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Competitiveness and economic development –

macroeconomic aspects and challenges

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Contents

Introduction

The present volume, “Competitiveness and economic development – macroeconomic aspects and challenges”, contains a collection of six papers addressing selected issues in economics and finance. The monograph concerns the current problems and challenges in the field of international economic relations, economics, and finance. The authors identify and assess the complexities of competitiveness and economic development, taking into account both theoretical and practical aspects.

The first article touches on the financial aspect concerning pension efficiency in European countries after the 2008 financial crisis. Its authors, Marcin Brycz and Daniel Sonnet, pay attention to lessons learned for the next crisis and show that the crisis worsened the financial stability and modernization level of European pension systems.

In the second article, the author’s attention is focused on inflation. Raphael Reinwald writes about sovereign debt and inflation and asks if we tamed the ghost. He describes and examines debt in times of crisis and poses a topical question: are we dealing with induced rising inflation? He then examines the fundamental causes of inflation and their relation to public debt in developed economies.

In the next article, Samundra Bhusal draws attention to an important problem concerning the development of decentralized finance and its impact on global financing structures and analyzes the changes that have occurred since the introduction of Bitcoin in 2009 and the changes due to blockchain technology. The author also argues that blockchain is the primary driver of technological innovation and is becoming essential for the further development of the banking system.

The fourth article deals with the regional competitiveness of selected Sub-Saharan African economies. Ebenezer Amoako assessed the competitiveness of 44 selected economies in Sub-Saharan Africa on the basis of panel data from 1980–2019. The author presents an application of stochastic production frontier analysis.

The subject matter of the fifth article, written by Magdalena Gielo-Politewicz, is the strategy for the sustainable development of aquaculture in the European Union. The author pays special attention to the contribution of aquaculture in the European Union to the development and life of the local communities.

In the last article, Rahman Fakhani develops an evaluation scheme to determine a country index incorporating sustainability factors to compare selected countries from a macroeconomic perspective, and on this basis makes a more detailed analysis in order to identify appropriate measures to address the threats of climate change.

The diversity of macroeconomic issues of competitiveness and development show a holistic approach to composing this volume, which offers a novel view on those aspects of the world economy.

We hope you find this publication interesting and useful.

We wish you pleasant reading!

Editors

Sopot, 2021

COMPETITIVENESS
AND ECONOMIC DEVELOPMENT
– MACROECONOMIC
ASPECTS AND CHALLENGES

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Pension efficiency in European Union countries after the 2008 financial crisis – lessons for the next turmoil

The pension system is one of the most challenging parts of a country's social security system, as demographic change hits many macroeconomic stability concerns – public debt in particular. The 2008 financial crisis revealed fiscal imbalances in many European countries, which made their governments reform the pension systems. Demographic change is the primary determinant of pension system performance, but not the only one. Its efficiency is measured in three dimensions: sustainability (impact on labor market, pension expenditures), adequacy (reduction of old-age income poverty), and modernization (gender inequality). Since the 2008 crisis, many European countries have lost macroeconomic soundness (Greece is a notable example). This, in turn, interferes with pension system efficiency. This paper aims to investigate the link between the 2008 crisis and pension system efficiency in the three mentioned dimensions. We hypothesize that the former has had a negative impact on all three of them. In order to evaluate our hypothesis, we use data on pension system efficiency provided by Chybalski and Gumola as our dependent variables and crisis factors provided by Bernanke as our independent variables. To ensure that the set of macroeconomic variables is consistent with Bernanke's, we apply principal component analysis to real economic data and compare it with Bernanke's using multi-information. We found that the 2008 crisis reduced the sustainability and modernization level of European pension systems but, surprisingly, enhanced their adequacy.

Keywords: pension system efficiency, financial crisis, principal component analysis, multi-information

JEL classification: G19, H55

Introduction

Pension system efficiency, or simply pension efficiency, is a relatively new branch of economic studies concerned with the longevity, consumption smoothing, poverty reduction, and equality of pension systems. The idea originated in the so-called Open Method of Coordination, a policy introduced by the European Commission at the Lisbon Summit in 2000. To challenge the issues of an aging society, three goals of the pension system were defined: adequacy, financial sustainability, and modernization. The first one refers to poverty and social exclusion among the elderly; the second – to financial soundness of the pension system and public finances (in other words, employment in the pre-retirement age group); the third – to equality among retirement subpopulations, in particular in terms of gender [EC, 2001; Chybalski, Gumola, 2018].

The three goals of pension system efficiency can be measured by numerous indicators [Chybalski, 2012; 2016]. However, as some of them are highly correlated, there is a need for careful selection. Those indicators are commonly used to annually investigate similarities within a group of countries, e.g. EU or OECD; on the whole, these groups were not stable in the years 2007–2015 [Chybalski, 2016; Chybalski, Gumola, 2018], although some countries created fairer clusters than others.

The 2005–2015 period was characterized by turbulence which influenced many pension system efficiency variables and forced governments to reform social security systems due to longevity risk and a rise in government deficit followed by a public debt spike. The 2008 financial crisis was the breaking point in the European economy; the first drop in the banking sector and financial markets was followed by persistent public debt rise and a sharp decrease in GDP growth.

