Impact of ICT exports and internet usage on carbon emissions: A case of OECD countries

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Abstract

This paper investigates the causal associations between Information and communication technology (ICT) exports, internet usage, economic growth, and CO_2 emission. We use two modes of ICT exports, namely ICT goods exports, and ICT services exports. Similarly, two modes have been used for internet usage, namely number of broadband connections per 100 people, and number of internet users per 100 people. By studying 28 OECD countries for 1991-2015 and employing an error-correction model for detecting Granger causality, we find a series of short-run causal associations among the four variables. The long-run causal association results show that the economic growth is likely to converge to the long-run equilibrium path in keeping with the changes in the other three variables. Our main finding is that the group of developing countries should foster an environment, which will not only boost the ICT service exports, but also will make the penetration of broadband connections in a better way.

JEL Classification Code: Q32, Q38, Q53, Q56, Q57

Keywords: ICT export; internet; CO_2; Granger causality; OECD

1. Introduction

Information and communication technology (ICT) determines the level of infrastructural development of a nation to a great extent. Creation of ICT infrastructure and exporting ICT goods and services contribute to the economic development of a nation. These contributions can be categorized in three major ways: (i) by improvement of employment opportunities, (ii) by improvement in imparting education (Sinha and Rastogi, 2017), and (iii) by increasing the productivity of the organizations by reducing operating cost and increasing efficiency (Vu, 2013; Ishida, 2015).

This study focuses on ICT exports: the extent to which ICT goods and services are exported, their economic and environmental linkages, and consequences of internet usage. ICT has been the focus of the academic researchers across the world, since the earliest works of MacBride (1980). The observable questions of this study is whether ICT exports boost economic growth, whether economic growth boosts ICT exports, or they influence each other, following a feedback path.

This paper discusses the associations between ICT exports and economic growth in presence of two other variables, namely internet usage and carbon dioxide (CO_2) emission.[1] Although researchers have already studied the causal association between ICT exports and economic growth in several contexts, the contribution of this study is to investigate about this association in presence of degree of internet usage and level of CO_2 emission. The impact of ICT infrastructure in boosting long-run economic growth is discussed in a number of articles using different measures of ICT infrastructure (Vu, 2013; Ishida, 2015). At the same time, researchers have also

[1] When fossil fuel is burnt, due to the combustion process, saturated and unsaturated hydrocarbons of the fossil fuel molecules are oxidized, and in that process, CO_2 is generated. Therefore, burning of fossil fuel converts oxygen into carbon dioxide, while fulfilling the demand of energy for achieving the economic growth. Owing to this reason, economic growth is considered as a cause behind the rise in CO_2 emissions.

pointed out the causal associations between degree of internet usage and access to ICT infrastructure, and the environmental consequences internet usage and ICT infrastructure. Following the trail of this literature, it can be said that ICT exports can affect economic growth directly (by enhancing the employment, education, and service delivery mechanisms) and indirectly (by influencing the usage of internet and catalyzing CO_2 emission). This quadrilateral framework has not been considered in the literature, so far.

<Insert Figure 1 here>

Figure 1 represents the conceptual framework of the associations between ICT exports, economic growth, internet usage, and CO_2 emission. This study additionally contributes to the literature in two ways. First, we have considered the data for OECD countries, which have been pioneering in the field of ICT, and second, from methodological perspective, we have used the panel cointegration and panel Granger causality tests for investigating the causal associations between the variables. From both data and methodological perspective, this study contributes to the literature by incorporating more advanced econometric technique, which has hardly been considered in this literature, and the data, which has hardly been studied following this particular framework.

Rest of the paper is organized as per the following: Section 2 reviews the relevant literature. Section 3 describes the data and the variables under consideration. Section 4 elucidates the empirical model being followed in this paper. Section 5 describes the results. Lastly, Section 6 concludes the study with policy implications.

2. Review of literature

The existing research works on the nexus between economic growth, CO_2 emission, ICT exports, and internet usage have been carried out in bits and pieces, and most of the developed models are either bivariate or trivariate. We have subdivided the review of relevant literature into three subsections, namely, (i) economic growth and CO_2 emission, (ii) economic growth and ICT exports, and (iii) economic growth and internet usage. We will discuss them in the subsequent subsections.

2.1. Causal association between economic growth and CO_2 emission

The first strand of literature looks into the causal association between economic growth and CO_2 emission. After the seminal work of Grossman and Krueger (1991), the studies on the impact of economic growth on environmental degradation started (Ibrahiem, 2016; Sinha and Bhattacharya, 2016 a, b, 2017; Paramati et al., 2017; Sinha et al., 2017; Sinha and Shahbaz, 2018). The literature started to focus majorly on the causal association between CO_2 emission and economic growth (Bosupeng, 2015; Siedenburg, 2015; Ramlall, 2016). The findings of these studies can be categorized into four themes, i.e. neutrality hypothesis (no causal association between CO_2 emission and economic growth), growth hypothesis (unidirectional causal association from economic growth to CO_2 emission), conservation hypothesis (unidirectional causal association from CO_2 emission to economic growth), and feedback hypothesis (bidirectional causal association between CO_2 emission and economic growth). Studies include Onafowora and Owoye (2014), Sinha (2014, 2015a, b), Sinha and Bhattacharya (2014), Sinha and Mehta (2014), Baek (2015), Shahbaz et al. (2015), Sinha and Sen (2016) and many others. Details of these studies are recorded in Appendix 1.

2.2. Causal association between economic growth and ICT exports

The second strand of literature focuses on the causal association between economic growth and ICT exports (goods and services). The basic premise of this association is that the growth in ICT exports cause rise in economic growth by boosting employment, education, and enhancing efficiency in service delivery mechanisms. On the other hand, rise in economic growth can always provide room for infrastructural development, in which ICT constitutes a major part. Therefore, rise in economic growth can cause rise in ICT exports. The studies carried out on this association have focused on both of these aspects, and these two aspects have been found in several contexts. Studies include Ishida (2015), Farhadi et al. (2012), Oulton (2012), and many others. Details of these studies are recorded in Appendix 1.

2.3. Causal association between economic growth and internet usage

The third strand of literature focuses on the causal association between economic growth and internet usage. The basic premise of this association is that the growth in the economic activities can lead towards rise in the degree of internet usage. After a certain lag, the rise in the degree of internet usage can contribute to economic growth. This contribution can be attributed to the creation of job opportunities, which in turn augment the economic growth. In the literature, we can find the evidence of both the directions for this association. The studies include Nardotto et al. (2015), Gruber et al. (2014), Mehmood and Mustafa (2014), and many others. Details of these studies are recorded in Appendix 1.

3. Data and variables

In this study, we have used the data for 28 OECD countries[2] over 1991–2015. We have further subdivided the data into two categories, namely developed and developing countries. Under the category of developed countries, we have considered Australia, Canada, France, Germany, Italy, Japan, South Korea, the United Kingdom, and the United States, and under the category of developing countries, we have considered Austria, Belgium, Chile, Denmark, Finland, Greece,

[2] Australia, Austria, Belgium, Canada, Chile, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Portugal, Puerto Rico, South Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States, and the Virgin Islands.

Ireland, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Portugal, Puerto Rico, Spain, Sweden, Switzerland, Turkey, and the Virgin Islands.

This study uses four variables. Those are: (a) Information and communication technology exports (ICT), which has been bifurcated into two parts: information and communication technology exports in good (variable: ICT_G) and information and communication technology exports in services (variable: ICT_S), (b) per capita carbon dioxide emissions from internet usage (variable: CO_2), (c) per capita gross national income (variable: GNI), and (d) the usage of internet (INT), which has been bifurcated into two parts: fixed broadband subscriptions per 100 people (variable: INT_B) and internet users per 100 people (variable: INT_U). Definitions of these variables are provided in Table 1 and the descriptive statistics of the variables are provided in Table 2. The annual time series data for all the variables and for all the 28 countries have been collected from the World Bank Indicators.

<Insert Table 1 here>

<Insert Table 2 here>

This study is intended to investigate, whether there are possible causal associations among these variables. There can be unidirectional, bidirectional, or no causality among the variables. The hypotheses of this study are built around these causal associations, and a graphical representation of these hypotheses is given in Figure 2.

<Insert Figure 2 here>

4. Empirical model

The empirical model employed in this study is intended to analyze the causal association between ICT exports, per capita carbon dioxide emissions from internet usage, per capita GNI, and the usage of internet. In doing so, we need to follow a certain sequence of procedures as per the following:

a. *Unit root testing:* The Augmented Dickey Fuller (ADF) (Dickey et al., 1991) unit root test is employed to identify the order of integration of time series variables. But it has the inherent difficulty of low power in discarding the null hypothesis of stationarity, predominantly for relatively undersized samples, and in order to surmount this concern, Levin-Lin-Chu (LLC) (Levin et al., 2002) and Im-Pesaran-Shin (IPS) (Im et al., 2003) panel unit root tests are employed, as both of the tests are superior in terms of explanatory power for relatively higher sample size. LLC presumes homogeneity in the autoregressive coefficients for all data points, while IPS presumes heterogeneity in those coefficients. LLC offers a panel-based ADF test and restricts the coefficient of lagged dependent variable to maintain it alike throughout cross sections. The test imposes homogeneity on autoregressive coefficient that points toward the existence/nonexistence of a unit root, whereas the intercept and trend may vary across individual series.

b. *Cointegration testing*: After discovering the stationarity of the series, panel cointegration test should be performed, as it is required to discover whether any long run association subsist among the variables, or not, and for this purpose, we perform Pedroni (2004) panel cointegration test. In order to decide the subsistence of heterogeneity of cointegrating vector(s), both within-dimension and between-dimension tests are carried out, and there are several statistics, which are being employed while carrying out these tests. Panel υ-statistic, panel ρ-statistic, panel PP- statistic (non-parametric) and panel ADF- statistic (parametric) are used for within-dimension tests, and group ρ-statistic, group PP- statistic (non-parametric) and group ADF-statistic (parametric) are used for between-dimension tests.

Along with the Pedroni panel cointegration test, this study also employs the Johansen-Fisher panel cointegration test. This test was first suggested by Maddala and Wu (1999) and this test the panel version of the cointegration test designed by Johansen and Juselius (1990). Trace and maximum eigenvalue statistics are the two major components of this cointegration analysis (Johansen, 1988, 1991).

c. *Granger causality testing*: In accordance with Engle and Granger (1987), if the variables under consideration are non-stationary and cointegrated in nature, then the vector error correction model (VECM) can be employed for looking into the sequential short-run causal association among the variables under consideration, for which F-test and Chi-square test are needed to be carried out by restricting the coefficients, followed by estimating them together. Apart from the short run causal association, the long run causal association can be determined by estimating the significance of the lagged error correction term in the VECM, for which t-test is needed to be carried out. Hypotheses of the study are as per the following:

H_{1A}: ICT Granger causes GNI	H_{4A}: GNI Granger causes CO_2
H_{1B}: GNI Granger causes ICT	H_{4B}: CO_2 Granger causes GNI
H_{2A}: GNI Granger causes INT	H_{5A}: ICT Granger causes INT
H_{2B}: INT Granger causes GNI	H_{5B}: INT Granger causes ICT
H_{3A}: CO_2 Granger causes INT	H_{6A}: ICT Granger causes CO_2
H_{3B}: INT Granger causes CO_2	H_{6B}: CO_2 Granger causes ICT

A graphical representation of these hypotheses is provided in Figure 2.

5. Results

5.1. Results of the stationarity tests

As we have discussed earlier, we employ two first generation panel unit root tests on the data. However, before carrying out the unit root tests, we conducted Pesaran (2007) test to check the cross-section dependence in the data. The null hypothesis of this test is that the cross sections are independent, and it is computed based on the average of pair-wise correlation coefficients of the ADF regression residuals for each unit. The test statistics are recorded in Table 3, and they show that the null hypothesis cannot be rejected. It signifies that the cross sections of all the panels are independent, and therefore, the first-generation panel unit root tests can be applied.

<Insert Table 3 here>

Heterogeneity of various sections is taken care of by LLC test, and the possibility of low power can be overruled because of the data volume. IPS test also takes care of the same, and it can eradicate the plausible serial correlation in the data. Null hypotheses of both the tests are that the variables are non-stationary and they have unit root(s). The results of both of these tests are recorded in Table 4. It can be seen that the first differences of the variables are significant at 1% level for both of the tests, thereby, indicating that they are integrated to order one, that is, the variables are I(1) in nature.

