Technological Readiness and Innovation as Drivers for Logistics 4.0*

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Abstract

The research purpose of this paper is to empirically examine the effects of technological readiness and innovation on logistics performance. To build up and maintain an important role in global supply chains, nowadays it is obvious that countries and logistics providers need to achieve competitive advantage in terms of digitalization. However, there is a lack of empirical studies about the impacts of information technologies and innovation potential on the logistics efficiency of countries. Hence, the study analyzes whether the corresponding pillars of the Global Competitiveness Index (GCI) matter for the Logistics Performance Index (LPI) and its dimensions. For determining the effects, the pooled regression approach is applied. The results show that technological readiness and innovation are positively and statistically significantly correlated with logistics performance: competence and quality of logistics services, efficiency of customs clearance processes, ability to track and trace consignments, frequency with which shipments reach consignee within scheduled or expected time, and ease of arranging competitively priced shipments. The findings of this study suggest that investments in innovations and technology progress improve countries’ logistics efficiency, which is an important prerequisite for enabling Logistics 4.0 and thus, Industry 4.0 and the digital transformation of the economy and society.

Keywords: Digitalization, Information Technologies, Innovation Potential, Logistics Performance, Industry 4.0

JEL Classification Code: L91, M16, O30, O31, O33

1. Introduction

Globalization and advances in information technologies represent both reality and opportunities for enterprises in the 21st century. Consequently, it became apparent that companies started to invest extensively in innovative data-enabled technologies, since recent years (Tsai & Tang, 2012). Vice versa, it can be noted that this trend is also fueled by some exceptional and disruptive technological achievements (e.g., blockchain) during the last decade, the further increasing global competition and even faster changing customer needs (Marini et al., 2014).

The digitization of manufacturing processes in terms of Industry 4.0 requires the interconnectivity and integration in order to ensure a superior value creation (Prause & Atari, 2017; Alibekova et al., 2020). Thereby, especially logistics is of high interest, as it has a crosscutting function and thus, affects all process-involved and dependent business units (Lai et al., 2008). In this context, particularly the term ‘Logistics 4.0’ receives growing attention, since recent years, which in a way accentuates that logistics as a central function plays an important role within the digital transformation of the manufacturing sector and thus, the underling Industry 4.0 vision. In reflection of
Barreto et al. (2017, p. 1251), the Logistics 4.0 paradigm can be summarized as the optimization of inbound and outbound logistics which must be supported by intelligent systems, embedded in software and databases from which relevant information is provided and shared through data-enabled technology systems (e.g., blockchain, IoT) in order to achieve a major automation degree. Thus, also logistics organizations are forced to consider how they can take advantage of the novel information technologies to better manage supply chain activities, safeguard smooth functioning of logistics operations and keep pace with competitors (Prause, 2014a & b). Apart from such efforts, further challenges of supply chain management and the logistics sector currently refer especially to environmental and sustainability issues (e.g., IMO regulations: Global Sulphur Cap 2020, Emission Control Areas like SECAs and NECAs), as well as transport-induced growth and infrastructure developments (e.g., TEN-T in Europe, Silk Road 2.0 in Asia) (Gerlitz et al., 2018; Henesey & Philipp, 2019; Madjidian et al., 2017; Philipp et al., 2020a & b, 2019a). Nonetheless, in particular, the technological progress associated with the Industry 4.0 paradigm is often regarded as the savior for managing these contemporary, as well as evergreen challenges in the context of logistics and especially supply chain management that are related to the dominating position of bigger players, establishment of trust and relationships between the different actors, fragmented structures, supply chain finance and lead-time as well as throughput (Beth et al., 2003; Henesey et al., 2020; Nyhuis & Wiendahl, 2008; Philipp, 2020a; Philipp et al., 2020b, 2019b & 2019c; Prause & Hunke, 2014; Zhao & Huchzermeier, 2018).

The growing significance of novel technologies became apparent as well most recently by the COVID-19 pandemic. Information technologies and related solutions play an active and crucial role in the provision of needed logistics and transport services. For instance, geographic information systems (GIS) and Big Data analytics are used to balance supply and demand of limited material resources – e.g. medical supplies (Zhou et al., 2020). Next to this, digital supply chain twins are used to support decision-making, since the first epidemic outbreaks (Ivanov, 2020).