We hypothesize that the 2008 crisis affected pension system efficiency in terms of adequacy, financial stability, and modernization. To verify this, we test for correlation between real economy data and financial variables provided by Bernanke [2018] on the one side and Chybalski and Gomola's [2018] pension system efficiency indicators on the other. We use multi-information in order to reveal the dependencies between both datasets, which we then exmine by panel regression.

1. Pension system efficiency indicators

A holistic pension approach – as postulated by OMC – is a powerful tool for analysing a country's pension system efficiency. Of interest to us are three indicators elaborated by Chybalski and Gumola [2018]:

adequacy: $$A_{j,t} = \frac{1}{4}\left(ARP_{j,t} + MRI_{j,t} + ARR_{j,t} + SBO/20_{j,t}\right) \quad [1]$$

sustainability: $$S_{j,t} = \frac{1}{3}\left(PE_{j,t} + EMP(55-64)_{j,t} + DWL_{j,t}\right) \quad [2]$$

modernization: $$M_{j,t} = \frac{1}{3}\left(dARP_{j,t} + dMRI_{j,t} + dARR_{j,t}\right) \quad [3]$$

where:
j – country,
t – time.

All of the measures are simply averages of aspect indices. The adequacy indicator ($A_{j,t}$) describes the overall condition of the pension efficiency of a given country in a given year. It consists of at-risk-of-poverty ratio among pensioners (ARP), median relative income ratio for people aged 65+ (MRI), aggregate replacement ratio (ARR), and inequality of income distribution for people aged 65+ (S80/20). It shows how the pension system fulfills its role in providing a safe and financially secure living in advanced age. It does not indicate the cost for the rest of society or the link to a previous working career. Sustainability ($S_{j,t}$) is an average of total pension expenditure to GDP ($PE_{j,t}$), the employment rate for people aged 55–64 (EMP55–64), and duration of working life (DWL). Sustainable pension systems ensure reasonable pension expenditure to GDP ratio, prevent earlier retirement, and increase overall working life duration. Modernization ($M_{j,t}$) is the gender equality of adequacy components. The lower the gender differences, the higher the level of modernization. The optimal pension system should provide sufficient funds for pensioners without bias and not burden public finances nor give incentives to leave the labor market.

2. Crisis theory

A wide range of crisis theories sprang up after the 1930s crisis, some of which are still being elaborated or have been rediscovered after 2008. A reasonable crisis theory should link financial distress to the real economy. Keeping in mind our hypothesis, a link between financial turmoil and the real economy and between the real economy and variables reflecting pension system efficiency should be indicated.

Signs of the coming crisis were visible in mid-2007 when two Bear Stearn's funds filed for bankruptcy and BNP Paribas halted calculation and withdrawals of its investment funds. A year later, Lehman Brothers defaulted, which sparked the crisis across the whole financial industry [Kacperczyk, Schnabl, 2010]. In the fourth quarter of 2008, most European countries experienced severe negative GDP growth. In December 2008, the Federal Reserve cut interests rates to virtually 0%. As conventional monetary policy ammunition ran out, quantitative easing was introduced by chairman Ben Bernanke [Blinder, 2010]. The policy helped financial markets recover in the US, but problems in the EU were still to come.

Filoso et al. [2017] present the financial crisis in Europe from two perspectives: macroeconomic imbalances and institutional failures. The former concerns economic fundamentals diversity in the EU countries, i.e., labor unit costs pushed by unions. Prior to the debt crisis, financial markets did not distinguish countries, so debt yields were similar. The latter concerns the failure of various institutions to step in and counter the crisis (this perspective being more appropriately applied to the Greek, Spanish, and Italian crises).

Excessive sovereign debt in EU countries made their governments' reform the pension system as the public debt burden increased. The pension system, in many cases, produces excess debt and retains massive savings. On the other hand, the latter may be used to cover extra expenses in turbulent years. A notable example are the so-called PIIGS countries, where the reforms aimed to strengthen public finances now and in the future. In Portugal, pension contribution for an elderly employee was reduced, tax allowance for pension contribution solidarity tax was reduced, solidarity tax was raised, and retirement age was tied to life expectancy. In Ireland, just after the crisis began, private pension funds were taxed, and thus some pension savings were transferred to the government budget directly, the demographic reserve was used to raise capital for failing banks, raise pension age, and provide an allowance for the poorest pensioners. In Italy, employer contribution and pension age were raised, and pension system finance parameters were tied to life expectancy. In Greece, privileged working groups were also included in the universal pension system. In Spain, likewise, pension age was raised and pension system finance parameters were tied to life expectancy, and households were allowed to withdraw some of their pension savings [Symeonidis, 2016; EC, 2018; OECD, 2012; 2014].

