Spatial relation between geo-climate zones and technological outputs to explain the evolution of technology

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Abstract: The purpose of this study is to analyse the relationship between geo-climate zones of the globe and innovative outputs in order to detect favourable mechanisms that can foster high technological change. Empirical analysis shows that geographical areas with tepid latitudes have higher levels of innovative outputs than non-temperate latitudes. In effect, warm temperate climate has an appropriate natural environment for humans and societies that, by means of a long-run process of adaptation and learning, creates fruitful platforms of institutions, communications and energy systems. These platforms use efficiently human and physical capital to support inventions, innovations and their diffusion, and consequently the path of economic growth. The linkages are discussed to substantiate a theoretical framework, which explains the temperate climate as one of contributing factors for the source and evolution of new technology.

Keywords: geography of innovation; technology; temperate climate; tepid latitudes; technological change; patent; technological output; innovative milieu; evolution of technology; source of technical change.

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1 Introduction

The economic literature shows that the technological innovation, a main element of the economic change, is driven by several concomitant forces that coexist in specific geo-economic places and time span. The geography of innovation analyses various factors concerning the origin and diffusion of technological innovations (e.g., spatial proximity, agglomeration, etc.), however the geo-economic interaction between climate zones and technological performances is hardly known (Feldman and Kogler, 2010; Feldman and Florida, 1994; Rosenberg, 1992; Smithers and Blay-Palmer, 2001; Howells and Bessant, 2012). In general, climate is a main geographical factor that affects the human activity and economic development of societies and plays a main role for supporting the source and evolution of technological innovations (Chhetri et al., 2010, 2012), though it is a difficult assumption to test (Abler et al., 2000; Ruttan, 1997; cf., Moseley et al., 2014; Robbins et al., 2014).

The study here confronts this problem by analysing the fruitful relationship between innovative outputs and climate zones of the globe.

The study design endeavours to substantiate this model with an empirical analysis. The results show that the tepid climate is one of contributing factors of the source of technological innovation and high innovative outputs in specific geo-economic places.

2 Conceptual grounding

Geographical characteristics of certain areas sustain concentration and location of innovative activities (cf., Krugman, 1991). The new economic geography argues that: “all production depends on and is grounded in the natural environment” [Hudson, (2001), p.300]. A vital element of the natural environment is the climate (based on atmosphere and hydrosphere), which is affected by latitude, altitude, land, water system, and so on. The climate, consequently, influences the natural resources and human activities. Montesquieu (1947[1748]) argued that the climate shapes human attitude, culture and also knowledge. In fact, the climate tends to influence the personality of humans and societies and their adaptation to environment by means of technological innovations [cf., Hayami and Ruttan, (1985), pp.506ff; Coe et al., 2012; Moseley et al., 2014; Robbins et al., 2014; Rodima-Taylor et al., 2012; Ayres, 1998; Coccia, 2014c]. Feldman and Kogler (2010, p.387) show the critical role of the natural advantages of resource endowments and climate in certain places to induce technological innovation. In particular, the human societies place demands on the natural environment in terms of inputs for the production processes (cf., Turner et al., 1994). This effective demand for some natural resources can promote the technological innovation, by a process of learning and adaptation to the
environment, which improves the use of inputs to support patterns of economic growth (Dicken, 2003). Ruttan (1997, pp.1520–2521) argues that the evolution and diffusion of new technology are due to changes in the geographical, economic and social environment (cf., also Goldberg, 1996; Coccia et al., 2012; Calabrese et al., 2005; Coccia, 1999, 2010e). In fact, Lichtenberg (1960) shows that, initially, the geographical factors rather than proximity to raw materials or markets influence the production of knowledge and support the cumulative nature of several innovations. At a later stage, knowledge spillovers sustain further technological change of certain places (cf., Feldman, (2003), pp.311–312; Gersbach and Schmutzler, 1999). In effect, the geo-economic areas with favourable climate tend to have a better ‘institutional thickness’ (Amin and Thrift, 1993), which provides a platform for organising people and resources to support knowledge creation, innovative outputs and spillovers (cf., Rosenthal Stuart and Strange, 2003). Audretsch and Feldman (1996) argue that the agglomeration of innovative activities and industry in large cities is based on natural advantages of the environment, such as available resources and other factors of the physical geography (e.g., climate, river, bay, etc.; cf., Bettencourt et al., 2007). In general, economic literature shows that high technological performances of geo-economic areas are due to several concomitant determinants, such as the leading role of societies during and after major conflicts (Coccia, 2015b), fruitful demographic change (Coccia, 2014c), high democratisation (Coccia, 2010a), good economic governance, and efficient path of institutional development, etc. (cf., Coccia, 2008a; 2009a, 2009b; 2010b; 2010d, 2012a; 2014a).

