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Productivity of organic and conventional agriculture – a common technology analysis

The raging debate on organic versus conventional agriculture, and with regard to the aspect of productivity in particular, is far from conclusive. In this analysis, we explore the productivity comparison further through the evaluation of a common production technology used in 74 countries around the world, over the period 2005 to 2014. We found conventional agriculture to be more productive than organic agriculture. Whilst productivity of conventional agriculture is exponentially rising, that of organic is declining, although it has a quadratic growth path. For every hectare of conventional agricultural land given up, only 0.54 hectares of organic land area is substituted. Based on an elasticity of substitution of 0.36, the isoquant is relatively vertical; therefore, much more conventional lands need to be substituted with an organic land area. Research into new and improved fertilising and pest control methods is essential as positive developments there would have a significant impact on organic land productivity.

Keywords: Conventional agriculture, elasticity of substitution, land productivity, marginal rate of substitution, organic agriculture

JEL classifications: Q12, Q16

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Introduction

Researchers and policy makers alike have recognised the importance of enhancing productivity to increase agricultural output (Martin, 2013). Since the amount of arable land available is limited, desired increases in production, the goal of many countries' agricultural policy, should be met largely through increases in agricultural productivity (Hailu *et al.*, 2016). Enhanced productivity to increase agricultural output can in turn improve subsistence farmers' ability to produce more and improve the levels of household food security and income (Gallup *et al.*, 1997). Observing productivity differences between organic and conventional agriculture is therefore crucial as this has implications for efficiency, profits and subsidies, which are important for policy.

The role of productivity in the debate on conventional-organic agriculture has necessitated publications that compared productivity of conventional and organic agriculture, culminating in some reviews: Badgley *et al.* (2007), De Ponti *et al.* (2012), Ponisio *et al.* (2014), Seufert *et al.* (2012) and Lakner and Breustedt (2016, 2017). The primary studies of the review publications, published over the years, have provided mixed conclusions. Whilst some suggest that organic agriculture is more productive than conventional agriculture (e.g. Tiedemann and Latacz-Lohmann, 2011; Aldanondo-Ochoa *et al.*, 2014), most argue the contrary, namely that conventional agriculture is more productive than organic agriculture (e.g. Kumbhakar *et al.*, 2009; Mayen *et al.*, 2009; Oude Lansink *et al.*, 2002; Tiedemann and Latacz-Lohmann, 2011). However, the conclusions of the productivity comparisons were derived from studies (and or production functions) that modelled organic and conventional agriculture as different technologies[1]. Since the production technology (relations) are different, that in itself is a source of variability. Therefore, the differences in productivity found between the production practices cannot be attributed solely to the differences in production practice and may lead to inappropriate policy recommendations. To eliminate the differences attributable to production technology (different production function), in this study, we assume a common production technology for conventional and organic agriculture. By so doing, we answer the following research questions: is conventional agriculture more productive than organic agriculture? How does organic input substitute for conventional input and finally, how do these change over time?

This article primarily contributes to the literature by assuming a common production technology for organic and conventional agriculture with a separate input variable, land, for each production practice. The focus on land productivity stems from the fact that, land is a principal physical asset certified in organic production and because this is the only farm resource with publicly available data, segregated along organic and conventional production practice. The secondary contribution is to the productivity debate on conventional and organic agriculture.

The next section provides a review of some pertinent literature. The data and sources, models to estimate land productivity and associated properties of the production function are described under section 3 as methodology. Section 4 captures the results and discussions of the reported estimations. The final section is the concluding remarks.

Literature Review

Given the slightly differing approach to the analyses, and in particular, the joint evaluation of one production practice for both production technologies, literature with a similar approach to this study in respect of organic and conventional farming is rare. We therefore review some studies with a

[1] Some studies such as Breustedt *et al.* (2011), Kramol *et al.*(2010), Onumah *et al.* (2013) and Beltrán-Esteve and Reig-Martínez (2014), estimated metafrontier (common technology). However, the estimates of marginal productivity of land and other organic inputs were not segregated in the results reported. Thus, separate productivity of organic and conventional inputs were not obtainable from such common technology estimations.

bearing on our results regarding the productivity of organic and conventional agriculture.

