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Co-evolution between Trust in Teachers and Higher Education toward Digitally-rich Learning Environments

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Abstract

Based on a powerful notion that the quality of higher education is crucial for innovation in a digital economy and that this quality is subject to a conception of trust in teachers to deliver good education as well as the advancement of information and communication technology (ICT), the dynamism of the co-evolution between Teacher trust and ICT was analyzed.

Using a unique dataset representing the above system and consisting of: 1) the rate of trust in teachers providing good education in the context of quality of education 2)their social status, 3)the level of higher education and 4) the state of ICT advancement toward digitally-rich learning environments, an empirical numerical analysis of 20 countries was attempted. These countries were classified as *advanced*, *semi-advanced* and *growing*.

It was found that while ICT advanced countries have embarked on a co-evolution of ICT and higher education and trust, the ICT growing countries have not been successful in this due to a vicious cycle between ICT and trust. Finland's educational success can be attributed to this co-evolution which corresponds to the emergence of un-captured GDP similarly to the leading edge of an ICT-driven disruptive business model. The paradox of education productivity in ICT growing countries can be attributed to disengagement from this cycle.

It is suggested that steady ICT advancement fully utilizing external resources in digitally-rich learning environments may be essential to ICT growing countries in achieving higher education. On the other hand, continuing innovation to transform learning environments into new digitally-rich learning environments should be maintained in ICT advanced countries.

A new approach for constructing the above-described co-evolution in a systematic way is explained and explored.

Keywords: Trust in teachers, Pedagogical love, Education productivity paradox, Digitally-rich learning environments, Blended learning, Un-captured GDP

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1. Introduction

High quality higher education is crucial for economies that want to move up the value chain beyond simple production processes and products (World Economic Forum: WEF, 2013*a*). Since this quality is subject to trust in teachers for delivering a strong education (OECD, 2014; Varkey Gems Foundation: VGF, 2014; Sahlberg, 2010; Stehlik, 2016) and the advancement of information and communication technology (ICT) leading to digitally-rich learning environments (UNESCO, 2003), the co-evolution between higher education, trust in teachers and advancement of ICT has been gaining increasing significance.

This paper aims to explore a new approach for constructing the above-mentioned co-evolution in a systematic way by using a unique dataset representing the a system consisting of the rate of trust in teachers to provide good education in the Global Teacher Status Index (VGF, 2014) that analyzes teacher's impact on educational performance[1], together with statistics on higher education level[2] (WEF, 2013*a*) and ICT advancement[3] (WEF, 2013*b)*. Using this system we undertook an empirical numerical analysis of 20 countries in relation to this co-evolution dynamism.

While the rate of trust in teachers was focused on younger students corresponding to PISA assessors, given that the result of the assessment represents institutional states of teachers as well as educational system of the nation[4] (VGE, 2013; HAAGSE, 2015;

[1] Aiming at identifying how the level of respect for teachers affects educational performance represented by such international comparative student assessment as PISA, VGF conducted a survey in 21 countries including the rating of "Trusting teachers to deliver a good education" (see **Appendix 3**). Given that trust in education consists of trust to a personality and also to system (Luhmann, 1979), this rate can be attributed to *trust to personality* and *trust to system* and the weights between them differ depending on the institution of respective countries examined. However, the objective of this analysis is to analyze the co-evolutional relationship between ICT, higher education and this value (whatever the weights of personality and system). In providing policy suggestions to each respective country analyzed, careful attention to the weights corresponding to respective countries would be paid.

[2] Given the primary objective of the contribution of higher education to economies moving up the value chain beyond simple production processes and products, "higher education" encompasses secondary and tertiary enrollment rates as well as the quality of education as evaluated by business leaders. The extent of staff training is also taken into consideration because of the importance of vocational and continuous on-the-job training for ensuring constant upgrading of workers' skills (WEF, 2013*a*, see the details **Table A6**).

[3] Networked Readiness Index (NRI) measured by the WEF (2013*b*) was used which measures worldwide advancement of ICT by computing the following four dimensions with ten pillars as indicated in parenthesis: (i) Environment (Political and regulatory environment, business and innovation environment), (ii) Readiness (Infrastructure, digital content, and affordability), (iii) Usage (Individual usage, business usage and government usage), and (iv) Impact (Economic impact and social impact).

[4] Cultural, political and economic factors and social standing play a role in the position of teachers in each country, and having an influence on how these might impact on education systems.

Stehlik, 2016), analysis using the above data can be considered to provide reasonable insight into system dynamics.

The 20 countries examined were classified into 3 groups: ICT advanced countries (*IAC: Finland, Singapore, Netherlands, Switzerland, UK, USA, Korea, Germany, Israel, Japan*), ICT semi-advanced countries (*ISC: Portugal, Spain*), and ICT growing countries (*IGC: Czech Republic, Turkey, Italy, China, Brazil, Greece*).

Given the significant shift from traditional teaching practice to blended learning[5] toward digitally-rich innovative learning environments (DILE) and also the significant effect of the learners ability of "overdrawing" past information on trust (Luhmann, 1979), the state of the country in this shift has become crucial for its performance.

IAC has shifted to DILE and constructed a co-evolutionary dynamism between ICT, higher education and trust. This corresponds to emerging un-captured GDP as observed in the ICT-driven disruptive business model (Watanabe et al., 2016*b*, 2017).
ISC are in transition from traditional teaching and learning environments to DILE and experiencing unsuccessful co-evolution due to a vicious cycle between ICT advancement and higher educational level enhancement.
IGC remain in traditional learning environments and suffer disengagement due to a mismatch between ICT advancement and trust in teachers.
These findings give rise to insightful suggestions to the respective countries concerning their successful co-evolution that depends on the state of their ICT advancement.

The paper is organized as follows: Section 2 reviews the significance of higher education in the progress towards digitally-rich learning environments. Section 3 analyzes the co-evolutionary dynamism in those 20 countries. The structural source of the contrast of co-evolution and disengagement in the 20 countries is analyzed in Section 4. Section 5 briefly summarizes some noteworthy findings, implications, and suggestions for future analysis.

[5] Blended learning is a formal education program in which student learns at least in part through delivery of content and instruction via digital and online media with some element of student control over time, place, path, or pace (Wikipedia).

2. Trust-based Higher Education towards Digitally-rich Learning Environments

While better educational outcomes are a strong predictor of economic growth, wealth and spending on education alone are not (OECD, 2011). Finland demonstrates the world's most outstanding educational performance (e.g., WEF, 2013*a*; Saarela et al., 2014), but no single factor can explain this performance. Teachers' capacity to teach in classrooms and work collaboratively in professional communities has been systematically built through academic teacher education (Sahlberg, 2010). It has been pointed out that "pedagogical love," the relationship between students, teachers, parents and even educational administrators based on trust, may be the secret to Finland's educational success (Stehlik, 2016).

The importance of the concept of trust in the educational context has been increasingly recognized, and a growing body of literature supports the idea that trusting relationships between teachers and students are fundamentally important, both for the students' ability to learn and for effective teaching. With a trustful relationship, teachers can anticipate students' behavior and feel encouraged to actively participate in lessons without the fear of being compromised by the teacher (Schlte-Pelkum et al., 2014). Trust in the education environment provides students an opportunity to take initiative in their learning (Brown et al., 2007).

Contrary to these expectations, Varkey Gems Foundation (VGF) who conducted an international comparative survey on the Global Teacher Status Index claimed that "there is no correlation between trusting teachers and educational outcomes. For example, Brazil places the most trust in their teachers, yet has one of the lowest learning outcomes in the 21 countries surveyed" (VGF, 2014).

These contradictory attitudes can largely be attributed to the dramatic advancement of ICT that has significant impact on the educational environment (UNESCO, 2003; OECD, 2010; Jeferry et al., 2014) but also often encounters some resistance (Oreg et al., 2015).

Luhmann (1979) defined trust in education as consisting of trust in personality and in the system as well. He postulated that trust is a consequence of "overdrawing" of past information, not only utilizing a student/teacher's own previous experiences but also inference thereon, allowing the learners to minimize risk and uncertainty. This postulate suggests that while advancement of ICT may enhance higher education and trust in teachers by accelerating "overdrawing" of past information by means of ICT

advancement, which leads to co-evolution between them, it may lessen the correlation between higher education and trust in teachers in the case of a digital divide in the learning environment.

Despite teachers' resistance to the use of advanced technology in education, there has been an ICT-leveraged rapid increase in blended learning, and technology has increased the breadth and depth of access to education (Chen et al., 2010). This is significant because it has been the hallmark of western education that co-location in time and space of teachers, students and resources is the *sine qua non* of education (Jeffery et al., 2014).

Learning environment as a broader setting than classroom, as the context in which learning is situated, has gained popularity. This environment consists of the physical and digital setting in which learners carry out their activities, and it includes all the tools, documents and other artifacts commonly found in that setting. Besides the physical and digital setting, the socio-cultural setting for ICT has become crucial in the innovative learning environment which should have the necessary technological, social and educational affordances to provide opportunities to learn (Zitter et al., 2012).

In this innovative learning environment, teachers need to be adequately prepared to implement a state-of-the-art ICT curriculum. Programs of professional development for teachers are most effective if directed to the stage of ICT development reached by schools (Anderson et al., 2002). In this context, we note that a hybrid model that combines reinforcement learning with supervised learning outperforms a pure supervised learning model and a pure reinforcement learning model (Henderson et al., 2008; Makela et al., 2014). Cross-fertilization leads to new forms of learning which integrate aspects of both formal and informal learning. Learning and working processes become intertwined, thus benefiting from the strengths of both formal, school-based learning and real-life experience (Iqbal et al., 2010; Zitter et al., 2012). Thus, new and emerging technologies are provoking a re-conceptualization of teaching and learning (Groff, 2013).

Out of these trends, blended learning has emerged, reminding us of the significance of trust in teachers in providing good-quality blended learning as a hybrid model in an innovative learning environment.However, despite the clear demonstration of the benefits of using technology in education, there continues to be a marked reluctance among academics to engage with online education (Anderson, 2008). It was revealed that teachers were much less positive than their students about the learning benefits of an online learning component (Heaton-Shrestha et al., 2009). Teachers' status can easily

be eroded, as learners can compare teacher-designed resources with video lectures across the world on similar topics and chat directly with experts in the field through their blogs (Greener, 2009). The potential for such comparisons often made teachers fear possible exposure to ridicule or unflattering comparisons (Jeffery et al., 2014). Some teachers claim that technology has no beneficial effect on learning and is even instrumental in maintaining students in a state of semi-disengagement (Heaton-Shrestha et al., 2009). Teachers who fail to recognize the benefits of online learning are less likely to create effective blended courses (Jeffery et al., 2014). In addition, many educators share experiences of students who are apathetic, and unwilling to engage in the learning experience, ultimately failing. These students have learned to withdraw from the classroom as a defense (Brown et al., 2007).

Peslak (2005), utilizing the US annual survey of computers, ICT and other technology, as well as library resources, in 2000-2001 assessed their contribution to educational test scores and revealed that ICT factors do not show consistent, positive relationships with higher educational scores. As one possible reason for this educational productivity paradox he saw that more time was spent with computers than with actual education and learning activities.

These contradictions in positive and negative aspects of blended learning can be attributed to distinct phases of ICT development in the innovative learning environment. UNESCO's Institute for Information Technology has evaluated the degree to which ICT has been integrated in an educational system, by distinguishing four distinct stages: (i) emerging, (ii) applying, (iii) infusing, and (iv) transforming (UNESCO, 2003). These stages offer us a lens through which we can observe how ICT has leveraged incremental and deep change in learning environments.

Faced with digitally-rich learning environments and in order to effectively utilize this potential for higher education, the key task for a nation is to find how to smoothly shift from traditional teaching practice to blended learning. One way to do this is by realizing the distinct stages of ICT integration in an education system.

Conflicts in a system generally emerge in the transitions between these stages before the transformation stage is reached. Success in transformation largely depends on the rigidity or flexibility of the school curriculum (Groff, 2013), which is strongly influenced by cultural, societal and institutional factors (Anderson et al., 2002). Therefore, an optimal balance between ICT and older educational technologies reflecting national and regional cultures is the key component of the organization's strategy (Anderson et al., 2002; UNESCO, 2003).

The foregoing review highlights the increasing orientation of trust-based higher

education towards digitally-rich learning environments and elastic institutional system, enabling a smooth transformation from traditional teaching practice to blended learning. However, no-one has analyzed the co-evolutionary dynamism between trust in teachers and higher education enabled by ICT advancement and a possible fear of disengagement in the transition phase considered as the fundamental source of the problem.

3. Co-evolutionary Dynamism between Trust in Teachers, Higher Education and ICT Advancement

3.1 ICT-Driven Education Development

Dramatic advancement of the Internet beyond anticipation in terms of its diffusion speed and scope has led to ICT-driven economic development worldwide. Consequently, the economic development (e.g., GDP per capita) trajectory of 120 nations (see **Appendix 1**) can be depicted by a logistic growth function initiated by the advancement of ICT (Zhao et al., 2013).

Given the strong correlation between economic development and enhancemed higher education level as demonstrated in **Fig. 1**, the contribution of ICT advancement to the risen education level can be depicted by a logistic growth function as demonstrated in the sigmoid curve in **Fig. 2** (see **Appendix 4**).

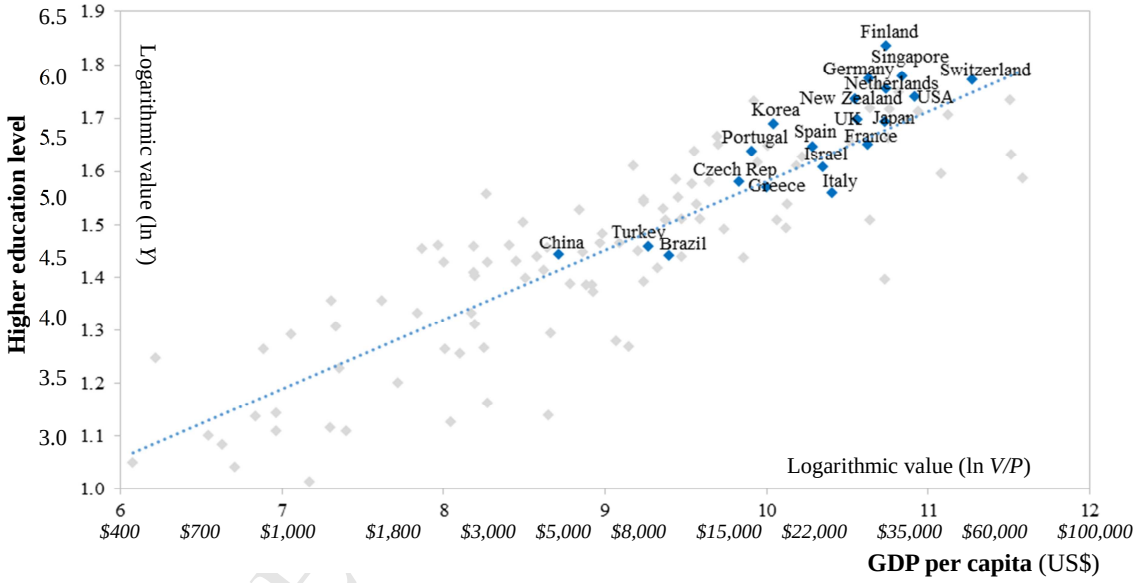


Fig. 1. Correlation between Economic Development and Higher Education Level in 112 Countries (2013).

Sources: [10], [32].

$$\ln Y = \underset{(5.55)}{0.289} + \underset{(23.19)}{0.131}\ln\frac{V}{P} \qquad \textit{adj. } R^2 = 0.830$$

Y: Higher education level, *V/P*: GDP per capita,

ICT top 120 countries excluding 8 countries with non-standardized performance, namely Luxembourg, Kuwait, Egypt, Botswana, Paraguay, Pakistan, Namibia, Suriname.

The countries named are the 20 selected countries[6]

The figures in parenthesis indicate t-statistics: all are significant at the 1% level.

[6] Based on the criteria introduced by Global Teacher Status Index (VGF, 2014) as representing each major continent and also different strands of educational systems (see **Appendix 3**).