3. Cost of credit intermediation

The cost of credit intermediation theory, stemming from Milton Friedman's breakdown of the monetary effects of the great depression [Friedman, Schwartz, 1963], was later popularized by Bernanke in numerous publications. Money contraction leads to a decrease in production. Bernanke [1983] gave additional variables to money aggregates and output regression, such as the first difference of deposits in failing banks and the first difference of liabilities of the failing business. Both regressors indicate non-monetary effects of the financial crisis; their significance proves the existence of additional effects – the condition of banks and business matters for output, the processing of information by banks is therefore destabilized, so the cost of credit intermediation rises. Finally, Bernanke [1990] describes the link between interest rates and spreads and the real economy, stating that different spreads predict different real economic variables (e.g. inflation can be predicted based on the spread between highest-quality commercial paper of 6-month maturity and treasury bills of 6-month maturity, while employment based on the spread between 1- and 10-year government bonds).

Bernanke [2018] discussed the link between the stages of the 2008 crisis and financial data representation. The financial data – particularly interest, spreads, prices, and indices – can be grouped into four areas and their robustness checked using factor analysis: 1) housing and mortgages, 2) non-mortgage credit, 3) short-term funding, and 4) bank solvency. Over the years 2006–2012 in the US, the housing factor dominated (until BNP rescue); then the funding factor, peaking in the time of Lehman Brothers collapse; next, until the stress tests, the credit factor; and lastly, when the European sovereign debt crisis began, the solvency factor. The crisis factors are linked to segments of the real economy, measured by correlation of forecasted variables and simulated values.

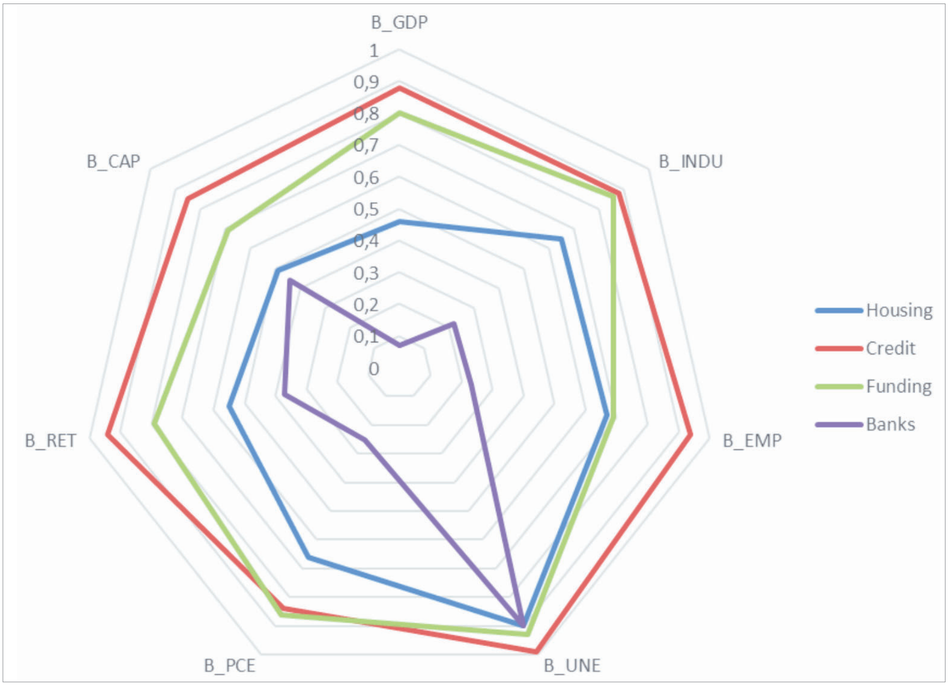

Figure 1. Correlation of actual and forecasted variables with simulated values

Notes: Macroeconomic indicators shown in the radar graph are: Gross Domestic Product Growth (GDP), Industrial production (INDU), Employment (EMP), Unemployment (UNE), Consumption Price Index (PCI), Retail Sales (RET), Capacity Utilization (CAP).

Source: [Bernanke, 2018].

The housing and funding factors affect all of the macroeconomic variables similarly. On the other hand, the solvency factor is highly correlated with unemployment, while the housing factor with unemployment, employment, and, to a lesser extent, inflation.

4. Methodology

In this study, we hypothesize that particular financial crisis factors affect particular pension system efficiency indicators (e.g. the solvency factor affects sustainability). To test our hypothesis, we use the database provided by Chybalski and Gumola [2018], taking adequacy (A), sustainability (S), and modernization (M) indicators for 27 countries in the years 2005, 2010, and 2015 as dependent variables.

Our independent variables are crisis factors obtained from real economy data[1]. First, we calculate the values of the principal components based on macroeconomic data and country dummies, using only the first 7 out of 34 components[2]. Then, we construct a mutual-information matrix to determine which principal components provide relatively much information about other principal components and crisis factors. The factor analysis performed by Bernanke resolved four financial crisis factors from many financial time series. The factors are used to obtain macro variables in dynamic simulation. Bernanke's correlations are interpreted as to how close the factors are to particular macro variables. We compute principal components based on a dataset consisting of the macro variables used by Bernanke, but for EU-27. Next, we resolve the similarity of our components and Bernanke's factors using a multi-information matrix, thus identifying which Principle Component represents Bernanke's factor.

We built our analysis by calculating the determination coefficient of all variables to obtain a common interpretation. In the next step, the multi-information matrix is calculated.