Although uncertified organic production has been in existence for some time, certified organic agriculture is relatively recent (Bouagnimbeck, 2013; Paull, 2013a,b; Djokoto, 2015). Nevertheless, the literature space is replete with studies that have contrasted organic and conventional agriculture in some respects, including productivity and efficiency. These have resulted in a major review by Lakner and Breustedt (2016; 2017). They concluded that organic farms show a lower productivity in three of four studies (Kumbhakar *et al.*, 2009; Mayen *et al.*, 2009; Oude Lansink *et al.*, 2002; Tiedemann and Latacz-Lohmann, 2011).

Using a selectivity model to capture potential sources of a selectivity bias, Kumbhakar *et al.* (2009) found that organic dairy farms in Finland were between 21% and 37% less productive than conventional farms (depending on the estimation model). Indeed, organic farms could produce 5.3% more output by producing according to the conventional farming approach. Mayen *et al.* (2010) applied a matching model to create a 'comparable conventional group'. Their results showed that the technology of organic dairy farms in the USA was 13% less productive than the conventional technology.

Tiedemann and Latacz-Lohmann (2011) also applied a matching-model for their efficiency and productivity comparison. They showed that there was no significant differences in total factor productivity for the full period between 1999 and 2006. The organic grassland farms and organic mixed farms could both increase their productivity in the observed period. Whilst organic arable farms had a slightly higher productivity at the beginning of the observed period, they could not maintain the level of productivity by the end of the period (Tiedemann and Latacz-Lohmann, 2011).

Oude Lansink *et al.* (2002) also found organic arable and livestock farms in Finland to be 23% less productive than conventional arable farms. The study involved modelling both groups; organic and conventional agriculture separately without any strategy to accommodate the problem of selectivity. The superiority of the productivity of conventional farms has been attributed to restrictions on type of resources permitted by organic regulations, informed by principles that underpin organic agriculture and the resulting standards. These restrictions concern the type of resources and consequently the technology organic agriculture uses (Beltran-Esteve and Reig-Martinez, 2014; Mayen *et al.*, 2010).

Methodology

To obtain land productivities require the estimation of a production function to arrive at the marginal productivities of conventional and organic land as factor inputs. We therefore specified equation 1.

$$y = f(CL, OL, LA, FT, PT) \tag{1}$$

where y is output in constant 2004-2006 USD. CL is conventional land area in hectares. This was constructed as total cultivated agricultural land area less cultivated organic land area. OL is cultivated organic land area in hectares, LA is number of the persons employed in agriculture. FT is tonnes of nitrogen, phosphorus and potassium consumed and PT refer to tonnes of active ingredients of agrochemicals (excluding fertilisers) used. Equation 1 was estimated as translog and Cobb-Douglas for years 2005 to 2014 (cross-sectional) and for 2005-2014 (panel), for both ordinary least squares (OLS) and stochastic frontier analysis (SFA) (Aigner *et al.*, 1977 and Meeusen and van den Broeck, 1977), without the inefficiency effects[2].

As the study seeks to compare the productivity of organic and conventional agriculture, a rigorous comparison requires an empirical test. This was accomplished using a parameter difference test (Cohen *et al.*, 2013). The test statistic was specified as:

$$Z = \frac{MPL_{OL} - MPL_{CL}}{\sqrt{SE_{OL}^2 + SE_{CL}^2}} \tag{2}$$

where Z is the test statistic which has a normal distribution, MPL_{OL} and MPL_{CL} are marginal products of organic land and conventional land respectively. SE_{OL} and SE_{CL} are standard errors of the estimates. The specification of this standard error is based on the common error variance. The null hypothesis is that there is no statistical difference between the estimates of the marginal products.

From equation 1, marginal rate of substitution is defined as

$$MTRS_{OL,CL} = -\frac{\partial \ln y}{\partial \ln OL} \Big/ \frac{\partial \ln y}{\partial \ln CL} = -\frac{MPL_{OL}}{MPL_{CL}} \tag{3}$$

where MPL_{CL} and MPL_{OL} are conventional land productivity and organic land productivity, respectively. The *MRTS* measures how much conventional land is given up for organic land. $MRTS_{CL,OL}$ is the slope of the isoquant and expresses how much CL decreases for a unit increase in OL (Chauhan, 2009; Jehle and Reny, 2011). The sign is negative because as CL decreases, OL increases. A high value of MRTS suggests more organic land replaces conventional land and *vice versa*.

