phases.

Data used for this study are drawn from the *ISO Survey 2017* (ISO Survey 2018).

The rest of the paper is organized into five sections. Section 2 provides some theoretical references on the modelling of the dynamics of diffusion of ISO 9001 certifications. Section 3 provides a detailed description of the methodology, with particular reference to data collection and the clustering procedure based on the *Dynamic Time Warping*. Section 4 explains and interprets the results of the analysis.

Section 5 summarizes the original contributions of this paper, its practical implications, limitations and suggestions for future research. Further material on the examined data and information on the *Dynamic Time Warping* approach are contained in the Appendix section.

2. LITERATURE REVIEW

The scientific literature on the diffusion of ISO 9001 certifications has been flourishing and in constant development for about fifteen years. In this period, a network of researchers has contributed from different perspectives: (i) proposing theoretical evolutionary models (Franceschini et al. 2004, 2011a; Salgado et al. 2016; Sampaio et al. 2011); (ii) comparing similar trends in different countries (Fotopoulos et al. 2010; Franceschini et al. 2010), (iii) drawing some parallelisms with the diffusion of other types of certifications (Franceschini et al. 2008, 2011b; Alonso-Almeida et al. 2013; Cabecinhas et al. 2018; Cabecinhas et al. 2019; Hernandez-Vivanco et al. 2019), and (iv) linking the number of certifications issued with macro-economic variables (Tricker 2009) or the performance of individual national organizations (Franceschini et al. 2018; Galetto et al. 2017; Sampaio et al. 2012). Many authors tried to find empirical evidences of the relation between the adoption of ISO 9001 certifications and business performance. One of the most interesting result is that certification contributes to business performance when the quality culture is well developed within organizations and when the predominant managerial motivation is to improve the performance and not just to conform to a standard (Anderson et al. 2009; Franceschini et al. 2006). To this purpose, Clougherty e Grajek identified three main drivers of ISO 9001 adoption among organizations (Clougherty & Grajek 2008):

- *Quality commitment signal*. Standards represent a signal of the organizations' commitment to follow a documented quality system, which has been proved to reduce trade barriers between commercial businesses, both at national and international level (Terlaak & King 2006).
- *Common language*. Certifications define a common language, which helps business relations to decrease trade and linguistic barriers, also reducing costs.
- *Conflict settling*. ISO 9001 standards may help to reduce and, in many cases, settle organizational disputes (Hoffman & Ventresca 2002). Furthermore, by clarifying the division of labour and responsibilities involved with complex inter-organizational productions, ISO 9001 certification minimizes inter-organizational conflict as it can help to clarify situations where faults are unintended and not due to opportunistic behaviour.

These three features are the basis of the relative diffusion of certifications in many countries, even in the presence of significantly heterogeneous cultural traditions.

3. THEORETICAL BACKGROUND

3.1 Diffusion of ISO 9001 certifications

According to data proposed in Table 1, withdrawn from the last ISO Survey available (ISO Survey 2018), the number of ISO 9001 certifications in Europe is historically higher than in other continents. This is probably also due to the fact that Europe was the first continent to adopt this standard.

Table 1 *Number of ISO 9001 certifications per geographic macro-areas, in the 1993-to-2017 period [**Source:** ISO (2018)]*

	Europe	Africa	Central and South America	Nord America	East Asia and Pacific	Central and South Asia	Middle East	TOTAL
1993	37779	1009	140	2613	4767	74	189	46571
1994	55400	1177	475	4915	7719	330	348	70364
1995	92611	1563	1220	10374	19766	1038	776	127348
1996	109961	2255	1713	16980	27885	1712	2194	162700
1997	143674	2555	2989	25144	42824	2963	3149	223298
1998	166255	3342	5221	33550	54671	3556	5251	271846
1999	190247	4928	8972	45166	81950	5508	6870	343641
2000	219173	4769	10805	48296	109217	6411	9003	407674
2001	269648	3903	14409	50894	155597	6348	9550	510349
2002	292878	4529	13679	53806	177767	9383	9724	561766
2003	242455	3769	9303	40185	185846	9162	7199	497919
2004	320748	4865	17016	49962	240938	13856	12747	660132
2005	377172	6763	22498	59663	266100	27966	13681	773843
2006	414208	7441	29382	61436	320320	44923	19195	896905
2007	431479	7446	39354	47600	354056	50379	21172	951486
2008	455303	8534	37458	47896	366491	44171	20469	980322
2009	500286	8435	35549	41947	408498	44432	24604	1063751
2010	530039	7667	49260	36632	396492	37596	18839	1076525
2011	459367	8164	51685	37530	402453	33577	17069	1009845
2012	469739	9674	51459	38586	396398	32373	19050	1017279
2013	458814	9816	52466	48579	387543	44847	20812	1022877
2014	453628	10143	50165	41459	414801	44790	21335	1036321
2015	439477	12154	49509	46938	422519	40822	22761	1034180
2016	451415	13378	52094	44252	480445	41370	22983	1105937
2017	387836	11210	45541	38218	513742	39887	20421	1056855

Examining aggregated data in Table 1, it can be seen that the total number of ISO 9001 certifications continued to grow steadily from 1993 to 2010 (see also Figure 1). The only exception was registered in 2003, with a 17% reduction in Europe and a 11% reduction in the world, compared to the year 2002. This is probably due to the changeover from the ISO 9001:1994 to the ISO 9001:2000 version (Franceschini et al. 2010; Fonseca and Domingues 2017).

In the years 2011 to 2016, it seems that certifications in Europe have reached a sort of saturation level around the value of about 450 000. In 2017, i.e., the last year examined, there was even a decrease below 400 000 units. According to ISO, the reasons can be traced back to various causes, including the following aspects: (i) some large certification bodies reported in past surveys the number of sites instead of that of certificates (ii) some important certification bodies did not participate to the last survey. On the other hand, the portion of certifications of East Asia and Pacific is progressively growing (see Figure 2). In fact, this is the macro-area with the highest share in 2017.