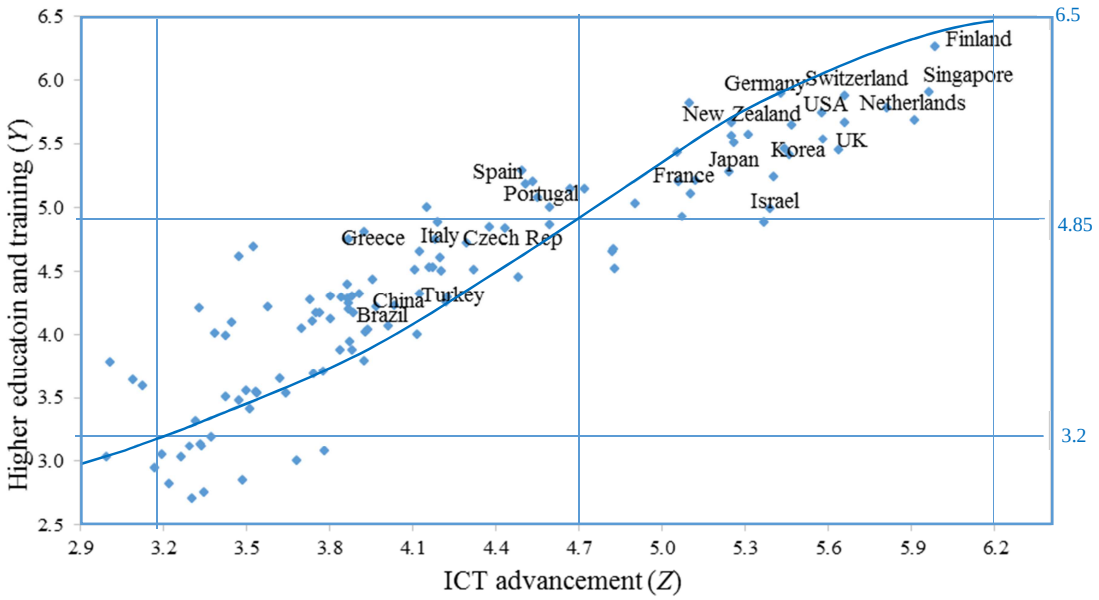


Fig. 2. ICT-driven Education Development in 120 Countries (2013)**.**
Sources: [32] [34].

3.2 The Stage of ICT Advancement

Thus, advancement of ICT plays a significant role in enhancing education levels worldwide.

With such understanding in mind, **Fig. 3** compares the advancement of ICT in 100 countries.

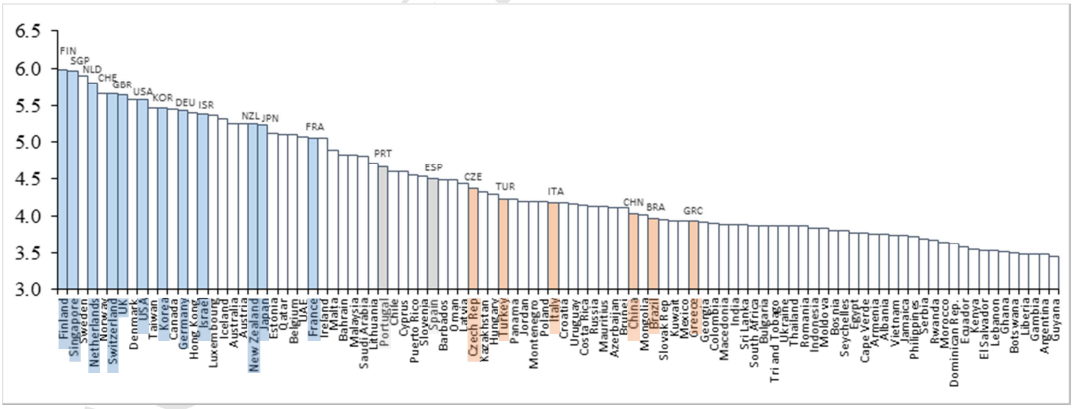


Fig. 3. Level of ICT Advancement by NRI in 100 Countries (2013).
Source: [34].

On the basis of global ICT advancement and its contribution to enhancing higher education together with trust in teachers, this paper focuses on the analysis of the co-evolutionary dynamism between trust in teachers and higher education enabled by ICT advancement. We consider 20 countries for which reliable trust in teacher data is

available (see **Appendix 3**).

Fig. 4 focuses on comparison of the level of ICT advancement in 20 countries by taking the average of NRI between 2012 and 2015 (see **Appendix 1**).

Looking at Fig. 4, we notice that the countries by their state of ICT advancement in the world can be classified into ICT advanced countries (*IAC*), ICT semi-advanced countries (*ISC*), and ICT growing countries (*IGC*) as follows:

IAC: Finland, Singapore, Netherlands, Switzerland, USA, UK, Korea, Germany, Japan, Israel, New Zealand and France;

ISC: Portugal and Spain;

IGC: Chez Republic, Turkey, Italy, China, Greece and Brazil.

Given the significant role of ICT advancement in enhancing higher education level, as reviewed earlier, these states play a decisive role in education: for example, blended learning has played a significant role in enhancing education, and dependency on this learning corresponds to the state of ICT advancement (UNESCO, 2003; Groff, 2013).

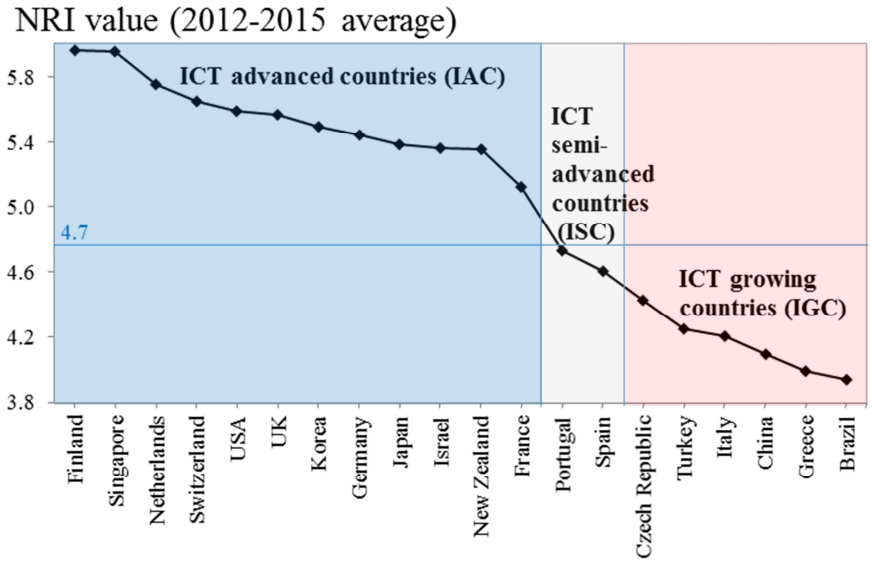


Fig. 4. Level of ICT Advancement by NRI in 20 Countries (2012-2015 average).
Source: [34].

Fig. 5. Compares the level of higher education among 20 countries.

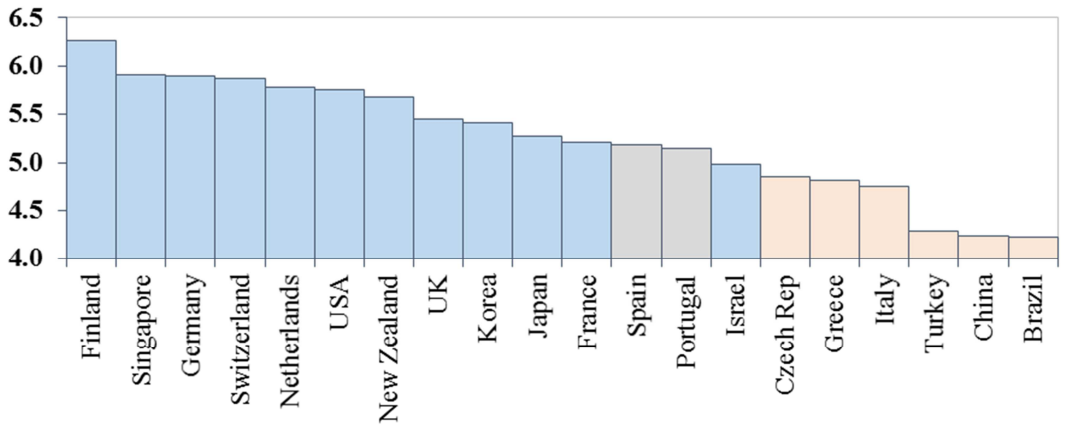


Fig. 5. Level of Higher Education in 20 Countries (2013).

Source: [32].

Fig. 6 compares the degree of trust in teachers among 20 countries.

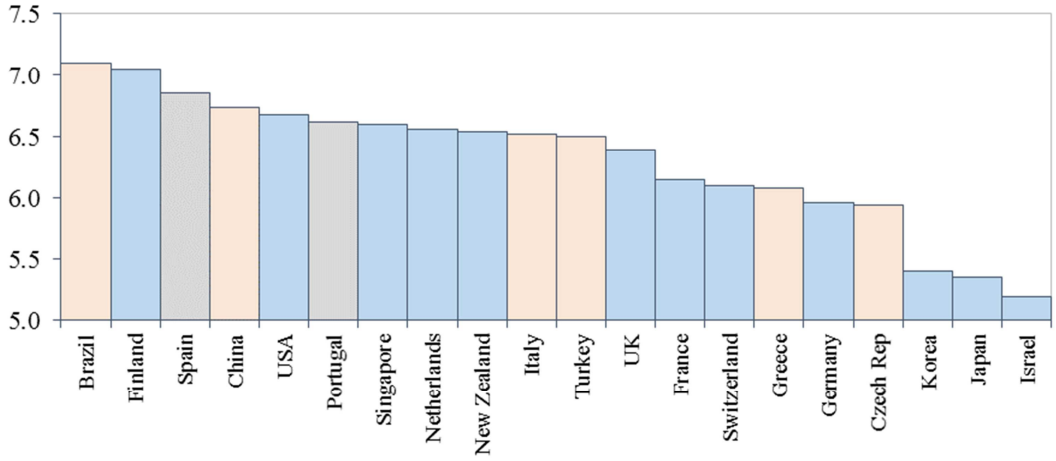


Fig. 6. Level of Trust in Teachers to Deliver a Good Education in 20 Countries (2013).

Source: [25].

With a hypothetical understanding that a successful shift from traditional teaching practice to blended learning and toward digitally-rich learning environments can largely be attributed to the co-evolutionary dynamics between ICT advancement, higher education and trust in teachers (Watanabe et al., 2015*b*, 2016*a*), this co-evolution in 20 countries is analyzed. **Tables A3-5** compare the advancement of ICT, higher education level, and trust in teachers among 20 countries. **Table A6** demonstrates the composition of higher education level.

3.3 Co-evolutionary Advancement between Trust in Teachers and Higher Education

Utilizing the foregoing data, the co-evolution between the advancement of teachers and higher education level in 20 countries was analyzed by dividing them into 12 ICT advanced countries (*IAC*), 2 ICT semi-advanced countries (*ISC*) and 6 ICT growing countries (*IGC*). The result of the analysis is illustrated in **Fig. 7**. We note that, contrary to Varkey Gems Foundation's observation that "There is no correlation between trusting teachers and educational outcomes" (VGF, 2014), there are strong correlations between them depending on the state of ICT advancement. While higher education level depends on trust in teachers in *IAC* and *ISC*, this correlation is opposite to that in *IGC*. In *IGC*, it is anticipated that trust in teachers spoils students' education, declining their higher educational level. (For detailed explanation of the analysis see **Appendix 5**).

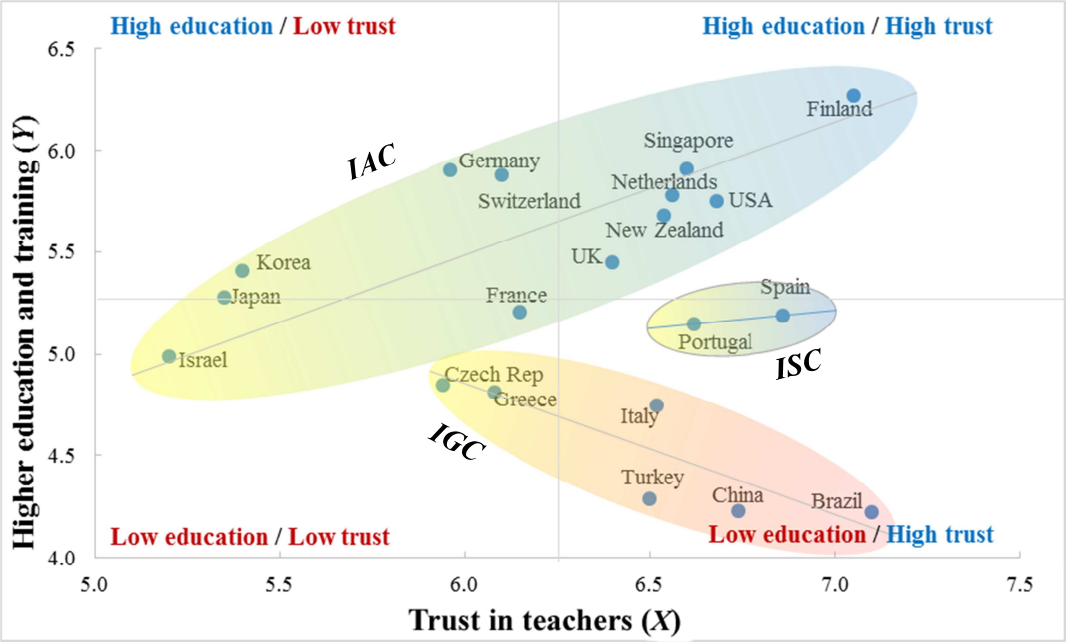


Fig. 7. Correlation between Trust in Teachers and Higher Education Level in 20 Countries (2013)**.** Sources: [25] [32].

$$\ln Y = \alpha + \sum_{i=1}^{3} [\beta_i D_i] \ln X \qquad i = 1 \text{ for } IAC \text{ (others} = 0), i = 2 \text{ for } ISC \text{ (others} = 0), i = 3 \text{ for } IGC \text{ (others} = 0).$$

$$\ln Y = \underset{(3.47)}{0.811} + \underset{(3.92)}{0.504} D_1 \ln X + \underset{(3.54)}{0.436} D_2 \ln X - \underset{(-3.07)}{0.874} D_3 \ln X + \underset{(4.01)}{2.329} D_3 \qquad \textit{adj.}\ R^2 = 0.872$$

D_1, D_2, D_3: Coefficient dummy variables corresponding to IAC, ISC and IGC, respectively.
The figures in parenthesis indicate *t*-statistics: all are significant at the 1% level**.**

Inspired by these observations, **Fig. 8** analyzes the effects of the higher education level on increasing trust in teachers. Fig. 8 demonstrates that while higher education demonstrates a positive correlation with trust in teachers in *IAC* and *ISC*, it shows an opposite effect in *IGC*: that is, while higher education stimulates trust in teachers in *IAC* and *ISC*, it results in decreasing the trust in *IGC*.

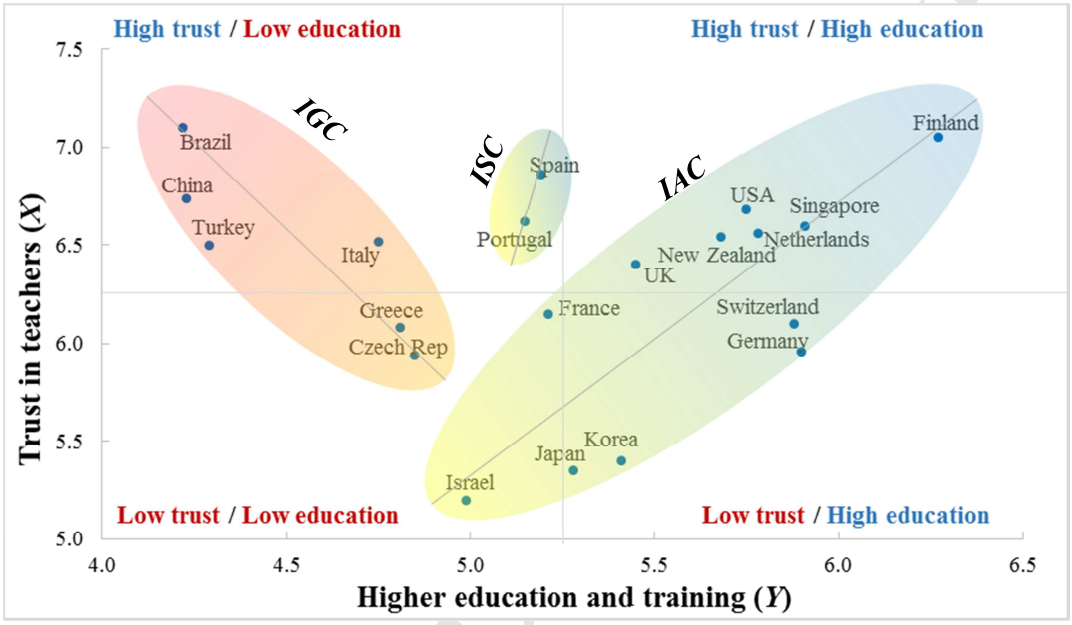


Fig. 8. Correlation between Higher Education Level and Trust in Teachers in 20 Countries (2013)**.**
Sources: [25] [32].

$$\ln X = \alpha + \sum_{i=1}^{3} [\beta_i D_i] \ln Y \qquad i = 1 \text{ for } IAC \text{ (others} = 0), i = 2 \text{ for } ISC \text{ (others} = 0), i = 3 \text{ for } IGC \text{ (others} = 0).$$

$$\ln X = -0.631 + 1.406 D_1 \ln Y + 1.545 D_2 \ln Y - 0.815 D_3 \ln Y + 3.726 D_3 + 0.114 D$$

(-1.51)# (5.86) (6.07) (-2.58)* (5.89) (2.85) ***adj.*** R^2 **= 0.707**

D: Dummy variables (France, UK = 1, others = 0).