Following the conversion of conventional land to organic certified land, an additional measure naturally emerged from equation 1 and 3; the elasticity of substitution ($\sigma_{CL,OL}$).

Mathematically:

$$\sigma_{OL,CL} = \frac{d \ln(CL/OL)}{d \ln|MTRS|} = \frac{\overline{OL}}{\overline{CL}} \cdot MRTS_{OL,CL} \tag{4}$$

where $\sigma_{OL,CL}$, the curvature of the isoquant (slope of MRTS), expresses the degree of substitution of conventional land with organic land. This follows from the calculus rule that the second order differential of a function produces the curvature of that function (Chiang and Wainwright, 2005; Jehle and Reny, 2011). A large elasticity of substitution connotes a flat isoquant and vice versa (Varian, 2006; Chauhan, 2009; Jehle and Reny, 2011; Munoz-Garcia, 2017). As long as the production function is quasi-concave, $\sigma_{OL,CL}$ can never be less than zero (Chauhan, 2009, Jehle and Reny, 2011).

[2] We avoided the estimation of inefficiency effects as it is not the focus of the article.

The data employed in the analysis may fit one form of the production function better than the other. Therefore, the two popular production functions; Cobb-Douglas and tranlog were fitted to the data and a choice was made between these, using log likelihood ratio tests.

$$D = -2 \cdot \ln \frac{Likelihood\ for\ the\ null\ model}{likelihood\ for\ the\ alternative\ model} \quad (5)$$

where D is the log likelihood statistic. In order to facilitate the time varying assessment of land productivity and the nature of substitution, cross-sectional production functions were estimated for each year, 2005 to 2014. The MRTS and $\sigma_{OL,CL}$ capture the nature of the substitution. To examine the time variance, a trend analysis was performed by fitting each indicator series to plausible functions; linear, quadratic and exponential. One function was appropriately selected based on most minimum value of mean absolute percentage error (MAPE), mean absolute deviation (MAD) and mean squared deviation (MSD). The future levels of the indicators were predicted using the selected function(s).

All data was obtained from FAOSTAT[3], except labour data that was extracted from UNCTADSTAT[4]. The FAO source of organic land area cultivated started from 2004. Number of countries with data on organic land area in 2004 was 36 and increased to 161 in 2014. In order to have 10-year period for the trend analyses, and also have appreciable number of observations, we chose to start from 2005, with 102 countries. Subsequently, all other production function variables from countries matched those of the 102 countries. However, some countries did not have corresponding data across all the variables. Eliminating these resulted in complete data on 74 countries (see Appendix). Despite the loss of 28 countries, the 74 countries (observations) per yearly cross-section, exceeded the limit of 30 required to assume normality of distributions including that of the error term.

Results and Discussion

As to descriptive statistics, mean conventional land area are in millions whilst the mean organic land area are in thousands (Table 1). Therefore, conventional land area exceeds organic land area. Mean conventional land area was constant as 26.9m ha for six out of the ten year period. However, organic land area showed more variation; rising from 201,023 ha in 2005 to 204,631 ha in 2006. The area cultivated dropped to 194,164 ha in 2007 and rose to 282,127 ha in 2011. The land area declined to 252,019 ha and rose to 292,474 ha. Thus, organic land area showed greater variability than conventional land area.

The translog functional forms for the OLS and SFA were first estimated using the panel data. However, some of the marginal products had a negative sign, contrary to theoretical requirements. More so, because objectives of the article require the use of marginal products, priority was given to conformance to theory above anything else. Cobb-Douglas functional form of OLS and SFA were then estimated and choice between these was made, using the log-likelihood ratio test. The null hypothesis that the OLS models were preferred to the SFA model could not be rejected. The choice of the Cobb-Douglas rather than the translog may have accounted for the failure to choose the SFA model. Nevertheless, the lack of inefficiency in the model was not considered to influence the marginal productivities.

Prior to discussing the results, the properties of the production functions were examined (Table 2). The adjusted R squared is above 90% with a highly significant F statistics. The production function has positive marginal products. Cobb-Douglas production functions are homogenous of degree 1 (returns-to-scale = 1), and this model conforms. The marginal products of organic and conventional land are inelastic just as the other marginal products. This seems to corroborate the OLS model being better representation of the data than the SFA.