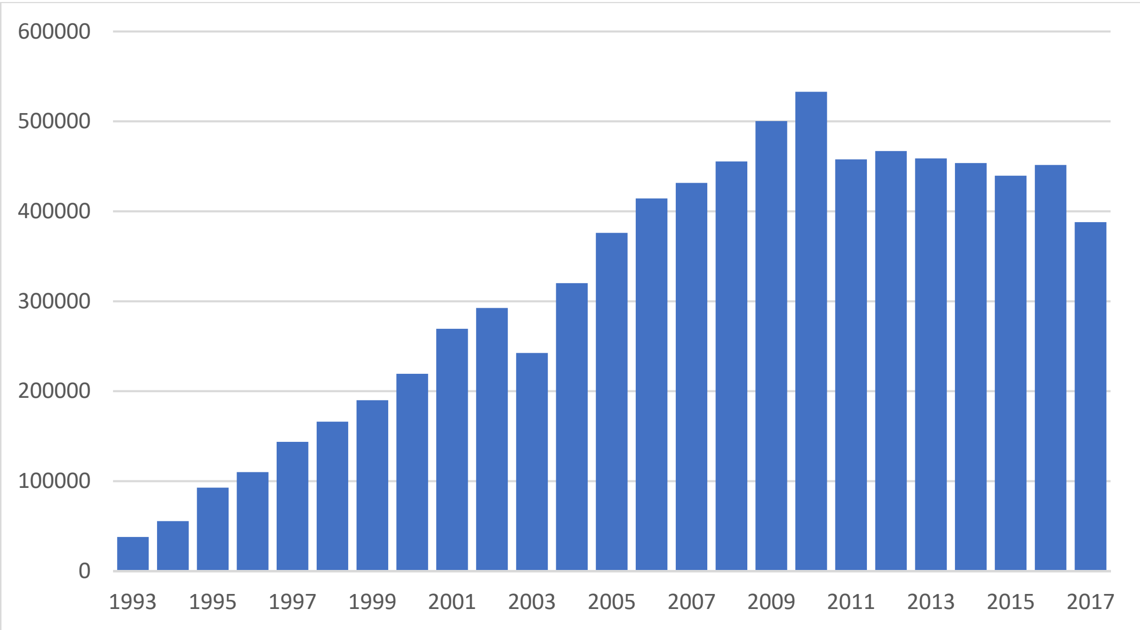

Figure 1 *Number of ISO 9001 certifications in Europe.*

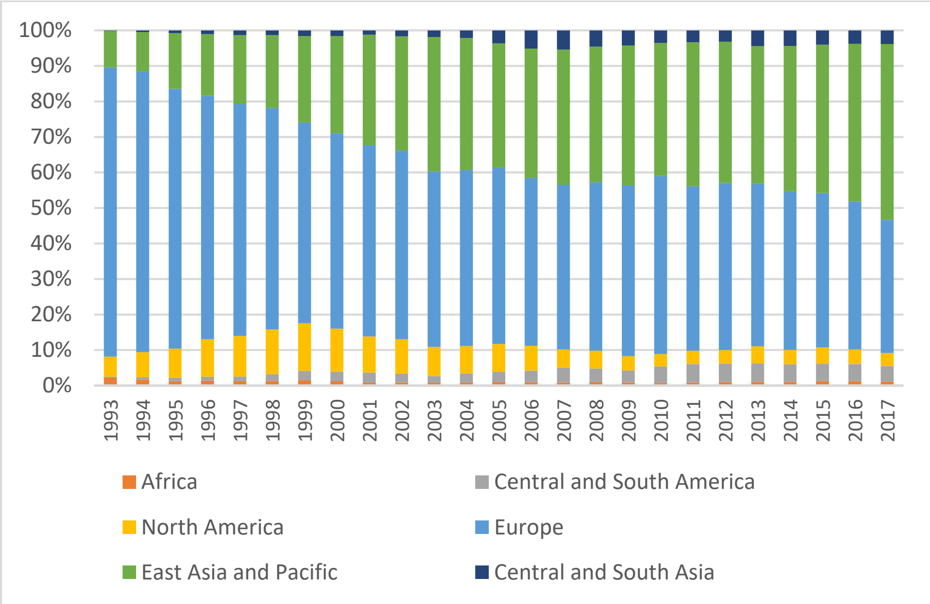

Figure 2 *World Regional Share of ISO 9001 certifications.*

3.2 Diffusion phases (patterns) in Europe

In general, the diffusion patterns of ISO 9001 certifications are not "synchronous": while for some countries these certifications have spread rapidly since their introduction, for other countries they have evolved more slowly and more uncertainly. Let us compare, for instance, certification data related to UK and Italy in the early '90s (see Table 2).

Table 2 *Number of ISO 9001 certifications in the 1993-to-2017 period for a selection of European countries (top six countries in terms of Gross Domestic Product) [**Source:** ISO (2018)].*

	France	Germany	Italy	Russia	Spain	UK
1993	1586	1534	864	5	320	28096
1994	3359	3470	2008	8	586	36825
1995	5536	10236	4814	22	1492	52595
1996	8079	12979	7321	56	2496	53099
1997	11920	20656	12134	95	4268	56696
1998	14194	24055	18095	132	6412	58963
1999	16028	30150	21069	541	8699	63700
2000	17170	32500	30367	1134	12576	63725
2001	20919	41629	48109	1517	17749	66760
2002	19870	35802	61212	1710	28690	60960
2003	15073	23598	64120	962	31836	45465
2004	21769	26654	84485	3816	40972	50884
2005	21700	39816	98028	4883	47445	45612
2006	21349	46458	105799	6398	57552	40909

2007	22981	45195	115359	11527	65112	35517
2008	23837	48324	118309	16051	68730	41150
2009	23065	47156	130066	53152	59576	41193
2010	29713	50583	143305	62265	59854	43293
2011	29215	49540	142853	13308	53057	41943
2012	29198	51701	136547	12488	59418	42304
2013	29598	56303	135939	11764	42644	42843
2014	29112	55344	139416	11213	35995	39982
2015	27844	52995	132870	9084	32730	40161
2016	23403	66233	150143	5083	34438	37901
2017	21808	64658	97646	3490	31984	37478

As a further example – while in the UK the number of certifications grew constantly until 2001, reaching a sort of saturation in the last decade, in France it continued to grow until 2015, eventually declining in 2016. The diffusion dynamics may probably depend on the peculiar politic and economic conditions of each country (Franceschini et al. 2004). Rather than different evolution trends, these patterns can be considered as different pictures of the same phenomenon, taken at different stages of its evolution (Franceschini et al. 2010).

According to several authors, three different phases of the diffusion of ISO 9001 certifications can be identified (Casadesús & Karapetrovic 2005; Llach et al. 2011; Marimon et al. 2009):

- *Growth* phase, in which the number of ISO 9001 certification grows constantly. In this phase, the certification is generally perceived as a distinguishing factor for organizations.
- *Maturity* or *saturation* phase, in which the number of certifications remains steady, probably because of the reduction of competitive gap between certified and non-certified organizations, and the limited number of potential organizations that can be still certified make ISO 9001 less desirable. However, this saturation effect strongly depends on the economic and productive structure of each country (Franceschini et al. 2004).
- *Decline* phase, in which the number of certifications gradually decreases, mainly due to the loss of appeal and the erosion of the benefits resulting from certification (Casadesús & Karapetrovic 2005).

Figure 3 shows a schematic representation of these three phases.