The figures in parenthesis indicate t-statistics: all are significant at the 1% level, except * and # at the 2% and 15% level, respectively.

The analyses in Figs. 7 and 8 demonstrate that increase in trust in teachers stimulates higher education, which in turn induces trust in teachers leading to co-evolution between them in *IAC* and *ISC*, whereas in *IGC* both disengage, resulting in a vicious cycle.

3.4 Co-evolutional Advancement between ICT and Trust in Teachers

Inspired by the foregoing findings on the co-evolution between trust in teachers and higher education in *IAC* and *ISC*, and their disengagement in *IGC*, the correlation between ICT advancement and trust in teachers was analyzed next.

Fig. 9 demonstrates the result of the analysis of the correlation between ICT advancement and trust in teachers in 20 countries classified by ICT advancement state.

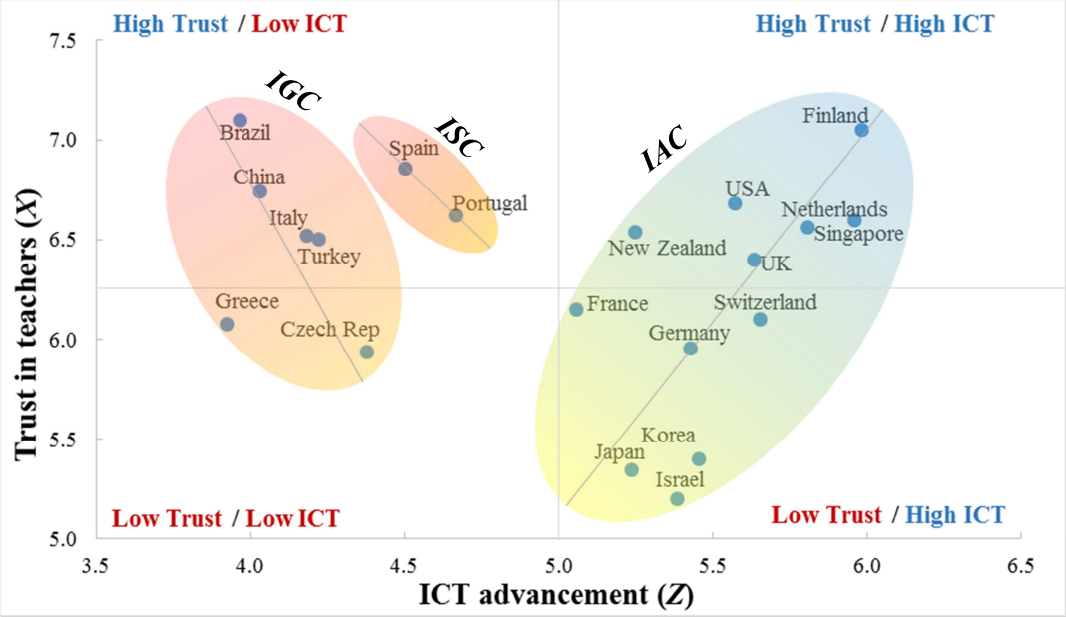


Fig. 9. Correlation between ICT Advancement and Trust in Teachers in 20 Countries (2013).
Sources: [25] [34].

$$\ln X = \alpha + \sum_{i=1}^{3} [\beta_i D_i] \ln Z \quad i = 1 \text{ for } IAC \text{ (others = 0)}, i = 2 \text{ for } ISC \text{ (others = 0)} = 3 \text{ for } IGC \text{ (others = 0)}.$$

$$\ln X = \underset{(7.82)}{4.177} + \underset{(2.50)^{**}}{0.524 D_1} \ln Z \underset{(-4.24)}{-1.490 D_2} \ln Z \underset{(-4.28)}{-1.613 D_3} \ln Z \underset{(-5.24)}{-3.216 D_1} \underset{(-7.82)}{-0.169 D} \quad \textbf{adj. } R^2 = \textbf{0.848}$$

D: Dummy variables (Japan, Israel, Czech Rep., Korea = 1, others = 0).

The figures in parenthesis indicate t-statistics: all are significant at the 1% level, except ** at the 3% level.

Fig. 9 shows that while advancement of ICT induces increase in trust in teachers in *IAC*, in line with the Luhmann's postulate (Luhmann, 1979), it demonstrates the opposite effect not only in *IGC* but also in *ISC*. Advancement of ICT contributes to the increase in trust in teachers in *IAC* as generally anticipated in case of digitally-rich learning environments. It is surprising to see that advancement of ICT has the effect of losing trust in teachers, not only in *IGC* but also in *ISC*.

Inspired by such surprising observation, **Fig. 10** analyzes the effect of trust in teachers on ICT advancement.

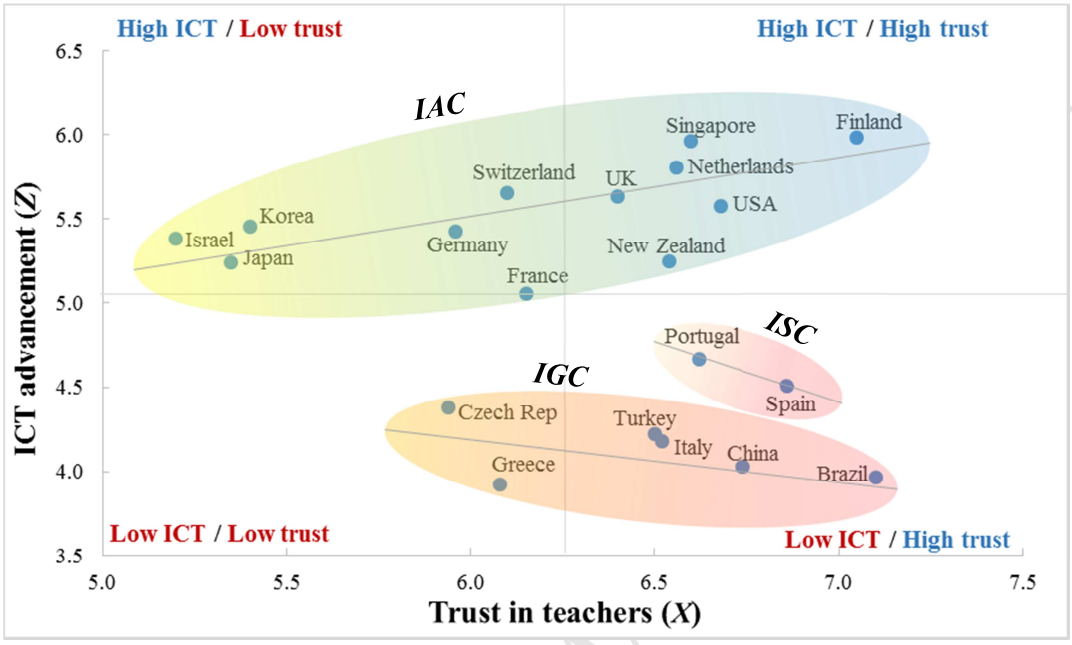


Fig. 10. Correlation between Trust in Teachers and ICT Advancement in 20 Countries (2013). Sources: [25] [34].

$$\ln Z = \alpha + \sum_{i=1}^{3} [\beta_i D_i] \ln X \qquad i = 1 \text{ for } IAC \text{ (others = 0)}, i = 2 \text{ for } ISC \text{ (others = 0)}, i = 3 \text{ for } IGC \text{ (others = 0)}.$$

$$\ln Z = 2.535 + 0.360 D_1 \ln X - 0.530 D_2 \ln X - 0.591 D_3 \ln X - 1.461 D_1 - 0.099 D$$

(10.03) (5.98) (-4.00) (-4.38) (-5.25) (-7.76) ***adj.* R^2 = 0.982**

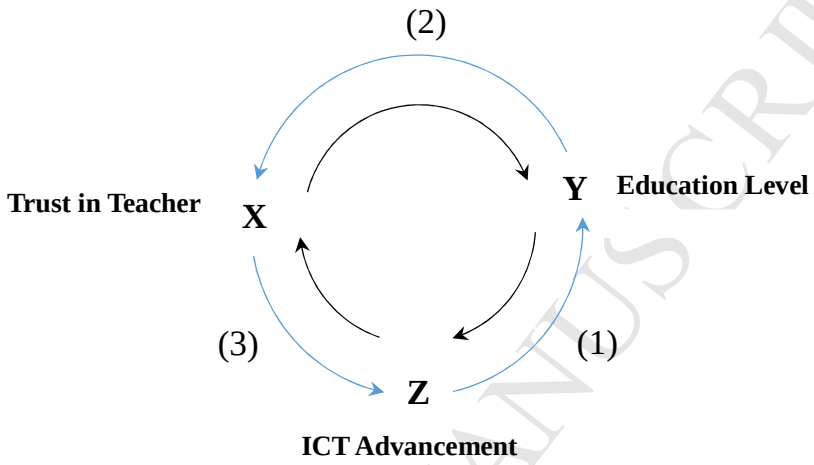
D: Dummy variables (France, New Zealand, Greece = 1, others = 0)
The figures in parenthesis indicate t-statistics: all are significant at the 1% level

Fig. 10 demonstrates a positive correlation between trust in teachers and ICT advancement also in *IAC*; as in Fig. 9, it changed to negative in *ISC* and *IGC*.

The analyses in Figs. 9 and 10 demonstrate the co-evolution between ICT advancement and trust in teachers in *IAC* similar to its co-evolution between trust in teachers and higher education. The effect is opposite in case of *IGC*, similar to its disengagement in the earlier correlation. In case of *ISC*, contrary to its co-evolution between trust in teachers and higher education, it changed to disengagement in case of the correlation between ICT advancement and trust in teachers. This unexpected contrast in *ISC* between co-evolution of trust and higher education, on one hand, and disengagement of ICT advancement and trust in *ISC*, on the other, suggests a possible system conflict in the transition of distinct phases of ICT advancement toward digitally-rich learning environments.

3.5 Co-evolution and Disengagement between ICT, Education Level, and Trust in Teachers

On the basis of the foregoing analyses, the co-evolution and disengagement between ICT advancement (*Z*), higher education level (*Y*) and trust in teachers (*X*) in *IAC*, *ISC* and *IGC* can be summarized as illustrated in **Fig. 11**.



	ICT advanced countries (*IAC*)	ICT semi-advanced countries (*ISC*)	ICT growing countries (*IGC*)
(1) *Z* and *Y*	+	+	+
(2) *Y* and *X*	+	+	-
(3) *X* and *Z*	+	-	-

Fig. 11. Co-evolution and Disengagement between ICT, Educational Level, and Trust in Teachers in 20 Countries Depending on ICT Advancement.

+ : Co-evolution (virtuous cycle), - : Disengagement (vicious cycle)

As summarized in Fig. 11, while the correlation between ICT advancement and higher education was demonstrated in co-evolution of all *IAC*, *ISC* and *IGC*, correlation between higher education and trust demonstrates contrast between co-evolution in *IAC* and *ISC*, and disengagement in *IGC*. Similarly, correlation between trust and ICT advancement demonstrates contrast between co-evolution in *IAC* and disengagement in *ISC* and *IGC*.

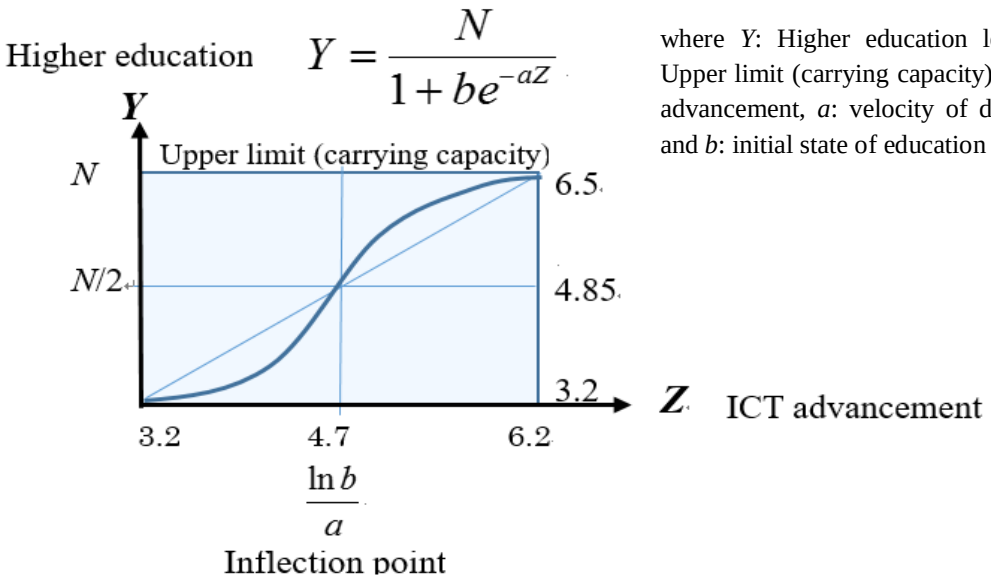
4. Structural Source of the Contrast of Co-evolution and Disengagement between ICT, Education Level, and Trust in Teachers

Inspired by these findings with respect to contrasting co-evolution and disengagement depending on the ICT development state (Cowen, 2011), thes structural source was analyzed and modeled.

4.1 Logistic Growth in ICT-driven Higher Education and its Bi-polarization

(1) Bi-polarization Fatality of Logistic Growth

As illustrated in Fig. 2, advancement of ICT contributes to enhancement of higher education level in line with a following logistic growth function:



where *Y*: Higher education level, *N*: Upper limit (carrying capacity), *Z*: ICT advancement, *a*: velocity of diffusion, and *b*: initial state of education level.

Fig, 12. Logistic Growth Function for ICT-driven Higher Education in 120 Countries (2013).

This logistic growth results in a bi-polarization as illustrated in **Fig. 13** (Tokumasu et al., 2009; Zhao et al., 2013; Watanabe et al., 2014, 2015*a*; see the details of this dynamism in **Appendix 5**).

The figure indicates that, while *marginal inducement of ICT through higher education enhancement* (d*Z*/d*Y*) increases as ICT advances ((d*Z*/d*Y*)/d*Z* > 0) when the ICT advancement level exceeds a certain threshold, an inflection point ($Z > \ln b/a$). In contrast, it decreases when the ICT advancement level remains lower than this threshold ($Z < \ln b/a$). This contrasting behavior between a virtuous cycle[7] and a vicious cycle as a consequence of a bi-polarization may play a decisive role in contrasting the co-evolution and disengagement between ICT advancement, higher education and trust

[7] Virtuous cycle depends on ICT's contribution to "overdrawing" of past information for trust increase (see Appendix 5).

in teachers depending on the state of ICT advancement (Watanabe et al., 2016*c*).