Despite the nominal differences showing that the marginal products of organic land is less productive than con-

Table 1: Mean of various production data.

Year	Output 2004-2006 (USD)	Conventional Land (Ha)	Organic Land (Ha)	Labour (Numbers)	Fertiliser (tonnes)	Pesticides (tonnes of active ingredients)
2005	16,702,207	26,928,841	201,023	12,224,054	1,524,988	40,196
2006	17,157,846	26,928,841	204,631	12,271,297	1,551,755	38,712
2007	17,808,767	26,928,841	194,164	12,303,608	1,665,091	42,527
2008	18,521,861	26,943,913	249,384	12,342,527	1,623,833	42,808
2009	18,629,624	26,928,841	269,073	12,377,405	1,611,020	41,891
2010	19,217,730	26,928,841	268,547	12,407,149	1,762,703	45,157
2011	19,912,673	26,928,841	284,127	12,431,743	1,822,713	46,437
2012	20,201,624	27,024,695	281,919	12,450,635	1,817,663	43,714
2013	20,803,162	27,131,966	252,019	12,462,284	1,834,682	43,805
2014	21,485,057	27,127,236	291,474	12,464,946	1,892,311	46,809
2006-2014	19,044,055	26,980,086	249,636	12,373,565	1,710,676	43,206

Source: own composition based on FAO (2016) data

[3] http://www.fao.org/faostat/en/#data

[4] http://unctadstat.unctad.org/wds/ReportFolders/reportFolders.aspx accessed on 25th December, 2016.

ventional land, a difference test was performed for the parameters of the panel model as well as the cross-sectional annual models. For the panel model, the test statistic of -3.88 confirms the conclusions from the nominal inspection.

The results of the cross-sectional annual model tests are similar[5]. The difference(s) between organic and conventional land productivity can be attributable to a couple of reasons. First, certified organic agriculture is relatively recent although uncertified organic production has been in existence for some time (Bouagnimbeck, 2013; Paull, 2013a, b; Djokoto, 2015). Second, the restrictions on type of resources permitted by organic regulations is informed by principles that underpin organic agriculture and the resulting standards. These restrictions relate to the type of resources and consequently the technology organic agriculture uses (Beltran-Esteve and Reig-Martinez, 2014; Mayen *et al.*, 2010). For example, synthetic fertilisers cannot be applied, pasture grazing of cattle is encouraged, and natural products are preferred to synthetic materials in pest control. In pest and disease management, there is heavy reliance on the regenerative capacity of nature for management. Thus, the limitations of the natural approaches may have resulted in lower productivity unlike for conventional agriculture. Whilst the finding of lower land productivity of organic land than conventional may partly justify subsidies, organic producers need to improve managerial capacity in order to increase their productivity. The development of processes and materials that will enhance organic land productivity is crucial in this regard. This finding is consistent with the conclusions of Lakner and Breustedt (2017).

Table 2: Results of Cobb-Douglas estimation.

Variables	Coefficients (Standard Errors)
CL	0.191*** (0.021)
OL	0.103*** (0.009)
LA	0.246*** (0.015)
FT	0.233*** (0.013)
PT	0.131*** (0.013)
Constant	3.978*** (0.183)
Model properties	
Number of observations	740
F(5, 734)	1,399***
Adj R-squared	0.904
Returns to scale	0.905
MRTS	0.540
Elasticity of substitution (σ_{OLCL})	0.358

*** Represents 1% level of statistical significance
Source: own composition

The MRTS (penultimate line of Table 2) shows that a decrease of 1 hectare of conventional land area would result in 0.54 hectares increase of organic land, in order that output will remain unchanged. Alternatively, from equation 2, MP_{OL} constitutes 54% of MP_{CL}. This is consequential, given the low MP_{OL}. The *MRTS* of 0.54 also conveys an idea of fair gradient of the isoquant at mean level of organic and conventional land areas. The finding suggests that organic land is replacing conventional land at quite an appreciable rate. Since the *MRTS* can be increased by increasing MP_{OL} relative to MP_{CL}, stakeholders in organic agriculture need to put in more at increasing productivity of organic land (agriculture).