However, the geography of innovation has not explored the vital relationship between technological outputs and geo-climate zones of the globe to explain the evolution of technology.

The next section presents a methodology to analyse this central scientific issue for the technical progress and human development in society.

3 Research design

The sample of this study is based on 109 countries. The main indicator of innovative output under study is the patent applications of residents (PAR) (1995–2001) using the dataset of the World Bank (2008). PAR are applications filed through the patent cooperation treaty procedure or with a national patent office for exclusive rights to an invention – a product or process that provides a new way of doing something or offers a new technical solution to a problem. In particular, patent applications of residents (PAR) indicate the current innovation of countries and also commercially promising inventions (cf., Coccia, 2010c, 2012b). According to Hunt and Gauthier-Loiselle (2011, p.32): “the purpose of studying patents is to gain insight into technological progress, a driver of productivity growth, and ultimately economic growth”. As a matter of fact, patents have a positive influence on patterns of technological innovation and they are the most common metrics of innovative output to analyse the technological performance of countries (cf., Jaffe and Trajtenberg, 2002; Coccia, 2010c, 2012a). This study also uses geographic and demographic variables to detect the barycentre of innovation across countries (Coccia, 2014c). In addition, the statistical analysis considers some climate zones of the globe based on world map of the Köppen-Geiger climate classification [see Kottek et al., (2006), p.260ff]. This climate classification of the Earth surface is associated to innovative outputs (patents) in order to analyse the variability of spatial patterns of the
technological innovation (cf., Zscheischler et al., 2012). In particular, this study divides the world in main climate zones (cf., Kottek et al., 2006):

- temperate climate – north and south (i.e., based on warm temperate climates and snow climates)
- non-temperate climate (i.e.: equatorial, arid and polar climates).

The countries are located in these specific climate zones considering their average latitude.

Data were subjected to horizontal and vertical cleaning, excluding some countries with missing values and/or outliers. The normal distribution of variables was checked by means of kurtosis and skewness coefficients. A logarithmic transformation has adjusted the distributions of some variables in order to apply correctly descriptive statistics, analysis of variance (ANOVA) and parametric estimates. In particular, the methodology of this study applies:

- **Descriptive statistics** based on arithmetic mean of patent applications of residents (PAR) for temperate and non-temperate climate of the globe.
- **ANOVA** considers the arithmetic means of PAR in two geo-climate zones (temperate and non-temperate climate). The expectation is that F-test rejects the statistical null hypothesis in favour of the alternative hypothesis: i.e., the expectation is that the average level of innovative outputs (measured by patents) in temperate latitudes is higher than non-temperate latitudes.
- **Estimated relationships and optimisation.** In order to determine the geo-economic area that is favourable/adverse to technological outputs, this study uses the following cubic models:

\[
\begin{align*}
\ln \text{PAR}_{1995-2001} & = \theta + \phi_1 \text{LONG} + \phi_2 \text{LONG}^2 + \phi_3 \text{LONG}^3 + \mu_{i,t} \\
\ln \text{PAR}_{1995-2001} & = \alpha + \delta_1 \text{LAT} + \delta_2 \text{LAT}^2 + \delta_3 \text{LAT}^3 + \varepsilon_{i,t}
\end{align*}
\]

where \( \text{PAR} \) = patent applications of residents (1995–2001), \( \text{LONG} \) = longitude, \( \text{LAT} \) = Latitude.

The equations (1) and (2) fit to the structure of data and are estimated by means of the ordinary least squares method (Girone and Salvemini, 1999). The mathematical optimisation methods compute the optimum/minimum that indicates the fruitful/adverse geographical zone for supporting/impeding technological innovations.