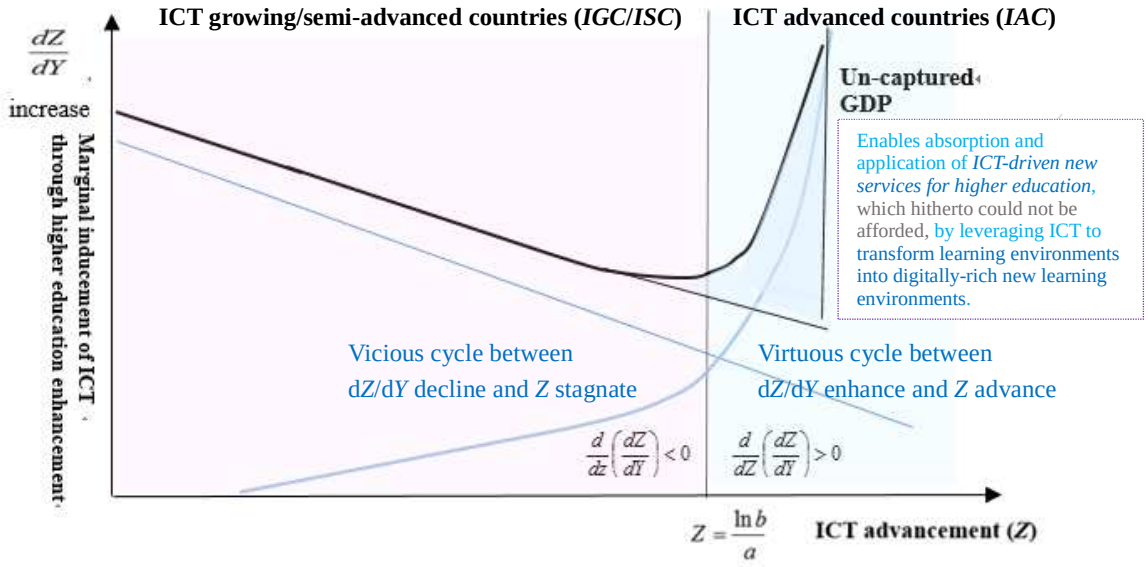


Fig. 13. Bi-polarization of ICT-driven Higher Education.

(2) Stages of ICT Integration in Education

According to the UNESCO's Institute for Information Technology, the degree to which ICT has been integrated in an educational system can be described by four distinct stages: (i) emerging, (ii) applying, (iii) infusing, and (iv) transforming (UNESCO, 2003), as illustrated in **Fig. 14**. These stages offer us a lens through which we can observe how ICT has leveraged the incremental and deep change in learning environments (Groff, 2013) and provide us a reasonable explanation of the foregoing bi-polarization behavior.

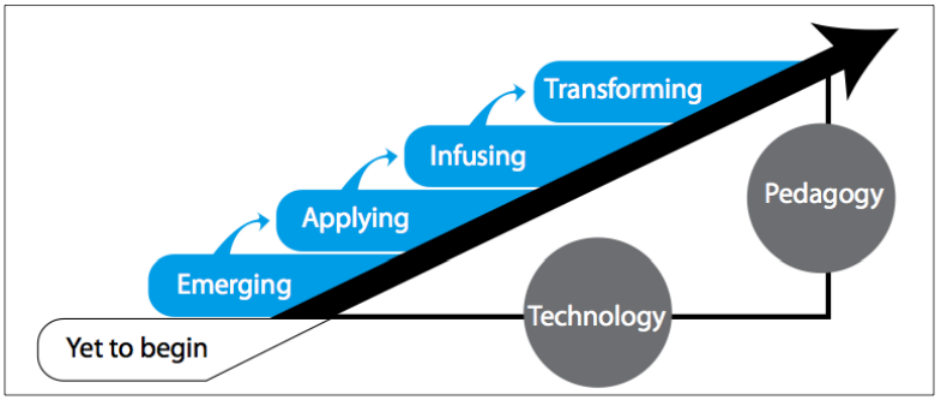


Fig. 14. Stages of ICT Integration in Education.

Source: Groff (2013) based on Anderson et al. (2002).

The first three stages represent learning environments using ICT as a means to solely move toward more digitally-rich learning environments (Groff, 2013). During these stages, *marginal productivity of ICT in enhancing higher education* (d*Y*/d*Z*) increases as the use of ICT advances and in the way that is generally anticipated[8]. However, the required ICT advances corresponding to ICT-driven new services cannot be afforded by such ICT use. This results in a vicious cycle: *marginal inducement of ICT* (d*Z*/d*Y*) declines as the ICT use continues as illustrated on the left of Fig. 13.

Learning environments that seek a more holistic change and dramatically overhaul the existing environments have leveraged ICT to complete the process leading to the fourth stage, the transformation through ICT. At this stage, ICT is not used as a lever for advancing toward more digitally-rich learning environments but to transform learning environments into digitally-rich new environments (Groff, 2013). Such new environments can absorb and effectively apply ICT-driven new services to higher education, which hitherto they could not afford. Therefore, in this transforming stage, *marginal productivity of ICT in enhancing higher education* (d*Y*/d*Z*) declines as ICT advances in its initial stage, and absorption and application of new services cannot be afforded. However, strong desire to enhance higher education in digitally-rich learning environments induces transcending innovation to transform learning environments into digitally-rich new learning environments that can absorb and effectively apply ICT-driven new services to higher education[9].

This desire leads to a virtuous cycle between ICT advancement and *marginal inducement of ICT through higher education enhancement* (d*Z*/d*Y*) as illustrated on the right of Fig. 13. This virtuous cycle enables absorption and application of ICT-driven new services to higher education, which hitherto could not be afforded, by leveraging ICT to transform learning environments into digitally-rich new learning environments. This behavior corresponds to the emergence of un-captured GDP[10] as observed in the forefront of ICT-driven disruptive business model (IDBM) (Watanabe et al., 2016*b*).
Foregoing review demonstrates the significance of stages of ICT integration in

[8] Advances of ICT toward more digitally-rich learning environments generally contribute to enhanced rewards via the use of ICT for education by increasing new functionality development. Given that schools seek to maximize profits in competitive learning environments, marginal productivity of ICT corresponds to the relative price of ICT in education enhancement (see the detail in Appendix 5).

[9] Transcending innovation *transforms learning environments into digitally-rich new learning environments which can absorb and effectively apply ICT-driven new services to higher education* while also increasing trust. This function is equivalent to co-evolutionary acclimatization through harnessing the vigor of counterparts for maintaining a virtuous cycle in the ICT advanced environments (Watanabe et al., 2015*a*). In this case, it can be said that “to harness the vigor of time” as trust depends on ”overdrawing” of past information (Luhmann, 1979).

[10] Un-captured GDP can be defined as added value providing for people utility and happiness beyond economic value. However, it cannot be measured by traditional GDP accounting that measures economic value (Watanabe et al., 2015*a*).

education in identifying the contrasting state of nation's ICT-driven higher education trajectory.

With this understanding, **Table 1** summarizes a matrix of key features in respective learning environments by stages of ICT integration in education. A given learning environment or education system can be mapped onto this matrix by being evaluated on various dimensions, such as content, pedagogy, curriculum, etc. (Groff, 2013).

Table 1 Learning Environments by Stages of ICT Integration in Education

Stage / Learning environments	Emerging	Applying	Infusing	Transforming
Vision	Limited, pragmatic, dominated by interested individuals	Driven by ICT specialists	Driven-by subject specialists	Entire learning community involved
Learning pedagogy	Teacher-centered	Teacher-centered; ICTs are a separate subject	Learner-centered; Collaborative	Critical thinking; Preferred learning styles; Collaborative, experimental
Development plan and policies	Accidental, restrictive, no planned funding	Limited; Centralized policies	Individual subject plans for ICTs; Permissive policies	ICTs are integral to overall school development plan (budget, professional development)
Facilities and resources	Limited and non-current digital resources; Restricted access	Diverse and varying in model, platform; Aligned with specific content and pedagogies	Diffused access to various digital resources; Support to implement these in various ways	Whole school learning and diverse learning environments; Web- based learning spaces, distance education, student self-management software
Understanding of curriculum	ICT literacy; Responsibility of individual teachers	Use of software and applications in discrete subjects (isolated)	Integrated; Resource-based learning, problem-solving project methodology	Virtual and real time contexts, modeling; Integrated curriculum delivery via the Web
Professional development	Individual interest	Training on ICT application; Involvement	Subject-specific; evolving	Integrated learning community; Innovative; Self- managed, personal vision and plan
Community	Accidental	Some parental and community involvement	Subject-based community, providing occasional guidance; Global and local networked communities	Broad-based learning community; Involving families, business, industry, organizations, universities, etc.; School as a learning resource for the community
Assessment	Responsibility of an individual teacher; Didactic; Paper-and-pencil based	Teacher-centered; Subject-focused	Learner-centered; Subject-oriented; Integrated; Multiple media to demonstrate alignment	Continuous; Holistic, open-ended, project- based; Learning community involvement

Source: Groff (2013) based on Center for Research on Lifelong Learning (2009).

Table 1 demonstrates that the state of the Internet access as well as quality of education system and management system are particularly decisive in shifting from the first three stages to the fourth stage, the transformation through ICT.

With this identification, **Fig. 15** characterizes and identifies the state of transformation through ICT in 20 countries by correlating ICT advancement by *NRI* and Internet access in schools.[11] On the basis of the collation of scores of governing factors of *NRI* (see Table A6) and with the key features of the stages of ICT integration in education featured in Table 1, Fig. 15 also identifies the stages of ICT integration in education in 20 countries.

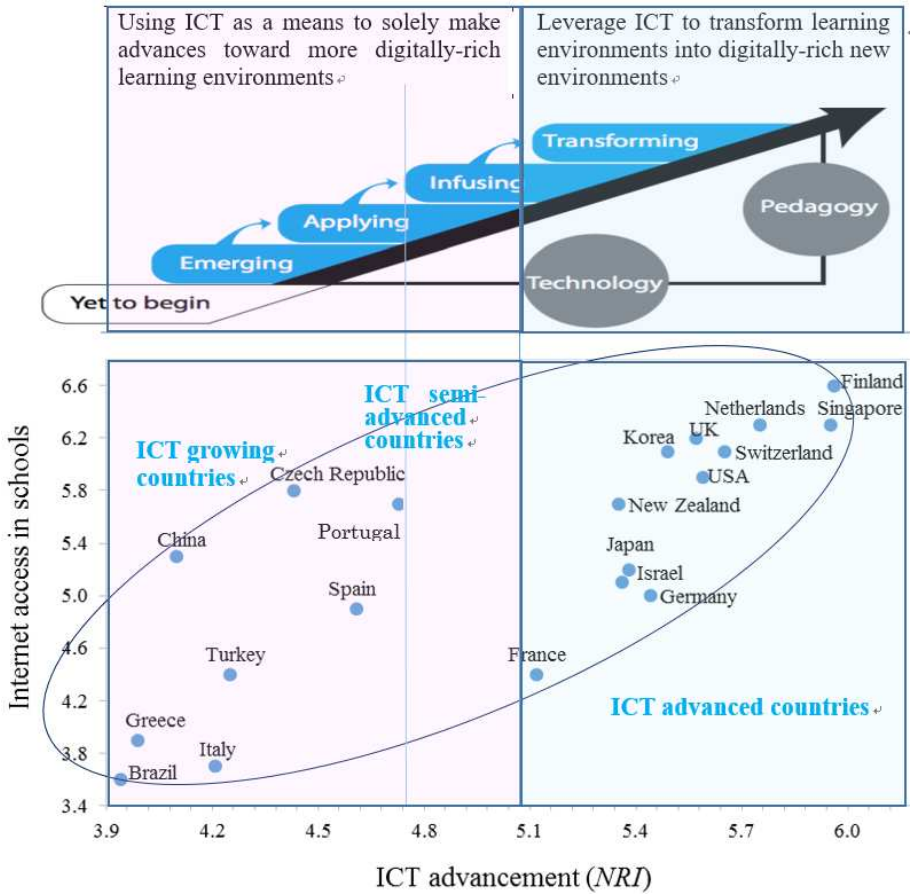


Fig. 15. Correlation between ICT Advancement and Internet Access in Schoo 20 Countries (2013).

Sources: [32], [34].

[11] Internet access in schools is one of the key component of higher education and training level as demonstrated in Table A6. This table also demonstrates the significance of the quality of education system and also the ability of education management at a higher education level.

Fig. 15 demonstrates that ICT advanced countries (*IAC*) have been moved to the transformation stage while ICT semi-advanced countries (*ISC*) and ICT growing countries (*IGC*) have still remained in the emerging, applying and infusing stages, thus providing support to the preceding analysis

Table 2 demonstrates the locomotives of such transformative innovation which trigger un-captured GDP emergence.

Table 2 Transformative Innovations for Digitally-rich Innovative Learning Environments

First-order innovations	**Second-order innovations**
blogs, wikis	augmented reality (AR)
social networking sites	simulations
virtual learning environments (VLE)	digital games
laptops, netbooks and tablet PCs	console games
interactive whiteboards	remote-response systems
Web apps	mobile/handheld computing
digital cameras, scanners, projectors	programming applications
e-learning	pico projectors
digital portfolios	electronic books

Source: Groff (2013).

Currently, first-order innovations are prevalent among many technology-rich learning environments, being implemented under the notion that by leveraging many of these tools together produces a dramatically different educational climate. Second-order innovations are more disruptive but essential to the emergence of un-captured GDP. They appear on the periphery of the educational landscape and are just beginning to see their full potential. These innovations are slowly gaining attention and traction at the forefront of digitally-rich learning environments and will likely see increased development and application over the next decade (Groff, 2013). Furthermore, they are expected to accelerate the creation of ICT-driven disruptive business models and the emergence of subsequent un-captured GDP.

4.2 ICT Elasticity to Trust in Teachers and to Higher Education

Bi-polarization fatality of logistic growth suggests contrasting behavior among 20 countries depending on their state of ICT advancement. Furthermore, given that the inflection point that distinguishes contrasting trajectories also distinguishes higher education level as illustrated in Fig. 12, the trajectories of those 20 countries can be identified by the matrix classified by the thresholds governed by the inflection point.

With this understanding, ICT elasticity to trust in teachers[12] and also ICT elasticity to higher education in the 20 countries were classified with the foregoing matrix depending on their state of ICT advancement (see the details in **Appendix 5**).

(1) ICT Elasticity to Trust in Teachers

On the basis of the identification of the positions of the 20 countries in digitally-rich learning environments with bi-polarization, the peculiar behavior of *ISC* in a transition from *IGC* to *IAC* indicates that, against our expectation, trust in teachers decreases as ICT advances.

This peculiar behavior was demonstrated by identifying ICT advancement (Z) elasticity to trust in teachers (X) and its composition as classified in **Table 3** (see the composition of respective elasticity in **Appendix 5**)

This explains the reason why *ISC* demonstrates, against general expectations, the peculiar behavior of trust decreasing with advancing ICT.

Table 3 Classification of ICT Elasticity to Trust in 20 Countries (2013)

ICT level \ Education level	$Y > \frac{N}{2}$	$Y < \frac{N}{2}$
$Z > \frac{\ln b}{a}$	$\varepsilon_{XZ} = \frac{d \ln X}{d \ln Z} > 0$ (1% increase in Z induces ICT advanced 12 countries (*IAS*)	
$Z < \frac{\ln b}{a}$	$\varepsilon_{XZ} = \frac{d \ln X}{d \ln Z} < 0$ ICT semi-advanced 2 countries (*ISC*)	$\varepsilon_{XZ} = \frac{d \ln X}{d \ln Z} < 0$ ICT growing 6 countries (*IGC*)

[12] Degree of percentage increase in trust in teachers by means of 1% increase in ICT advancement.

(2) ICT Elasticity to Higher Education

This finding leads to another noteworthy finding, namely, that the advancement of ICT may be in decline in higher education, depending on the position in the digitally-rich learning environments.

Therefore, similarly to Table 3, this behavior was demonstrated by identifying ICT advancement (*Z*) elasticity to higher education (*Y*) and its composition as classified in **Table 4** (see the composition of the respective elasticity in **Appendix 5**).

Table 4 Classification of ICT Elasticity to Higher Education in 20 Countries (2013)

ICT level \ Education level	$Y > \frac{N}{2}$	$Y < \frac{N}{2}$
$Z > \frac{\ln b}{a}$	$\varepsilon_{YZ} = \frac{\ln Y}{\ln Z} > 0$ ICT advanced 12 countries (*IAC*)	
$Z < \frac{\ln b}{a}$	$\varepsilon_{YZ} = \frac{\ln Y}{\ln Z} < 0$ ICT semi-advanced 2 countries	$\varepsilon_{YZ} = \frac{\ln Y}{\ln Z} > 0$ ICT advanced 6 countries (*IGC*)

This reveals the unexpected behavior that advancement of ICT results in decline of higher education level in a particular position in the digitally-rich learning environments, as has been observed in *ISC* in its transition from *IGC* to *IAC*.