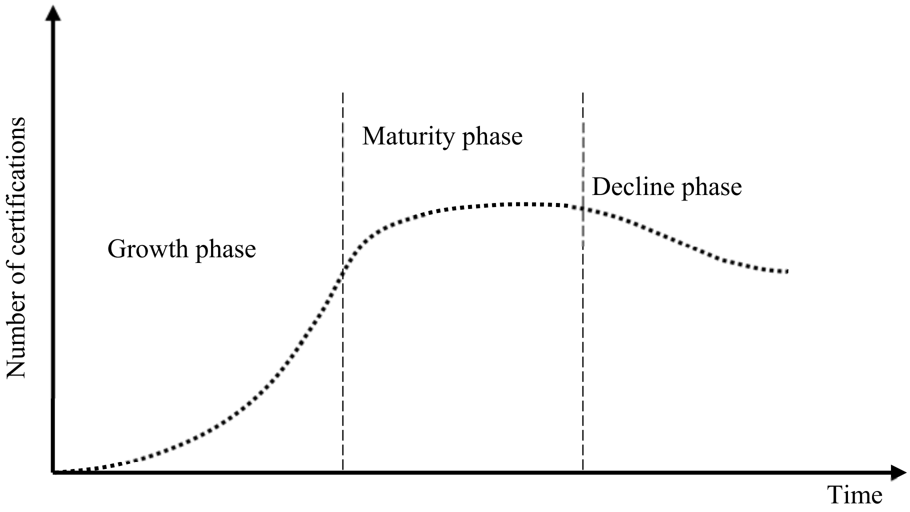

Figure 3 *Schematization of the three diffusion phases of ISO 9001 certifications.*

Considering, for example, the situation in the UK (see data in Table A.1 and A.2), these three phases can be clearly identified and are followed by a new "not-yet-identified" phase, in which the number of certifications stabilizes at a certain level, with some fluctuations around it. Based on the results of a cluster analysis of the data related to the major European countries, the next sections will update the existing diffusion model by proposing an additional development phase.

4. METHODOLOGY

Data used in this analysis refer to the number of certifications issued in the major European countries, in the period 1993-2017, (see Tables A.1 and A.2 in Appendix A). Only a sample of relatively large European countries was considered, due to the limited information concerning the other ones; as a conventional rule, we selected only those countries with at least 500 certifications issued in the year 2006 (Franceschini et al. 2010). Below is the list of selected countries:

1	Austria	11	Greece	21	Romania
2	Belarus	12	Hungary	22	Russia
3	Belgium	13	Ireland	23	Slovakia
4	Bulgaria	14	Italy	24	Slovenia
5	Croatia	15	Latvia	25	Spain
6	Czech Republic	16	Lithuania	26	Sweden
7	Denmark	17	The Netherlands	27	Switzerland
8	Finland	18	Norway	28	Turkey
9	France	19	Poland	29	Ukraine

10	Germany	20	Portugal	30	United Kingdom

The time series concerning the number of ISO 9001 certifications are then clustered using a specific *agglomerative* hierarchical clustering algorithm, borrowed from Data Mining techniques. In this algorithm, initially each *data point* (i.e., a time series concerning the certifications issued in a certain country) is considered as an individual cluster. At each iteration, the similar clusters merge with other clusters until *k* clusters are formed.

Translating into basic operations, this algorithm includes the following steps:

- Compute a so-called *dissimilarity* matrix;
- Let each data point be a cluster;
- Merge the two closest clusters and update the *dissimilarity matrix*;
- Repeat until *k* clusters remains.

Key operation is the computation of the *dissimilarity* of two clusters. In general, merges are determined in a "greedy" manner, selecting the most similar data points. To this purpose, an appropriate dissimilarity function is defined (see Appendix B). Graphically, the final output of the clustering consists of a hierarchical tree, known as *dendrogram*; Appendix C contains the dendrogram resulting from the proposed clustering. For further details, we refer the reader to (Rokach & Maimon 2005).

The main criticality in the use of hierarchical clustering algorithms is the definition of the measure of dissimilarity. The *Dynamic Time Warping* (DTW) approach was chosen for this study (Bemdt & Clifford 1994; Keogh & Pazzani 2001; Keogh & Ratanamahatana 2005). In fact, this approach is flexible and well suited to some peculiar features concerned with the time series relating to ISO 9001 certifications, such as:

- The time of initial adoption of these certifications may vary from country to country;
- The diffusion dynamics can be faster or slower – for example, some phases may be longer for some countries than for others – depending in general on external factors (e.g., public administrations encouraging/forcing organizations to obtain certification);
- At a certain moment, different countries will not necessarily experience the same phase (see Figure 3); e.g., some countries may have already shown the decline phase while others are still experiencing the growth phase.

The DTW method has been used in various application fields, including the most disparate ones, such as voice recognition and motor-activity recognition. In a nutshell, this method allows to "align" two time series (even with a different number of elements) and to compute their *distance* (or dissimilarity).

Although many other (dis)similarity measures can be used, the DTW algorithm is an interesting approach to solve the problem of the temporal mismatch between time series, due to the "asynchronous" diffusion of the ISO 9001. In general, the DTW uses a dynamic programming approach to find the optimal alignment of two time series through a non-linear distortion (i.e., the so-called *warp*) with respect to the independent variable (typically time), so that the distance measure between the series is minimized (Keogh & Ratanamahatana 2005). Appendix B provides a more detailed explanation of the method.

Table 3 contains the dissimilarity values related to a sub-sample of countries; in order to facilitate comparison between countries of different sizes, the initial data – i.e., the series with the number of certificates issued annually for a certain country – have been normalised by dividing by the corresponding maximum value of the series (Franceschini et al. 2004, 2010; Marimon et al. 2009).

The matrix in Table 3 shows that France, Germany and Italy seem to have similar diffusion pattern, being their distance values relatively low. On the other hand, the diffusion patterns of Russia and UK seem to be dissimilar from each other and from the rest of the countries.

Table 3 *Dissimilarity Matrix of a sub-sample of European countries, containing the dissimilarity values resulting from the DTW approach.*

	France	**Germany**	**Italy**	**Russia**	**Spain**	**UK**
France	0					
Germany	1.31	0				
Italy	1.23	1.37	0			
Russia	6.57	6.83	5.94	0		
Spain	2.16	2.62	2.26	3.45	0	
UK	4.19	5.40	6.85	11.13	4.06	0

4. RESULTS

The application of the aforementioned clustering algorithm produced an optimal number of nine clusters: four major (containing three or more countries) and five minor clusters which contain countries with singular behaviours that can therefore be considered as "anomalies". See Appendix C for further details concerning the results of the clustering. The Group-Average hierarchical clustering algorithm was applied in order to group the clusters (Rokach & Maimon 2005); precisely, this technique defines the distance between two clusters as the average distance between each of their members.

Figure 4 shows the ISO 9001 certifications diffusion patterns for the countries belonging to the first cluster, the biggest one in terms of number of countries. A trend of constant growth can be noticed for all the countries over the period 1993-2017, eventually reaching a saturation level during the last five-eight years. The growth phase model proposed by Franceschini et al. (2010) is well recognizable for the countries in this cluster.