In sum, it can be deduced that especially disruptive innovations that arise in the course of the digitalization and Industry 4.0 influence most powerful the development of new paradigms, principles and models in supply chain and logistics management – as exemplified by Logistics 4.0 vision. As stressed by Ivanov et al. (2019) as well as Hoffmann and Prause (2018), the application and useful implementation of innovative technologies (e.g., IoT, CPS, delivery robots), as well as smart and connected products and services will facilitate the development of digital supply chains and smart logistics operations. In turn, it can be postulated that the level of technological readiness and innovation potential of a country form the basis for the improvement of the logistics and business performance as well as the aspired digital transformation of the economy and society (Philipp, 2020a & b; Philipp et al., 2020b; Sumiati, 2020). Some previous studies investigated the impacts of information technologies on logistics performance of companies (i.e., micro logistics level) (e.g., Kayikci, 2018; Lin & Ho, 2009), or on country level the relationship between competitiveness and logistics efficiency (Önsel Ekici et al., 2016; Çemberci et al., 2015), logistics performance and trade (Gani, 2017) as well as environmental degradation (Liu et al., 2018). However, to the best of our knowledge, the impacts of technological readiness and innovation potential on logistics efficiency of countries (i.e., macro logistics level) were not investigated so far. Accordingly, the present study aims to fill this research gap by examining empirically the effects of technological readiness and innovation on logistics performance. Consequently, the study investigates the relevance of the corresponding pillars of the Global Competitiveness Index (GCI) for the Logistics Performance Index (LPI) and its dimensions. To reach the indicated research objective, among other things countries were pooled into high, upper middle, lower middle, and low-income economies in the course of a multiple regression analysis. The results reveal that technology readiness and innovation potential are positively and statistically significantly correlated with the logistics efficiency of countries: (1) quality of trade and transport-related infrastructure, (2) competence and quality of logistics services. Therefore, it can be implied among other things that policy measures should target to improve the technological and innovative basis in order to promote the logistics performance of their country and thus, the digital transformation.

The article is structured as follow: A literature review is presented in section two. Afterwards the methodology is set out in chapter three. Building upon this, the results of the empirical analysis are showcased in the fourth part, whereby the paper rounds up with a discussion and conclusion including implications for research and policy.

2. Literature Review

Recent research studies on Industry 4.0 highlighted that the fourth industrial revolution will change not only the manufacturing sector, but also other industries and their corresponding supply chains. In this context and by concerning the logistics sector, it must be noted that Industry 4.0 becomes relabeled by the term Logistics 4.0. As stated by Delfmann et al. (2018), the implementation of the envisaged Industry 4.0 vision “without Logistics 4.0 is just unthinkable as the globalization of the economy
without logistics networks that span the world (p.2).” Ergo, the digital transformation of the economy and society will not be safeguarded, if logistics is neglected or the logistics performance is not adequately met. As highlighted by Hofmann and Rüsch (2017), Industry 4.0 can only become reality, if logistics is able to supply production systems with the necessary input factors according to the right time, quality and place requirements. Principally, Logistics 4.0 – also known as smart logistics – is regarded as a specific management approach for developing, designing, managing and realizing change-oriented networks of object flows (e.g., goods, information, values) based on pattern recognition, generalization and self-organization, enabled through the usage of new technologies and innovative services (Wehberg, 2016). Therefore, flexibility and the ability of logistics systems to adjust and adapt is an essential requirement within the Logistics 4.0 paradigm (Schmidtke et al., 2018). Consequently, the central strategic questions is how to improve the logistics performance in order to enable and facilitate the digital transformation and Industry 4.0.