4.3 The Effect of Blended Learning and Teachers' Resistance

(1) The Position of 20 Countries in ICT-driven Higher Education Trajectory

Realizing the bi-polarization nature of the logistic growth that governs ICT-driven higher education trajectory in 120 countries toward digitally-rich learning environments, as reviewed in Fig. 13, and also by the classification of the possible trajectories in such bi-polarization as reviewed in Tables 3 and 4, the positions of 20 selected countries in their trajectories can be identified as illustrated in **Fig. 16**.

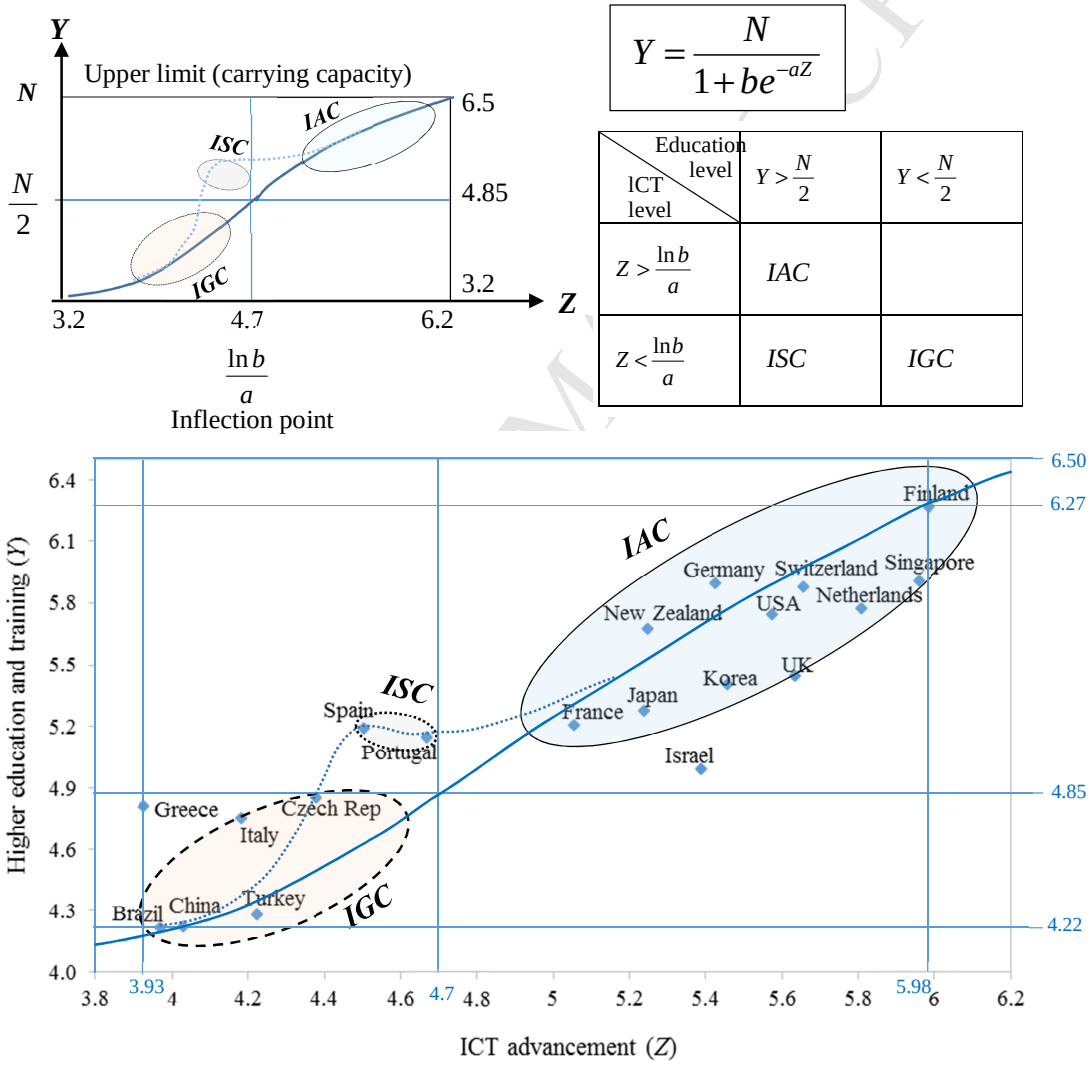


Fig. 16. Positions of 20 Countries in ICT-driven Higher Education Trajectory (2013).

(2) Blended Learning and Teacher's Resistance

Prompted by the empirical findings above, particularly by the peculiar behavior of *ISC* in transition from *IGC* to *IAC* bringing a decline in its higher educational level with the advancement of ICT, the effect of the shift to blended learning and teacher's resistance against this shift was reviewed as they demonstrate the concave educational level in the transition from traditional technical practice.

The use of the Web and other Internet technologies in education have exploded in the last couple of decades (Chen et al., 2010), leading to the creation of digitally-rich learning environments as reviewed in Tables 1 and 2.

Fig. 17 illustrates a scheme of ICT advancement contributing to higher education. Blended learning, which introduces digital and online media to education system by harnessing the vigor of the advancement of the Internet, is certain to increase the speed of this trend (Jeffrey et al., 2014).
Under these circumstances, contribution of ICT advancement to higher education can be developed in a hybrid manner through traditional teaching practice and blended learning as illustrated in Fig. 17 by the diphasic logistic sum of two functions with inflection and stability points (Mischan et al., 2015).

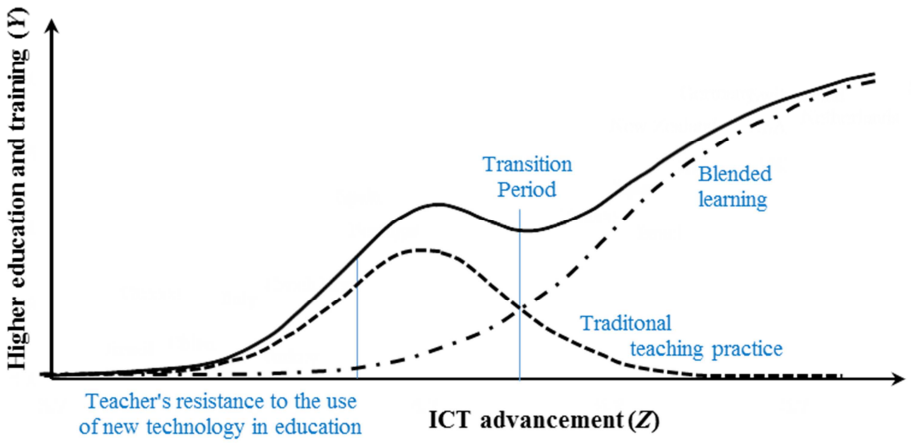


Fig. 17. Scheme of the Contribution by ICT Advancement to Higher Education by Stage.

While strong resistance by teachers to the use of new technology in education can impede the dependency on blended learning (Anderson, 2008), once a certain higher

education level has been attained, increasing dependency on blended learning will overcome this resistance (Jeferry et al., 2014) leading to a co-evolution between the advancement of ICT and further dependency on blended learning. This is demonstrated by the strong correlation between ICT advancement and higher dependency on the Internet access in schools as shown earlier in Fig. 15. The figure shows a significant correlation between ICT advancement and the Internet access in schools and suggests co-evolution between ICT advancement and blended learning boosted by the dependency on the Internet.

However, before this co-evolution can be realized, transition to blended learning results in decline in higher education at its transition period as illustrated in Fig. 17.

A careful examination of Fig. 16 reveals that *ISC* is in transition from *IGC* to *IAC*, which is contrary to a normal trajectory as demonstrated in *IGC*, and *IAC* shows a slightly negative coefficient. This corresponds to the decline in the transition period.

With this observation, **Fig. 18** identifies the state of hybrid development of 20 countries in 3 groups.

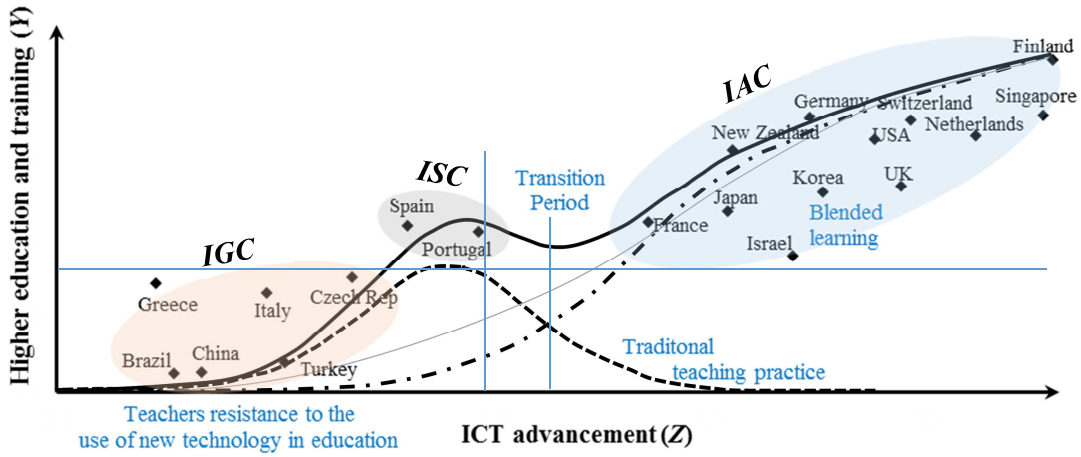
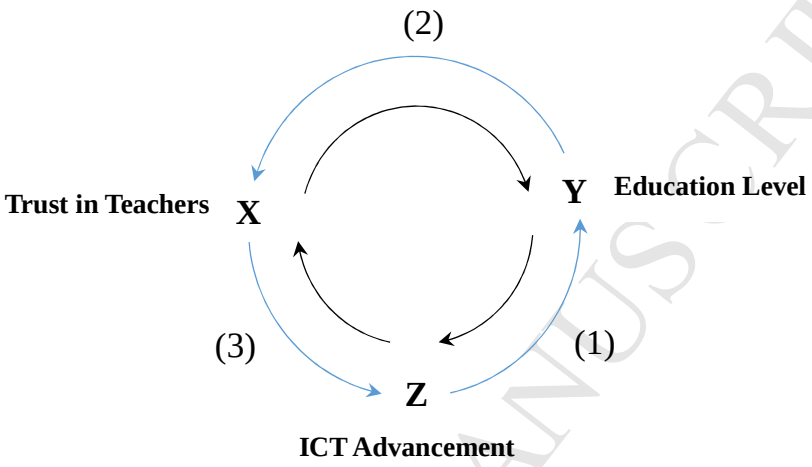


Fig. 18. State of Hybrid Development in 20 Countries.

Fig. 18 demonstrates that *ISC*'s concave trend is a consequence of transition from traditional teaching practice to blended learning. This justifies the findings of Table 4, which reveals the unexpected behavior of advancement of ICT resulting in decline of higher education level in a particular position in digitally-rich learning environments, as has been observed in *ISC* in its transition from *IGC* to *IAC*.

4.4 Co-evolution and Disengagement Reassessed

The finding urge us to reassess the co-evolution and disengagement dynamism between ICT, higher education level, and trust in teachers in the 20 countries (Fig. 11). **Fig. 19** presents the reassessment.



	ICT advanced countries (*IAC*)	ICT semi-advanced countries (*ISC*)	ICT growing Countries (*IGC*)
(1) *Z* and *Y*	+	-	+
(2) *Y* and *X*	+	+	-
(3) *X* and *Z*	+	-	-

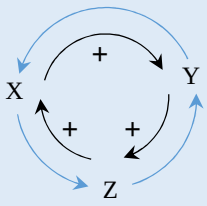
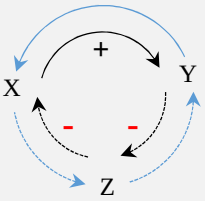
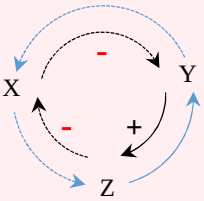
Fig. 19. Re-assessment of Co-evolution and Disengagement between ICT, Educational Level and Trust in Teachers in 20 Countries Depending on ICT Advancement.

+ : Co-evolution (virtuous cycle), - : Disengagement (vicious cycle)

Fig. 19 reveals that contrary to general understanding as summarized in Fig. 11, advancement of ICT decreases higher education level in *ISC* as a result of its transition from traditional teaching practice to blended learning.

This re-assessment identifies the state of digitally-rich learning environments and subsequent co-evolution and disengagement for the 20 countries which depend on the state of their ICT advancement. This identification will provide insights to the respective countries regarding their priority countermeasures for the co-evolution

between ICT advancement. In this regard, higher education enhancement and trust in teachers increase as suggested in **Fig. 20.**

	State of digitally-rich learning environments and subsequent co-evolution		*Priority countermeasures*
ICT advanced countries ***(IAC)***		***Shifted to DILE*** *Constructed co-evolutionary dynamism between Z, Y and X.*	1. *Continued transcending innovation to transform learning environments into DILE* 2. *Transfer transforming experiences to ISC and IGC.* 3. *Harnessing the vigor of growth potential from IGC.*
ICT semi-advanced countries ***(ISC)***		***Transition from TTLE to DILE*** *Unsuccessful co-evolution due to a vicious cycle between Z and Y.*	1. *Transforming Y-Z disengagement into co-evolution by making full utilization of X-Y co-evolution* 2. *Learning the DILE shift experiences from IAC* 3. *Accelerating the shift to DILE.*
ICT growing countries ***(IGC)***		***Remain TTLE*** *Disengagement due to a mismatch between Z and X.*	1. *Enhancing Y by making full utilization of external resources on Z based on Z-Y co-evolution* 2. *Transforming X-Y disengagement into co-evolution by learning experiences from ISC and IAC* 3. *Stepwise introduction, absorption, application, diffusion and transformation of Z by collaborating with ISC and IAC*

DILE: Digitally-rich Innovative Learning Environments

TTLE: Traditional Teaching and Learning Environments

X: Trust in teachers ***Y***: Higher education level ***Z***: ICT advancement

\+ Co-evolution (virtuous cycle), - Disengagement (vicious cycle).

Fig. 20. State of Digitally-rich Learning Environments, Subsequent Co-evolution and Priority Countermeasures.

5. Conclusion

With the notion that the quality of higher education is crucial for innovation in a digital economy and that this quality is subject to a sophisticated system with trust in teachers and advancement of ICT, the dynamism of co-evolution between them was analyzed.

An empirical numerical analysis of 20 countries was attempted with the help of a unique dataset representing the above-described system consisting of the rate of trust in teachers for providing good education in the context of quality of education system and the social status of teachers..

Noteworthy findings include:

(i) ICT-driven trust-based higher education is becoming crucial for nations' competitiveness in digitally-rich learning environments (DILE),

(ii) In such environments, ICT advancement, higher education, and trust in teachers are closely interweaved with each other,

(iii) The 20 countries examined can be divided into 3 groups: ICT advanced countries (*IAC: Finland, Singapore, Netherlands, Switzerland, UK, USA, Korea, Germany, Israel, Japan*), ICT semi-advanced countries (*ISC: Portugal, Spain*), and ICT growing countries (*IGC: Czech Republic, Yurkey, Italy, China, Brazil, Greece*),

(iv) Given the significant shift from traditional teaching practice to blended learning towards DILE, the state of the country in this shift has become crucial for its performance,

(v) *IAC* has shifted to DILE and constructed co-evolutionary dynamism between ICT, higher education and trust,

(vi) This co-evolution corresponds to emerging un-captured GDP as observed in the leading edge of ICT-driven disruptive business model,

(vii) *ISC* is in the transition from traditional teaching and learning environments (TTLE) to DILE and to unsuccessful co-evolution due to a vicious cycle between ICT advancement and higher educational level enhancement, and

(viii) *IGC* remains TTLE and suffers disengagement due to a mismatch between ICT advancement and trust in teachers.

These findings give rise to insightful suggestions to the respective countries about their successful co-evolution being dependent on their state of ICT advancement:

(i) For *IAC*, continued transcending innovation, which transforms learning environments into digitally-rich new learning environments, should be maintained,

(ii) Successive innovation for further DILE is required so as to correspond to the decline in marginal productivity of ICT advancement for higher education

enhancement,

(iii) Timely transfer of the co-evolutionary resources to *IGC* is needed to harness its vigor in a programmatic way,

(iv) Inspired by the emergence of un-captured GDP, ICT-driven disruptive business model toward digitally-rich learning environments should be explored,

(v) For *ISC*, clear understanding of the state of transition from *IGC* to *IAC* should be maintained,

(vi) Given the peculiar phenomena particular to this transition, namely, that advancement of ICT brings a decline in higher education, an optimal supplement compensating this decline should be taken,

(vii) Effective utilization of external resources for accelerating the shift to DILE should be provided,

(viii) For *IGC*, effective utilization of external resources for steady advancement of ICT should be undertaken on a priority basis, and

(ix) Consistent effort for a steady shift to DILE should be made in a programmatic way while maintaining an optimal balance with TTLE.