- **Spatial analysis with the decomposition of territorial dispersion.** For all 109 countries of the sample, this study has selected the top ten cities with higher population from the geographical database GeoNames (2014) to have the most important and representative cities per country. The top ten cities (in terms of population) are associated to their geographical coordinates (longitude and latitude) in order to compute the centre of gravity of the country: i.e., arithmetic mean of the geographical coordinate (longitude \( x_i \) and latitude \( y_i \)) of cities weighted with their populations \( n_i \) [see Girone and Salvemini, (1999), vol. 2]. This geographical barycentre of the country \( (x, y) \), based on large cities, is a strong indicator of
agglomerative forces and engines of innovative outputs (cf., Dicken, 2003). In fact, economic geography shows the benefits of urbanisation economies, based on larger cities and urban areas, which sustain innovations by means of the accumulation of human and physical capital (Bettencourt et al., 2007). Big cities, with clustering of socio-economic activities and high aggregate demand, encourage the emergence and growth of a variety of infrastructural, economic, social and cultural facilities, and as a consequence, of technological outputs [Dicken, (2003), p.22ff]. These data are applied for a spatial analysis of the variability by means of the decomposition of territorial dispersion and decomposition of normal deviation, considering temperate and non-temperate climate [cf., Girone and Salvemini, (1999), vol. 2 for details on this spatial analysis]. In short, the decomposition of the territorial dispersion is given by (X = longitude; Y = latitude):

\[ \text{Dev}(X, Y) = \sum_{k=1}^{K} \sum_{i=1}^{I} \left( (x_i + \bar{x}_k)^2 + (y_i + \bar{y}_k)^2 \right) n_{ki} + \sum_{k=1}^{K} \left( (\bar{x}_k + \bar{x})^2 + (\bar{y}_k + \bar{y})^2 \right) N_k \]

4 Results

Table 1 shows that PAR (an indicator of technological performances) have an arithmetic mean in temperate latitudes higher than non-temperate latitudes.

<table>
<thead>
<tr>
<th></th>
<th>Non-temperate climate</th>
<th>Temperate climate</th>
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<tbody>
<tr>
<td>Par applications of residents (PAR)</td>
<td>23.21</td>
<td>235.81</td>
</tr>
<tr>
<td>1995–2001</td>
<td></td>
<td></td>
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</tbody>
</table>

Table 2 Analysis of variance (ANOVA)

\[ F = \frac{\text{MS}_{\text{between}}}{\text{MS}_{\text{within}}} \]

\[ H_0 \text{ Average level of technological outputs in temperate latitudes = average level of technological outputs in non-temperate latitudes} \]

\[ H_1 \text{ Average level of technological outputs in temperate latitudes \geq average level of technological outputs in non-temperate latitudes} \]

\[ F = 350.972 \]

Significance (0.00)

Degrees of freedom 514

Hence, the ANOVA rejects the \( H_0 \)

Note: Variable is a arithmetic mean of LN patent 1995–2001 per million people.

ANOVA confirms that the average Patent applications of residents (PAR) 1995–2001 per million people in temperate climate are so much greater than levels in non-temperate climate that is credible the alternative statistical hypothesis: that is, higher levels of technological output are positively associated to areas with temperate climate (Table 2).

The estimated relations of geographic coordinates (1) and (2) are:
\[ \ln \text{PAR}_{1995-2001} = 3.9 - 0.02 \text{LONG} - 0.0003 \text{LONG}^2 + 0.000003 \text{LONG}^3 + u_{i,t} \tag{3} \]

\[ \ln \text{PAR}_{1995-2001} = -0.64 + 0.032 \text{LAT} + 0.0034 \text{LAT}^2 - 0.00004 \text{LAT}^3 + \varepsilon_{i,t} \tag{4} \]

where \( \text{PAR} \) = patent applications of residents 1995–2001 per million people; \( \text{LONG} \) = longitude; \( \text{LAT} \) = latitude. The parameters of equations (3) and (4) are significant at \( p < 0.001 \).

In order to determine the geographical centre of gravity of the globe that optimally supports technological outputs (i.e., \( \text{PAR} \) = patent applications of residents 1995–2001), the maximum of the estimated relationships of geographic coordinates (3) and (4) is calculated by means of the calculus. The geographical barycentre of the globe that maximises the innovative outputs has longitude \((90^\circ 52')\) and latitude \((60^\circ 59')\): innovative outputs tend to localise in temperate climate of the hemisphere. Vice versa, the geographical barycentre of the globe that minimises the innovative outputs has longitude \((-24^\circ 12')\) and latitude \((-4^\circ 19')\), within a non-temperate climate. This result also confirms that innovative outputs are higher in the tepid latitudes of the globe.