Recent studies analyzed on company level (i.e., micro logistics level) the impact of varying innovative technologies on logistics performance. Hence, it can be stated that specific novel technology applications provide a sustainable mean for firms to improve their logistics performance (Lai et al., 2010). For instance, there is a positive association between the adoption of the RFID technology and supply chain performance in case of logistics service providers (Lin & Ho, 2009). Next to this, a study from Martinez et al. (2019) showed that within customer order management (COM), which commonly forms an integral part of supply chain management, a reduction in the processing time for placing orders by 65%, for amending orders by 60%, and human-processing savings by around 50% are achievable through the adoption of blockchain (incl. smart contracts). Additionally, a study on transport companies by Nelson et al. (2017) showed that the usage of blockchain and smart contracts bears the potential to increase the profit margin in supply chains by 2 to 4%. Furthermore, it was also showcased in recent studies that from a holistic perspective the enhancement of the technological basis concerning the entire performance process of firms comprising planning, procurement, manufacturing, delivering and return results in improved logistics costs as well as processes with optimized workflows and reduced lead times (Kayikci, 2018). Moreover, Ardito et al. (2019) identified in their study a subset of enabling technologies pertaining to the fourth industrial revolution that can be considered as most relevant for an effective supply chain integration of firms (here: Industrial IoT, cloud computing, Big Data analytics, etc.). Apart from this, Strange and Zucchella (2018) in their research study assessed how the widespread adoption of new information technologies and solutions (i.e., IoT, Big Data analytics, robotic systems and additive manufacturing) affect the organization of activities within global value chains. Correspondingly, it can be stated that the adoption of innovative technologies generates both benefits and challenges for individual supply chain actors and stakeholders (Dallasega et al., 2018).

On macro logistics level, the study from Önsel Ekici et al. (2016), where an artificial neural network (ANN) and cumulative belief degrees (CBD) approach was applied, showed that improvements in specific indicators of the GCI have important positive impacts on the logistics performance of a country. Methodologies based on use a set of research procedures, techniques and methods, including methods for collecting and processing data (Kireyeva & Satybaldin, 2019). Building upon this, they further pointed out that improvements in logistics have the potential to enhance economic growth, as investments and infrastructure upgrades increase demands for goods and services. In contrast to this study with limitations in form of potential subjective perceptions concerning selection and allocation of GCI indicators to LPI dimensions, in the present study, the objective focus is on the holistic pillars (1) technological readiness and (2) innovation of the GCI and their relationships to the LPI and its dimensions – which to the best of our knowledge was not examined in the academic research landscape until now. Vice versa, the study of Çemberci et al. (2015) highlighted that if a country targets to enhance its competitiveness in a global context (i.e., GCI), it needs to make improvements in the three dimensions of logistics services (i.e., LPI pillars): international transportation, tracking and tracing, as well as timelines.

The study of Gani (2017) revealed among other things the unidirectional relationship between logistics infrastructure and services (both dimensions of LPI) and international trade (mostly exports), whereby, the relationship between logistics performance and exports was analyzed as well by Kabak et al. (2018). Moreover, the research from Liu et al. (2018) showcased that logistics performance (incl. LPI dimensions) is significantly related to environmental degradation. On the one hand, international shipment significantly decreases CO2 emissions, whereby on the other hand timeliness of logistics significantly intensifies the CO2 emissions. In addition, the study revealed as well that further dimensions of the LPI such as tracking and tracing, service quality and competence, infrastructure quality, and efficiency of customs also have a significant impact on the environment.

To sum up: Although there exist several scientific studies that focused on the effects of innovations and technologies on logistics efficiency on micro level, there is a lack of empirical research studies that focalized on the impacts of technological readiness and innovation on
logistics performance on macro level. Deeply rooted in the fact that the technological and innovative basis of a country may be regarded as one of the crucial determining factors for the logistics efficiency as well as the digital transformation of the economy and society, the great significance becomes evident to analyze these potential relationships. In respect to this background, the following central research question will be answered in the present study: What are the impacts of the (1) technological readiness and (2) innovation potential on the logistics performance of countries?