<Insert Table 4 here>

5.2. Results of the cointegration tests

As the variables are integrated to order one, now we can check the possibility of any long-run association among the variables. As discussed earlier, we have employed Pedroni (2004) panel cointegration test and Johansen-Fisher panel cointegration test (Maddala and Wu, 1999). Results of both the tests are recorded in Table 5 and Table 6 respectively. The results of the cointegration tests signify that there are cointegrating associations among the variables across the four cases and the three categories. Therefore, the associations indicated by equations (17)-(20) hold true for long-run. Once the cointegrating associations among the variables are ensures, now we can conduct the Granger causality tests using the VECM approach.

<Insert Table 5 here>

<Insert Table 6 here>

5.3. Results of the Granger causality tests

Once we have found that the variables are cointegrated, we have employed the VECM approach to find out the possible causal associations among the variables across three contexts. First, we will look into the long run causal association, and then we will look into the short run causal associations.

5.3.1. Results of the long run causal associations

The results for long run causal associations are shown in Tables 7–9, and the significance of the association is depicted by the significance of the error correction term ECT(-1). For the developed countries, GNI is likely to converge to its long run equilibrium path in keeping with the changes in ICT_G or ICT_S, INT_B or INT_U, and CO_2. In spite of the different measures of ICT and INT being used, GNI has been found to have long run causal association with ICT, INT, and CO_2.

Considering CO_2 emission, values of ECT(-1) have been found to be significant for all the cases of INT_B, and a few cases of INT_U, irrespective of the different measures of ICT. Therefore, it can be inferred that in the long run, the causal association between CO_2 emission and other variables is pertinent, only when the number of broadband connections per 100 people is considered.

On the other hand, when we look into the short run causal associations between the variables, then we can experience a huge variation of results. The results are not only varying with the group of countries, but also with the measures of ICT and INT. We will discuss those results in the subsequent section.

5.3.2. Results of the short run causal associations

5.3.2.1. Group of developed countries

Case 1: Causality between ICT_G, GNI, INT_B, and CO_2

In this case, we find the existence of bidirectional causality between number of broadband connections per 100 people and economic growth [INT_B⇔GNI], and number of broadband connections per 100 people and CO_2 emission [INT_B⇔CO_2]. Unidirectional causal associations are found from economic growth to ICT goods exports, CO_2 emission to economic growth, and ICT goods exports to CO_2 emission [GNI→ICT_G; CO_2→GNI; ICT_G→CO_2]. Moreover, neutrality hypothesis is found for ICT goods exports and number of broadband connections per 100 people [ICT_G ≠ INT_B].

Case 2: Causality between ICT_G, GNI, INT_U, and CO_2

In this case, we find the existence of bidirectional causality between number of internet users per 100 people and economic growth [INT_U⇔GNI], and economic growth and CO_2 emission [GNI⇔CO_2]. Unidirectional causal associations are found from economic growth to ICT goods exports and ICT goods exports to CO_2 emission [GNI→ICT_G; ICT_G→CO_2]. Apart from that, neutrality hypothesis is found for ICT goods exports and number of internet users per 100 people [ICT_G ≠ INT_U], and CO_2 emission and number of internet users per 100 people [CO_2 ≠ INT_U].

Case 3: Causality between ICT_S, GNI, INT_B, and CO_2

In this case, we find the existence of bidirectional causality between number of broadband connections per 100 people and economic growth [INT_B⇔GNI], number of broadband connections per 100 people and CO_2 emission [INT_B⇔CO_2], and economic growth and CO_2 emission [GNI⇔CO_2]. Unidirectional causal association is found from CO_2 emission to ICT services export [CO_2→ICT_S]. Here, neutrality hypothesis is found for ICT services export and economic growth [ICT_S ≠ GNI] and ICT service exports and number of broadband connections per 100 people [ICT_S ≠ INT_B].

Case 4: Causality between ICT_S, GNI, INT_U, and CO_2

In this case, we find the existence of bidirectional causality between number of internet users per 100 people and economic growth [INT_U⇔GNI], and economic growth and CO_2 emission [GNI⇔CO_2]. Unidirectional causal association is found from CO_2 emission to ICT services export [CO_2→ICT_S]. Here, neutrality hypothesis is found for ICT services export and economic growth [ICT_S ≠ GNI], ICT service exports and number of internet users per 100 people [ICT_S ≠ INT_U], and number of internet users per 100 people and CO_2 emission [INT_U ≠ CO_2].

<Insert Table 7 here>

<Insert Figure 3 here>

5.3.2.2. Group of developing countries

Case 1: Causality between ICT_G, GNI, INT_B, and CO_2

In this case, we find the existence of bidirectional causality between ICT goods exports and economic growth [ICT_G⇔GNI], ICT goods exports and number of broadband connections per 100 people [ICT_G⇔INT_B], number of broadband connections per 100 people and economic growth [INT_B⇔GNI], and ICT goods exports and CO_2 emission [ICT_G⇔CO_2]. Unidirectional causal association is found from CO_2 emission to number of broadband connections per 100 people [CO_2→INT_B]. Moreover, neutrality hypothesis is found for economic growth and CO_2 emission [GNI ≠ CO_2].

Case 2: Causality between ICT_G, GNI, INT_U, and CO_2

In this case, we find the existence of bidirectional causality between ICT goods exports and economic growth [ICT_G⇔GNI], number of internet users per 100 people and economic growth [INT_U⇔GNI], economic growth and CO_2 emission [GNI⇔CO_2], and ICT goods exports and CO_2 emission [ICT_G⇔CO_2]. Unidirectional causal association is found from number of internet users per 100 people to ICT goods exports [INT_U→ICT_G]. Apart from that, neutrality hypothesis is found for number of internet users per 100 people and CO_2 emission [INT_U ≠ CO_2].

Case 3: Causality between ICT_S, GNI, INT_B, and CO_2

In this case, we find the existence of bidirectional causality between ICT services exports and economic growth [ICT_S⇔GNI], number of broadband connections per 100 people and economic growth [INT_B⇔GNI], and number of broadband connections per 100 people and CO_2 emission [INT_B⇔CO_2]. Unidirectional causal associations are found economic growth to CO_2 emission, and from CO_2 emission to ICT services exports [GNI→CO_2; CO_2→ICT_S]. Here, neutrality hypothesis is found for ICT service exports and number of broadband connections per 100 people [ICT_S ≠ INT_B].

Case 4: Causality between ICT_S, GNI, INT_U, and CO_2

In this case, we find the existence of bidirectional causality between number of internet users per 100 people and economic growth [INT_U⇔GNI], economic growth and CO_2 emission [GNI⇔CO_2], and ICT services export and CO_2 emission [ICT_S⇔CO_2]. Unidirectional causal association is found from ICT services export to number of internet users per 100 people [ICT_S→INT_U]. Here, neutrality hypothesis is found for ICT services export and economic growth [ICT_S ≠ GNI], and number of internet users per 100 people and CO_2 emission [INT_U ≠ CO_2].

<Insert Table 8 here>

<Insert Figure 4 here>

5.3.2.3. All countries

Case 1: Causality between ICT_G, GNI, INT_B, and CO_2

In this case, we find the existence of bidirectional causality between ICT goods exports and economic growth [ICT_G⇔GNI], number of broadband connections per 100 people and economic growth [INT_B⇔GNI], and number of broadband connections per 100 people and CO_2 emission [INT_B⇔CO_2]. Unidirectional causal associations are found from number of broadband connections per 100 people to ICT goods exports and from CO_2 emission to ICT goods exports [INT_B→ICT_G; ICT_G→CO_2]. Moreover, neutrality hypothesis is found for economic growth and CO_2 emission [GNI ≠ CO_2].

Case 2: Causality between ICT_G, GNI, INT_U, and CO_2

In this case, we find the existence of bidirectional causality between ICT goods exports and economic growth [ICT_G⇔GNI], number of internet users per 100 people and economic growth [INT_U⇔GNI], economic growth and CO_2 emission [GNI⇔CO_2]. Unidirectional causal associations are found from number of internet users per 100 people to ICT goods exports and from CO_2 emission to ICT goods exports [INT_U→ICT_G; CO_2→ICT_G]. Apart from that, neutrality hypothesis is found for number of internet users per 100 people and CO_2 emission [INT_U ≠ CO_2].

Case 3: Causality between ICT_S, GNI, INT_B, and CO_2

In this case, we find the existence of bidirectional causality between number of broadband connections per 100 people and economic growth [INT_B⇔GNI], and number of broadband connections per 100 people and CO_2 emission [INT_B⇔CO_2]. Unidirectional causal associations are found from economic growth to CO_2 emission [GNI→CO_2]. Here, neutrality hypothesis is found for ICT service exports and economic growth [ICT_S ≠ GNI], ICT service exports and number of broadband connections per 100 people [ICT_S ≠ INT_B], and ICT service exports and CO_2 emission [ICT_S ≠ CO_2].

Case 4: Causality between ICT_S, GNI, INT_U, and CO_2

In this case, we find the existence of bidirectional causality between number of internet users per 100 people and economic growth [INT_U⇔GNI], and economic growth and CO_2 emission [GNI⇔CO_2]. Unidirectional causal association is found from ICT services export to economic growth, from ICT services export to number of internet users per 100 people, from CO_2 emission to ICT services export, and from ICT services export to CO_2 emission [ICT_S→GNI; ICT_S→INT_U; CO_2→INT_U; ICT_S→CO_2]. Here, neutrality hypothesis is not found for any of the cases.

<Insert Table 9 here>

<Insert Figure 5 here>

The findings of short run causal associations among the variables across all the samples are recorded in Table 10. Graphical representations of the results are given in Figs. 3–5.

<Insert Table 10 here>

5.3.3. Results of the generalized impulse response functions

Results obtained by means of the Granger causality analysis are majorly based on the past changes in the series, and it does not reflect upon the response of a series with respect to any unanticipated shock in other series. We have employed generalized impulse response functions (GIRFs) to get past this issue. It is used to check the response of the endogenous variables to the innovations on their present and future values. The significance of the shocks is determined by the position of the horizontal line in the GIRFs within the confidence band, i.e. if the line is within the confidence band, then the effect of the shocks are not significant.

Fig. 6a through Fig. 8d demonstrates the GIRFs of the four VAR models across the three samples and four cases[3]. The impulse response functions are provided on the responses of ICT exports (ICT_G and ICT_S), CO_2 emissions, internet usage (INT_B and INT_U), and economic growth to their own shocks and other endogenous variables. This analysis endows us with further support in terms of finding out the stable long run associations among the variables.

<Insert Figure 6a here>

<Insert Figure 6b here>

<Insert Figure 6c here>

<Insert Figure 6d here>

<Insert Figure 7a here>

<Insert Figure 7b here>

<Insert Figure 7c here>

<Insert Figure 7d here>

<Insert Figure 8a here>

<Insert Figure 8b here>

<Insert Figure 8c here>

<Insert Figure 8d here>

6. Conclusion and policy implications

[3] Case 1: ICT_G, GNI, INT_B, CO_2
Case 2: ICT_G, GNI, INT_U, CO_2
Case 3: ICT_S, GNI, INT_B, CO_2
Case 4: ICT_S, GNI, INT_U, CO_2

The estimation methodology used in this study has not been used much in the literature in a context like this. We have first established the long-run association between ICT exports, internet usage, CO_2 emission, and economic growth. We received results for long-run and short-run causal associations. The long-run causal association results show that the economic growth is likely to converge to the long-run equilibrium path in keeping with the changes in the other three variables. The short-run causal association results demonstrate a wide variety of directions of the causal associations, among which the existence of feedback hypothesis can also be found. The empirical contribution of this study is in terms of analyzing the impact of digital economy on the environmental quality, and policy recommendations emerging from this study can show a way how to achieve the objectives of sustainable development goals (SDGs) by means of the growth of digital economy. This study addresses the research gap in the literature by providing the evidence of how the emergence of ICT infrastructure can help in achieving the objectives of SDGs, and thereby, can ensure the sustainable development in these economies.