The elasticity of substitution (σ_{OLCL}) (last line of Table 2), which is the curvature of the isoquant, is 0.36 and is lower than the *MRTS*. This is because equation 3 shows that the σ is the *MRTS*, weighted by the ratio of organic-to-conventional land area. Since this ratio is less than 1, the σ would certainly be less than the *MRTS*. Following the fact that a large elasticity of substitution connotes a flat isoquant (Chauhan, 2009; Jehle and Reny, 2011; Munoz-Garcia, 2017), the mean value of elasticity of substitution of 0.36 connotes a relatively vertical isoquant. This is to say that, a large change in the slope of the isoquant is required in order to produce a small change in the organic-conventional land ratio. By implication, organic land would replaces conventional at a slow pace.

Following the successful estimation of the Cobb-Douglas functional form for the panel data, we disaggregated the balanced panel of 740 observations into annual cross-sections of 74 countries for 2005 to 2014, and estimated Cobb-Douglas production function for each. It is evident from Table 3 that the OLS is preferred to SFA for all the 10 estimations.

Table 4 presents the results of trend analysis. Since the quadratic model has the most of the lowest accuracy measures, it was adjudged to be the best line of fit for the MP_{OL} for the period.

Equation 6 describes time path of the MP_{OL}.

$$Y_t = 0.0908 + 0.0086\,t - 0.00072\,t^2 \tag{6}$$

Unlike, organic, the marginal product of conventional land hikes in 2007 to 0.22 from 0.15 in 2006 (Figure 1). Although MP_{CL} also remained within a band (0.15 and 0.20), this was higher than that of the band of MP_{OL}. Within this band, MP_{CL} appear to be rising over the period 2008 to 2014. The fitted trend line, is an exponential curve (equation 7).

Table 3: Loglikelihood ratio tests

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Restricted	-49.413	-49.132	-57.740	-56.549	-52.534	-55.741	-56.915	-51.731	-58.745	-56.933
Unrestricted	-49.413	-49.132	-58.040	-56.549	-52.426	-55.601	-56.735	-51.731	-58.745	-56.933
LR	4.0E-06	1.2E-05	6.0E-01	2.0E-05	-2.2E-01	-2.8E-01	-3.6E-01	1.0E-05	8.0E-06	4.0E-06
df	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Decision	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept

Source: own composition

[5] These are not reported but available on request.

Table 4: Trend analysis of marginal products and substitution measures.

Accuracy measure	Linear	Quadratic	Exponential	S-curve
		MP_{OL}		
MAPE	57.427	56.850	55.784*	-
MAD	0.023	0.022*	0.030	-
MSD	0.001	0.001*	0.001	-
		MP_{CL}		
MAPE	8.225	8.104	7.927*	9.387
MAD	0.015	0.015	0.015*	0.017
MSD	0.001	0.001*	0.001	0.001
		MRTS		
MAPE	79.122	79.311	72.733*	-
MAD	0.153	0.153*	0.205	-
MSD	0.048	0.048*	0.058	-
		Elasticity of substitution		
MAPE	81.249	81.052	74.488*	-
MAD	0.102	0.102*	0.138	-
MSD	0.021	0.021*	0.026	-

MAPE-mean absolute percentage error. MAD-Mean absolute deviation. MSD-Mean squared deviation. *-lowest value among peers.
Source: own composition

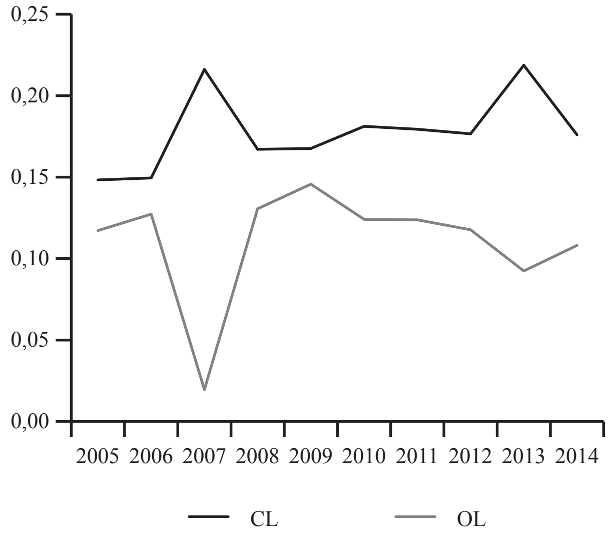

Figure 1: Time path of marginal products and trend lines.
Source: own composition

$$Y_t = 0.1573 \cdot (1.0213^t) \tag{7}$$

The substitution measures (Figure 2); MRTS and elasticity of substitution, have moved together, rising from 2005 to 2006, declined sharply in 2007, rising in 2009, then a general decline afterwards. The joint movement is not surprising as it was noted earlier that the elasticity of substitution is the organic-conventional land ratio weighting of the *MRTS*. In the case of the elasticity of substitution, over time, the curvature of the isoquant is becoming smaller and smaller, indeed, the isoquant is becoming more vertical by the year. The similarity of the substitution measures result in a quadratic trend curve for both of them.