This paper explored a new systematic approach for the co-evolution between ICT advancement, higher education enhancement and an increase in trust in teachers, thus advancing the existing knowledge on this subject. However, we should note the limitations of this study which are (i) our dependency on the value of trust in teacher's data, which was available only for 21 countries (ii) shortage of detailed micro-analyses covering the effects of specific initiatives such as vision, leadership and curriculum. Further work should focus on in-depth analysis of institutional systems accelerating or impeding this co-evolution and on detailed micro-analysis of specific initiatives including vision, leadership and curriculum. Further analysis of peculiar behavior at a transition in digitally-rich learning environments is another important subject to be undertaken. For that, a wider empirical analysis covering more countries should be considered. Furthermore, with the notion that trust depends on "overdrawing" on past information, a business model constructing a co-evolutionary acclimatization through harnessing the vigor of time should be envisioned.

Acknowledgement

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Appendix 1 Level of ICT Advancement in the World

Table A1 Level of ICT Advancement by NRI in 144 Countries (2013)

	Country		Value		Country		Value		Country		Value
1	FIN	Finland	5.98	**51**	HRV	Croatia	4.17	**101**	IRN	Iran, Islamic Rep.	3.43
2	SGP	Singapore	5.96	**52**	URY	Uruguay	4.16	**102**	GTM	Guatemala	3.42
3	SWE	Sweden	5.91	**53**	CRI	Costa Rica	4.15	**103**	PER	Peru	3.39
4	NLD	Netherlands	5.81	**54**	RUS	Russian Federation	4.13	**104**	PRY	Paraguay	3.37
5	NOR	Norway	5.66	**55**	MUS	Mauritius	4.12	**105**	PAK	Pakistan	3.35
6	CHE	Switzerland	5.66	**56**	AZE	Azerbaijan	4.11	**106**	KHM	Cambodia	3.34
7	GBR	UK	5.64	**57**	BRN	Brunei Darussalam	4.11	**107**	SEN	Senegal	3.33
8	DNK	Denmark	5.58	**58**	CHN	China	4.03	**108**	VEN	Venezuela	3.33
9	USA	USA	5.57	**59**	MNG	Mongolia	4.01	**109**	HND	Honduras	3.32
10	TWN	Taiwan, China	5.47	**60**	BRA	Brazil	3.97	**110**	UGA	Uganda	3.30
11	KOR	Korea, Rep.	5.46	**61**	SVK	Slovak Republic	3.95	**111**	NAM	Namibia	3.29
12	CAN	Canada	5.44	**62**	KWT	Kuwait	3.94	**112**	TJK	Tajikistan	3.29
13	DEU	Germany	5.43	**63**	MEX	Mexico	3.93	**113**	NGA	Nigeria	3.27
14	HKG	Hong Kong	5.40	**64**	GRC	Greece	3.93	**114**	BGD	Bangladesh	3.22
15	ISR	Israel	5.39	**65**	GEO	Georgia	3.93	**115**	ZMB	Zambia	3.19
16	LUX	Luxembourg	5.37	**66**	COL	Colombia	3.91	**116**	ZWE	Zimbabwe	3.17
17	ISL	Iceland	5.31	**67**	MKD	Macedonia, FYR	3.89	**117**	SUR	Suriname	3.13
18	AUS	Australia	5.26	**68**	IND	India	3.88	**118**	KGZ	Kyrgyz Republic	3.09
19	AUT	Austria	5.25	**69**	LKA	Sri Lanka	3.88	**119**	BOL	Bolivia	3.01
20	NZL	New Zealand	5.25	**70**	ZAF	South Africa	3.87	**120**	CIV	Côte d'Ivoire	3.00
21	JPN	Japan	5.24	**71**	BGR	Bulgaria	3.87	**121**	GAB	Gabon	2.97
22	EST	Estonia	5.12	**72**	TTO	Trinidad and Tobago	3.87	**122**	MLI	Mali	2.97
23	QAT	Qatar	5.10	**73**	UKR	Ukraine	3.87	**123**	BEN	Benin	2.97
24	BEL	Belgium	5.10	**74**	THA	Thailand	3.86	**124**	CMR	Cameroon	2.95
25	ARE	UAE	5.07	**75**	ROU	Romania	3.86	**125**	NIC	Nicaragua	2.93
26	FRA	France	5.06	**76**	IDN	Indonesia	3.84	**126**	NPL	Nepal	2.93
27	IRL	Ireland	5.05	**77**	MDA	Moldova	3.84	**127**	TZA	Tanzania	2.92
28	MLT	Malta	4.90	**78**	BIH	Bosnia	3.80	**128**	ETH	Ethiopia	2.85
29	BHR	Bahrain	4.83	**79**	SYC	Seychelles	3.80	**129**	MWI	Malawi	2.83
30	MYS	Malaysia	4.82	**80**	EGY	Egypt	3.78	**130**	BFA	Burkina Faso	2.80
31	SAU	Saudi Arabia	4.82	**81**	CPV	Cape Verde	3.78	**131**	DZA	Algeria	2.78
32	LTU	Lithuania	4.72	**82**	ARM	Armenia	3.76	**132**	LBY	Libya	2.77
33	PRT	Portugal	4.67	**83**	ALB	Albania	3.75	**133**	MOZ	Mozambique	2.76
34	CHL	Chile	4.59	**84**	VNM	Vietnam	3.74	**134**	TLS	Timor-leste	2.72
35	CYP	Cyprus	4.59	**85**	JAM	Jamaica	3.74	**135**	MRT	Mauritania	2.71
36	PRI	Puerto Rico	4.55	**86**	PHL	Philippines	3.73	**136**	SWZ	Swaziland	2.69
37	SVN	Slovenia	4.53	**87**	SRB	Serbia	3.70	**137**	MDG	Madagascar	2.69
38	ESP	Spain	4.51	**88**	RWA	Rwanda	3.68	**138**	LSO	Lesotho	2.68
39	BRB	Barbados	4.49	**89**	MAR	Morocco	3.64	**139**	YEM	Yemen	2.63
40	OMN	Oman	4.48	**90**	DOM	Dominican Republic	3.62	**140**	GIN	Guinea	2.61
41	LVA	Latvia	4.43	**91**	ECU	Ecuador	3.58	**141**	HTI	Haiti	2.58
42	CZE	Czech Republic	4.38	**92**	KEN	Kenya	3.54	**142**	TCD	Chad	2.53
43	KAZ	Kazakhstan	4.32	**93**	SLV	El Salvador	3.53	**143**	SLE	Sierra Leone	2.53
44	HUN	Hungary	4.29	**94**	LBN	Lebanon	3.53	**144**	BDI	Burundi	2.30
45	TUR	Turkey	4.22	**95**	GHA	Ghana	3.51				
46	PAN	Panama	4.22	**96**	BWA	Botswana	3.50				
47	JOR	Jordan	4.20	**97**	LBR	Liberia	3.48				
48	MNE	Montenegro	4.20	**98**	GMB	Gambia, The	3.47				
49	POL	Poland	4.19	**99**	ARG	Argentina	3.47				
50	ITA	Italy	4.18	**100**	GUY	Guyana	3.45				

Source: The Global Information Technology Report 2013 (World Economic Forum, 2013*b*).

Table A2 Level of ICT Advancement by NRI in 20 Countries (2012-2015)

Country	2012-15 average	2012	2013	2014	2015
Finland	**5.96**	5.81	5.98	6.04	6.00
Singapore	**5.95**	5.86	5.96	5.97	6.00
Netherlands	**5.75**	5.60	5.81	5.79	5.80
Switzerland	**5.65**	5.61	5.66	5.62	5.70
USA	**5.59**	5.56	5.57	5.61	5.60
UK	**5.57**	5.50	5.64	5.54	5.60
Korea	**5.49**	5.47	5.46	5.54	5.50
Germany	**5.44**	5.32	5.43	5.50	5.50
Japan	**5.38**	5.25	5.24	5.41	5.60
Israel	**5.36**	5.24	5.39	5.42	5.40
New Zealand	**5.35**	5.36	5.25	5.27	5.50
France	**5.12**	5.12	5.06	5.09	5.20
Portugal	**4.73**	4.63	4.67	4.73	4.90
Spain	**4.61**	4.54	4.51	4.69	4.70
Czech Republic	**4.43**	4.33	4.38	4.49	4.50
Turkey	**4.25**	4.07	4.22	4.30	4.40
Italy	**4.21**	4.17	4.18	4.18	4.30
China	**4.10**	4.11	4.03	4.05	4.20
Greece	**3.99**	3.99	3.93	3.95	4.10
Brazil	**3.94**	3.92	3.97	3.98	3.90

Value measured by the Networked Readiness Index (NRI).

Sources: The Global Information Technology Report 2012, 2013, 2014, 2015 (World Economic Forum, 2012, 2013*b*, 2014, 2015).

Appendix 2 Co-evolutionary Structure in 20 Countries

Table A3 Level of ICT Advancement by NRI in 20 Countries (2013)

	Country	Value		Country	Value		Country	Value		Country	Value
1	Finland	5.98	**9**	USA	5.57	**21**	Japan	5.24	**45**	Turkey	4.22
2	Singapore	5.96	**11**	Korea	5.46	**26**	France	5.06	**50**	Italy	4.18
4	Netherlands	5.81	**13**	Germany	5.43	**33**	Portugal	4.67	**58**	China	4.03
6	Switzerland	5.66	**15**	Israel	5.39	**38**	Spain	4.51	**60**	Brazil	3.97
7	UK	5.64	**20**	New Zealand	5.25	**42**	Czech Republic	4.38	**64**	Greece	3.93

The figures on the left hand side indicate the world rank out of 144 countries (see Table A1).

Source: The Global Information Technology Report 2013 (World Economic Forum, 2013*b*).

Table A4 Level of Higher Education in 20 Countries (2013)

	Country	Value		Country	Value		Country	Value		Country	Value
1	Finland	6.27	**7**	USA	5.75	**24**	France	5.21	**41**	Greece	4.81
2	Singapore	5.91	**9**	New Zealand	5.68	**26**	Spain	5.19	**42**	Italy	4.75
3	Germany	5.90	**17**	UK	5.45	**28**	Portugal	5.15	**65**	Turkey	4.29
4	Switzerland	5.88	**19**	Korea	5.41	**34**	Israel	5.00	**70**	China	4.23
6	Netherlands	5.78	**21**	Japan	5.28	**39**	Czech Republic	4.85	**72**	Brazil	4.22

The figures on the left hand side indicate the world rank out of 148 countries.

Source: The Global Competitiveness Report 2013-2014 (World Economic Forum, 2013*a*).

Table A5 Level of Trust in Teachers to Deliver a Good Education in 20 Countries (2013)

	Country	Value		Country	Value		Country	Value		Country	Value
1	Brazil	7.10	**6**	Portugal	6.62	**11**	Turkey	6.50	**16**	Germany	5.96
2	Finland	7.05	**7**	Singapore	6.60	**12**	UK	6.40	**17**	Czech Republic	5.94
3	Spain	6.86	**8**	Netherlands	6.56	**13**	France	6.15	**19**	Korea	5.40
4	China	6.74	**9**	New Zealand	6.54	**14**	Switzerland	6.10	**20**	Japan	5.35
5	USA	6.68	**10**	Italy	6.52	**15**	Greece	6.08	**21**	Israel	5.20

The figures on the left hand side indicate the world rank out of 21 countries (18. Egypt is excluded).

Source: 2013 Global Teacher Status Index (Varkey GEMS Foundation, 2014).

Table A6 Composition of Higher Education Level (2013)

Country	5th pillar: Higher education and training	5.01 Secondary education enrollment, gross %	5.02 Tertiary education enrollment, gross %	5.03 Quality of the education system	5.04 Quality of math and science education	5.05 Quality of management schools	5.06 Internet access in schools	5.07 Availability of research and training services	5.08 Extent of staff training
Finland	**6.27**	107.97	95.15	5.93	6.26	5.64	6.57	5.87	5.52
Singapore	**5.91**	107.00	72.00	5.77	6.29	5.75	6.30	5.44	5.23
Germany	**5.90**	103.32	-	5.14	5.05	5.10	5.03	6.10	5.12
Switzerland	**5.88**	95.46	56.75	5.98	5.80	6.09	6.11	6.47	5.57
Netherlands	**5.78**	121.46	65.41	5.17	5.31	5.66	6.25	6.09	5.14
USA	**5.75**	96.04	94.81	4.63	4.41	5.49	5.95	5.67	4.96
New Zealand	**5.68**	119.08	82.56	5.19	5.38	5.16	5.67	4.93	4.95
UK	**5.45**	105.34	59.75	4.62	4.37	5.89	6.16	5.61	4.73
Korea	**5.41**	97.08	103.11	3.82	5.10	4.45	6.11	4.81	4.21
Japan	**5.28**	102.20	59.74	4.10	4.66	4.04	5.16	5.52	5.35
France	**5.21**	113.59	57.67	4.21	5.19	5.80	4.41	5.42	4.33
Spain	**5.19**	128.52	82.63	3.60	3.86	5.83	4.92	4.82	3.72
Portugal	**5.15**	109.10	65.49	3.96	4.07	5.52	5.67	5.00	4.01
Israel	**5.00**	102.12	62.48	4.00	4.03	4.68	5.08	4.77	4.24
Czech Republic	**4.85**	90.78	64.85	3.69	3.96	3.95	5.79	5.00	4.03
Greece	**4.81**	109.46	89.38	3.10	4.28	3.85	3.91	3.83	3.47
Italy	**4.75**	100.40	64.98	3.64	4.26	4.98	3.67	4.79	3.21
Turkey	**4.29**	82.11	55.42	3.41	3.52	3.76	4.45	4.23	4.05
China	**4.23**	81.36	26.79	4.02	4.42	4.11	5.32	4.36	4.26
Brazil	**4.22**	105.83	25.63	2.98	2.56	4.54	3.60	4.71	4.30

5.01 Secondary education enrollment rate (ISCED levels 2 and 3)

Gross secondary education enrollment rate | 2011 or the most recent year available

Sources: UNESCO Institute for Statistics (accessed June 21, 2013, and April 21, 2013); ChildInfo.org Country Profiles; national sources

5.02 Tertiary education enrollment rate (ISCED levels 5 and 6)

Gross tertiary education enrollment rate | 2011 or the most recent year available

Sources: UNESCO Institute for Statistics (accessed June 21, 2013); national sources

5.03 Quality of the educational system

How well does the educational system in your country meet the needs of a competitive economy? [1 = not well at all; 7 = extremely well] | 2012–13 weighted average

Source: World Economic Forum, Executive Opinion Survey

5.04 Quality of math and science education

In your country, how would you assess the quality of math and science education in schools [1 = extremely poor—among the worst in the world; 7 = excellent—among the best in the world] | 2012–13 weighted average

Source: World Economic Forum, Executive Opinion Survey

5.05 Quality of management schools

In your country, how would you assess the quality of business schools [1 = extremely poor—among the worst in the world; 7 = excellent—among the best in the world] | 2012–13 weighted average

Source: World Economic Forum, Executive Opinion Survey

5.06 Internet access in schools

In your country, how widespread is Internet access in schools? [1 = nonexistent; 7 = extremely widespread] | 2012–13 weighted average

Source: World Economic Forum, Executive Opinion Survey

5.07 Local availability of specialized research and training services

In your country, to what extent are high-quality, specialized training services available? [1 = not available at all; 7 = widely available] | 2012–13 weighted average

Source: World Economic Forum, Executive Opinion Survey

5.08 Extent of staff training

In your country, to what extent do companies invest in training and employee development? [1 = not at all; 7 = to a great extent] | 2012–13 weighted average

Sources: The Global Competitiveness Report 2013-2014, Executive Opinion Survey (World Economic Forum, 2013*a*).