Nature of the causal association between ICT exports and economic growth varies across the group of developing and the developed countries. For the group of developed countries, economic growth affects the ICT goods export, whereas no causal association was found for the case of ICT service exports. On the other hand, for the group of developing countries, feedback hypothesis is supported for the causal association between ICT goods export and economic growth. Considering the usage of broadband connections, evidence of feedback hypothesis is found for the causal association between ICT services export and economic growth. Therefore, it is quite evident that the developing economies have a scope of boosting up their economy by means of bringing the ICT service exports up. At the same time, the regulations and government initiatives should also be supportive enough to create an environment for boosting up ICT services exports. The developed countries have created such an environment for ICT goods export. However, these countries perhaps do not need to create the same for ICT services export, as most of their ICT service projects are outsourced to the developing countries.

Following the literature, existence of feedback hypothesis has been found between internet usage and economic growth. Growth in internet usage has been boosting the economic growth, and at the same time, economic growth has been opening several job opportunities, which call for virtual platform. However, there are negative environmental consequences of this aspect.

The negative environmental consequences of the aforementioned association can be seen in terms of ambient air pollution, which has been taken as CO_2 emission in this study. For the developed countries, feedback hypothesis is supported for the causal association between CO_2 emission and degree of internet usage considering number of broadband connections, whereas neutrality hypothesis is supported for the case of total number of internet users. For the group of developing countries, neutrality hypothesis is supported for the case of total number of internet users, feedback and conservation hypothesis are supported for the case of total number of broadband connections. Moving on, the environmental consequences of the ICT exports can also be seen in the revealed causal associations. For the group of developed countries, growth hypothesis can be seen for the case of ICT goods exports, and conservation hypothesis can be seen for the case of ICT services exports. For the group of developing countries, feedback hypothesis can be seen for the case of ICT goods exports, and for ICT services exports, evidence of both feedback hypothesis and conservation hypothesis can be found. These results signify that the usage of internet and ICT products and services can have serious environmental consequences in terms of ambient air pollution. The cooling technologies being used in these products in turn increase the ambient air temperature, which catalyzes the generation of several pollutants. On the other hand, energy being consumed by these products is on rise, and therefore, this continuous consumption of energy is also creating ambient air pollution by means of fossil fuel combustion. The governments should impose carbon or environmental tax on the organizations, which are dealing with internet service providing or ICT product or service manufacturing, and these taxes will be based on the amount of energy consumed for cooling purpose, and the number of subscribers using their products or services.

Now, in the wake of the service industry, it can never be advised to get away from using the ICT infrastructure, as this is foundation of the digital economy. Therefore, the policies should be designed in such a way that the economic growth achieved by means of the growth in ICT infrastructure can be sustained, as well as the issues of climatic shift also can be handled. So, in spite of utilizing more energy in cooling the ICT products, the organizations might use the natural resources effectively for this purpose. For example, using the flow of air or water, the cooling purpose can be solved, and it will not consume energy in any form. Moreover, the heat being generated from the ICT products can be used for energy generation, which will help these nations in catering to the rising demand of energy. However, in order to achieve success in this, people-public-private partnership should be encouraged, so that more number of people can help the organizations and the policymakers to spread awareness of these initiatives. The rising number of users in the digital domain can help in spreading the awareness regarding these initiatives, and if required, the new organizations can also be helped by crowdfunding following this way. Then the implementation cost of these initiatives can be borne by these organizations, and the fiscal balance of the nations can be kept intact. Organizations thus formed can also help in creating more jobs, which will again cater to the economic growth of these nations. Moreover, creation of more jobs will create more demand of energy, for which the governments of these nations have to reply on the renewable energy solutions, and in doing so, the government should dictate these newly formed companies to utilize the energy created from the heat of the ICT products. In this way, these nations will be able to achieve the following objectives of sustainable development goals (SDGs), i.e. (a) SDG 7 – affordable and clean energy, (b) SDG 8 – decent work and economic growth, and (c) SDG 13 – climate action (UNDP, 2017). These policy actions can have a possible solution to achieve the mentioned SDG objectives.

In a nutshell, our results show that the environmental consequences of economic growth can produce inconclusive results, if the degree of internet usage and ICT exports are not considered within a comprehensive multivariate sustainable development and inclusive growth framework. Further research on this aspect can be taken up by considering the per capita heat generation out of these IT-enabled infrastructure, along with the revenue generated out of them. From the perspective of the policy makers, governing bodies of the OECD countries should focus on the environmental consequences of the economic growth, which is the resultant of the IT infrastructural growth. While considering the environmental aspects, the policy makers also provide a sustainable business environment for ICT service exports, especially in the developing countries. The penetration of broadband connections should reach enough number people, so that they can also contribute to the economic growth.