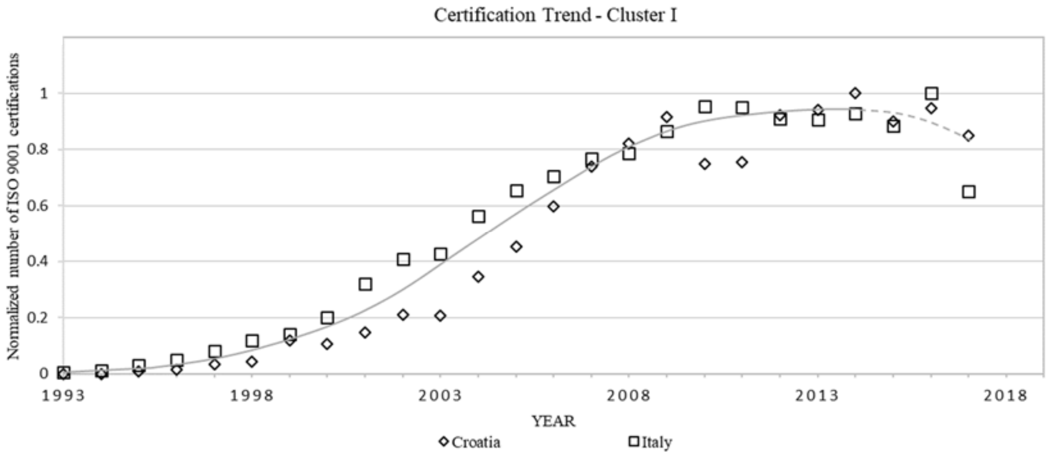

Figure 4 *Diffusion pattern for a selection of countries in cluster I. Bulgaria, Croatia, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Switzerland, Latvia, Greece and Slovakia belong to this cluster. The grey line qualitatively represents the general trend of this cluster.*

Some Central European and Scandinavian countries belong to the second cluster (see Figure 5). For these countries, the growth of ISO 9001 certifications slowed down in the early 2000s, when they probably entered their maturity phase.

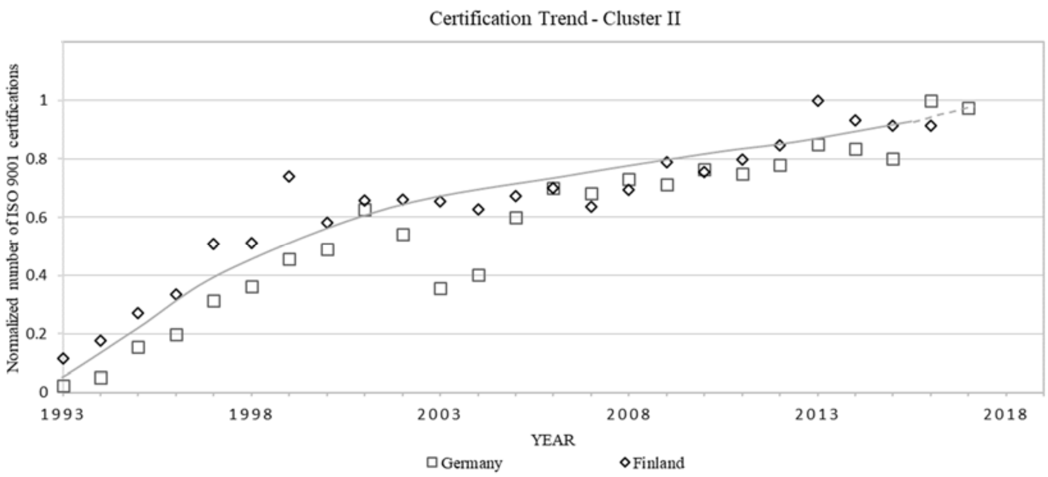

Figure 5 *Diffusion pattern for a selection of countries in cluster II. Finland, France, Germany and Norway belong to this cluster. The grey line qualitatively represents the general trend of this cluster.*

Figure 6 shows the general pattern of the third cluster; these countries (Austria, Sweden, Belgium and Czech Republic) already experienced the growth and maturity phases and are currently facing a sort of decline.

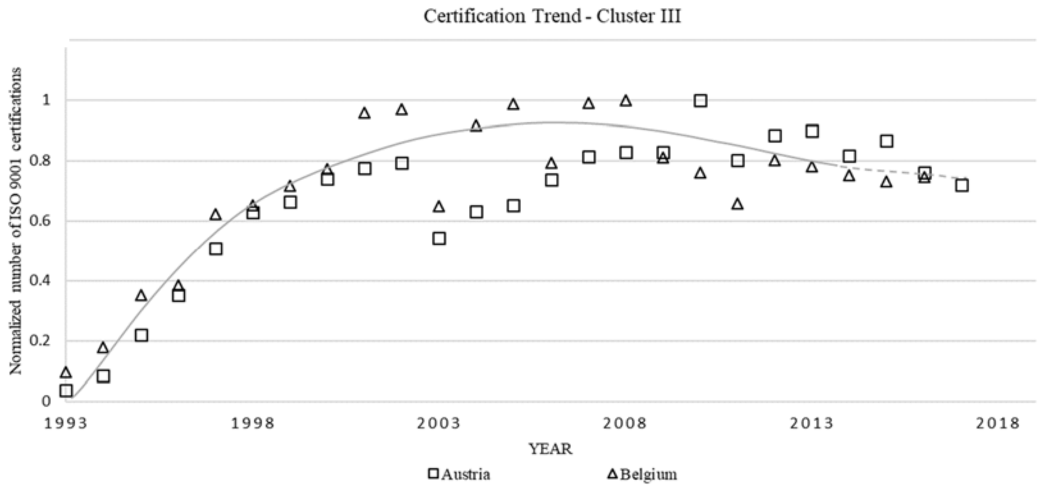

Figure 6 *Diffusion pattern for a selection of countries in cluster III. Austria, Sweden, Belgium and Czech Republic. The grey line qualitatively represents the general trend of this cluster.*

Hungary, Ukraine, Spain and Turkey belong to cluster IV (see Figure 7). The typical trend of certification diffusion in these countries includes the three afore-mentioned phases (growth, maturity and decline) but also a subsequent one, which we have referred to as *post-decline* phase. This new phase seems to complete (at least at the time of writing) the three-phase diffusion model previously theorized (see Sect. 3.2). In the next section, we will provide a practical interpretation of this new phase. In general, the results of this analysis can be seen as an evidence of the novel four-phase diffusion model theorized in this paper. Since the afore-presented clusters can be considered as snapshots of the same phenomenon, taken at different times, post-decline probably represents the future evolution of countries that are still experiencing the first three phases (i.e., those in clusters I, II and III).