3. Research Methods and Materials

In previous studies that targeted to examine the relationships between varying factors and logistics performance, several methods were applied. For instance, the system-generalized method of moment (GMM) regression model was used by Liu et al. (2018). Gani (2017) applied a regression analysis, too. Against this, Kabak et al. (2018) applied a novel scenario analysis-based approach. Önsel Ekici et al. (2016), used an ANN and CBD approach, whereas Çemberci et al. (2015) applied hierarchical regression analysis. Certain scientists used methods based on the calculation of complex and integral indices in the dynamics of a number of indicators proposed by experts and adapted to the conditions of Kazakhstan (Satpayeva, 2017; Nurlanova et al., 2019). Hence, in the frame of the present study that targets to empirically examine the impacts of technological readiness and innovation potential on logistics performance, as statistical methods, the correlation and multiple regression analysis were selected. The usage of these methods is justified by the circumstance that they allow among other things to determine the strength and direction of the effects between the variables under investigation.

In the frame of the present research, secondary data was gathered from two prominent indices. In detail, the LPI and its dimensions as well as specific pillars from the GCI were chosen for the study. The GCI is yearly published within the global competitiveness report since 2004 by the World Economic Forum (WEF) and evaluates the factors that collectively determine the level of country’s productivity. Within the GCI, the indicators are structured meanwhile within twelve pillars, whereby for presentation purpose, they are allocated in four main categories (enabling environment, human capital, markets and innovation ecosystem) (GCI, 2018). Against this, the LPI is a dataset that was issued for the first time in 2007, and since 2010, is published every second year by the World Bank in order to measure countries’ logistics performance (Arvis et al., 2018). The LPI is aggregated based on six dimensions (customs, infrastructure, international shipments, logistics quality and competence, tracking and tracing, timeliness).

The study sample embraces 29 countries, which were grouped in the further discourse of the study in high, upper middle, lower middle and low-income economies (cf. Table 1).

These countries were chosen for reasons of data availability concerning the selected variables along the period under investigation (i.e., 2007, 2010, 2012, 2014, 2016, 2018 – databases from WEF and World Bank). Consequently, the GCI and LPI as well as their pillars and dimensions represent composite indicators that can be extracted for an independent analysis. Selected variables for the study are overall GCI (GCI-O), technological readiness (GCI-T), innovation (GCI-In) (GCI, 2018; GCI, n.d.), overall LPI (LPI-O), customs (LPI-C), infrastructure (LPI-I), international shipments (LPI-S), logistics quality and competence (LPI-QC), tracking and tracing (LPI-TT), timeliness (LPI-T) (LPI, n.d.). An explanation of the variables is shown in Table 2.

<table>
<thead>
<tr>
<th>Income group</th>
<th>No. countries</th>
<th>%</th>
<th>Sample</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-income economies</td>
<td>80</td>
<td>36.7</td>
<td>11</td>
<td>Australia, Belgium, Chile, France, Germany, Italy, Japan, Latvia, Singapore, Switzerland, United States</td>
</tr>
<tr>
<td>Upper middle-income economies</td>
<td>60</td>
<td>27.5</td>
<td>8</td>
<td>Argentina, China, Kazakhstan, Malaysia, Mexico, Russian Federation, Thailand, Turkey</td>
</tr>
<tr>
<td>Lower middle-income economies</td>
<td>47</td>
<td>21.6</td>
<td>6</td>
<td>Egypt Arab Rep., India, Indonesia, Kyrgyz Republic, Pakistan, Ukraine</td>
</tr>
<tr>
<td>Low-income economies</td>
<td>31</td>
<td>14.2</td>
<td>4</td>
<td>Chad, Niger, Tajikistan, Uruguay</td>
</tr>
<tr>
<td>Total</td>
<td>218</td>
<td>100.0</td>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>

Source: Compiled by the authors, based on the classification from Neil and Umar (2016)
Table 2: Variables retrieved from GCI and LPI