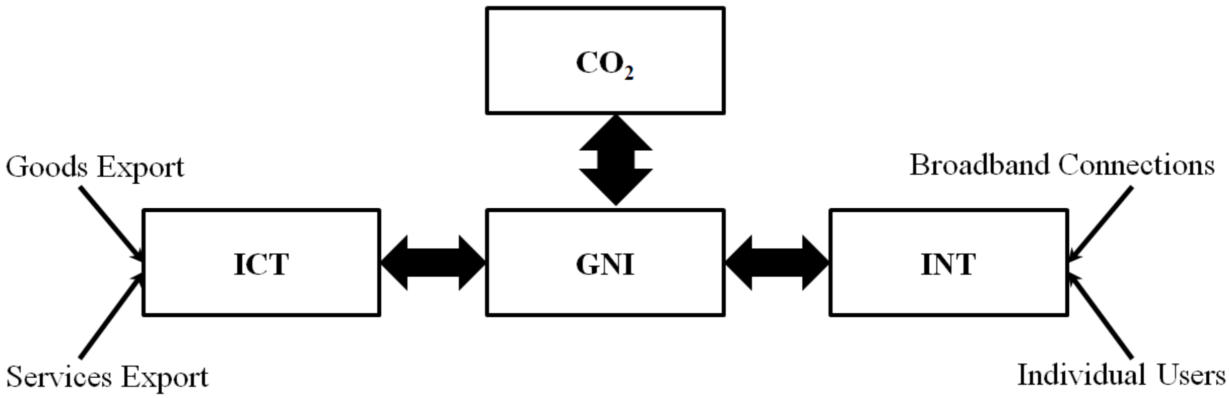

Figure 1: Proposed Model

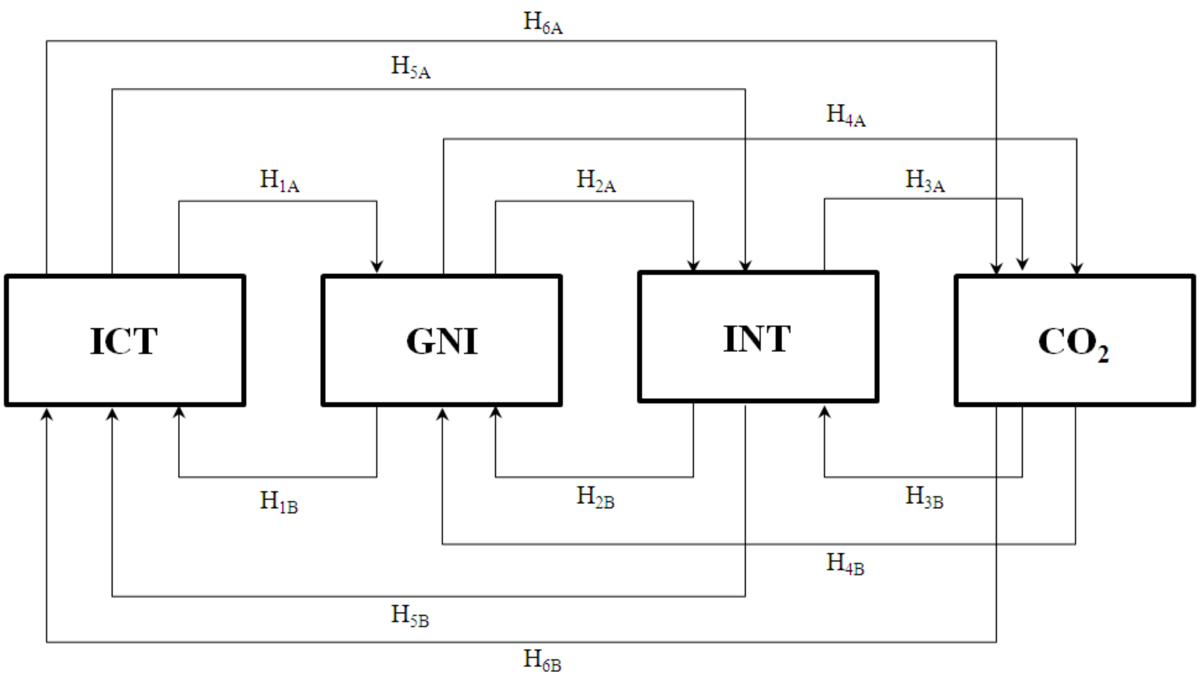

Figure 2: Proposed Hypotheses

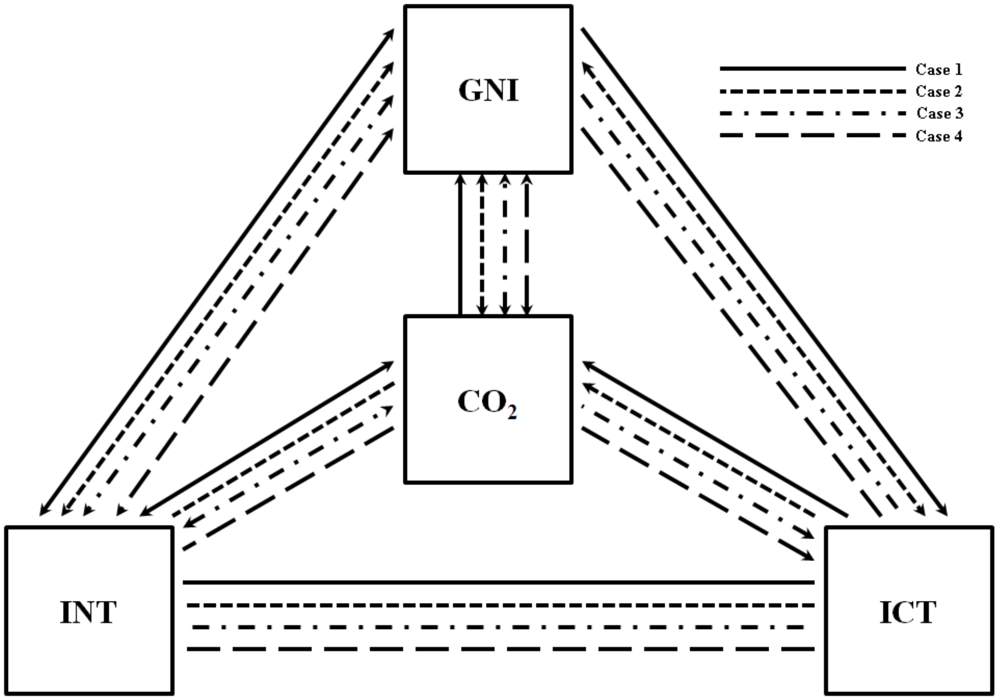

Figure 3: Short run causal associations for developed countries

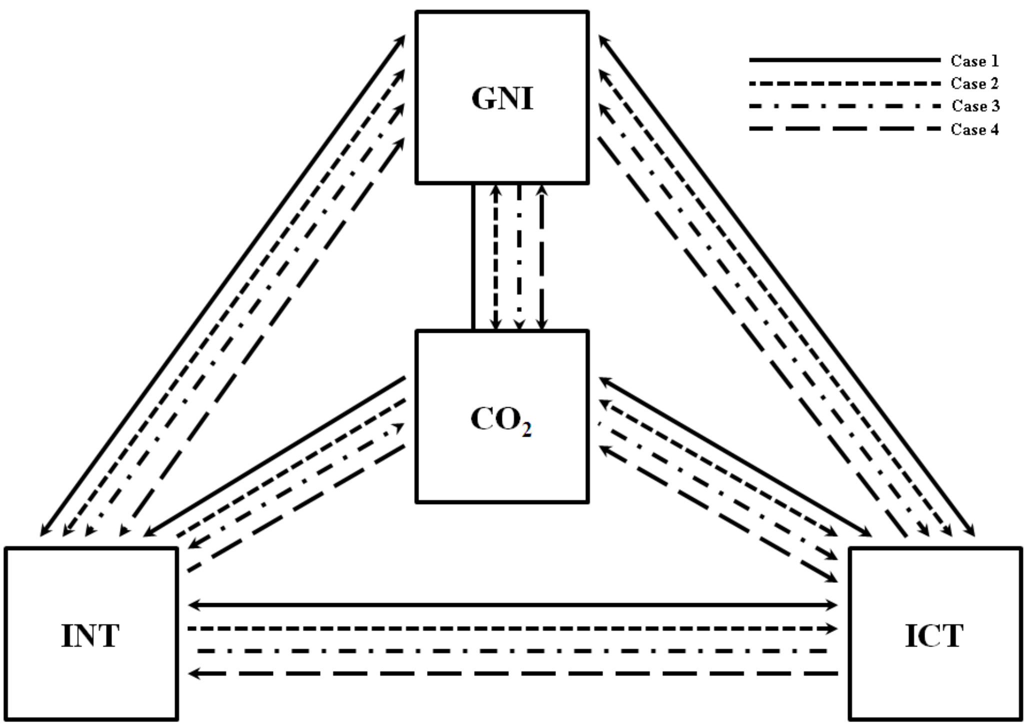

Figure 4: Short run causal associations for developing countries

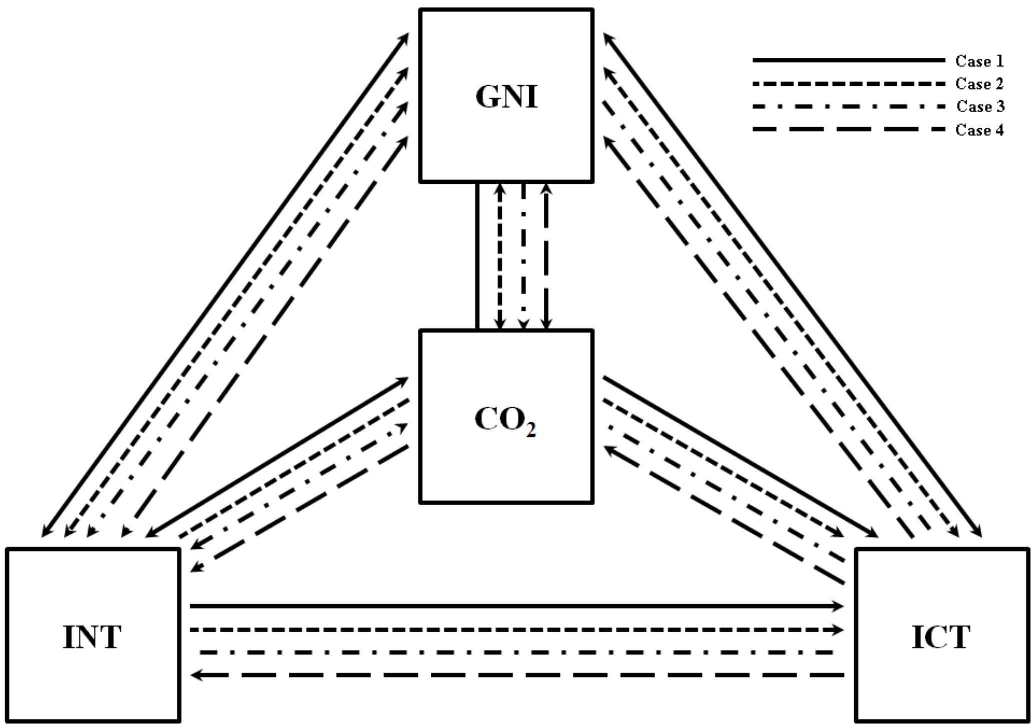

Figure 5: Short run causal associations for all countries

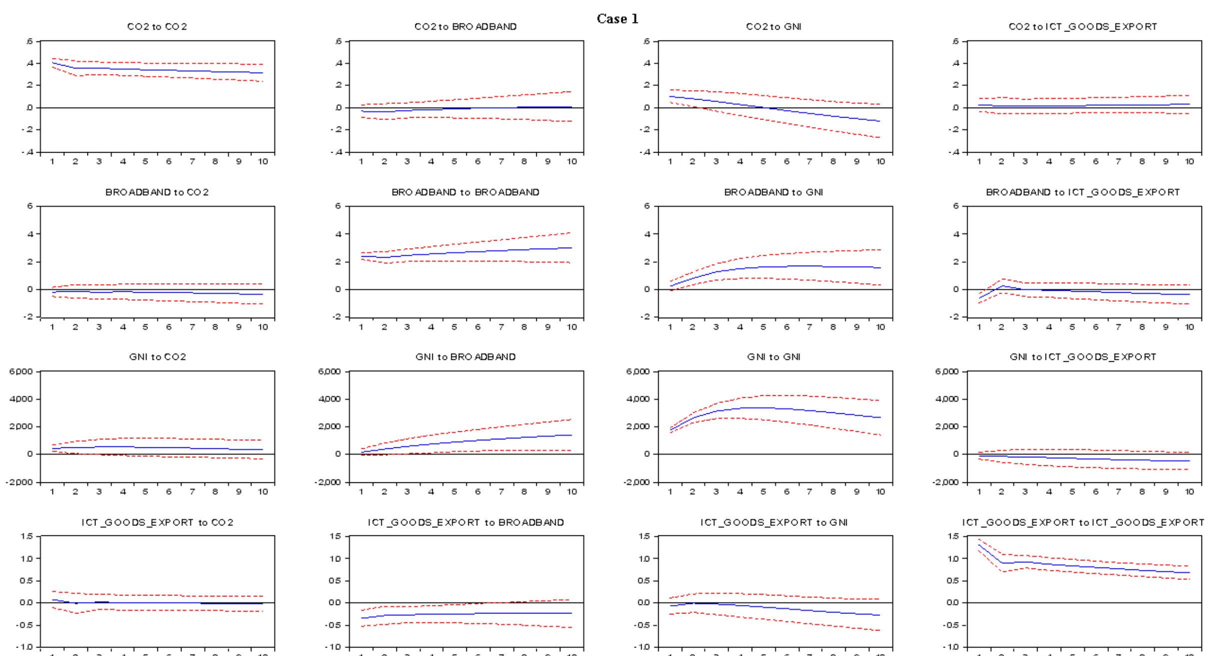

Figure 6a: Generalized impulse functions for the group of developed countries (Case 1)

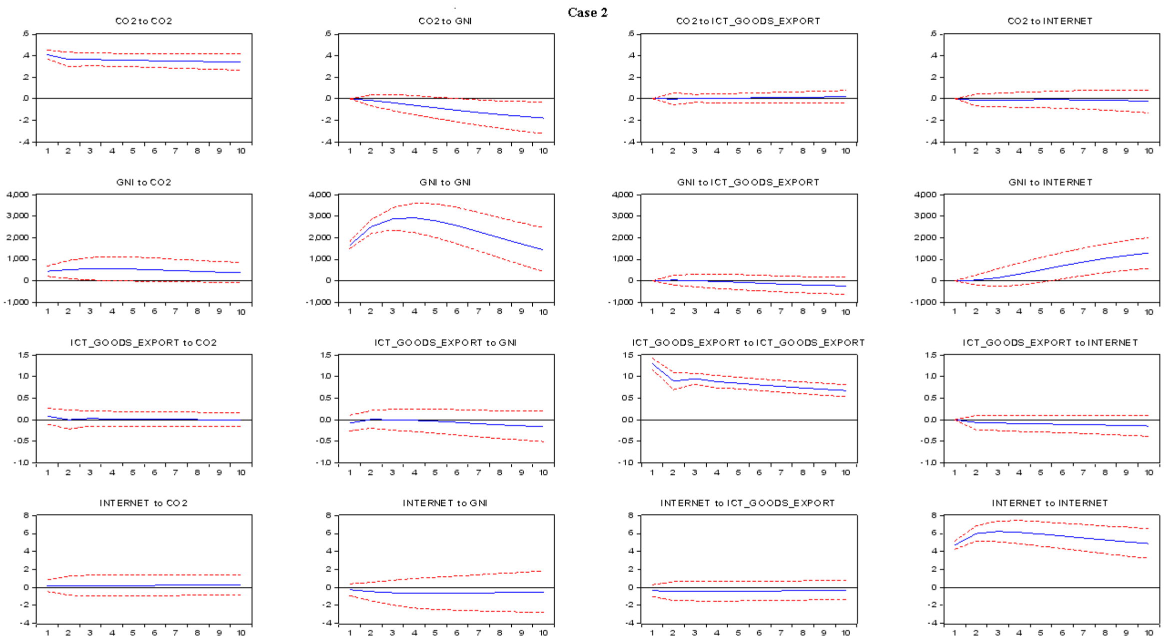

Figure 6b: Generalized impulse functions for the group of developed countries (Case 2)

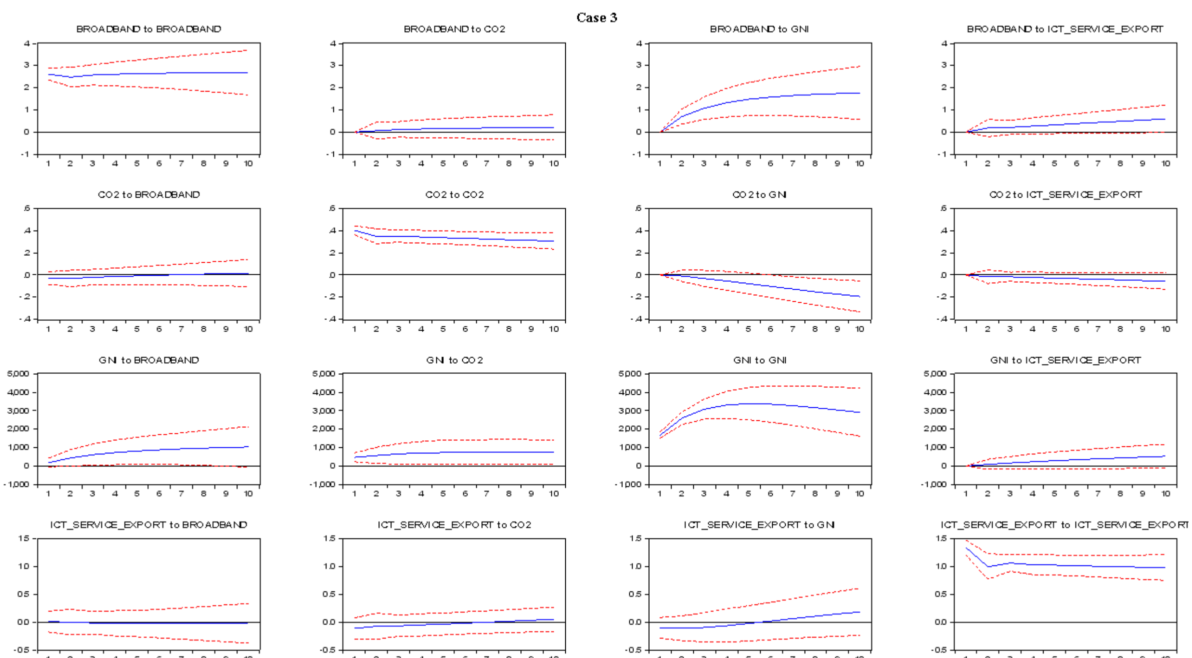

Figure 6c: Generalized impulse functions for the group of developed countries (Case 3)