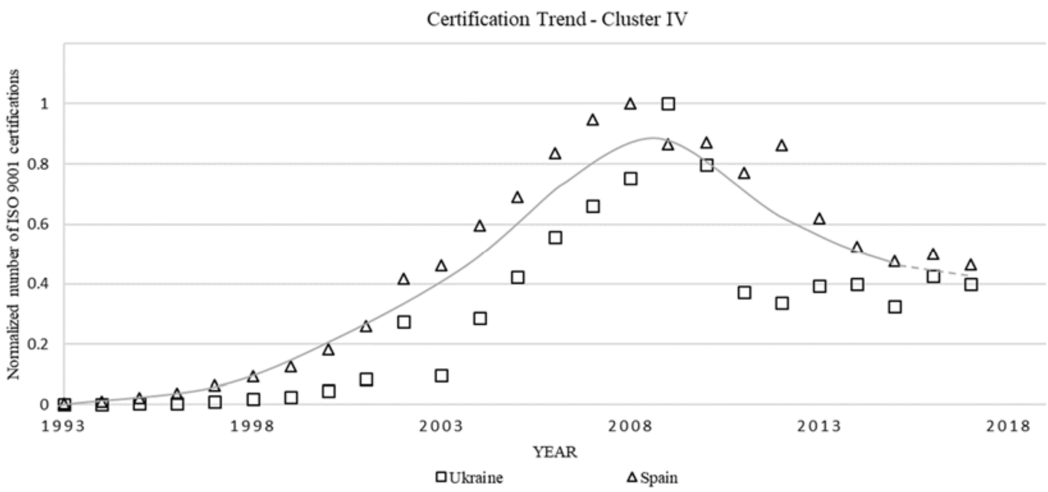

Figure 7 *Diffusion pattern for a selection of countries in cluster IV. Hungary, Ukraine, Spain and Turkey belong to this cluster. The grey line qualitatively represents the general trend of this cluster.*

The remaining (minor) clusters are those to which countries with singular diffusion patterns belong and can therefore be considered as anomalies. These anomalies may be due to several factors, including noise in ISO survey data or nation-specific political/social dynamics.

For the sake of completeness and as an example of anomaly Fig. 8 reports the cluster containing Russia and Belarus. For this group, the data reveal the presence of some “oddities”: i.e., in some years, the number of certifications collapses by an order of magnitude and then goes up again to the previous levels. The authors’ interpretation is that the two sudden “collapses” in the number of certifications of Russia and Belarus are somehow conditioned by the launch of an international reintegration initiative for former-Soviet countries, i.e. the so-called (Russian-led) *Custom Union*, founded in 2011 and re-founded, after four years of questionable effectiveness, in 2015 into the so-called *Eurasian Economic Union* (Vinokurov 2017). This international initiative has involved Russia, Belarus, Kazakhstan, Armenia and Kyrgyzstan, imitating – in a certain antagonistic way – the European Union (EU) model and contributing to divert the attention of companies from (former Soviet) countries from Western markets. This led to an inevitable loss of interest in ISO 9001 certification, which – although representing an almost indispensable condition for trade with Western countries – is not historically relevant for trade between former Soviet countries.

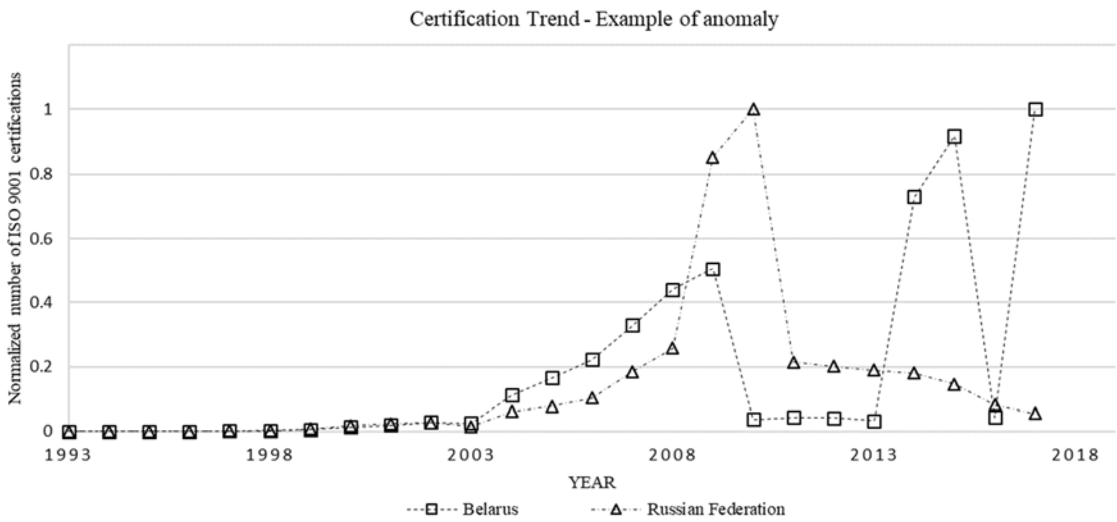

Figure 8 *Example of anomaly: diffusion pattern of ISO 9001 certifications in Belarus and Russia*

A common aspect of all the anomalies is that they are generally linked to exceptional international events/disruptions, which have led to an economic/political/social reorganization of entire nations. The fact that economic variables may affect the number of certifications was also documented in (Salgado et al. 2016).

5. CONCLUDING REMARKS

According to the last ISO Survey, the number of ISO 9001 certifications issued in 2017 was almost 1060000 in 201 countries. Although this result reflects the international prominence of this standard, the analysis confirmed interesting differences between European countries, showing that some countries have reached for several years now a sort of saturation/stabilization in terms of number of certifications.

Precisely, four relevant clusters of European countries have been found. These clusters can be considered as pictures of the same diffusion phenomenon, taken at different evolution stages. In general, the diffusion of ISO 9001 certifications can be decomposed into four consecutive phases: *growth*, *maturity*, *decline* and *post-decline*. The theorization of the last phase – in which the number of certifications seems to stabilize around a level that is significantly lower than the peak of the time-series curve – represents an important novelty for the existing literature.

The first two clusters (I and II) clearly show the growth and maturity phases, with a sort of saturation pattern in the latter years. On the other hand, the two other phases of decline and post-decline are peculiar of the countries in the remaining two clusters (III and IV): while the former cluster includes countries having just experienced the decline phase and eventually approaching a new post-decline phase, the latter cluster includes countries that have experienced the post-decline phase for more than ten years. Summarizing, the overall trend seems to be the same for each country, but timing and dynamics tends to vary from country to country.