The housing factor shares the highest portion of information with Principal Component 2 (1.974 bit). The funding factor shares information with PC4 (1.678 bit). Crisis factors are correlated with each other in different ways than in Bernanke's [2018] example. In the EU data, the housing factor shares much information with the funding factor (1.414 bit), the solvency factor, and other crisis factors (1.193 bit).

1 Real GDP growth, industrial production, total employment, unemployment (percentage of the active population), price index (final consumption), retail trade, employment in industry. Data come from the Eurostat database.

2 The first seven components are correlated with seven macroeconomic variables and country dummy, the remaining components with country dummy only.

Table 1. Multi-information matrix for principal components and crisis factors

	Housing	Credit	Funding	Solvency
PC1	0.981	0.693	0.827	0.981
PC2	1.386	0.693	0.981	0.827
PC3	1.163	0.539	0.827	0.981
PC4	0.981	0.539	1.163	0.981
PC5	0.827	0.693	0.981	0.827
PC6	1.163	0.693	0.827	0.981
PC7	0.827	0.539	0.981	0.827
Housing	1.386	0.693	0.981	0.827
Credit	0.693	1.099	0.539	0.875
Funding	0.981	0.539	1.386	0.827
Solvency	0.827	0.875	0.827	1.386

Notes: The outcome in nats (to convert into bit, multiply by $\log_2 e$ = ~1.4427). Shrinkage estimation was used to improve reliability [Meyer, 2008]. The whole sample is split into four nodes in the process of discretization.

Source: Own elaboration.

In the next stage, we indicate which crisis factor affects a particular pension system efficiency (adequacy, sustainability, and modernization). For this, we employ a panel regression with fixed effects.

Principal components (PC2 and PC3) explain pension system efficiency of Adequacy, Sustainability, and Modernization well; in all cases, parameters are significant with high t-ratio and models to characterize reasonable within R-squared for Adequacy and Sustainability.

The parameter's sign for adequacy is positive, which implies both crisis factors (PC2 and PC4 for European economies; reflecting the housing and funding factors) rise that type of pension efficiency in the European countries. Sustainability and Modernization of pension systems are negatively tied to the housing and funding factors.

The difference in signs between adequacy and the rest of the pension system indicators must be explained. The EC [2012] stated that many EU countries decided to put pressure on sustainability, trading off adequacy and security, the indicated deterioration adequacy component, when crisis eased (that is when sustainability improvement took effect). The issue needs further explanation after controlling for EU countries' reforms. Moreover, Adequacy and Sustainability are negatively correlated with components in EU countries.

Table 2. Panel regression of adequacy, sustainability, and modernization for pension system efficiency, 2005–2015

Adequacy				
	coefficient	std. error	t-ratio	p-value
const	0.5578	0.0000	7.94E+15	0.0000
PC2	0.0925	0.0166	5.5780	0.0000
PC4	0.0949	0.0233	4.0780	0.0004
LSDV	R-squared	0.8691		
Within	R-squared	0.4351		
DW		1.7399		
Joint test on named regressors:				
F(2, 26) = 15.6308, P(F(2, 26) 15.6308) = 3.48e-005				
Sustainability				
	coefficient	Std. error	t-ratio	p-value
const	0.4089	0.0000	1.09E+16	0.0000
PC2	–0.0612	0.0076	–8.025	0.0000
PC4	–0.0463	0.0086	–5.382	0.0000
LSDV	R-squared	0.9797		
Within	R-squared	0.6538		
DW		1.8918		
Joint test on named regressors:				
F(2, 26) = 32.6912, P(F(2, 26) 32.6912) = 8.00e-012				
Modernization				
	coefficient	std. error	t-ratio	p-value
const	0.6615	0.0000	1.03E+16	0.0000
PC2	–0.0641	0.0230	–2.791	0.0097
PC4	–0.1031	0.0320	–3.218	0.0034
LSDV	R-squared	0.7432		
Within	R-squared	0.2071		
DW		1.7318		
Joint test on named regressors:				
F(2, 26) = 5.0835, P(F(2, 26) 5.0835) = 0.0082				

Notes: Robust standard errors: [Arellano, 2003].

Source: Own elaboration.

The Modernization pension system indicator is negatively tied to crisis factors; the more severe crisis is that the difference between men and women narrows. It can also be somewhat explained by reforms, which in most cases were to lower the pension amount of those with higher pensions (male pensioners).

Conclusions

This study questions the link between the financial crisis and pension system efficiency regarding the three main aspects: adequacy, sustainability, and modernization. In Europe, the most visible are the housing, funding, and solvency factors, with the last one being correlated with the two others, which therefore have significant effect on the pension system.

Further study can concentrate on a deeper explanation of why financial crisis affects adequacy and sustainability in the opposite direction. On the one hand, adequacy and sustainability are ambitious goals, but logic suggests that financial crisis should affect these variables negatively. Further research of the subject could focus on the role of pension system efficiency reform after the crisis.