Appendix 3 Measurement of Trust in Teachers in the Global Teacher Status Index

1. The Varkey Gems Foundation (VGF) developed the "Global Teachers Status Index" in 2013 with the objective to understand the roles of cultural, political and economic factors, and social standing play in the status of teachers in different countries, and how these might impact on education systems.
2. VGF conducted a survey of 1,000 representative respondents in each of the following 21 countries: Brazil, China, Czech Republic, Egypt, Finland, France, Germany, Greece, Israel, Italy, Japan, the Netherlands, New Zealand, Portugal, Turkey, Singapore, South Korea, Spain, Switzerland, the UK and the USA. These countries were chosen based on their performance in PISA[13] and TIMSS[14] assessments to represent each major continent and as representative of different standards of education systems.
3. The survey contains the question concerning trust in teachers for delivering good education by rating "Trusting teachers to deliver a good education." To address this issue, the survey asked respondents to rate (on rating scale of 10: from 0 = do not trust at all, to 10 = trust completely), **to what extent would you trust or not trust teachers to deliver good education for your children?**
4. Identity of this rating is conducted taking into account
    i. the contextual understanding of the social status of teachers, and
    ii. perceptions of the quality of the educational system
5. The data for the study was collected by the polling company Populus by using a WBS with a balanced sample of 16 to 70-year-olds formed by: age; gender; and region. Individuals were invited to participate in the survey from a large database of online internet mailing lists.
6. To ensure the reliability and representation of the national surveys the VGF claimed to adopt strict procedures, e.g., the quotes on age, gender and region in each country, samples monitoring on the basis of education levels, urban, rural locations and ethnic minorities. A country specific population census information to construct the final balanced sample for each country was used. The survey required the compulsory double opt-in registration of respondents by valid postcode and address as a proof of

[13] Performance for International Student (PISA)
[14] Trends in International Mathematics and Science Study (TIMSS)

identification. To further assure the trustworthiness of the sample, the quality checks were built and any respondent failing such test was removed from the sample.

7. In literature the terms such as trust, confidence and trustworthiness are often used interchangeably. The literature on trust has various topics: definitions, measurement of trust, types of trust, the importance of trust relationship between stakeholders in different contexts, trust in governing complex systems and trust in digital age, etc. In the education context, lot of research exists about the importance of trust relationships between teachers, students, parents, leadership and policy makers, etc.

8. In literature it is mentioned that the measurement of trust is an important but challenging task because it may have both quantifiable and non-quantifiable elements. The different methods to measure trust include counting the frequency of trusting behavior, extent of trusting behavior or using surveys to measure trusting attitudes, the last being the most common method. The measurement of trust by surveys and barometers (such as Edelman, Eurobarometer, European Social Survey, Gallup, International Social Survey Programme, PEW and World Values Survey) is a common practice but each approach has its own strengths and weaknesses.

Appendix 4 Regression Analysis of Groups with Heterogeneous Performance

Regression analysis of groups with heterogeneous performance as *IAC*, *ISC* and *IGC* (Figs. 7-10) are conducted by introducing coefficient dummy variables depending on the group, as follows (the case of Fig. 7):

$$\mathbf{ln}\boldsymbol{Y} = \boldsymbol{\alpha} + \sum_{\boldsymbol{i=1}}^{\mathbf{3}} [\boldsymbol{\beta_i}\, \boldsymbol{D_i}]\ \mathbf{lnX} \qquad \text{where } \alpha, \beta_i \text{: coefficients, and } D_i \text{: dummy variables.}$$

$i = 1\ for\ \boldsymbol{IAC}\ (others = 0), i = 2\ for\ \boldsymbol{ISC}\ (others = 0), i = 3\ for\ \boldsymbol{IGC}\ (others = 0).$

Data Construction

Group	Country	Y	lnY	X	lnX	D_1	D_2	D_3	D_1lnX	D_2lnX	D_3lnX
IAC	Finland	6.270	1.836	7.050	1.953	1	0	0	1.953	0	0
IAC	France	5.210	1.651	6.150	1.817	1	0	0	1.817	0	0
IAC	Germany	5.900	1.775	5.960	1.785	1	0	0	1.785	0	0
IAC	Israel	4.990	1.607	5.200	1.649	1	0	0	1.649	0	0
IAC	Japan	5.280	1.664	5.350	1.677	1	0	0	1.677	0	0
IAC	Netherlands	5.780	1.754	6.560	1.881	1	0	0	1.881	0	0
IAC	New Zealand	5.680	1.737	6.540	1.878	1	0	0	1.878	0	0
IAC	Singapore	5.910	1.777	6.600	1.887	1	0	0	1.887	0	0
IAC	Korea	5.410	1.688	5.400	1.686	1	0	0	1.686	0	0
IAC	Switzerland	5.880	1.772	6.100	1.808	1	0	0	1.808	0	0
IAC	UK	5.450	1.696	6.400	1.856	1	0	0	1.856	0	0
IAC	USA	5.750	1.749	6.680	1.899	1	0	0	1.899	0	0
ISC	Portugal	5.150	1.639	6.620	1.890	0	1	0	0	1.890	0
ISC	Spain	5.190	1.647	6.860	1.926	0	1	0	0	1.926	0
IGC	Brazil	4.220	1.440	7.100	1.960	0	0	1	0	0	1.960
IGC	China	4.230	1.442	6.740	1.908	0	0	1	0	0	1.908
IGC	Czech Rep	4.850	1.579	5.940	1.782	0	0	1	0	0	1.782
IGC	Greece	4.810	1.571	6.080	1.805	0	0	1	0	0	1.805
IGC	Italy	4.750	1.558	6.520	1.875	0	0	1	0	0	1.875
IGC	Turkey	4.290	1.456	6.500	1.872	0	0	1	0	0	1.872

IAC: ICT advanced countries, ***ISC:*** ICT semi-advanced countries, ***IGC:*** ICT growing countries.
X: Trust in teachers, ***Y:*** Higher education and training.

Regression model

$$\ln Y = \underset{(3.47)}{0.811} + \underset{(3.92)}{0.504}\, D_1 \ln X + \underset{(3.54)}{0.436}\, D_2 \ln X - \underset{(-3.07)}{0.874}\, D_3 \ln X + \underset{(4.01)}{2.329}\, D_3 \qquad \textbf{adj. } R^2 = \mathbf{0.872}$$

D_1, D_2, D_3: Dummy variables corresponding to IAC, ISC and IGC, respectively.
The figures in parenthesis indicate t-statistics: all are significant at the 1% level.

Correlation Analysis with Coefficient Dummy Variables
– Correlation with Different Slopes

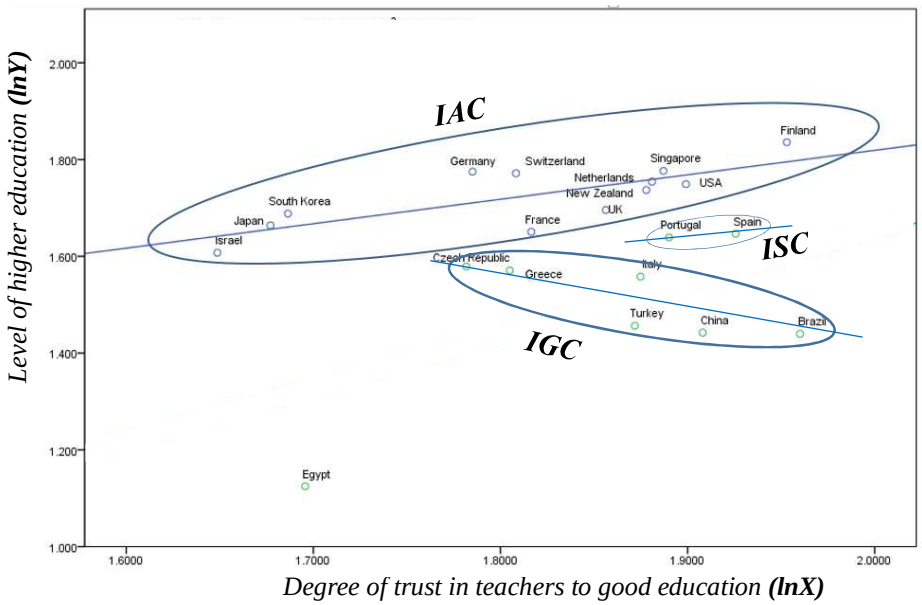
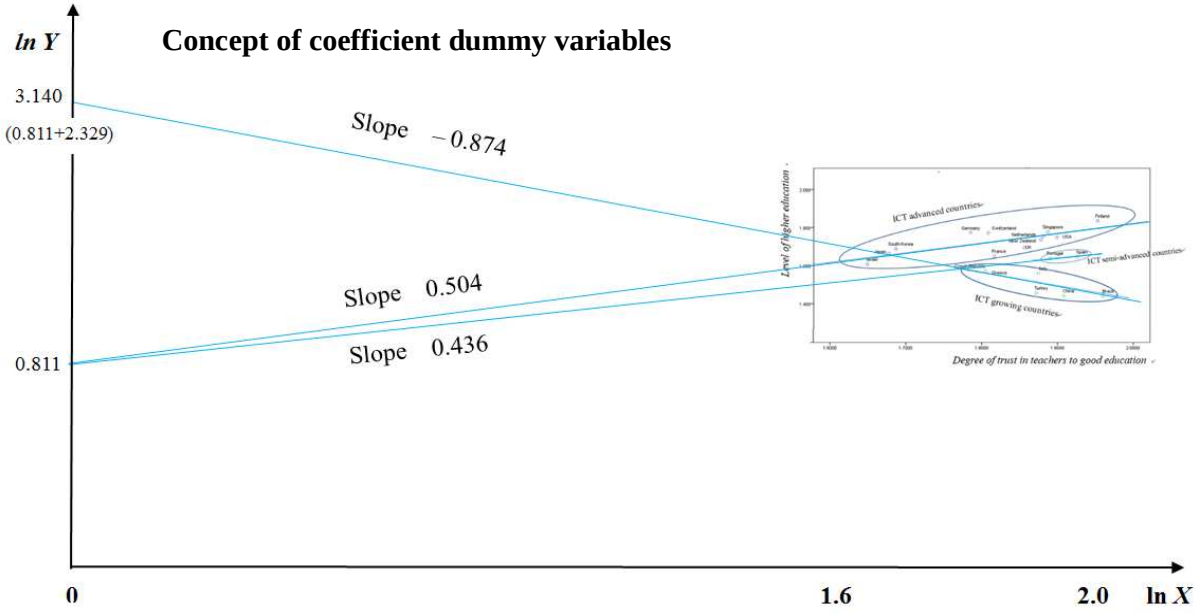


Fig. 7. Correlation between Trust in Teachers and Higher Education Level in 20 Countries *(2013)*.



$$\ln Y = 0.811 + 0.504 D_1 \ln X + 0.436 D_2 \ln X - 0.874 D_3 \ln X + 2.329 D_3$$

(3.47) (3.92) (3.54) (-3.07) (4.01) ***adj.* R^2 = 0.872**

Appendix 5 Logistic Growth Function and Its Bi-polarization Nature

A5.1 Estimate of Logistic Growth Function for ICT-driven Higher Education in 120 Countries in 2013

ICT-driven education development toward digitally-rich learning environments in 120 Countries in 2013 is illustrated by the following sigmoid curve as demonstrated in Fig. 2 (**Fig. A1**):

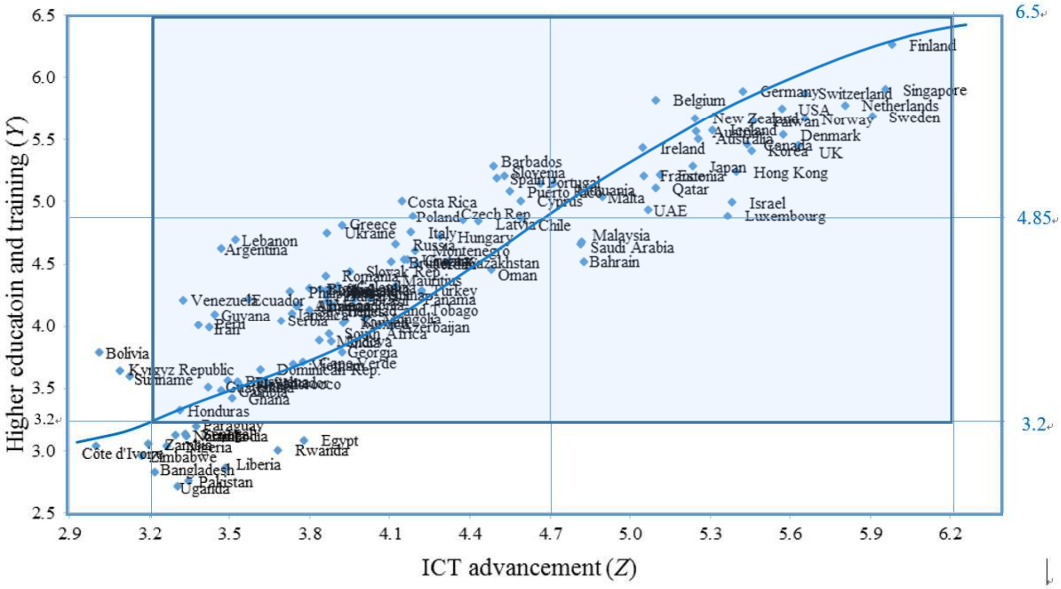


Fig. A1. ICT-driven Education Development in 120 Countries (2013)**.**

Sources: Same as Fig. 2.

Focusing on the scope between (*Z, Y*) from (3.2, 3.2) to (6.2, 6.5) as highlighted in Fig. A1, since it is observed that the above trajectory shows sigmoid growth, the following logistic growth function was estimated:

$$\frac{dY}{dZ} = aY\left(1-\frac{Y}{N}\right) \qquad \text{(A1)}$$

$$Y = \frac{N}{1+be^{-aZ}} \qquad \text{(A2)}$$

where *Y*: Higher education level, *N*: Upper limit (carrying capacity), *Z*: ICT advancement level, *a*: velocity of diffusion, and *b*: initial state of education level.

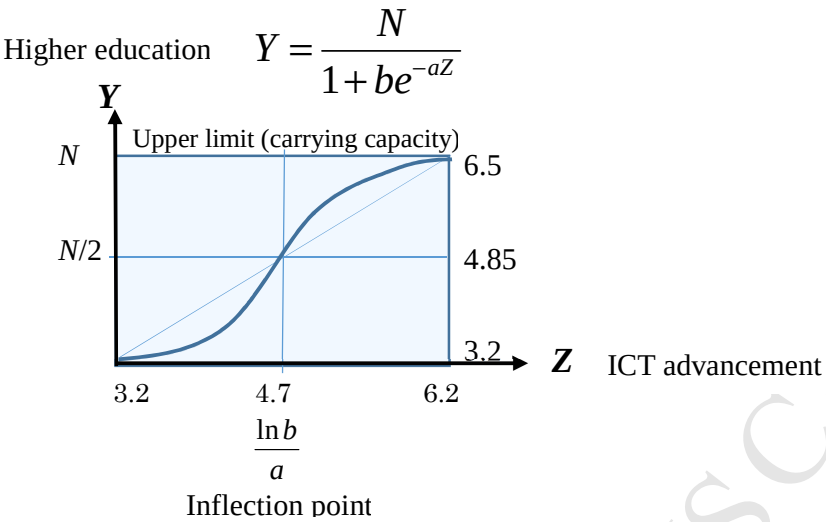


Fig. A2. Estimated Logistic Growth Function.

With the observation that the carrying capacity and the inflection point of the sigmoid curve are estimated as 6.5 and 4.7, respectively as illustrated in **Fig. A2**, by means of heuristic spline interpolation approach, the following logistic growth function for 120 countries in 2013 was estimated.

$$Y' = \frac{3.30}{1+13.50e^{-1.74Z'}} \qquad \text{(A3)}$$

where $Y' = Y - 3.20$, $Z' = Z - 3.20$.

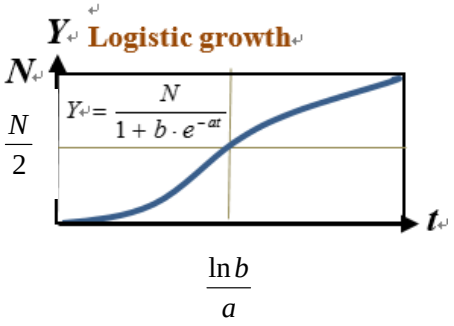
This estimated function behaves similarly to the observed sigmoid curve as

$N = 3.30 + 3.20 = 6.50$, inflection point $\overline{Z} = \frac{\ln b}{a} + 3.20 = 1.50 + 3.20 = 4.70$

Thus, the estimated function is considered to demonstrate the ICT-driven education development trajectory in 120 countries in 2013.