At this point, a question that may be raised is: "*What are the contingent causes of the sort of "late stabilization" characterizing the post-decline phase?*". Our interpretation is that, once the maturity phase is over and the decline phase has begun, the trend of the certifications related to a certain country is governed by two opposing external stimuli (partly mentioned in Sect. 2):

1. *Incentive to certification*, which includes, for example, the competitive advantage over competitors, the promotion by governmental bodies, the fact that certification represents a *conditio sine qua non* to operate in certain markets, etc. (Franceschini et al. 2011a);
2. *Incentive to decertification* (i.e., reduction of the propensity to obtain certification), which includes, for example, costs and bureaucratic burden in the application of ISO 9000 standards, apparent lack of advantages for organizations with a well-rooted quality culture, etc. (Casadesús & Karapetrovic 2005).

Although the first stimulus favours the diffusion of certifications, it tends to attenuate as the diffusion itself increases. Symmetrically, although the second stimulus encourages decertification, it tends to attenuate with increasing decertification itself. The characteristic "late stabilization" of the post-decline phase can therefore be interpreted as a point of equilibrium between these two stimuli. Curiously, we note that the magnitude of the post-decline level is around 60% of the peak of the curve, which is generally recorded in the maturity phase (see Figure 7). This means that, on average, three out of five organizations continue to be certified during the post-decline period, while the remaining two decided to waive certification with respect to the peak moment. The 60% value is probably not a "magic" number, but it could depend on contingent causes that are likely to change from country to country. Perhaps variations in (at least one of) the two opposing stimuli can result in further variations in the stabilization level of the post-decline (e.g., "jumping" to a different level).

The analysis of ISO 9001 diffusion models can (i) drive certification bodies to better understand the effects of their businesses and making short-to-medium-term forecasts, and (ii) support organisations that are considering whether or not to obtain a certification in some contexts.

The main limitation of this research is that the results obtained can be conditioned (i) by the accuracy of the data provided by the ISO Survey and (ii) by the clustering technique adopted.

Future research should focus on the results found in this study, especially the post-decline phase, trying to better interpret the drivers and variables affecting it. It could also be interesting to expand this analysis to a wider geographical area and verify whether the proposed results apply to non-European countries too.

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APPENDIX A – Additional tables

See the following additional tables.

***Table A.1** Number of ISO 9001 certifications for the major European countries (1993-2005) (ISO, 2018).*

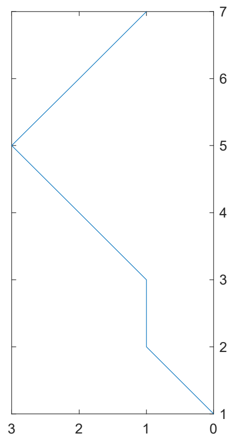
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Austria	200	434	1133	1824	2627	3245	3421	3826	4000	4094	2809	3259
Belarus					6	14	26	58	78	115	102	447
Belgium	464	870	1716	1871	3042	3176	3495	3760	4670	4725	3167	4471
Bulgaria			3	14	42	96	199	259	469	629	842	1685
Croatia		2	22	38	96	121	336	302	415	590	580	966
Czech Republic	18	47	180	366	746	1443	1500	3855	5627	8489	2565	10781
Denmark	608	916	1314	1387	1902	2200	1962	2258	2163	1900	935	1050
Finland	324	496	772	951	1445	1450	2105	1651	1870	1872	1861	1784
France	1586	3359	5536	8079	11920	14194	16028	17170	20919	19870	15073	21769
Germany	1534	3470	10236	12979	20656	24055	30150	32500	41629	35802	23598	26654
Greece	46	90	248	348	682	764	1050	2173	2325	3180	1615	2572
Hungary	23	58	309	423	1341	1660	3282	4672	6362	9254	7750	10207
Ireland	893	1132	1617	2056	2534	2854	3100	3330	3700	2845	1132	1683
Italy	864	2008	4814	7321	12134	18095	21069	30367	48109	61212	64120	84485
Latvia				1	1	14	39	94	67	93	73	484
Lithuania			2	3	29	40	91	173	202	280	324	487
Netherlands	1502	2718	5284	7986	10380	10570	10620	11036	12745	13198	9917	6402
Norway	172	400	890	1109	1273	1503	1509	1600	1703	1344	1171	1368
Poland	1	16	130	260	669	768	1012	2075	2622	3091	3216	5753
Portugal	85	181	389	535	819	944	1131	1696	2474	3061	3417	4733
Romania		6	42	61	214	269	466	1032	1670	2463	2052	5183
Russian Federation	5	8	22	56	95	132	541	1134	1517	1710	962	3816
Slovakia	5	11	59	135	404	575	560	522	827	1544	1148	2008
Slovenia	16	43	99	152	467	502	521	843	1026	973	465	1811
Spain	320	586	1492	2496	4268	6412	8699	12576	17749	28690	31836	40972
Sweden	365	618	1095	1931	2789	3489	3786	4358	4652	4039	3107	4687
Switzerland	569	945	2065	3701	4653	6426	7124	8660	8605	10299	8300	11549
Turkey	65	106	434	606	1284	1607	1672	2278	2949	3941	3248	5009
Ukraine	1	4	8	14	30	56	82	151	269	893	308	934
United Kingdom	28096	36825	52595	53099	56696	58963	63700	63725	66760	60960	45465	50884

Table A.2 *Number of ISO 9001 certifications for the major European countries (2006-2017) (ISO, 2018)*

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Austria	3806	4203	4272	4277	5161	4138	4562	4637	4211	4470	3922	3707
Belarus	882	1308	1749	2014	151	171	170	130	2905	3657	175	3979
Belgium	3865	4822	4875	3950	3715	3207	3915	3812	3661	3562	3634	3121
Bulgaria	3097	4663	5323	5322	6248	5001	6037	5378	5729	5441	5951	5397
Croatia	1676	2073	2302	2567	2102	2117	2584	2636	2806	2529	2659	2381
Czech Republic	12811	10458	10089	14031	16242	12697	10679	12679	13229	10648	10568	11180
Denmark	1840	1794	1574	1683	1856	1505	2780	1527	1689	1865	2498	2656
Finland	1986	1804	1975	2243	2147	2265	2403	2838	2648	2596	2592	2644
France	21349	22981	23837	23065	29713	29215	29198	29598	29112	27844	23403	21808
Germany	46458	45195	48324	47156	50583	49540	51701	56303	55344	52995	66233	64658
Greece	4753	5132	6747	5034	4322	4168	4796	7293	5445	6187	7303	7056
Hungary	15008	10473	10187	7122	8083	6825	7232	7186	6909	5789	6559	5946
Ireland	2225	1999	2237	2136	2359	1875	2331	2388	2067	2323	2393	2568
Italy	105799	115359	118309	130066	143305	142853	136547	135939	139416	132870	150143	97646
Latvia	625	342	500	708	809	787	791	923	1000	1115	866	962
Lithuania	697	809	815	1111	1207	1168	1165	1110	1214	1238	1150	1289
Netherlands	18922	18922	13597	12260	11213	11072	11417	11415	10429	10381	10326	9991
Norway	1467	1703	1666	1871	1882	1756	1589	2080	2377	2467	2002	2475
Poland	8115	9184	10965	12707	12195	10984	10105	10527	9574	10681	12152	11846
Portugal	5851	5283	5128	5051	5588	4638	6650	7041	8006	7498	7160	7150
Romania	9426	9633	10737	15865	16200	14345	18014	18450	18984	20524	12209	12031
Russian Federation	6398	11527	16051	53152	62265	13308	12488	11764	11213	9084	5083	3490
Slovakia	2195	2840	3476	3475	3895	3787	4281	3891	4598	5683	5716	3592
Slovenia	2182	1886	1945	1688	1701	1658	1595	1993	1672	1481	1848	1720
Spain	57552	65112	68730	59576	59854	53057	59418	42644	35995	32730	34438	31984
Sweden	4839	5233	5377	5346	5687	4901	4846	4613	4998	4316	4041	4093
Switzerland	10984	11077	11724	11581	12110	10358	11542	12030	11205	12218	11212	10252
Turkey	12350	12802	13217	13705	10680	9446	7608	7178	8969	8538	6889	6131
Ukraine	1808	2150	2453	3252	2592	1207	1091	1275	1297	1052	1382	1303
United Kingdom	40909	35517	41150	41193	43293	41943	42304	42843	39982	40161	37901	37478