<table>
<thead>
<tr>
<th>No.</th>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Overall GCI (GCI-O)</td>
<td>The Global Competitiveness Index (GCI) evaluates the factors that collectively determine the level of a country's productivity – the most important driver of long-term improvements in living standards.</td>
</tr>
<tr>
<td></td>
<td>1.1. Technological readiness (GCI-T)</td>
<td>The pillar technological readiness measures the agility with which an economy adopts existing technologies to enhance the productivity of its industries, with specific emphasis on its capacity to fully leverage information and communication technologies (ICTs) in daily activities and production processes for increased efficiency and enabling innovation for competitiveness. Whether the technology used has or has not been developed within national borders is irrelevant for its ability to enhance productivity. The central point is that the firms operating in the country need to have access to advanced products and blueprints and the ability to absorb and use them. Among the main sources of foreign technology, foreign direct investment (FDI) often plays a key role, especially for countries at a less advanced stage of technological development.</td>
</tr>
<tr>
<td></td>
<td>1.2. Innovation (GCI-In)</td>
<td>The pillar innovation focuses on countries’ innovation potential. Innovation is particularly important for economies as they approach the frontiers of knowledge, and the possibility of generating more value by merely integrating and adapting exogenous technologies tends to disappear. In these economies, firms must design and develop cutting-edge products and processes to maintain a competitive edge and move toward even higher value-added activities. This progression requires an environment that is conducive to innovative activity and supported by both the public and the private sectors. In particular, it means sufficient investment in research and development (R&amp;D), especially by the private sector; the presence of high-quality scientific research institutions that can generate the basic knowledge needed to build the new technologies; extensive collaboration in research and technological developments between universities and industry; and the protection of intellectual property.</td>
</tr>
<tr>
<td>2.</td>
<td>Overall LPI (LPI-O)</td>
<td>Logistics Performance Index examines the ease of supplying goods and the state of trade logistics at the national and international levels.</td>
</tr>
<tr>
<td></td>
<td>2.1. Customs (LPI-C)</td>
<td>The dimension customs represents an indicator for the efficiency of customs clearance processes.</td>
</tr>
<tr>
<td></td>
<td>2.2. Infrastructure (LPI-I)</td>
<td>The dimension infrastructure represents an indicator for the quality of trade and transport-related infrastructure.</td>
</tr>
<tr>
<td></td>
<td>2.3. International shipments (LPI-S)</td>
<td>The dimension international shipments represents an indicator for the ease of arranging competitively priced shipments.</td>
</tr>
<tr>
<td></td>
<td>2.4. Logistics quality and competence (LPI-QC)</td>
<td>The dimension logistics quality and competence represents an indicator for the competence and quality of logistics services.</td>
</tr>
<tr>
<td></td>
<td>2.5. Tracking and tracing (LPI-TT)</td>
<td>The dimension tracking and tracing represents an indicator for the ability to track and trace consignments.</td>
</tr>
<tr>
<td></td>
<td>2.6. Timeliness (LPI-T)</td>
<td>The dimension timeliness represents an indicator for the frequency with which shipments reach consignee within scheduled or expected time.</td>
</tr>
</tbody>
</table>

Source: Compiled by the authors, based on: GCI (2018, p.318-319), Arvis et al. (2018)
The variables GCI-T and GCI-In were chosen for the present analysis, since according to the scientific literature, they represent the crucial levers for enabling Logistics 4.0 and thus, Industry 4.0. These variables are the explanatory variables. The endogenous variables are the LPI-variables. Hence, in the present study, it is hypothesized that the technological readiness and innovation have a positive impact on the logistics performance. To reveal the effects of technological readiness and innovation on logistics performance the pooled regression approach was selected, whereat for the statistical analysis, the software program SPSS Statistics 20 was used. The usual linear model can be described as:

\[
Y_{it} = B_1 + B_2 \cdot X_{1, it} + B_3 \cdot X_{2, it} + \ldots + u_{it}
\]  

\(1\)

where \(Y_{it}\) is the endogenous variable, \(X_{j, it}\) are the explanatory variables, \(B_j\) are the coefficients, \(B_1\) present the intercept term and \(u_{it}\) is a time-varying random component. The country index is \(i\) and the time index is \(t\).

4. Results

4.1. Variable Analysis

In a first step, positive correlations were detected between technological readiness (GCI-T) and innovation (GCI-In) (0.830), technological readiness (GCI-T) and logistics performance (LPI-O) (0.843), as well as innovation (GCI-In) and logistics performance (LPI-O) (0.856), which are all significant at the 0.01 level (1-tailed).