The housing, funding, and solvency factors affect adequacy, and sustainability can serve as a prognosis for the next crisis. In 2020, the pandemic caused a new kind of economic crisis. Although different from the 2008 financial crisis, some elements are common. It can be described as a triple threat: a demand shock, a supply shock, and a financial shock [Triggs, Kharas, 2020]. The first and the second component came from the lockdown policy which aimed to decrease the number of infected people and prevent the public health system from collapsing. Businesses that depend on large gatherings of people, such as tourism, hospitality, or open-air entertainment, are affected the most. Supply shock was a result of logistic chain problems. The third one was caused by a decreased ability to pay debts by closed businesses. Central banks worldwide had to step in and increase quantitative easing policies introduced after the 2008 crisis. Since lowering interest rates and raising the quantity of money was not enough to counter the economic turmoil, another policy was introduced – the so-called “helicopter drop” – to direct new money to closed businesses to prevent a spike in unemployment. All in all, a massive amount of new money entered the market.

This last kind of shock is similar to the 2008 crisis. On the other hand, its magnitude and volatility are different, as crisis performance in 2008 and 2020 is not the same. In previous crises, the shock occurred once, when Lehman Brothers collapsed, and was propagated through the economy. At present, the magnitude of the crisis is alternating with high volatility, as it depends on the number of infected people. The number of infected people varies as described in the SIR model. Lockdown policy and easing alternately with excess money generates high consumption, investment, and housing market volatility. According to our research of the pandemic crisis, as more money circulates in the market, interest is lower, high bank soundness and new investment in the housing market and higher fatality among pensioners should enhance the sustainability of the pension system significantly. As sustainability and adequacy run oppositely, one can assume that adequacy should decrease (mainly due to higher inflation and unfavorable relative prices).

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Raphael Reinwald
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Sovereign debt and inflation – did we tame the ghost? Debt in times of crisis and its cointegration with inflation

With sovereign debt levels at record highs in western democracies – a problem exacerbated by the pandemic – the world faces the question of induced rising inflation on the horizon. This article presents a comprehensive review of literature about the most severe world economic crisis in the 20th and 21st centuries – the great depression and the great recession – as well as the debt levels preceding and following them. Furthermore, it investigates root causes of inflation and its connection with sovereign debt in developed economies. Finally, applying a vector error correction model, it shows the existence of a cointegrating relationship between debt and inflation in the US (and a positive sign of the former on the latter), confirming a moderate macroeconomic correlation between the two. Hence, despite the long period of high debt and low inflation fueling a recent-experience bias, the answer to question posed in the title is negative. The conclusion is that without substantial debt reduction over time, the (Western) world economies will again see a rising inflation regime. Informed and independent central banks are therefore ever-more important.

Keywords: great depression, great recession, debt–inflation nexus, inflation targeting, vector error correction model

JEL classification: C5, E5, E5, H5, N1

Introduction – current sovereign debt situation

With sovereign debt[1] rising to historically high levels in absolute as well as relative debt to GDP ratio terms [IMF, 2020], and monetary and fiscal stimuli (overall budget deficits) simultaneously at record levels due to the global pandemic, hinting at even bigger extremes in the future, the question of the consequences of these debt levels is being asked more and more frequently.

[1] This article mainly considers gross national debt (if not indicated otherwise) and does not consider and net (in any form) the claims (and debt security holdings) against other countries. It also does not add corporate or household debt which also generally rised in recent decades (on average among countries).

A new study [DB, 2020] showed that the world's sovereign debt amounts to USD 248 trillion, whereas before the 2008 global financial crisis – labeled as the great recession or great financial crisis and followed by bank bail-outs, massive government stimuli packages, "unconventional" QE measures by central banks, and a European sovereign debt crisis amid Greece's double deficit and (short) default-on-debt a few years later[2] – it was only USD 172 trillion.

In macro-economic research, various kinds of relationships between debt (ratios) and other standard macro-variables like GDP growth, output gap, money aggregates (like M3), short/long term interest rates and corresponding interest tenures/curves, asset prices, consumption, CPI/inflation or expectations thereof have been investigated in either direction. Models in use are equilibrium-based ones like DSGE models (e.g. with Kalman-filter-type estimators), regressive, time-series ones like vector auto-regressive VARIMA/VAR, or vector error correction ones with long-and short term factors (VECM). The null hypothesis of our article (H0) is that there is no positive correlation between debt and inflation (i.e. "we tamed the ghost"). A VECM model will be used here to estimate the effects of debt on inflation and to show that there is a positive correlation between debt and inflation (i.e. higher debt leads to higher inflation). However, first, other causes and implications of debt are presented. Then, origins of inflation are briefly discussed, and the model evaluated.

Especially after the 2008 crisis, the impact of debt on GDP growth and even debt-bearing ability (default-expectations) was well researched. The reason for the debt – apart from long-running deficits in countries like Italy or Greece, due to structural economic problems – was the financial crisis and its policy response by governments and central banks.

This policy response was primarily due to the lessons learned from the most severe recession in the 20th century, the great depression.

1. Sovereign debt

1.1. The great depression and crisis, their causes and (economic) policy responses

The causes of the great depression have been extensively discussed and are in some specific areas a matter of ongoing debate [Humphrey, Timberlake, 2019], but a widely accepted consensus – albeit assigning different weights to the underlying factors – was achieved after the publication on certain seminal works [Friedman,

[2] Greece defaulted on a USD 1.7 billion IMF payment on 29 June 2015.