The decomposition of the territorial dispersion of patent applications of residents (PAR) shows that the territorial dispersion of innovative outputs is mainly within groups (temperate climate and non-temperate climate), however the divergence of the barycentre between non-temperate and temperate latitudes also plays a vital role to explain the average difference between innovative outputs of geographical areas. In addition, the normal decomposition of total deviation (a different formula in comparison to decomposition of the territorial dispersion) stresses that an important source of variability of innovative outputs is between sets of temperate and non-temperate climate \((40.62\%)\), confirming the positive association between technological outputs and tepid latitudes.

### 4.1 Remarks on empirical analyses

The statistical analysis shows, ceteris paribus, that average innovative outputs seem to be associated to temperate climate where there are favourable factors of physical, human and economic geography. In short, technological innovations thrive in tepid latitudes. On the contrary, adverse natural environment in non-temperate climate negatively affects the evolution of technology. In particular, the non-temperate climate tends to have societies with low investment in physical and human capital, and low economic efficiency in the use of these factors to support technological innovations and level of income (cf., North Douglass, 1981). These weak socio-economic mechanisms are due to negative historical developmental paths also associated to difficult environmental conditions. However, Acemoglu et al. (2001) argue that: “once the effect of institutions is controlled for, countries in Africa or those closer to the equator do not have lower incomes”.

In addition, the statistical analysis shows the high variability of innovative performances within the areas of temperate and non-temperate climate, because the relation between climate and technological outputs is also affected by other socio-institutional and cultural factors (Coccia, 2012b, 2011, 2014a, 2014c). For instance, Spain and the UK are in the same geo-climatic zone (temperate), but Spain has an annual
average of about 57 patents per million people, whereas the UK has an annual average of roughly 334 patents (cf., Coccia, 2014c). Institutions, level of democratisation, cultural factors and other economic elements differ across societies and tend to generate, \textit{ceteris paribus}, a great variability of economic and technological performances across countries localised within similar geo-economic areas with similar climate.

In brief, the climate may be one of contributing factors to innovative outputs of societies, but there are also other factors that explain the different patterns of technological innovation within similar latitudes, such as efficiency of national system of innovation, intensity of demographic change, predominant religion, level of democratisation, efficient economic governance, leading role in major conflicts, etc. (cf., Coccia, 2010a, 2012b, 2014c, 2014a, 2015b).

5 The \textit{plexus} supporting high innovative outputs in tepid latitudes

The statistical evidence seems in general to support the causal model in Figure 1: in average, higher innovative outputs can be also explained by the location of countries in tepid latitudes (north and south of the globe), \textit{ceteris paribus}. This result is due to some fruitful linkages: climate affects the natural environment, resources and human activities. In particular, tepid latitudes attract humans that place demands on the natural environment in terms of inputs for the production processes (cf., Coccia, 2014b). This effective demand for some natural resources fosters the technological innovations, with processes of learning and adaptation to the environment, in order to use better the inputs and support the path of socio-economic growth. In particular, geographically concentration of human resources and capital creates dense social networks and trustful environment to support patterns of technological innovation and path-dependency of new technology (Lee and Rodriguez-Pose, 2013). In effect, concentration of people and social interactions in tepid latitudes can sustain an effective circulation and diffusion of information, encouraging discoveries, inventions and innovations by new combinations of ideas and technical knowledge. Kuznets (1960, p.328) states: “population growth produces an absolutely larger number of geniuses, talented men, and generally gifted contributors to new knowledge whose native ability would be permitted to mature to effective levels when they join the labour force”.

In addition, concentration of humans in tepid latitudes leads to greater demand for goods and services, and as a consequence, to the demand-driven innovation that further induces economic growth. These complex linkages (plexus) generate an impetus for the technological progress in some specific places with tepid latitudes (cf., Coe et al., 2012). Hence, innovative activity is a fruitful combination of tangible and intangible elements in specific places that supports the source and evolution of technological innovation (innovative milieu). Climate may be one of main contributing factors for the technological change and economic growth of these areas.