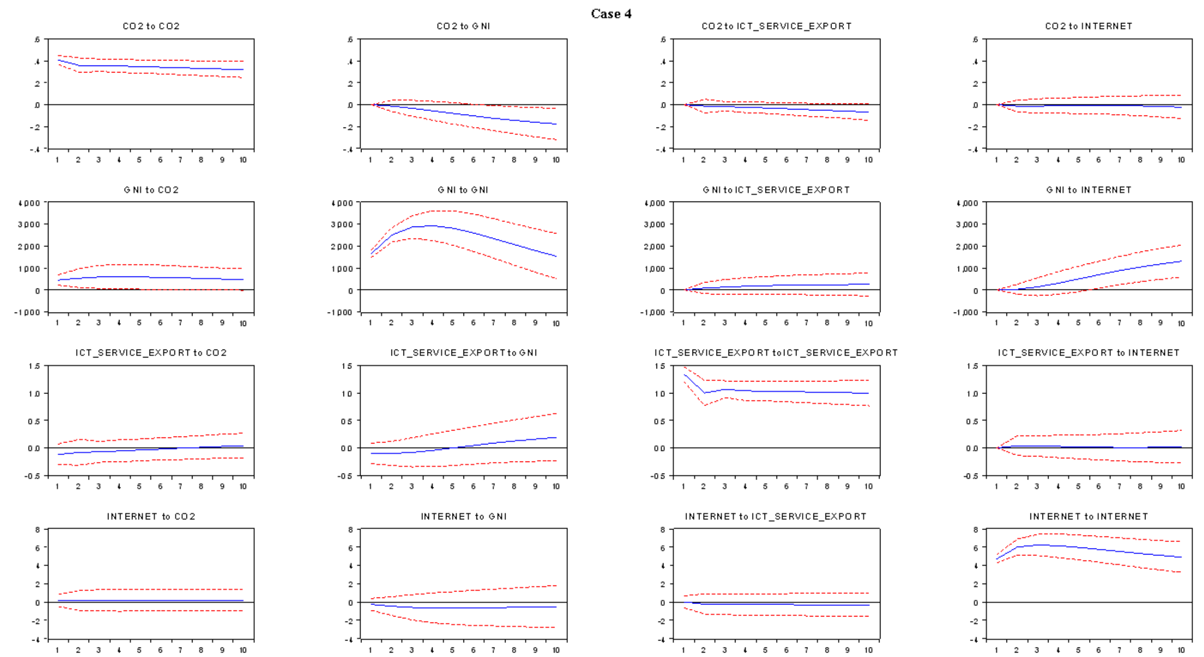

Figure 6d: Generalized impulse functions for the group of developed countries (Case 4)

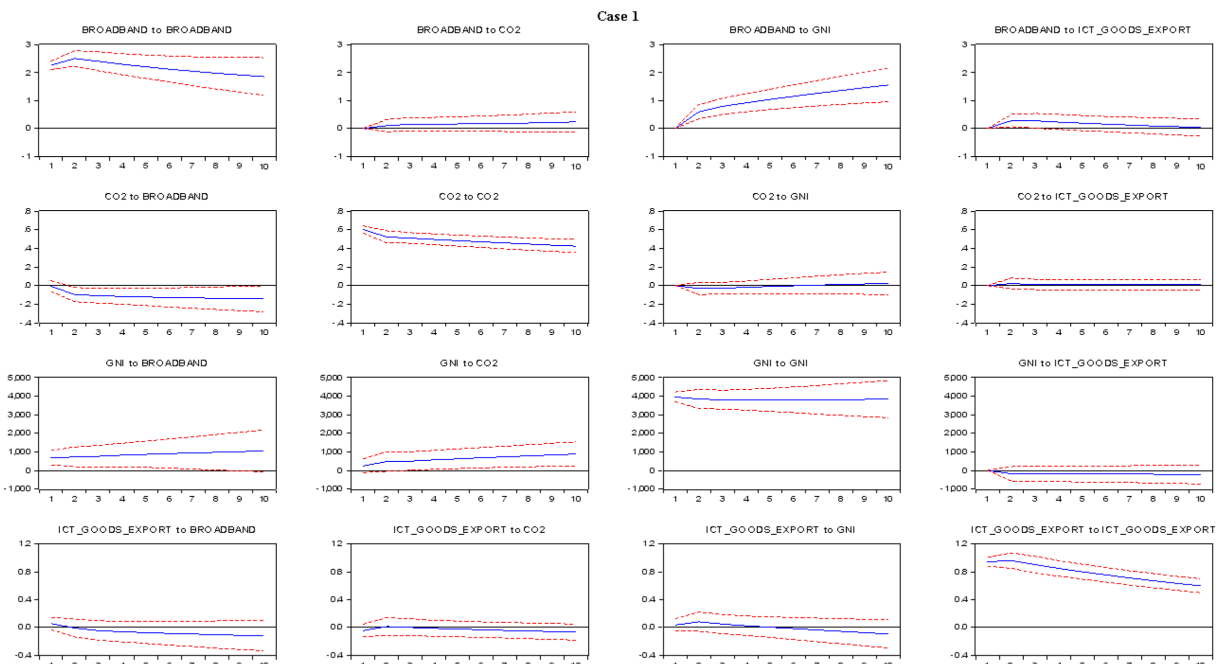

Figure 7a: Generalized impulse functions for the group of developing countries (Case 1)

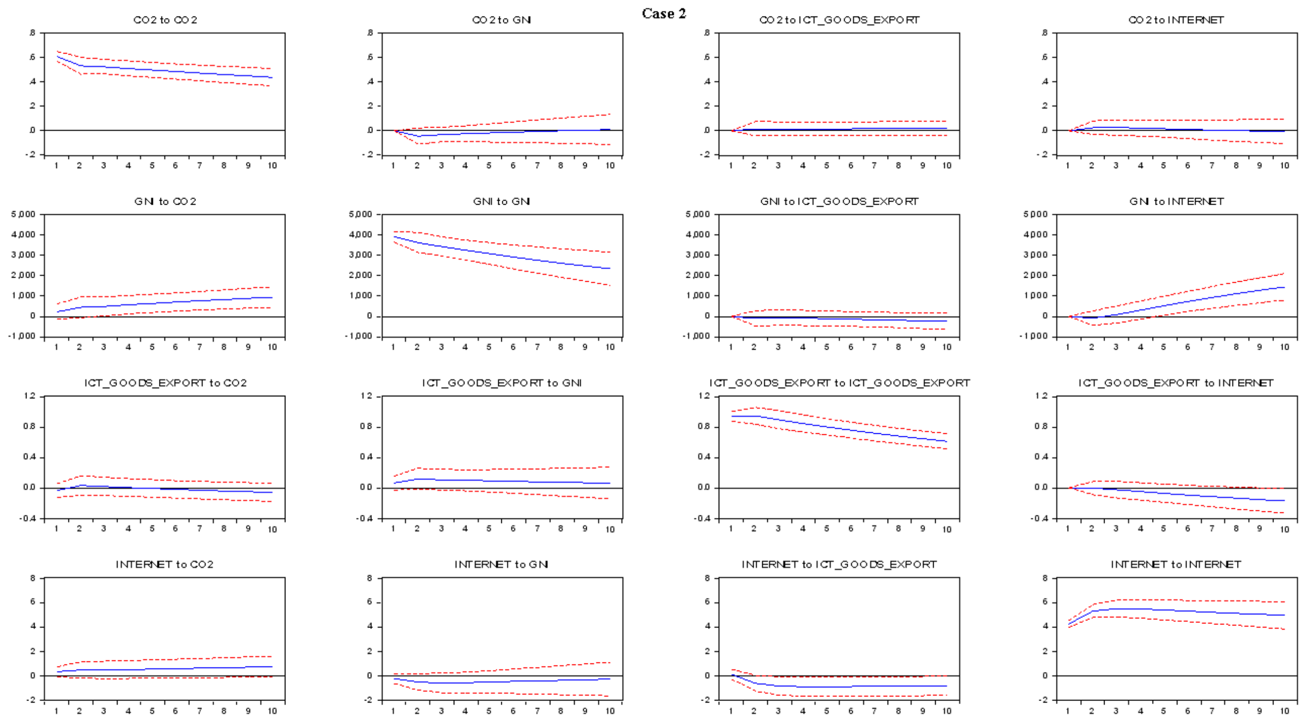

Figure 7b: Generalized impulse functions for the group of developing countries (Case 2)

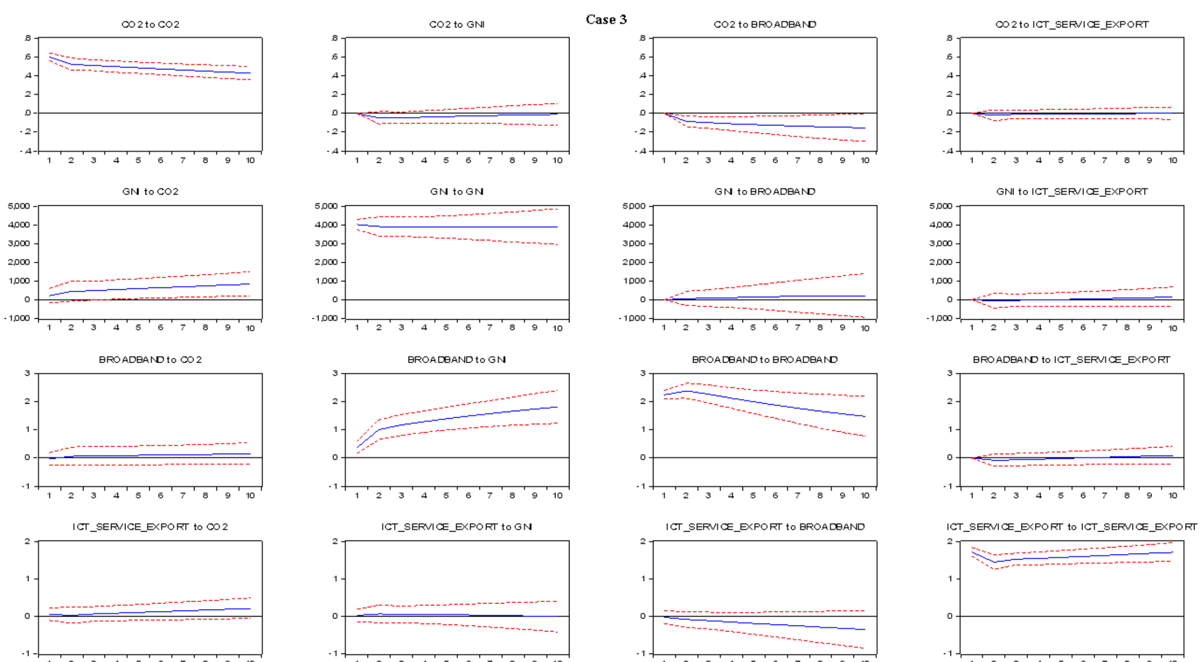

Figure 7c: Generalized impulse functions for the group of developing countries (Case 3)

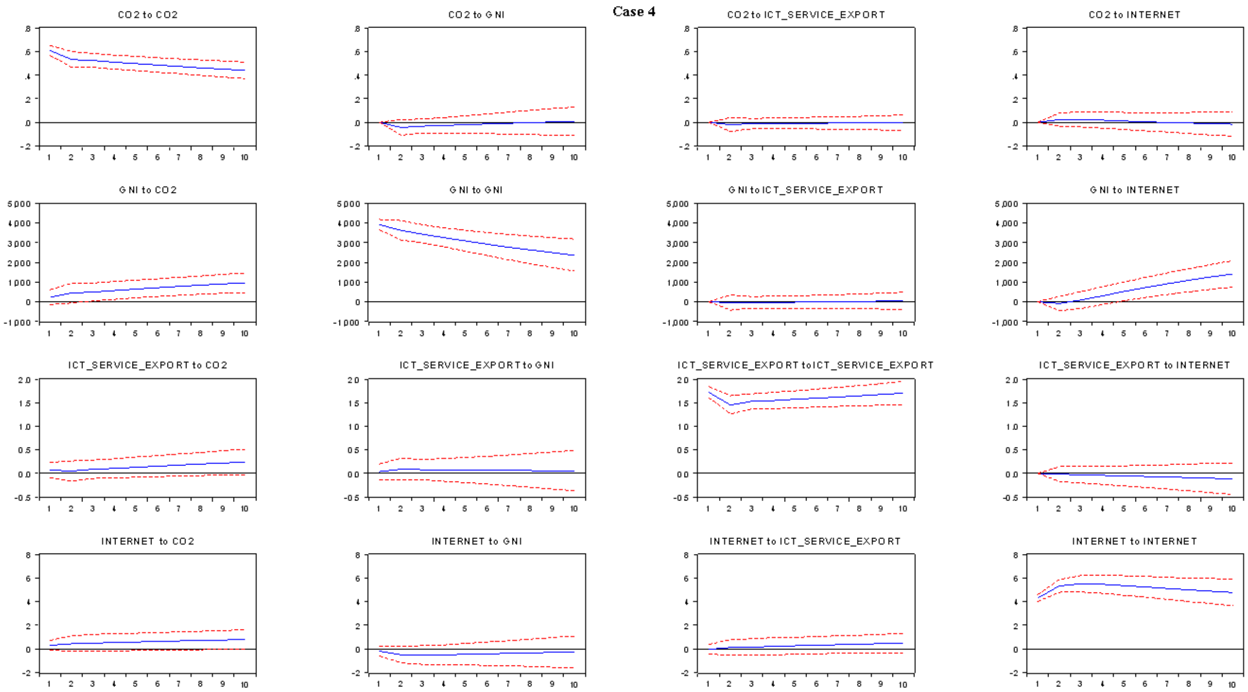

Figure 7d: Generalized impulse functions for the group of developing countries (Case 4)