Additionally, in the further discourse, the relationship between both indices (GCI-O and LPI-O) was further analyzed by a regression analysis. The received R Squared measure is 0.786, which suggests that about 78% of the variation (LPI-O) can be explained by the predictor variable (GCI-O). The corresponding regression equation has the following form (cf. coefficients in Table 3):

\[
LPI\_O_{it} = 1.107 + 0.220 \cdot GCI\_T_{it} + 0.308 \cdot GCI\_In_{it} + u_{it}
\]  

\(2\)

Given the positive effects of technological readiness and innovation on logistics performance, the empirical analysis was extended in order to examine if selected pillars of GCI mattered for the underlying dimensions of the LPI. Thereby, positive correlations were detected between the two indices, as well as the corresponding pillars and dimensions (R = 0.758–0.887), which are all significant at the 0.01 level (2-tailed).

Furthermore, the results of the regression analysis show that innovation potential (GCI-In) and technological development level (GCI-T) effect the quality of trade and transport-related infrastructure (LPI-I, R Squared = 0.806), the competence and quality of logistics services (LPI-QC, R Squared = 0.790), the efficiency of customs clearance processes (LPI-C, R Squared = 0.785), the ability to track and trace consignments (LPI-TT, R Squared = 0.762), the frequency with which shipments reach consignee within scheduled or expected time (LPI-T, R Squared = 0.695), the ease of arranging competitively priced shipments. (LPI-S, R Squared = 0.628). The corresponding detailed results are showcased in Table 4.

4.2. Country Analysis

In a second step, a country analysis was conducted in order to further prove and underline the research findings. As it can be abstracted from the results of the previous study part, technological readiness and innovation potential positively impact the logistics performance. This finding is also visible in the case of pooled data (i.e. according to the four classified groups of economies). As it can be derived from Figure 1, the higher the level of competitiveness (GCI-O) of a country, the higher is the logistics performance (LPI-O) and vice versa. Hence, low-income countries show on average low index results (LPI-O = 2.4, GCI-O = 3.6), whereby high-income economies show on average high index scores (LPI-O = 3.8, GCI-O = 5.2). The corresponding average index results of the lower middle-income and upper middle-income economies are graduated in-between according to the expected hierarchy (lower middle-income countries: LPI-O = 2.8, GCI-O = 4.0; upper middle-income countries: LPI-O = 3.1, GCI-O = 4.5).

Table 3: Results of regression analysis of LPI and selected GCI pillars

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>Std. Error</th>
<th>Beta</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>1.107</td>
<td>0.086</td>
<td></td>
<td>12.868</td>
<td>0.000</td>
</tr>
<tr>
<td>GCI-T</td>
<td>0.220</td>
<td>0.032</td>
<td>0.426</td>
<td>6.769</td>
<td>0.000</td>
</tr>
<tr>
<td>GCI-In</td>
<td>0.308</td>
<td>0.039</td>
<td>0.503</td>
<td>7.986</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Note: R Squared = 0.789 (Adjusted R Squared = 0.787); Dependent Variable: LPI-O.
Source: Compiled by the authors.
Table 4: Results of regression analysis of LPI dimensions and selected GCI pillars