Schwartz, 1963; Temin, 1976; Bernanke, 1983; Field, 1984; Romer, 1993; Eichengreen, 1992].

In the cascade of events, a stock market crash (1929), high debt levels (shares on margin/debt), and the following banking and financial crisis spurred a recession in the real economy and spilled over to most other countries (especially in Europe). In the US alone, between 1929 and 1933, industrial production fell 47%, the GDP declined by more than 30%, and unemployment reached a peak of more than 20% [Duignan, 2020].

The Keynesian perspective initially attributed the depression to a fall in demand and lower aggregate expenditures in the economy that contributed to a massive decline in income and employment well below the average. Instead of fiscal expansion, the government tried to balance the budget. While this definitely contributed to the depression [Keynes, 2007; Hayes, 2006], Friedman and Schwartz [2008, p. 247; 1963] showed that the main reason for (the severity of) the great depression was the failure of the Federal Reserve to swiftly lower interest rates, extend the monetary base and supply, and inject liquidity into the banking and financial system as monetary contraction was at 35% and prices dropped by an average of 33% [Cecchetti, 1992, pp. 141–156; Mendoza, Smith, 2006, pp. 82–114]. Nowadays, there is mainstream support for the debt deflation theory developed by Fisher [1933, pp. 337–357] and Minsky, and later extended by Bernanke [1983, pp. 257–276], and the expectations hypothesis [Romer, 1993, pp. 19–39] that builds further on the monetarist research. These are accompanied by several (less impactful) non-monetary explanations like communication (guidance) failures, trade barriers (e.g. Smoot–Hawley tariff act), and rising protectionism [Madsen, 2001, pp. 848–868; Timothy, Prescott, 2007; Eichengreen, Irwin, 2010, pp. 871–897]. An additional factor to be considered as contributing to the situation was the then-existing gold standard [Bernanke, James, 1991, pp. 33–68; Eichengreen, 1992], forcing central banks to have less flexibility and putting inherent deflationary pressure on the economy.

The reasons and developments are summarized by Eichengreen and Parker, in a well-written manner by Caldwell and O'Driscoll, but mainly by Bernanke, who also proves that incomplete adjustment of nominal wages was a further important factor leading to monetary non-neutrality and warning of "credit crunches" [Eichengreen, 2014; Parker, 2003; Caldwell, O'Driscoll, 2007, pp. 70–74; Bernanke, 2004; 1995].

Having attributed the causes of the 1929 financial crisis mainly to "mismanagement" (not enough money supply, too high interest rates, not enough liquidity/LTRO-tenders) of the central bank, Bernanke along with his G7 colleagues made sure central banks lowered interest rates (Fed fund rate, ECB main refinancing rate) to around 0% (zero lower-bound) and announced a plan to maintain it for a longer timeframe (forward guidance), lowered intermediate- and long-term interest rates with large-scale asset purchases (quantitative easing), provided liquidity and emergency loans to banks and acted as lender of last resort. This was accompanied by a common pledge from G20 governments to maintain free trade and act against protectionism, create central bank swap lines, e.g. for the dollar, use joint (prudential) regulatory oversight[3], raise capital buffers (P2R/Gs, CBRs[4] including systemic buffers), undertake deleveraging efforts, and introduce deficit- and debt-controlling mechanisms (debt limits by law or even constitutions) for the long run. Furthermore, prudential financial oversight [Bernanke, 2011], including the observation of asset prices [Bean, 2003] and non-gaussian correlations (e.g. within collateralized debt obligations, credit default swaps, and its pricing models) and distributions with heavy tails ("black swan events") were strengthened as well as interbank lending regulated in an improved way[5].

These additional financial stability regulations were needed, since, i.a., intentional mispricing of (subprime) housing loans and excessive (overdebt based) expansion in the housing sector triggered the great recession. It was further fueled by mispriced derivatives and MBAs[6] relying on non-realistic Gaussian models and correlations and wrong non-default considerations, as well as and (non-)premia considerations with regard to counterparties and inter-banks in the short run – not to mention wrong-way risks. Moreover, insufficient capital buffers and too much financial leverage, combined with moral hazards (like "too big to fail" – banks, disincentivized rating agencies relying on the so-called Greenspan put, i.e., that the central bank is buying enough assets and will ensure liquidity if a recession occurs) accelerated the great recession [FCIC, 2011; Bernanke, 2010; Islam, Verick, 2019; 2011; Coghlan et al., 2018; Hayford, Malliaris, 2011, pp. 73–90; Fligstein, Goldstein, 2014; Solimano, 2020].

A coordinated response followed in terms of expansionary monetary and fiscal policy. Enormous stimuli packages like the ARRA in the US, tax cuts, and strengthening of automatic stoppers and fiscal stabilizers like subsidised short-time employment[7] within the economic areas and countries, as well as international G20 coordination including treasuries/finance ministers, heads of state and

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[3] Basel III, Financial Stability Board's Global Systemically Important Banks, Single Supervisory Mechanism, Single Resolution Mechanism with a credit counterparty (default) risk revision and Banking Recovery and Resolution Directive in the EU, as well as the Dodd–Frank Act and the Volcker rule in the US.