A5.2 Scheme of the Bi-polarization Fatality of Logistic Growth

Logistic growth function as a function of time *t* (substitute *t* for *Z* in Eqs (A1–A3)) can be developed to the following bi-polarization function:



$$\frac{dY}{dt} = aY\left(1-\frac{Y}{N}\right) = \frac{aN}{1+be^{-at}}\left(1-\frac{1}{1+be^{-at}}\right)$$

$$= \frac{aN}{(1+be^{-at})}\cdot\frac{be^{-at}}{(1+be^{-at})} = \frac{aN}{(1+be^{-at})}\cdot\frac{1}{(1+\frac{1}{b}e^{at})}$$

$$= \frac{aN}{(2+be^{-at}+\frac{1}{be^{-at}})}$$

$$\frac{aN}{\frac{dY}{dt}} = 2 + be^{-at} + \frac{1}{be^{-at}}$$

$$y = 2 + x + \frac{1}{x}$$

$$y \equiv \frac{aN}{\frac{dY}{dt}},\quad x \equiv be^{-at}$$

Fig. A3. Illustrates this bi-polarization that is fatal to logistic growth function. The figure on the left illustrates the increase of time *t* and marginal *Y* (d*Y*/d*t*) toward the origin of coordinates. Rotating this figure by 180 degrees leads to a normal axis display as illustrated on the right. This figure indicates that in the normal logistic growth as a function of time *t*, marginal *Y* (d*Y*/d*t*) increases as time goes by and as it is generally anticipated within the time shorter than a certain threshold. However, there is a change to reverse once this threshold is exceeded, the marginal increase declining against expectations.

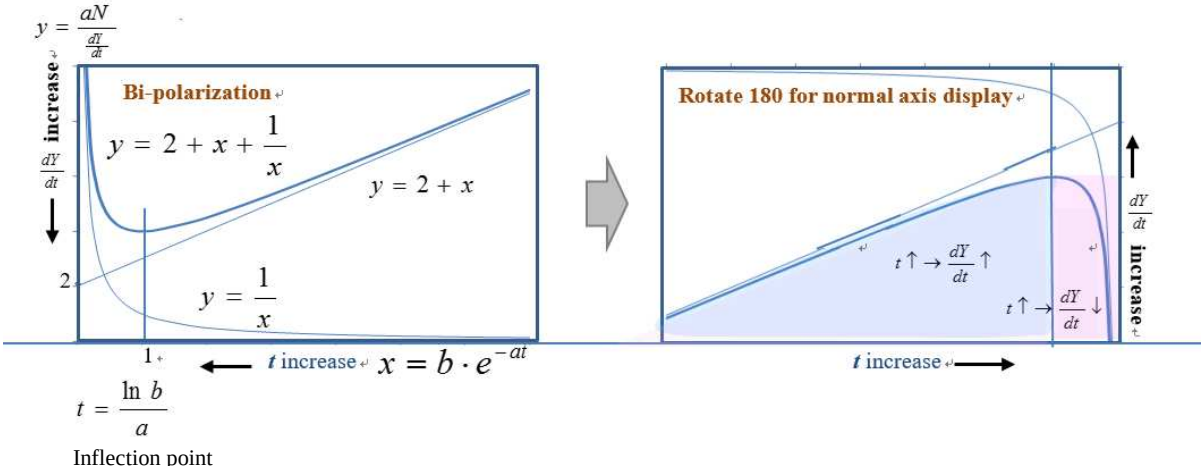


Fig. A3. Bi-polarization Fatal to Logistic Growth Function.

By the preceding reviews (Zhao et al., 2013; Watanabe et al., 2014), given that ICT advance is proportional to time *t*, ICT-driven education development trajectory in 120 countries can be depicted by a logistic growth function consisting of ICT advancement (*Z*) and higher education (*Y*) as demonstrated in Fig. 2. Consequently, this trajectory leads to bi-polarization between ICT advanced countries (*IAC*) and ICT semi-advanced countries (*ISC*) as well as ICT growing countries (*IGC*) similar to the figure on the right in Fig. A3 and as demonstrated by the middle figure in **Fig. A4**.

Fig. A4 illustrates the whole perspective of the bi-polarization of ICT advancement as a consequence of a trap in ICT advancement derived from its two-faced nature (Watanabe et al., 2014, 2015*a*). Unexpected decline in *marginal productivity of ICT enhancing higher education* (d*Y*/d*Z*) in *IAC* can be attributed to a trap in ICT advancement (the top figure in Fig. A4) derived from the two-faced nature of ICT, that is, while advancement of ICT, centered on the dramatic advancement of the Internet, generally contributes to enhanced prices of ICT by increasing new functionality development, the dramatic advancement of the Internet reacts to decreases in prices of ICT due to its nature of favoring freebies, easy copying, and mass standardization. Given that schools seek to maximize profit in competitive learning environments, the marginal productivity of ICT corresponds to the relative price of ICT which, unlike the new services created, declines as ICT advances.

This can be attributed to a mismatch between the value of such new services and learning environments in transition toward digitally-rich learning environments that absorb and effectively apply such services to higher education. This is similar to the emergence of un-captured GDP that the Internet provides: utility and happiness to people that cannot be captured through traditional GDP data (Watanabe et al., 2015*a*).

In order to avoid such a vicious cycle, *IAC* endeavors to leverage transcending innovation to redesign learning environments into digitally-rich new learning environments that can absorb, effectively apply new services and also increase trust in a co-evolutional manner. As a result, a higher *marginal productivity of ICT* is expected as demonstrated in **Fig. A5**. A virtuous cycle is thus established between *marginal inducement of ICT through higher education* (d*Z*/d*Y*) enhancement and ICT (*Z*) advancement as illustrated in the bottom figure in Fig. A4.

In contrast, while *ISC* and *IGC* expect their higher education enhancement through the *marginal productivity of ICT* increase as ICT advances, as illustrated in the middle

figure in Fig. A4, these countries cannot afford the required ICT advances by themselves. The result is a vicious cycle of d*Z*/d*Y* declining as *Z* advances, as illustrated in the bottom figure in Fig. A4.

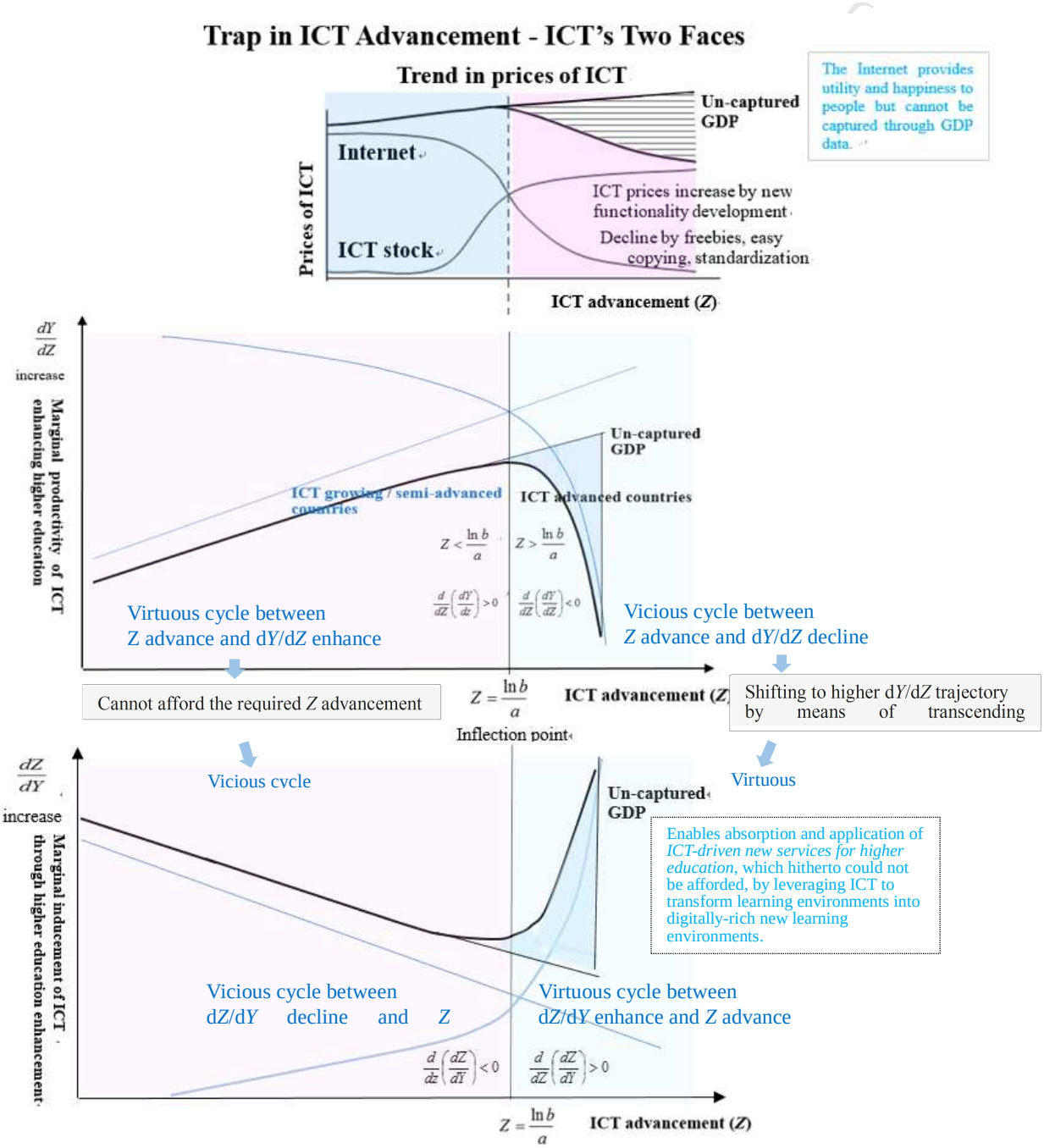


Fig. A4. Perspective of Bi-polarization of ICT Advancement.

Marginal productivity of ICT enhancing higher education can be depicted as follows:

$$\frac{dY}{dZ} = aY(1-\frac{Y}{N}) = aY(1-\frac{1}{FD}) \qquad \text{(A1')}$$

where *FD*: functionality development.

Transcending innovation increases *FD* by its co-evolution between absorbing, applying new services for higher education and increasing trust as ICT advances, leading to enhanced marginal productivity of ICT as illustrated in Fig. A5.

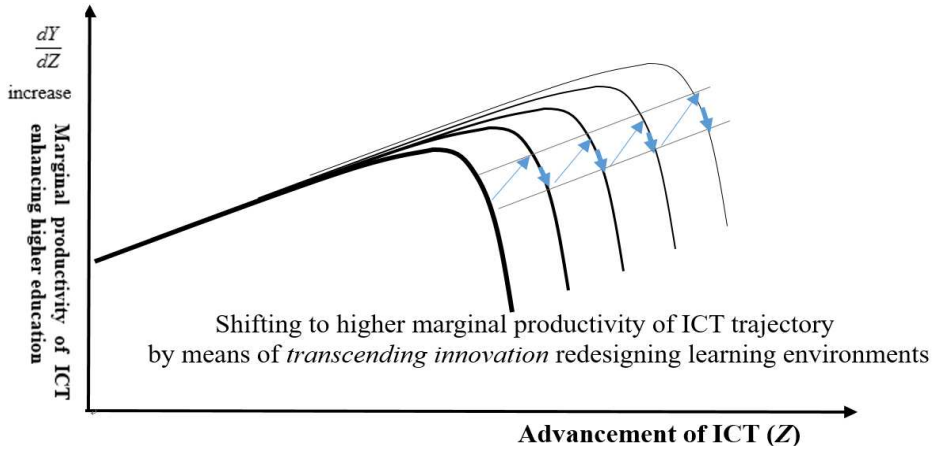


Fig. A5. Scheme of Sustaining Marginal Productivity of ICT by means of Transcending Innovation.

Table A7 summarizes ICT's role for digitally-rich learning environments between *IAC* and *ISC*/*IGC*.

Table A 7 The Contrast of ICT's Role for Digitally-rich Learning Environments between ICT Advanced Countries and Semi-advanced/Growing Countries

ICT semi-advanced countries (*ISC*), ICT growing countries (*IGC*)	**ICT advanced countries (*IAC*)**
Using ICT as a means to solely move toward more digitally-rich learning environments	Leveraging ICT to transform learning environments into digitally-rich new learning environments that can absorb and effectively apply ICT-driven new services to higher education.
While d*Y*/d*Z* is enhanced as *Z* advances, the required *Z* advancement cannot be afforded, resulting in a vicious cycle of d*Z*/d*Y* decline as *Z* advances.	While d*Y*/d*Z* declines as *Z* advances, there is a shift to a higher level of d*Y*/d*Z* by means of transcending innovation, leading to a construction of a virtuous cycle between d*Z*/d*Y* enhancement and *Z* advance.

A5.3 ICT Elasticity to Trust in Teachers and Higher Education

Elasticity of ICT advancement to trust in teachers increase (Z elasticity to X) can be depicted as follows:

$$\frac{d\ln X}{d\ln Z}=\frac{d\ln X}{d\ln Y}\cdot\frac{d\ln Y}{d\ln Z}=\frac{d\ln X}{d\ln Y}\cdot\frac{dY}{dZ}\cdot\frac{Z}{Y}=\frac{d\ln X}{d\ln Y}\cdot\frac{Z}{Y}\cdot\frac{dy}{dZ}\cdot\frac{dY}{dy}=\frac{d\ln X}{d\ln Y}\cdot\frac{Z}{Y}\cdot\frac{dy}{dZ}\cdot\left(\frac{Y(N-Y)}{N}\right)^2\cdot\frac{1}{(2Y-N)}$$

where $y=\frac{aN}{\frac{dY}{dZ}}=\frac{aN}{aY(1-\frac{Y}{N})}=\frac{N^2}{Y(N-Y)}$ (substitute Z for t in the left figure in Fig. A3).

Therefore, this elasticity in 20 countries can be classified depending on their levels of education and ICT as demonstrated in **Table A8**.

Table A8 Classification of ICT Elasticity to Trust in 20 Countries (2013)

Education Level / ICT level	$Y>\frac{N}{2}$				$Y<\frac{N}{2}$			
	$\frac{d\ln X}{d\ln Y}$	$\frac{dy}{dZ}$	$\frac{1}{(2Y-N)}$	$\frac{d\ln X}{d\ln Z}$	$\frac{d\ln X}{d\ln Y}$	$\frac{dy}{dZ}$	$\frac{1}{(2Y-N)}$	$\frac{d\ln X}{d\ln Z}$
$Z>\frac{\ln b}{a}$	+	+	+	+				
	ICT advanced 12 countries (*IAC*)							
$Z<\frac{\ln b}{a}$	+	-	+	-	-	-	-	-
	ICT semi-advanced 2 countries (*ISC*)				ICT growing 6 countries (*IGC*)			
Reference	Fig. 8 Fig. A3				Fig. 8 Fig. A3			

Table A8 demonstrates the structural sources contrasting positive elasticity in *IAC* and disengagement in *ISC* and *IGC*.

Furthermore, elasticity of ICT advancement to higher education enhancement (Z elasticity to Y) can be developed as follows:

$$\frac{d\ln X}{d\ln Z}=\frac{d\ln X}{d\ln Y}\cdot\frac{d\ln Y}{d\ln Z}$$

Therefore, Z elasticity to Y

$$\frac{d\ln Y}{d\ln Z}=\frac{d\ln X}{d\ln Z}\cdot\frac{d\ln Y}{d\ln X}$$

Table A9 Classification of ICT Elasticity to Higher Education in 20 Countries (2013)

Education Level / Ela-sticity / ICT level	$Y>\frac{N}{2}$			$Y<\frac{N}{2}$		
	$\frac{d\ln X}{d\ln Z}$	$\frac{d\ln Y}{d\ln X}$	$\frac{d\ln Y}{d\ln Z}$	$\frac{d\ln X}{d\ln Z}$	$\frac{d\ln Y}{d\ln X}$	$\frac{d\ln Y}{d\ln Z}$
$Z>\frac{\ln b}{a}$	+	+	+			
	ICT	advanced	12 countries			
$Z<\frac{\ln b}{a}$	-	+	-	-	-	+
	ICT semi-advanced 2 countries (*ISC*)			ICT	advanced	6 countries
Reference	Table A8 Fig. 7			Table A8 Fig. 7		

Table A9 demonstrates the structural sources contrasting positive elasticity in *IAC* and *IGC* with disengagement in *ISC*.

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Highlights

Co-evolution between trust in teachers, higher education and ICT advance was elucidated.

New approach for constructing the above co-evolution in a systematic way was explored.

Institutional sources of education productivity paradox were identified.

Institutional enablers enhancing pedagogical love were identified.

Innovation transforming learning environments into digitally-rich new environments was stressed.