<table>
<thead>
<tr>
<th>Technological readiness and innovation</th>
<th>B</th>
<th>Std. Error</th>
<th>Beta</th>
<th>t</th>
<th>Sig.</th>
<th>Note: R Squared = 0.785 (Adjusted R Squared =0.783); Dependent Variable: LPI-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>on customs</td>
<td>(Constant) 0.729</td>
<td>0.093</td>
<td>7.838</td>
<td>0.000</td>
<td>Note: R Squared = 0.806 (Adjusted R Squared =0.804); Dependent Variable: LPI-I</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GCI-T 0.244</td>
<td>0.035</td>
<td>0.440</td>
<td>6.931</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GCI-In 0.319</td>
<td>0.042</td>
<td>0.486</td>
<td>7.659</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Technological readiness and innovation</td>
<td>(Constant) 0.501</td>
<td>0.102</td>
<td>4.904</td>
<td>0.000</td>
<td>Note: R Squared = 0.628 (Adjusted R Squared =0.624); Dependent Variable: LPI-S</td>
<td></td>
</tr>
<tr>
<td>on infrastructure</td>
<td>GCI-T 0.251</td>
<td>0.039</td>
<td>0.393</td>
<td>6.513</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GCI-In 0.413</td>
<td>0.046</td>
<td>0.544</td>
<td>9.016</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Technological readiness and innovation</td>
<td>(Constant) 1.545</td>
<td>0.096</td>
<td>16.097</td>
<td>0.000</td>
<td>Note: R Squared = 0.790 (Adjusted R Squared =0.788); Dependent Variable: LPI-QC</td>
<td></td>
</tr>
<tr>
<td>on international shipments</td>
<td>GCI-T 0.181</td>
<td>0.036</td>
<td>0.417</td>
<td>4.992</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GCI-In 0.212</td>
<td>0.043</td>
<td>0.412</td>
<td>4.926</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Technological readiness and innovation</td>
<td>(Constant) 0.936</td>
<td>0.091</td>
<td>10.268</td>
<td>0.000</td>
<td>Note: R Squared = 0.762 (Adjusted R Squared =0.759); Dependent Variable: LPI-TT</td>
<td></td>
</tr>
<tr>
<td>on logistics quality and competence</td>
<td>GCI-T 0.199</td>
<td>0.034</td>
<td>0.364</td>
<td>5.788</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GCI-In 0.366</td>
<td>0.041</td>
<td>0.564</td>
<td>8.974</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Technological readiness and innovation</td>
<td>(Constant) 1.048</td>
<td>0.098</td>
<td>10.664</td>
<td>0.000</td>
<td>Note: R Squared = 0.695 (Adjusted R Squared =0.691); Dependent Variable: LPI-T</td>
<td></td>
</tr>
<tr>
<td>on tracking and tracing</td>
<td>GCI-T 0.250</td>
<td>0.037</td>
<td>0.450</td>
<td>6.723</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GCI-In 0.304</td>
<td>0.044</td>
<td>0.463</td>
<td>6.920</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Technological readiness and innovation</td>
<td>(Constant) 1.753</td>
<td>0.097</td>
<td>18.140</td>
<td>0.000</td>
<td>Note: R Squared = 0.762 (Adjusted R Squared =0.759); Dependent Variable: LPI-TT</td>
<td></td>
</tr>
<tr>
<td>on timeliness</td>
<td>GCI-T 0.195</td>
<td>0.036</td>
<td>0.405</td>
<td>5.345</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GCI-In 0.267</td>
<td>0.043</td>
<td>0.467</td>
<td>6.165</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

Source: Compiled by the authors

Figure 1: LPI and GCI structured according to income groups

Source: Compiled by the authors
Figure 2: Technological readiness and Innovation potential in comparison to logistics performance

Source: Compiled by the authors
Additionally, the fact that a country’s technological readiness predetermines its logistics performance is observable as well in case of a corresponding scatter diagram. For instance, Australia, Belgium, France, Germany, Japan, Singapore, Switzerland and the United States show the highest technological readiness and the highest scores regarding logistics efficiency. In contrast, Chad, Kyrgyz Republic, Niger and Tajikistan have the lowest degree of technological progress as well as logistics performance. Moreover, the country profiles also show that economies with high innovation potential usually also have a high level of logistics efficiency. For instance, Belgium, France, Germany, Japan, Singapore, Switzerland and the United States have the highest values in both (sub-)indices. In comparison, such countries as Chad, Kyrgyz Republic and Niger show the lowest level in terms of innovation development and effectiveness of logistics. The respective scatter diagrams are highlighted in Figure 2.

Accordingly, the results of the country analysis demonstrate as well that country’s technological readiness and innovation potential are significant drivers for the logistics performance and thus, Logistics 4.0. Since, the level of technological readiness and innovation potential of a country form the basis for the improvement of the logistics efficiency, it can be stated that countries that exhibit great technological progress and innovation capabilities are more likely to achieve the digital transformation of their economy and society, than economies that face a low technological and innovative basis. Vice versa, since the development of Industry 4.0 depends on the logistics efficiency and, thus, the smart provision of the necessary input factors according to right time, quality and place requirements, it can be further noted that investments in information technologies and innovations are crucial for enabling Logistics 4.0.