[4] Pillar 2 Requirements and Guidances, i.e. additional regulatory capital after pillar 1 (4% CET-1, 1.5 % AT-1, 2.5 % Tier-2 as RWA %) for internal measurements and controlling coming e.g. from ICAAP and CBR.fter taking credit counterparty risks into account, CVA and CCR models were introduce

[5] Ad. Regulation here was improved with the so called "small"- and "big-bang"-concept, leading further to new interbank offered rates (SOFR, SONIA, ESTER).

[6] Mortgaged-backed assets/securites, ABS-vehicles with mortagages as loans.

[7] Termed "Kurzarbeit", first introduced in Germany and Central European countries and then copied throughout the world.

central banks (including the BIS), were all efforts used to stabilize the respective economies.

Swift and coordinated measures probably prevented the world from a second depression were widely credited and viewed as generally successful [Bernanke, 2011; Eskander, 2017]. However, the result inevitably was record sovereign debt. Furthermore, there was fear of high inflation[8] after monetary expansion and leveraging (expansion) of central banks' balance sheets – which did not occur, as we will see later.

1.2. The consequence of the crisis – debt and ways to reduce it

There are three main ways of reducing debt (more precisely debt/GDP ratios) without cutting spending [Best et al., 2019; RBC GAM, 2020; Sunder-Plassmann, 2014]. The first and most sustainable one is a higher growth rate and hence GDP expansion by way of higher economic activity, employment and sales, and thus higher income tax. However, it is obviously a tool more readily available for emerging economies, which in developed (post-)industrial countries would have a more negligible effect. The second possibility is to use seigniorage and inflation (if the debt is mainly domestic) to "inflate away" (nominal) debt by allowing higher inflation rates, which are hard to scale back, while controlling for other factors, which are hard to control. Inflation reduces debt levels best when it is unanticipated and temporary. It is commonly combined with low-interest rates, capital controls, high reserve requirements, etc., and then called "financial repression". Yet in a globalized economy, an extreme form of financial repression is hard to maintain as capital flight is inevitable; furthermore, the quantitative findings suggest only moderate success [Fukunaga et al., 2019]. The third way is default or restructuring (haircuts, discounts, prolongation of bonds, etc.). This implicates mistrust on the part (future) investors, massive distortion and negative economic impact (shocks) with high loss of welfare in the short run (in the long run it is better than the second option and sometimes unavoidable to prevent an even more severe future default – otherwise the costs are too high) [Best et al., 2019]. Across 45 crisis episodes, debt relief averaged 21% of GDP for advanced economies (1932–1939) and 16% of GDP for emerging markets (1979–2010) [Reinhardt, Trebesch, 2014].

Often various combinations were used by governments in the past. To summarize, the best option is (longer-term) GDP growth, yet more demanding to achieve for developed economies, and structural reforms (avoiding new deficits) need time to unfold. Default or restructuring can only be advised in rare, unbearable cases to prevent long-suffering and eventually more cost-intensive defaults

[8] Especially in countries very hard hit by hyperinflation in the past, like Germany in the 1930s, but partly also in the US in the late 1970s (until the Fed regained control in the early 1980s under Volcker).

[Adam, Grill, 2011; Reinhardt, Trebesch, 2014]. The break-down of the creditors and judicial clauses and renegotiation possibilities (domestic debt or not, institutions or corporate holders – PSI/private sector involvement, redemption or default clauses, etc. [Yue, 2005, pp. 176–187]) as well as future prospects of economic recovery and debt bearing ability have to be taken into consideration. Financial repression and higher (yet moderate [Bai et al., 2001, pp. 245–251]) inflation can only to some extent support reducing debt burdens; optimal financial repression (strategy) [Bencivenga, Smith, 1992, pp. 767–790] still depends on the economic circumstances and creditors' expectations and can only be optimal without commitment, in (sudden) times of crisis or during wartimes [Chari, Kehoe, 2016; Dovis et al., 2020].

Hence it becomes evident that avoiding high debt in the first place is crucial.

However, to reach a substantial reduction in fiscal deficits, the question remains when (and to what extent) one should reduce the deficit (vide Greek sovereign debt crisis).

The discussion amid this crisis evolved into an "austerity vs. expansionary fiscal battle" with Krugman and Summers on one side and Reinhart, Rogoff on the other [Mencinger et al., 2014, pp. 403–414]. However, there was agreement in the academic literature that Greece missed the opportunity to reduce its primary deficits for many years and should have balanced its budget. Pensions and social transfers increased by 7% of GDP from the time of the Euro adoption to 2009, with public wages similarly impacted. This drove the overall fiscal deficit from 4 to 15% of GDP in 2009 [Thomsen, 2019]. In the crisis itself, the Greek government first followed a deficit-reduction approach (EU-Troika and IMF requirements for further loans) for quite some time but later declined a further conditional support package and turned to a more expansive policy. The IMF changed its policy stance and promoted a more expansive fiscal policy when showing a higher (corrected) fiscal multiplier (and subsequently more contractionary damage) than expected before [Batini et al., 2014; IMF, 2013]. Nevertheless, it also promoted a longer-term debt-reducing strategy and showed willingness to communicate.