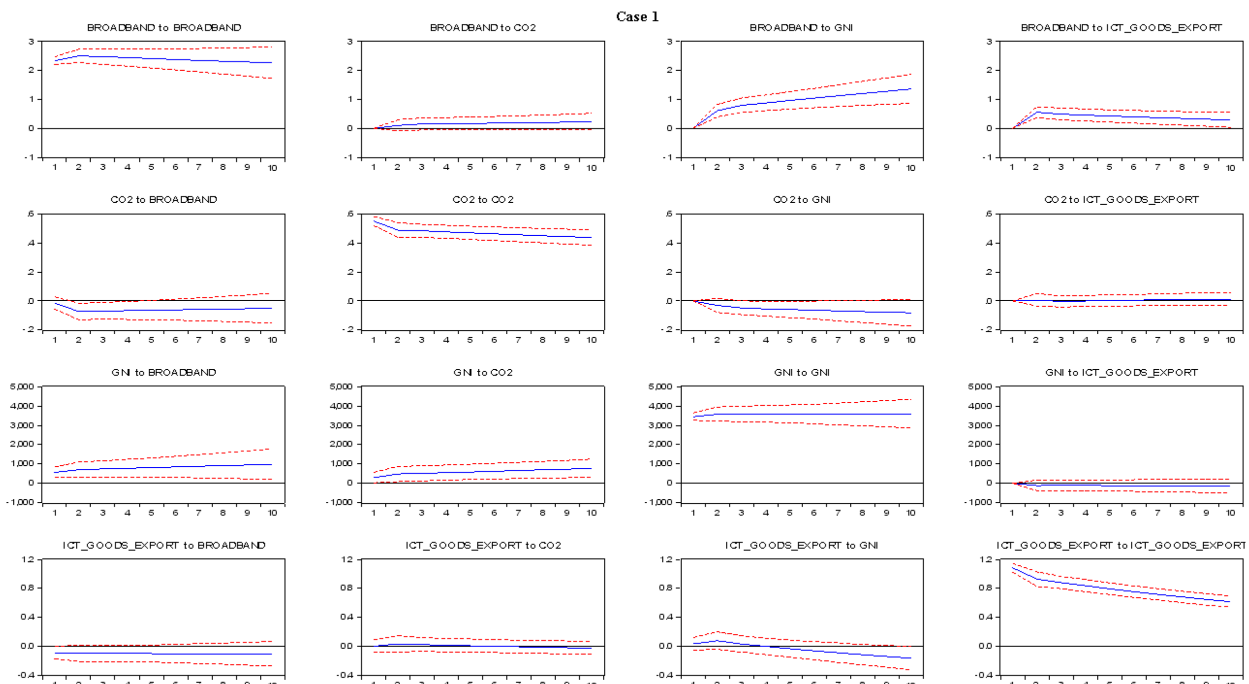

Figure 8a: Generalized impulse functions for the group of all countries (Case 1)

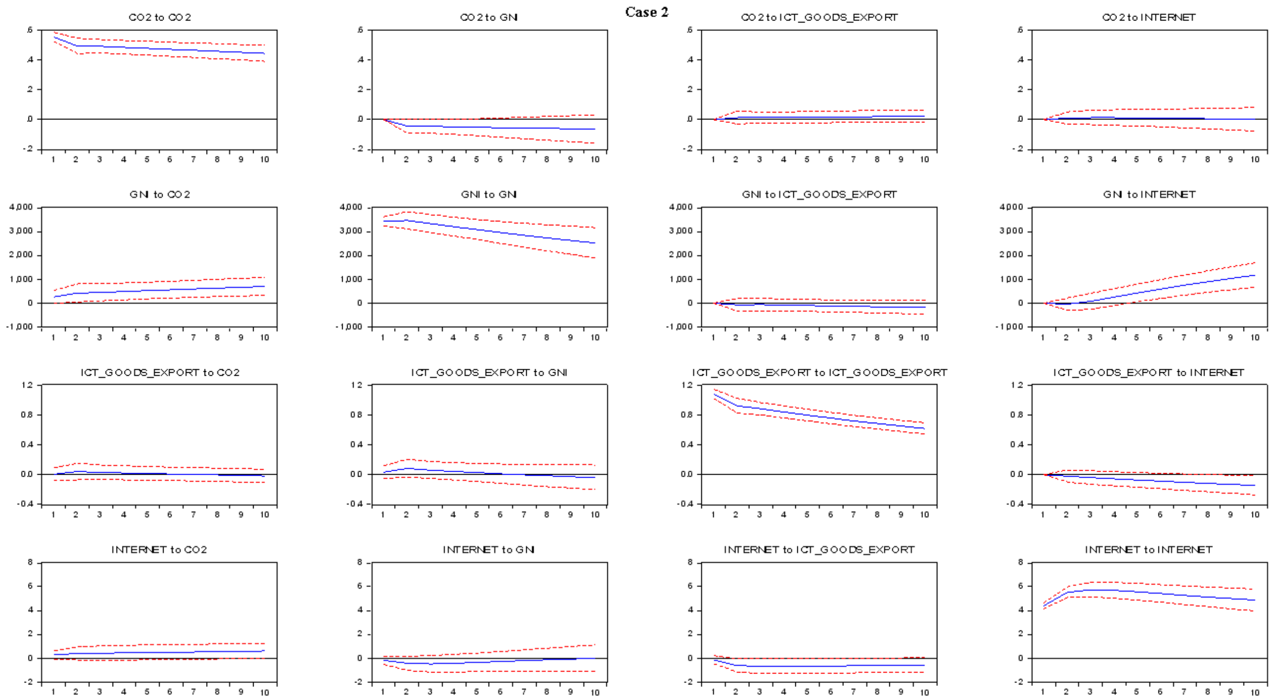

Figure 8b: Generalized impulse functions for the group of all countries (Case 2)

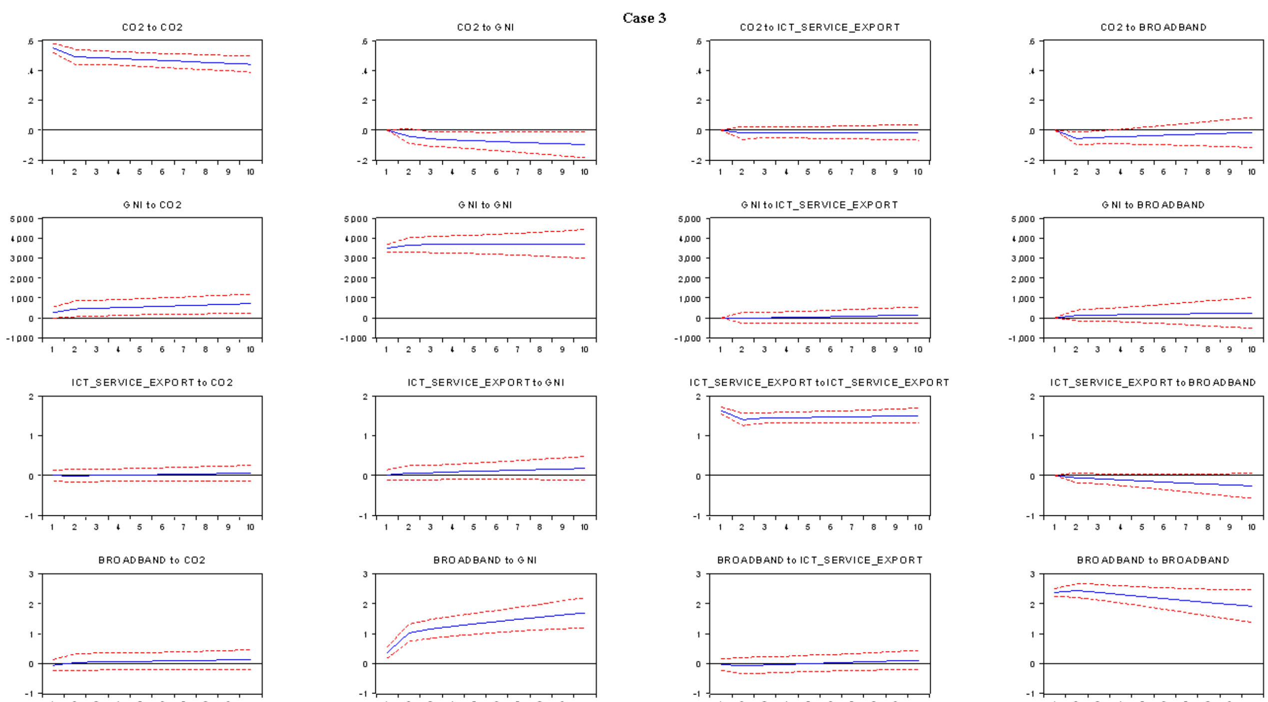

Figure 8c: Generalized impulse functions for the group of all countries (Case 3)

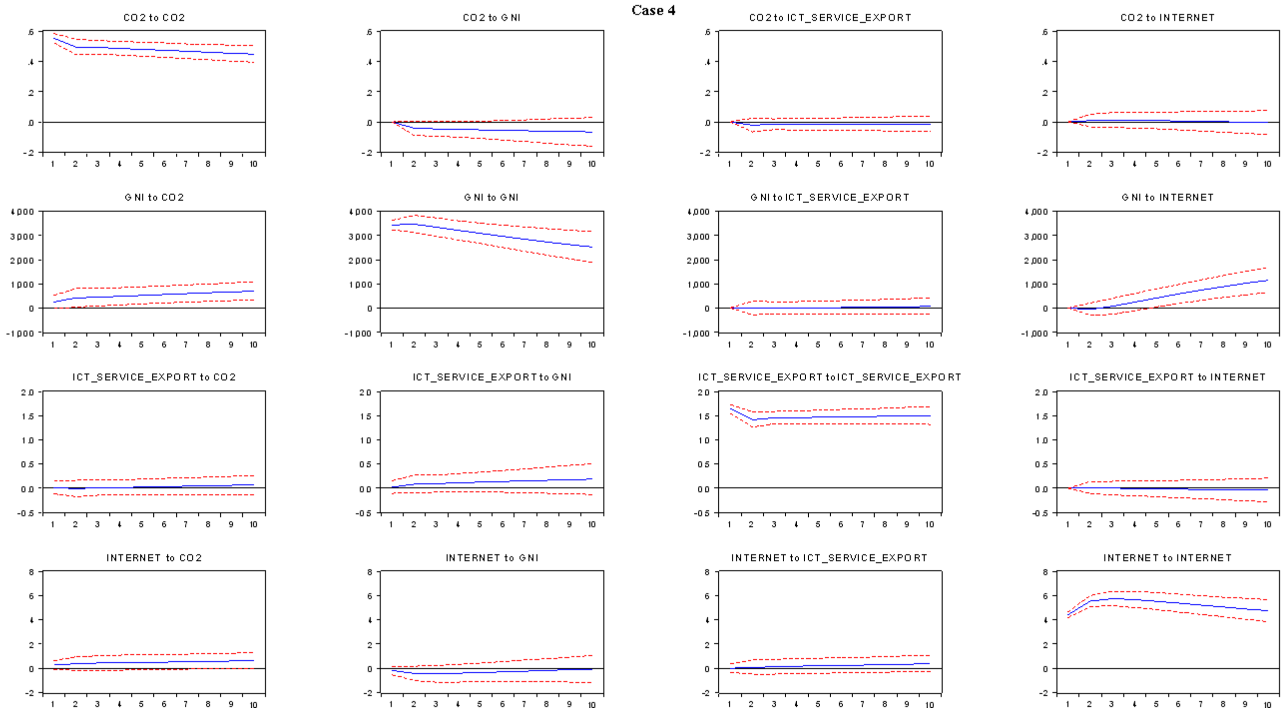

Figure 8d: Generalized impulse functions for the group of all countries (Case 4)

Table 1: Definition of the variables

ICT_G	**ICT goods exports (% of total goods exports):** Information and communication technology goods exports include telecommunications, audio and video, computer and related equipment; electronic components; and other information and communication technology goods.
ICT_S	**ICT service exports (% of service exports):** Information and communication technology service exports include computer and communications services (telecommunications and postal and courier services) and information services (computer data and news-related service transactions).
GNI	**GNI per capita (current US$):** GNI per capita is the gross national income, converted to U.S. dollars using the World Bank Atlas method, divided by the midyear population.
INT_B	**Fixed broadband subscriptions (per 100 people):** Fixed broadband subscriptions refers to fixed subscriptions to high-speed access to the public Internet (a TCP/IP connection), at downstream speeds equal to, or greater than, 256 kbit/s.
INT_U	**Internet users (per 100 people):** Internet users are individuals who have used the Internet (from any location) in the last 12 months. Internet can be used via a computer, mobile phone, personal digital assistant, games machine, digital TV etc.
CO_2	**CO_2 emissions from internet usage (metric tons per capita):** Carbon emissions from internet usage in per capita terms in ton per km.