5. Conclusions

The present study investigated the effects of technological readiness and innovation on the logistics performance of countries. The analysis made it possible to deduce the comprehensive picture of the degree of technological and innovative progress in respect of logistics performance in the context of countries and their respective development level. Building upon the conducted research, it was empirically determined and substantiated that technological readiness and innovation potential are important promoter for the formation and development of logistics efficiency of economies. Accordingly, the statistical analysis has proven that both factors – technological and innovative basis of a country – significantly affect the logistics performance.

The digitalization of logistics processes requires a high level of technological readiness and innovation capabilities. This is reflected upon the development level of the investigated countries and their corresponding results in the two indices – GCI and LPI. Accordingly, technological readiness and innovation development predetermine the effectiveness of logistics and the quality of logistics services, which represent important prerequisites for enabling Logistics 4.0 and thus, Industry 4.0 as well as the digital transformation of the economy and society.

According to the endogenous growth theory, economic growth and prosperity is achieved rather by the occurring internal activities and interactions within a system than by external forces (Romer, 1994 & 1986). Hence, the actions or interactions of entities like companies or individuals determine economic growth and sustainable development of logistics clusters (Prause, 2014b; Aizenman & Marion, 1993). Following Romer (1987 & 1990), the main engine for economic growth is technological and thus, innovation progress, which is induced by physical capital and associated with new knowledge generation on labor side as well as innovative capacity.

In contrast, Lucas (1988) put emphasis on human capital as the crucial factor for innovation and thus, economic growth. Transferred into the context of the present research, it can be stated that the technological change implied by the theory, nowadays has to make association with the fourth industrial revolution (Industry 4.0) and the digital transformation in the economy and society. In respect to these insights, it can be noted that on a first glance as a main policy implication by echoing the findings from this study, it can be emphasized that continuous investment in innovations and technological development positively affect and thus, improve the logistics performance of countries. Nevertheless, since in reflection of the endogenous growth theory, digitalization and the related need for a digital transformation as an internal force in companies will have a greater impact on economic growth than external forces coming from regulations that do not function as direct investments in human capital, it can be noted that policy measures should rather target to set the fruitful frame conditions for the digital transformation. Hence, this means that policy measures and investments should primary target to facilitate human capital for enabling innovations and technology progress, as well as ease technology developments and innovations in the private sector in order to enable Logistics and Industry 4.0, as well as the digital transformation of the society and economy, which in the long-term will contribute to smart economic growth (Philipp, 2020b). Accordingly, it is the task of companies to smartly integrate digital technologies into their logistics processes and activities in order to improve the quality of logistics service (Moldabekova et al., 2020). As stated by Nguyen and Luu (2020), the management has the responsibility to increase the awareness and perception of Industry 4.0 adoption and personal relevance of the certain novel technologies in order to safeguard implementation success.
A namable, but plausible limitation in the present study can be seen in the lack of available data concerning a number of countries based on both indices (i.e., GCI and LPI) according to the period under investigation, which limited the sample frame towards 29 countries. This represents a methodological limitation, which obviously refers to the lack of data. Regarding future research activities, it becomes necessary to study comprehensively the different enabling technologies of Industry 4.0 in diverse areas of logistics in order to detect critical technologies fields, by which high sustainable economic growth is achievable, and which contribute to the achievement of the aspirated Logistics 4.0 vision. As the literature review findings in the present study imply, researchers already started to investigate certain information technology applications in the logistics sectors. However, for dedicated and appropriate decision-making, a holistic picture about the impacts of the different data-enabled technologies on the logistics performance is necessary. This can been seen as a difficult endeavor, since specific logistics tasks require company-specific solutions. However, this study paved the way for such investigations on micro logistics level by providing the empirical and theoretical foundation on macro logistics level, as the present research has shown that technological readiness and innovation potential positively and statistically significantly impact country’s logistics performance.

References