This \textit{plexus}, supporting innovations, can be schematically summarised in the parallel diagram of Figure 2.
In short, tepid latitudes induce some natural advantages for socio-economic activities and are a main force of attraction of humans that trigger fruitful patterns of technological innovation. Ethnologists, such as Tylor and Morgan, viewed: “the production of novelties—new ideas, new ways of doing things, and the like—as the underlying force that propels cultures up the ladder of cultural complexity” [as quoted by O’Brien and Shennan, (2010), p.4]. Kremer (1993, pp.684–685) notices that: “among technologically separate societies, those with higher population had faster growth rates of technology and population” (cf., Coccia, 2014c). Tepid climate and demographic factors create a natural environment that can support human activities and societies, such as the transmission of knowledge by face-to-face interaction, high intensive contacts among people and sharing of common attitudes/interests towards specific knowledge and technology (cf., von Hippel, 1994; Cavallo et al., 2014, 2014a). As a matter of fact, physical and human geography in tepid latitudes can establish platforms and infrastructures for innovative outputs that induce fruitful historical developmental paths (cf., Coe et al., 2012; Coccia, 2010). The technological innovation, de facto, is a human activity associated mainly to temperate climate; it is a strategy by which complex societies adapt to resource endowments, and environmental, climate and socio-economic changes (cf., Chhetri et al., 2012; see Singer et al., 1961). Especially, the technological change is a human activity of learning and adaptation to the environment in order to take advantage of important territorial opportunities and/or to cope with consequential environmental threats.

Figures 3 and 4 show interesting maps that confirm the origin of the Lithic (stone) technology mainly in temperate latitudes of the northern hemisphere; in fact, several anthropological studies display the distribution of Mousterian industries and other palaeolithic industries of the Neanderthal man in geographical zones at north of the tropic of cancer where humans had a fruitful natural environment for the origins of complex societies and agriculture. Climate and other geographical factors of these places have created the appropriate socio-economic environment where various innovations thrived to support, consequently, paths of economic growth [cf., Singer et al., (1958), vol. 1; O’Brien and Shennan, 2010].

Figure 2   *Plexus* (interwoven combination of parts in a socio-economic system) in temperate climate to support technological and economic progress
Figure 3  Distribution of Mousterian industries

Note: Flint tools associated primarily with Neanderthal man, see dense network, mainly in temperate climate above the tropic of cancer.

Source: Singer et al. (1961, Vol. 1, Map I)

Figure 4  Distribution of upper Palaeolithic industries of the blade and burin tradition – about 150,000 years ago

Note: The area of these objects is mainly in temperate climate above the north tropic.

Source: Singer et al. (1961, vol. 1, p.37)
Hence, tepid climate has a vital role for human activity to create factors for supporting adaptation and learning processes to the environment that lead to fruitful initiatives for scientific opportunities, discoveries, inventions and diffusion of innovations. Geo-economic space and temperate climate, associated to other physical and socio-cultural factors, can originate a fruitful technical knowledge atmosphere in specific areas (innovative milieu). These conditions induce historical development pathways of some technological innovations in certain places. Moreover, even in the present of globalising world, critical economic and innovative activities are geographically localised mainly in tepid latitudes due to path-dependency mechanisms (cf., Dicken, 2003). In general, the human activities tend to agglomerate and to form urban areas, mainly in temperate climate with a better natural environment, for sharing the costs of a whole range of services and for creating a variety of infrastructural, economic and cultural facilities. These characteristics are basic for generating technological innovations (cf., Coccia, 2012, 2012c, 2012d, 2012e, 2014d, 2014e; Coccia and Wang, 2015). As a consequence, firms and research labs, main subjects in the production of technological innovation, tend also to operate in temperate places in order to benefit of localisation economies [Dicken, (2003), p.23; Coccia, 2001, 2001a, 2005a, 2005b, 2006, 2007, 2006c, 2006b, 2009c, 2009d, 2014; Coccia and Rolfo, 1999, 1999a, 2007, 2009, 2010, 2013; Coccia and Cadario, 2014; Coccia et al., 2015]. This study shows that some geo-economic areas persist to support high innovative outputs through a process of cumulative and self-reinforcing development (e.g., some European countries). Tepid climate is a fundamental factor to aggregate humans and create complex societies in order to support profitable paths of technological innovation. These patterns are based on processes of learning and adaptation to the geo-economic environment in order to take advantage of important opportunities, to respond to scarce resources and/or to cope with consequential environmental threats (cf., Rodima-Taylor et al., 2012; Olwig, 2012). Of course, temperate climate is a necessary but not sufficient condition for fostering technological innovations. Temperate climate has to be associated to other socio-economic factors to support innovative outputs and long-run technological change (cf., Coccia, 2006a, 2009e, 2009a, 2010c, 2011; 2012b, 2013, 2014c, 2014a). Overall, then the summary of findings shows that:

Technological change is a human activity of learning and adaptation to the socio-economic environment, mainly in tepid latitudes, in order to take advantage of important territorial opportunities, and/or to cope with consequential environmental threats and scarce resources.