Table 2: Descriptive statistics of the variables

	Min	Max	Mean	Std. Dev.	CV
Developed countries					
ICT_G	0.27	47.13	11.90	10.61	0.10583
ICT_S	12.59	44.74	27.04	8.60	0.36532
GNI	7550.00	65480.00	32102.01	11895.21	0.00023
INT_B	0.32	42.57	17.95	11.68	0.13160
INT_U	0.52	93.71	45.80	32.32	0.04385
CO_2	5.19	20.21	11.46	4.45	0.57848
Developing countries					
ICT_G	0.05	60.80	7.89	9.35	0.09019
ICT_S	0.70	72.41	20.63	14.02	0.10491
GNI	2510.00	107689.19	29423.75	20953.54	0.00007
INT_B	0.05	45.77	14.42	11.70	0.10535
INT_U	0.08	97.90	40.20	32.66	0.03769
CO_2	2.35	27.43	8.23	4.12	0.48411
All countries					
ICT_G	0.05	60.80	9.18	9.94	0.09284
ICT_S	0.70	72.41	22.69	12.89	0.13665
GNI	2510.00	107689.19	30284.62	18564.37	0.00009
INT_B	0.05	45.77	15.56	11.80	0.11170
INT_U	0.08	97.90	42.00	32.63	0.03944
CO_2	2.35	27.43	9.27	4.49	0.45997

Table 3: Cross-section dependency test

	Developed countries	Developing countries	All countries
ICT_G	0.519(2)	0.621(2)	0.494(2)
ICT_S	0.993(4)	0.987(4)	0.968(5)
GNI	0.288(3)	0.855(4)	0.629(4)
INT_B	0.411(1)	0.537(1)	0.690(1)
INT_U	0.925(5)	0.644(1)	0.518(2)
CO_2	0.240(2)	0.910(1)	0.843(1)

Note: Lag lengths are shown in parentheses after the p-value.

Table 4: Results of unit root tests

	ICT_G	ICT_S	GNI	INT_B	INT_U	CO_2
Developed Countries						
Case 1:	-12.0232[a,i]	NA	-2.01512[a,i]	-3.05382[a,i]	NA	-12.3230[a,i]
	-13.5313[a,l]	NA	-2.92945[a,l]	-6.15663[a,l]	NA	-12.0600[a,l]
Case 2:	-12.0232[a,i]	NA	-2.01512[a,i]	NA	-6.20802[a,i]	-12.3230[a,i]
	-13.5313[a,l]	NA	-2.92945[a,l]	NA	-5.96902[a,l]	-12.0600[a,l]
Case 3:	NA	-10.9616[a,i]	-2.01512[a,i]	-3.05382[a,i]	NA	-12.3230[a,i]
	NA	-4.52767[a,l]	-2.92945[a,l]	-6.15663[a,l]	NA	-12.0600[a,l]
Case 4:	NA	-10.9616[a,i]	-2.01512[a,i]	NA	-6.20802[a,i]	-12.3230[a,i]
	NA	-4.52767[a,l]	-2.92945[a,l]	NA	-5.96902[a,l]	-12.0600[a,l]
Developing Countries						
Case 1:	-15.7815[a,i]	NA	-5.96751[a,i]	-9.58091[a,i]	NA	-16.0763[a,i]
	-17.7600[a,l]	NA	-3.44699[a,l]	-11.1248[a,l]	NA	-17.7173[a,l]
Case 2:	-15.7815[a,i]	NA	-5.96751[a,i]	NA	-9.45637[a,i]	-16.0763[a,i]
	-17.7600[a,l]	NA	-3.44699[a,l]	NA	-10.9016[a,l]	-17.7173[a,l]
Case 3:	NA	-19.1636[a,i]	-5.96751[a,i]	-9.58091[a,i]	NA	-16.0763[a,i]
	NA	-8.50681[a,l]	-3.44699[a,l]	-11.1248[a,l]	NA	-17.7173[a,l]
Case 4:	NA	-19.1636[a,i]	-5.96751[a,i]	NA	-9.45637[a,i]	-16.0763[a,i]
	NA	-8.50681[a,l]	-3.44699[a,l]	NA	-10.9016[a,l]	-17.7173[a,l]
All Countries						
Case 1:	-18.6114[a,i]	NA	-6.05136[a,i]	-10.2949[a,i]	NA	-20.2147[a,i]
	-22.2387[a,l]	NA	-4.49701[a,l]	-12.3225[a,l]	NA	-18.9998[a,l]
Case 2:	-18.6114[a,i]	NA	-6.05136[a,i]	NA	-12.0581[a,i]	-20.2147[a,i]
	-22.2387[a,l]	NA	-4.49701[a,l]	NA	-12.7510[a,l]	-18.9998[a,l]
Case 3:	NA	-20.9188[a,i]	-6.05136[a,i]	-10.2949[a,i]	NA	-20.2147[a,i]
	NA	-8.35708[a,l]	-4.49701[a,l]	-12.3225[a,l]	NA	-18.9998[a,l]
Case 4:	NA	-20.9188[a,i]	-6.05136[a,i]	NA	-12.0581[a,i]	-20.2147[a,i]
	NA	-8.35708[a,l]	-4.49701[a,l]	NA	-12.7510[a,l]	-18.9998[a,l]

Note 1: Case 1: ICT_G, GNI, INT_B, CO2; Case 2: ICT_G, GNI, INT_U, CO2;
Case 3: ICT_S, GNI, INT_B ,CO2; Case 4: ICT_S, GNI, INT_U, CO2

Note 2: "i" signifies IPS test and "l" signifies LLC test at the first differences of the parameters

Note 3: a signifies values at 1% significance level

Table 5: Pedroni panel cointegration test results

Developed Countries		*Case 1*	*Case 2*	*Case 3*	*Case 4*
Panel v-Statistic	Normal	2.561760[a]	1.154774[c]	2.744403[a]	-2.097730[a]
	Weighted	5.586817[a]	0.956093	1.022637[c]	-1.115971[c]
Panel rho-Statistic	Normal	-0.047454	-0.935749	1.474060[c]	2.398056[c]
	Weighted	0.540512	-0.084837	-0.136573	2.670726
Panel PP-Statistic	Normal	-4.345795[a]	-3.566923[a]	-0.296621	1.635081[c]
	Weighted	-2.858159[a]	-2.108166[b]	-1.210057[c]	2.238615
Panel ADF-Statistic	Normal	-4.784237[a]	-3.685363[a]	-2.111044[b]	-2.275993[a]
	Weighted	-4.353755[a]	-2.718713[a]	-2.841917[a]	-1.260663[c]
Group rho-Statistic		1.849520	1.000556	0.934858	-1.728055[b]
Group PP-Statistic		-2.376128[a]	-1.894134[b]	-1.086241[c]	-3.147406[a]
Group PP-Statistic		-4.200553[a]	-2.814832[a]	-3.558021[a]	-1.662350[a]
Developing Countries		*Case 1*	*Case 2*	*Case 3*	*Case 4*
Panel v-Statistic	Normal	23.23183[a]	9.601579[a]	12.561325[a]	0.504191
	Weighted	6.882689[a]	3.386695[a]	3.162071[a]	-0.685537
Panel rho-Statistic	Normal	1.654423	2.063176	-0.430035	0.327323
	Weighted	0.450962	0.609099	0.117329	-1.267529[c]
Panel PP-Statistic	Normal	-0.082537	-0.117462	-3.086089[a]	-1.464335[c]
	Weighted	-2.884181[a]	-3.446289[a]	-2.598542[a]	-4.252303[a]
Panel ADF-Statistic	Normal	-1.734365[b]	-3.505219[a]	-3.947223[a]	-2.396198[a]
	Weighted	-4.271056[a]	-5.551483[a]	-3.922250[a]	-4.438077[a]
Group rho-Statistic		1.795235	2.020353	0.647922	0.307535
Group PP-Statistic		-3.764871[a]	-3.539284[a]	-4.712509[a]	-5.266371[a]
Group PP-Statistic		-4.395985[a]	-6.007646[a]	-5.829270[a]	-5.804209[a]
All Countries		*Case 1*	*Case 2*	*Case 3*	*Case 4*
Panel v-Statistic	Normal	17.39432[a]	6.508866[a]	2.004110[b]	1.394416[c]
	Weighted	8.810730[a]	2.926961[a]	1.582758[c]	1.189590[c]
Panel rho-Statistic	Normal	1.053672	1.740120	-1.849922[b]	-0.384195
	Weighted	0.670790	0.804127	-1.174612[c]	0.173687
Panel PP-Statistic	Normal	-3.323491[a]	-2.968533[a]	-4.672110[a]	-2.224499[b]
	Weighted	-3.906679[a]	-4.942909[a]	-3.687080[a]	-1.342951[c]
Panel ADF-Statistic	Normal	-5.395152[a]	-4.968687[a]	-7.662136[a]	-2.925590[a]
	Weighted	-6.023772[a]	-6.530730[a]	-6.573130[a]	-3.375133[a]
Group rho-Statistic		2.527412	2.742822	0.618970	2.101682
Group PP-Statistic		-4.448468[a]	-3.410339[a]	-3.721509[a]	-0.774056
Group PP-Statistic		-6.002703[a]	-6.050436[a]	-8.808094[a]	-5.701188[a]

Note 1: Case 1: ICT_G, GNI, INT_B ,CO2

Case 2: ICT_G, GNI, INT_U, CO2

Case 3: ICT_S, GNI, INT_B ,CO2

Case 4: ICT_S, GNI, INT_U, CO2

Note 2: a signifies values at 1% significance level; b signifies values at 5% significance level; c signifies values at 10% significance level

Table 6: Johansen-Fisher panel cointegration test results

	Null hypothesis	Fisher Statistic (from trace test)	Fisher Statistic (from max-eigenvalue test)
Developed countries			
Case 1	None	113.7[a]	94.18[a]
	At most 1	39.69[a]	30.82[b]
Case 2	None	157.4[a]	124.6[a]
	At most 1	55.36[a]	47.18[a]
Case 3	None	67.95[a]	46.75[a]
	At most 1	34.38[a]	25.75[c]
Case 4	None	92.20[a]	65.65[a]
	At most 1	42.62[a]	31.36[b]
Developing countries			
	Null hypothesis	Fisher Statistic (from trace test)	Fisher Statistic (from max-eigenvalue test)
Case 1	None	220.6[a]	186.2[a]
	At most 1	75.51[a]	66.14[a]
Case 2	None	214.2[a]	126.5[a]
	At most 1	116.9[a]	74.33[a]
Case 3	None	154.8[a]	98.37[a]
	At most 1	83.65[a]	82.99[a]
Case 4	None	177.9[a]	136.6[a]
	At most 1	76.05[a]	56.66[b]
All countries			
	Null hypothesis	Fisher Statistic (from trace test)	Fisher Statistic (from max-eigenvalue test)
Case 1	None	334.3[a]	280.4[a]
	At most 1	115.2[a]	96.96[a]
Case 2	None	371.6[a]	251.1[a]
	At most 1	172.3[a]	121.5[a]
Case 3	None	222.7[a]	145.1[a]
	At most 1	118.0[a]	108.7[a]
Case 4	None	270.1[a]	202.3[a]
	At most 1	118.7[a]	88.01[a]