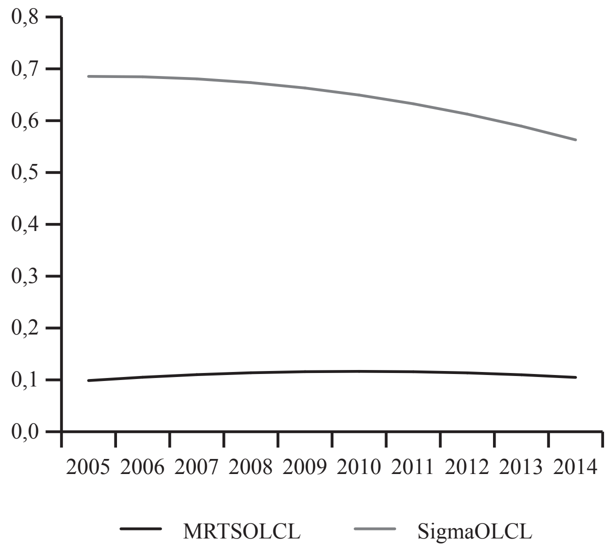

Figure 2: Substitution measures.
Source: own composition

Concluding Remarks

The raging debate on organic-conventional agriculture, and with regard to productivity in particular, is far from conclusive. This article explored the productivity comparison further, through the estimation of a common production technology for 74 countries around the world, for the period 2005 to 2014. Conventional agriculture was found to be more productive than organic agriculture. Thus, whether from different production technologies or the same, organic land is found to be less productive than conventional land.

Whilst productivity of conventional agriculture is exponentially rising, that of organic is declining, although with a quadratic growth path. For every hectare of conventional agricultural land given up, only 0.540 hectare of organic land area is substituted. Based on elasticity of substitution of 0.358, the isoquant is relatively straight (vertical), therefore, much more conventional land need to be substituted for, with organic land area. The above results require increased research in organic agriculture that would generate knowledge to increase output of organic produce. Further, new and improved fertilising and pest control productivity enhancing research is essential, as increase in these, would have a significant impact on land productivity. This would contribute to increased efficiency. Increased land productivity means more output per unit of land cultivated, therefore more profit as there will be less currency cost per unit of output, particularly as certification fees are partly based on land area certified. The level of marginal rate of substitution and elasticity of substitution demands re-invigoration of the promotion of organic technology by stakeholders in the organic movement.

An interesting question that could not be addressed is, what is the optimal input ratio (organic-conventional land) that will enable the production technology attain at least constant returns-to-scale? Had the translog function been appropriate, this could have been established by the Ray (1998) approach. Further research can explore this.

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Appendix: List of countries

Algeria	France	Norway
Argentina	Germany	Panama
Armenia	Ghana	Poland
Austria	Greece	Portugal
Azerbaijan	Guatemala	Republic of Korea
Belgium	Guyana	Romania
Belize	Honduras	Rwanda
Bhutan	Hungary	Slovenia
Bolivia (Plurinational State of)	Iceland	Spain
Brazil	India	Sri Lanka
Burkina Faso	Ireland	Sweden
Burundi	Italy	Switzerland
Canada	Jordan	Thailand
Chile	Kyrgyzstan	The former Yugoslav Republic of Macedonia
China, mainland	Latvia	Timor-Leste
Colombia	Lithuania	Togo
Costa Rica	Madagascar	Turkey
Croatia	Malawi	Ukraine
Cyprus	Malaysia	United Kingdom
Czechia	Mali	Uruguay
Denmark	Mexico	
Dominican Republic	Mozambique	
Egypt	Nepal	
El Salvador	Netherlands	
Estonia	New Zealand	
Fiji	Nicaragua	
Finland	Niger	

Source: own composition