APPENDIX B – Dynamic Time Warping

In order to understand the logic of the Dynamic Time Warping (DTW) clustering algorithm, let us consider two time series, $\boldsymbol{u} = (u_1, \dots, u_n)$ and $\boldsymbol{v} = (v_1, \dots, v_m)$, with a different number of elements ($n \neq m$), as shown in the example of Figure B.1. For each pair of elements (u_i, v_i), a distance function can be defined as $\delta(u_i, v_j) = |u_i - v_j|$.



1	0	0	1	2	1	**1**
2	1	1	0	1	**0**	2
3	2	2	1	**0**	1	-3
2	1	1	**0**	1	0	-2
1	0	**0**	1	2	1	-1
1	**0**	0	1	2	1	-1
0	**1**	1	2	3	2	0
v*/*u	1	1	2	3	2	0

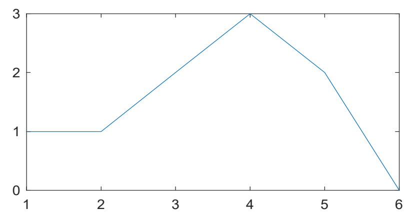


Figure B.1 *Example of a matrix for two time series,* **u** *(horizontal axis) and* **v** *(vertical axis). The elements contained into the matrix are the values of $\delta(u_i, v_j)$. Grey cells highlight the warping path, i.e. the map of the elements of* **u** *on* **v***, which minimizes the sum of the $\delta(u_i, v_j)$ values (see also Eq. A.1).*

The two time series are arranged in the form of a matrix where each element depicts the “difference” between two elements of the two time series. A *warping path* aligns the elements of the two series, in the way that the distance between them is minimized (Keogh & Ratanamahatana 2005). The path is a sequence of vertically, horizontally or diagonally contiguous values that connects the first element (bottom-left) to the last element (top-right) of the matrix. This path, which can be represented by a vector $\boldsymbol{w} = (w_1, \dots, w_{\max(n,m)})$, is a sequence of matrix elements (w_k) that are relatively small numbers, typically close to the diagonal, denoting the elements of the first series that are closer to those of the second series. We specify that the w_k elements correspond to some specific $\delta(u_i, v_j)$ values; e.g., in the matrix of Figure B.1, these elements are highlighted in grey and $\boldsymbol{w} = (1, 0, 0, 0, 0, 0, 1)$. The distance between the series (i.e. the DTW similarity distance) is then computed as follows:

$$DTW(S_1, S_2) = \sum_{k=1}^{\max(n,m)} w_k. \quad \text{(A.1)}$$

For the previous example, the DTW similarity distance is

$$DTW(\boldsymbol{u}, \boldsymbol{v}) = 2. \quad \text{(A.2)}$$

Similar considerations hold for the comparison of time series relating to the number of certifications from different countries. Figure B.2 reports the matrix of δ values relating to the time series of Austria and Bulgaria. The distance function used for this evaluation, as well as for the cluster analysis of the proposed example, is the Euclidean distance:

$$(\delta(u_i, v_j) = \sqrt{(u_i - v_j)^2}). \quad \text{(A.3)}$$

Austria																								
0.95	0.91	0.87	0.73	0.60	0.44	0.32	0.29	0.21	0.18	0.16	0.41	0.32	0.30	0.22	0.14	0.12	0.12	0.05	0.15	0.07	0.05	0.14	0.09	**0.19**
0.87	0.83	0.79	0.65	0.52	0.36	0.24	0.21	0.13	0.10	0.08	0.33	0.24	0.22	0.13	0.06	0.04	0.04	0.13	0.07	0.01	0.03	**0.05**	**0.00**	0.11
0.92	0.88	0.83	0.70	0.56	0.41	0.29	0.25	0.18	0.14	0.12	0.37	0.29	0.26	0.18	0.10	0.09	0.09	0.08	0.12	0.03	**0.02**	0.10	0.05	0.16
0.86	0.82	0.78	0.64	0.51	0.35	0.23	0.20	0.12	0.09	0.07	0.32	0.23	0.21	0.12	0.05	0.03	0.03	0.14	0.06	**0.02**	0.04	0.04	0.01	0.10
0.97	0.93	0.88	0.75	0.61	0.46	0.34	0.30	0.22	0.19	0.17	0.42	0.33	0.31	0.23	0.15	0.14	0.14	0.03	0.16	**0.08**	0.07	0.15	0.10	0.21
0.80	0.76	0.72	0.58	0.45	0.29	0.17	0.14	0.06	0.03	0.01	0.26	0.17	0.15	0.06	0.01	0.03	0.03	0.20	**0.00**	0.08	0.10	0.02	0.07	0.04
1.00	0.96	0.92	0.78	0.65	0.49	0.37	0.34	0.26	0.22	0.21	0.46	0.37	0.35	0.26	0.19	0.17	0.17	**0.00**	0.20	0.12	0.10	0.18	0.13	0.24
0.85	0.81	0.77	0.63	0.50	0.34	0.22	0.19	0.11	0.08	0.06	0.31	0.22	0.20	0.11	0.04	**0.02**	**0.02**	0.15	0.05	0.03	0.05	0.04	0.01	0.09
0.85	0.81	0.77	0.63	0.50	0.34	0.22	0.19	0.11	0.08	0.06	0.31	0.22	0.20	0.11	**0.04**	0.02	0.02	0.15	0.05	0.03	0.05	0.04	0.01	0.09
0.75	0.71	0.66	0.53	0.39	0.24	**0.12**	**0.08**	**0.00**	**0.03**	**0.05**	**0.20**	**0.11**	**0.09**	**0.01**	0.07	0.08	0.08	0.25	0.06	0.14	0.15	0.07	0.12	0.01
0.50	0.46	0.41	0.28	0.14	**0.01**	0.13	0.17	0.25	0.28	0.30	0.05	0.14	0.16	0.24	0.32	0.33	0.33	0.50	0.31	0.39	0.40	0.32	0.37	0.26
0.36	0.32	0.27	0.14	**0.00**	0.15	0.27	0.31	0.39	0.42	0.44	0.19	0.28	0.30	0.38	0.46	0.47	0.47	0.64	0.45	0.53	0.54	0.46	0.51	0.40
0.27	0.23	0.19	**0.05**	0.08	0.24	0.36	0.39	0.47	0.51	0.52	0.27	0.36	0.38	0.47	0.54	0.56	0.56	0.73	0.53	0.61	0.63	0.55	0.60	0.49
0.13	0.10	**0.05**	0.08	0.22	0.37	0.49	0.53	0.61	0.64	0.66	0.41	0.50	0.52	0.60	0.68	0.69	0.69	0.87	0.67	0.75	0.76	0.68	0.73	0.63
0.10	0.06	**0.02**	0.12	0.25	0.41	0.53	0.56	0.64	0.67	0.69	0.44	0.53	0.55	0.64	0.71	0.73	0.73	0.90	0.70	0.78	0.80	0.72	0.77	0.66
0.08	0.04	**0.01**	0.14	0.28	0.43	0.55	0.59	0.67	0.70	0.72	0.47	0.56	0.58	0.66	0.74	0.75	0.75	0.92	0.73	0.81	0.82	0.74	0.79	0.68
0.04	**0.00**	0.04	0.18	0.31	0.47	0.59	0.62	0.70	0.73	0.75	0.50	0.59	0.61	0.70	0.77	0.79	0.79	0.96	0.76	0.84	0.86	0.77	0.82	0.72
0.03	**0.01**	0.05	0.19	0.32	0.48	0.60	0.63	0.71	0.74	0.76	0.51	0.60	0.62	0.71	0.78	0.80	0.80	0.97	0.77	0.85	0.87	0.78	0.83	0.73
0.02	**0.02**	0.07	0.20	0.34	0.49	0.61	0.65	0.73	0.76	0.78	0.53	0.62	0.64	0.72	0.80	0.81	0.81	0.98	0.79	0.87	0.88	0.80	0.85	0.74
0.01	**0.03**	0.08	0.21	0.35	0.50	0.62	0.66	0.73	0.77	0.79	0.54	0.62	0.65	0.73	0.81	0.82	0.82	0.99	0.80	0.88	0.89	0.81	0.86	0.75
0.00	**0.04**	0.08	0.22	0.35	0.51	0.63	0.66	0.74	0.77	0.79	0.54	0.63	0.65	0.74	0.81	0.83	0.83	1.00	0.80	0.88	0.90	0.81	0.86	0.76
0.00	**0.04**	0.08	0.22	0.35	0.51	0.63	0.66	0.74	0.77	0.79	0.54	0.63	0.65	0.74	0.81	0.83	0.83	1.00	0.80	0.88	0.90	0.82	0.87	0.76
	0.04	**0.08**	**0.22**	**0.35**	**0.51**	**0.63**	**0.66**	**0.74**	**0.78**	**0.79**	**0.54**	**0.63**	**0.65**	**0.74**	**0.81**	**0.83**	**0.83**	**1.00**	**0.80**	**0.88**	**0.90**	**0.82**	**0.87**	**0.76**
	Bulgaria																							

Figure B.2 *Example of application of the DTW approach to the time series relating to two different European countries (Austria and Bulgaria). The cells of the matrix belonging to the warping path are highlighted in grey.*

For the provided example, the DTW similarity distance is $DTW(\boldsymbol{u}, \boldsymbol{v}) = 1.44$.

APPENDIX C – Clustering Dendrogram

This appendix section contains the dendrogram of the clustering result. The *x*-axis shows the countries, numbered according to the convention defined in the list in Sect. 4. On the *y*-axis, the dendrogram shows the distance – evaluated according to the DTW approach – between the various groups.

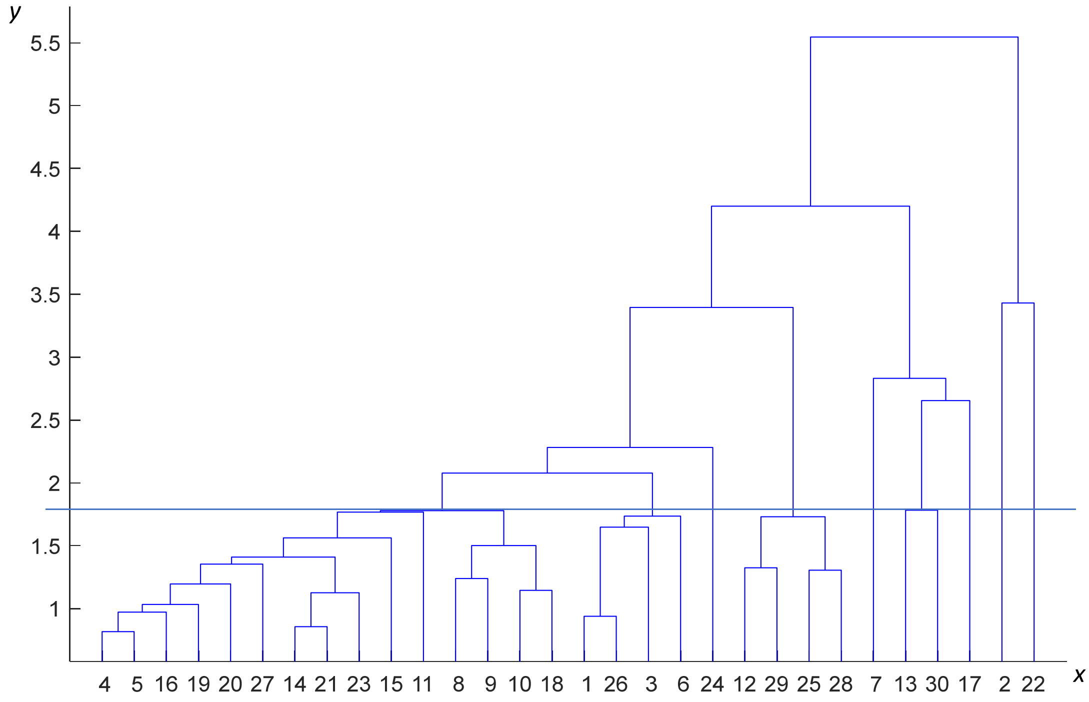


Figure C.1 *Dendrogram of the clustering result. The horizontal line represents the cutting threshold. Countries are numbered according to the codification introduced in Section 4.*