6 Concluding observations

Climate is a main geographical factor of the natural environment that supports the human activities and development of societies. Human and physical capital tend to be affected by climate conditions (Abler et al., 2000) and tepid latitudes provide main stimuli for social, technological and economic change (Hayami and Ruttan, 1985; cf., Rosenberg, 1992; Smithers and Blay-Palmer, 2001). In fact, the progress of societies in tepid latitudes has generated major innovations to reduce the influence and dependence from scarce resources of the natural environment (Hayami and Ruttan, 1985).

The study here shows that temperate geo-economic areas of the globe have higher levels of technological outputs than non-temperate climate. This result may be due to the
fruitful congruence of geographical and socio-cultural factors since Palaeolithic period (DiGiano and Racelis, 2012; cf., Martin and Sunley, 1998; O’Brien and Shennan, 2010). In particular, the tepid latitudes have created better conditions for supporting the resilience (ability to adapt) of population to the geo-economic environment also by means of new technological innovations. Rodima-Taylor et al. (2012, p.107) claim that: “innovations are human adaptations to changing needs and socio-economic conditions, and are therefore embedded in social processes”. Moreover, the climate also affects the cultural traits of societies that react and self-adapt, by a process of learning, to natural environmental conditions and resource endowments in order to reinforce their socio-economic progress with scientific and technological advances (cf., Chhetri et al., 2012).

Overall, climate and other factors of the physical geography create the fortune of certain places and support technological pathways that induce fruitful historical development paths. These patterns of technological innovation are also influenced by a variety of socio-cultural and economic determinants (cf., Smithers and Blay-Palmer, 2001).

As a matter of fact, technological innovation seems to be a strategy change of advanced societies in response to current and/or expected environmental stimuli or their effects, in order to reduce risks and/or to exploit beneficial opportunities (Coccia, 2015a, 2013a).

The results of this study are, of course, tentative. We know that other things are often not equal in turbulent environment, such that no rule will be true in all situations. In fact, Wright (1997, p.1562) properly says: “in the world of technological change, bounded rationality is the rule”. The vital role of climate on technological innovation deserves to be analysed considering simultaneously other social, psychological, historical, cultural and anthropologic factors of human societies.

Most of the focus in this study is on a basic and partial linkage between temperate climate and technological innovation, clearly important but not sufficient for broader understanding of the source and evolution of new technology.

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References


Spatial relation between geo-climate zones and technological outputs


Notes


3 Algeria, Argentina, Armenia, Australia, Austria, Azerbaijan, Bangladesh, Belarus, Belgium, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Cuba, Cyprus, Czech Republic, Denmark, Ecuador, Egypt Arab Rep., Estonia, Ethiopia, Finland, France, Gambia, Georgia, Germany, Ghana, Greece, Guatemala, Haiti, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Iran Islamic Rep., Iraq, Ireland, Israel, Italy, Japan, Kazakhstan, Kenya, Korea, Rep. Kyrgyz, Latvia, Lesotho, Libya, Lithuania, Luxembourg, Macedonia-FYR, Madagascar, Malawi, Malaysia, Malta, Mauritius, Mexico, Moldova, Monaco, Mongolia, Morocco, The Netherlands, New Zealand, Nicaragua, Norway, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Saudi Arabia, Serbia and Montenegro, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Swaziland, Sweden, Switzerland, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, UK, USA, Uruguay, Uzbekistan, Venezuela, Vietnam, Zambia, Zimbabwe.

4 Technology is based on inventions and innovations. Invention is a commercially promising product or service, based on new science and/or technology that meets the requirements for a patent application and/or the patent is already granted. Innovation, which already has a valid and granted patent, is the successful entry of a new science or technology-based product into a particular market [cf., Coccia, (2010c), p.252].

5 One of the necessary conditions for the function \( f(x) \) of one variable to have a maximum or a minimum is:

\[
\frac{df(x)}{dx} = 0 \quad \text{for } x = x^*
\]

in this case \( x \) is a stationary point.

6 Plexus is the interwoven combination of parts in a system.