Note 1: Case 1: ICT_G, GNI, INT_B ,CO2

Case 2: ICT_G, GNI, INT_U, CO2

Case 3: ICT_S, GNI, INT_B ,CO2

Case 4: ICT_S, GNI, INT_U, CO2

Note 2: a signifies values at 1% significance level; b signifies values at 5% significance level; c signifies values at 10% significance level

Note 3: Null hypothesis explicates the number of cointegrating vectors

Table 7: Causality results for Developed countries

Dependent Variable	*Independent Variable*				*Error Correction term*
Case 1					
	ΔICT_G	ΔGNI	ΔINT_B	ΔCO_2	*ECT(-1)*
ΔICT_G	-	6.606701[c]	4.550988	3.530557	-0.079250
ΔGNI	0.677023	-	11.76222[a]	19.94523[a]	-4.313547[a]
ΔINT_B	1.029797	17.39920[a]	-	7.223640[c]	-0.489888[a]
ΔCO_2	10.74645[b]	4.084685	6.668991[c]	-	-0.172044[a]
Case 2					
	ΔICT_G	ΔGNI	ΔINT_U	ΔCO_2	*ECT(-1)*
ΔICT_G	-	6.294653[c]	2.275930	2.407720	-0.185362[c]
ΔGNI	0.797485	-	14.47562[a]	18.83248[a]	-1.282393[a]
ΔINT_U	0.883682	8.578799[b]	-	0.660288	-0.000100
ΔCO_2	10.08135[b]	6.389629[c]	1.800156	-	-0.331113
Case 3					
	ΔICT_S	ΔGNI	ΔINT_B	ΔCO_2	*ECT(-1)*
ΔICT_S	-	1.371073	0.419315	7.437327[c]	-0.000814
ΔGNI	2.548894	-	10.42598[b]	20.28007[a]	-41.93500[a]
ΔINT_B	0.956267	18.02009[a]	-	6.855672[c]	-0.023419
ΔCO_2	0.912294	6.451249[c]	7.279543[c]	-	-0.548145[a]
Case 4					
	ΔICT_S	ΔGNI	ΔINT_U	ΔCO_2	*ECT(-1)*
ΔICT_S	-	1.855607	1.172851	7.705943[c]	-0.004215
ΔGNI	2.373465	-	14.13892[a]	18.10708[a]	-8.039793[a]
ΔINT_U	0.738598	8.340952[b]	-	1.285246	-0.046840[b]
ΔCO_2	2.678141	7.612626[c]	1.714894	-	-2.120107

Note 1: Case 1: ICT_G, GNI, INT_B ,CO2

Case 2: ICT_G, GNI, INT_U, CO2

Case 3: ICT_S, GNI, INT_B ,CO2

Case 4: ICT_S, GNI, INT_U, CO2

Note 2: a signifies values at 1% significance level; b signifies values at 5% significance level; c signifies values at 10% significance level

Table 8: Causality results for Developing countries

Dependent Variable	*Independent Variable*				*Error Correction term*
Case 1					
	ΔICT_G	ΔGNI	ΔINT_B	ΔCO_2	*ECT(-1)*
ΔICT_G	-	7.481126[c]	13.70508[a]	8.883038[c]	-0.000891[c]
ΔGNI	8.260975[c]	-	6.079298[c]	2.431310	-11.037899[a]
ΔINT_B	6.242074[c]	21.67565[a]	-	11.06275[b]	-0.003880
ΔCO_2	6.010215[c]	3.946967	3.293883	-	-0.032121[a]
Case 2					
	ΔICT_G	ΔGNI	ΔINT_U	ΔCO_2	*ECT(-1)*

ΔICT_G	-	12.52065[a]	8.557183[b]	6.921167[c]	-0.031806
ΔGNI	10.70609[a]	-	8.379607[b]	6.114654[c]	-21.87065[a]
ΔINT_U	0.417825	12.84311[a]	-	2.822616	-0.015071[b]
ΔCO_2	8.285203[c]	7.450192[c]	0.745395	-	-0.002750[a]
			Case 3		
	ΔICT_S	*ΔGNI*	*ΔINT_B*	*ΔCO_2*	*ECT(-1)*
ΔICT_S	-	6.251594[c]	1.737718	7.114635[c]	-0.047238
ΔGNI	7.355348[c]	-	6.027622[c]	2.554344	-0.013957[a]
ΔINT_B	4.728078	15.39502[a]	-	10.23445[b]	-0.165205[b]
ΔCO_2	1.162843	8.727238[b]	9.115834[a]	-	-0.012492[a]
			Case 4		
	ΔICT_S	*ΔGNI*	*ΔINT_U*	*ΔCO_2*	*ECT(-1)*
ΔICT_S	-	2.336201	1.329710	8.156331[c]	-0.048838
ΔGNI	4.543422	-	9.282313[b]	6.296222[c]	-0.008813[a]
ΔINT_U	20.75848[a]	11.16163[b]	-	3.950659	-0.016833
ΔCO_2	6.327299[c]	5.920167[c]	0.313094	-	-0.020469[a]

Note 1: Case 1: ICT_G, GNI, INT_B ,CO2

Case 2: ICT_G, GNI, INT_U, CO2

Case 3: ICT_S, GNI, INT_B ,CO2

Case 4: ICT_S, GNI, INT_U, CO2

Note 2: a signifies values at 1% significance level; b signifies values at 5% significance level; c signifies values at 10% significance level

Table 9: Causality results for all countries

Dependent Variable	*Independent Variable*				*Error Correction term*
			Case 1		
	ΔICT_G	*ΔGNI*	*ΔINT_B*	*ΔCO_2*	*ECT(-1)*
ΔICT_G	-	10.80889[b]	13.04977[a]	10.37599[b]	-0.005474
ΔGNI	8.127596[c]	-	13.17426[a]	1.908641	-0.225966[a]
ΔINT_B	4.740742	45.72727[a]	-	14.79355[a]	-0.000863[a]
ΔCO_2	4.026383	5.600100	6.126154[c]	-	-0.023225[a]
			Case 2		
	ΔICT_G	*ΔGNI*	*ΔINT_U*	*ΔCO_2*	*ECT(-1)*
ΔICT_G	-	17.49370[a]	11.54992[a]	7.981765[b]	-0.006665
ΔGNI	11.55097[a]	-	15.50779[a]	7.465417[b]	-0.192343[a]
ΔINT_U	0.907082	16.43151[a]	-	4.222026	-0.001556
ΔCO_2	2.639105	9.051468[b]	1.091306	-	-0.080863[a]
			Case 3		
	ΔICT_S	*ΔGNI*	*ΔINT_B*	*ΔCO_2*	*ECT(-1)*
ΔICT_S	-	4.575275	1.451851	2.760911	-0.040839
ΔGNI	3.184034	-	8.262217[c]	2.522880	-0.268129[a]
ΔINT_B	4.104855	32.12274[a]	-	9.180621[c]	-0.186794
ΔCO_2	1.548963	6.410014[c]	12.17865[a]	-	-0.006390[a]

Case 4					
	ΔICT_S	*ΔGNI*	*ΔINT_U*	ΔCO_2	*ECT(-1)*
ΔICT_S	-	2.236273	0.748243	1.878183	-0.059173
ΔGNI	6.229463[c]	-	16.99066[a]	7.782578[b]	-0.223841[a]
ΔINT_U	19.55303[a]	15.37221[a]	-	6.000058[c]	-0.045703[c]
ΔCO_2	6.122412[c]	9.034354[b]	0.218782	-	-0.001719[a]

Note 1: Case 1: ICT_G, GNI, INT_B ,CO2

Case 2: ICT_G, GNI, INT_U, CO2

Case 3: ICT_S, GNI, INT_B ,CO2

Case 4: ICT_S, GNI, INT_U, CO2

Note 2: a signifies values at 1% significance level; b signifies values at 5% significance level; c signifies values at 10% significance level

Table 10: Directions of causal associations

		ICT & GNI	*ICT & INT*	*GNI & INT*	*INT & CO_2*	*GNI & CO_2*	*ICT & CO_2*
Developed Countries	Case 1	ICT <= GNI	ICT ≠ INT	INT ⇔ GNI	INT ⇔ CO_2	GNI <= CO_2	ICT => CO_2
	Case 2	ICT <= GNI	ICT ≠ INT	INT ⇔ GNI	INT ≠ CO_2	GNI ⇔ CO_2	ICT => CO_2
	Case 3	ICT ≠ GNI	ICT ≠ INT	INT ⇔ GNI	INT ⇔ CO_2	GNI ⇔ CO_2	ICT <= CO_2
	Case 4	ICT ≠ GNI	ICT ≠ INT	INT ⇔ GNI	INT ≠ CO_2	GNI ⇔ CO_2	ICT <= CO_2
Developing Countries	Case 1	ICT ⇔ GNI	ICT ⇔ INT	INT ⇔ GNI	INT <= CO_2	GNI ≠ CO_2	ICT ⇔ CO_2
	Case 2	ICT ⇔ GNI	ICT <= INT	INT ⇔ GNI	INT ≠ CO_2	GNI ⇔ CO_2	ICT ⇔ CO_2
	Case 3	ICT ⇔ GNI	ICT ≠ INT	INT ⇔ GNI	INT ⇔ CO_2	GNI => CO_2	ICT <= CO_2
	Case 4	ICT ≠ GNI	ICT => INT	INT ⇔ GNI	INT ≠ CO_2	GNI ⇔ CO_2	ICT ⇔ CO_2
All Countries	Case 1	ICT ⇔ GNI	ICT <= INT	INT ⇔ GNI	INT ⇔ CO_2	GNI ≠ CO_2	ICT <= CO_2
	Case 2	ICT ⇔ GNI	ICT <= INT	INT ⇔ GNI	INT ≠ CO_2	GNI ⇔ CO_2	ICT <= CO_2
	Case 3	ICT ≠ GNI	ICT ≠ INT	INT ⇔ GNI	INT ⇔ CO_2	GNI => CO_2	ICT ≠ CO_2
	Case 4	ICT => GNI	ICT => INT	INT ⇔ GNI	INT <= CO_2	GNI ⇔ CO_2	ICT => CO_2

Note 1: Case 1: ICT_G, GNI, INT_B ,CO2

Case 2: ICT_G, GNI, INT_U, CO2

Case 3: ICT_S, GNI, INT_B ,CO2

Case 4: ICT_S, GNI, INT_U, CO2

Note 2: <= / => shows unidirectional causality; ⇔ shows bidirectional causality; ≠ shows no causality

Appendix 1: Details of the studies

Author	Context	Methodology	Results
Theme: Causal association between economic growth and CO_2 emission			
Baek (2015)	Arctic countries (1960-2010)	EKC analysis	$PGDP \rightarrow CO_2$
Shahbaz et al. (2015)	99 countries (1975-2012)	VECM and Granger causality	$GDP \leftrightarrow CO_2$
Onafowora and Owoye (2014)	6 African countries (1970-2010)	ARDL Bounds test	$GDP \leftrightarrow CO_2$
Sinha (2014)	India (1971-2010)	Granger causality	$GDP \neq CO_2$
Sinha and Bhattacharya (2014)	India (1971-2010)	Disintegrated Granger causality	$GDP \leftrightarrow CO_2$
Sinha and Mehta (2014)	India (1960-2010)	VECM and Granger causality	$GDP \leftrightarrow CO_2$
Sinha and Sen (2016)	BRIC countries (1980-2013)	VECM and Granger causality	$GDP \leftrightarrow CO_2$
Theme: Causal association between economic growth and ICT exports			
Ishida (2015)	Japan (1980-2010)	ARDL Bounds test	$ICT \neq GDP$
Farhadi et al. (2012)	159 countries (2000-2009)	GMM analysis	$ICT \leftrightarrow GDP$
Oulton (2012)	19 countries (1970-2007)	Growth Accounting	$ICT \leftrightarrow GDP$
Theme: Causal association between economic growth and internet usage			
Nardotto et al. (2015)	The UK (2005-2009)	Panel Regression analysis	$INT \rightarrow GDP$
Gruber et al. (2014)	EU countries (2005-2011)	3SLS analysis	$INT \rightarrow GDP$
Mehmood and Mustafa (2014)	24 Asian countries (2001-2011)	Panel Regression analysis	$INT \rightarrow GDP$

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