Therefore the (optimal) fiscal reduction also remains a matter of timing and determining at which point (and severity) of the economic cycle as well as in which individual debt situation (absolute debt, relation of debt/GDP, debt structure and tenure, creditor structure) a country is (when applying fiscal measures) [cf. Alesina et al., 2019, pp. 5–6]. However, fiscal and debt reduction in some forms (better reduce spending than rise taxes [Alesina et al., 2019]) and areas (e.g. pension cuts) is possible without impacting growth-friendly expansions in others.

Hence in moderate or growing (pro-cyclical) GDP times, debt reduction is favorable and high debt can have negative effects on growth and prosperity [Reinhardt, Rogoff, 2010, pp. 573–578].

Famous proponents of "sustainable" debt levels (< 90%, longer-term and for emerging countries 60% of GDP as in the European Maastricht treaty [Reinhardt, Rogoff, 2010, pp. 573–578]) and structural deficit reduction measures are – among general mainstream economists – Carmen Reinhart and Kenneth Rogoff [Reinhardt, Rogoff, 2009]. Even after some corrections had to be made to their seminal original study (due to a calculation mistake discovered by a student a.o.), other economists and Rogoff's second longer-reaching study confirmed the original findings.

As I investigate the empirical relationship between debt and inflation, I briefly discuss some origins and causes of the dependent variable inflation.

2. The roots and causes of inflation

The common causes of inflation are less "slack" in the product or labor markets, upward pressure on prices, and rising wages. The wage-price spiral is better understood from the demand side. However, prices are often empirically "sticky" (neo-Keynesian approach), and relative prices must be considered. Furthermore, Friedman [1977, pp. 451–472] showed that there is no long-run trade-off between unemployment and inflation (cf. famous flat Philipps curve result), and inflation expectations (and "anchoring") are an important supply-side factor (among other factors, like production costs, which in most cases are related to higher labor costs or demand for natural resources) [Schwarzer, 2018, pp. 195–210; Cochrane, 2020]. Hence monetary policy alone (incl. forward guidance and controlling expectations) can, in a lagged fashion [Batini, Nelson, 2001], control inflation. However, recent empirical findings on long-term monetary expansion without inflation and fiscal arguments hint that Friedman's ideas are not comprehensive enough (financial sector specifics and an equilibrium real interest rate have to be taken into account); at the same time, one can now reject neo-Fisherian explanations with empirical confidence [Batini, Nelson, 2001; Demary, Hüther, 2015]. Other factors, like globalization with its pressure on wages and relative money supply [Fed, 2013], "saving gluts" [Rachel, Smith, 2015] from demographical trends [Summers, 2014; Weizsäcker, 2014, pp. 42–61], the flight of money into assets like stocks and houses ("asset price inflation"), and oil prices, play an important role as well. Governments must therefore contribute through, e.g., sufficient investment in infrastructure, demographic incentives ("family policy") and, most importantly, productivity-enhancing measures. With more substantial recovery, inflation seemed to return, and the Fed could slowly rise rates; up until 2019 the problem was less dramatic, with a slightly lower "new normal" [Brainard, 2015, pp. 414–422; Feldstein, 2018, pp. 415–422; Powell, 2019; DW, 2020].

The rising inflation in the western hemisphere at the beginning of 2021 (already in Q4 2020 in the US and the Eurozone), when the economies started to slowly recover after lockdown, could be seen even more clearly.

The IMF further adjusted the CPI to pandemic-related purchasing patterns (as they shifted dramatically during that time) and conducted a study which showed that inflation during the first three months of the pandemic was considerably higher than before (using the pre-COVID-19 CPI) [Reinsdorf, 2020].

The St. Louis Fed explained the implications of the pandemic on future CPI measurement and baskets of purchases in more detail and found out that with an adjusted CPI measure, inflation was rapidly approaching 2% at the end of 2020 and is roughly 50 base points higher than non-adjusted [McCracken, Amburgey, 2020]. In either case, due to massive government spending and monetary expansion, inflation is accelerating along an upward slope, in a textbook fashion. NBER confirmed the findings [Maas, 2020] based on the original work done in another NBER paper [Cavallo, 2020].

Ongoing discussions about the impediments and precise impact of the forecast inflation (and its projected absolute values) point to scenarios ranging from relatively moderate increases to extreme spikes [e.g. Harvey, Dunn, 2020]. Even Keynesian economists and self-described fiscal "doves" are increasingly concerned about rising inflation and the too large COVID-19 stimulus legislation program of the Biden administration, as mentioned by former IMF chief economist [Blanchard, 2021].

There is also a fiscal, debt-related side left to inflation – Friedman noted that it is only inflationary to run deficits if they are financed by "printing money", yet recent research hints that it is only part of the explanation [Cochrane, 2011], for in both explanations debt plays an important role [Borio, 2018, pp. 29–31].

Discussions (regarding the representativeness, the very core inflation definition, appropriateness of technological substitutes/progress, etc.) surrounding CPI as a standard measure for inflation are not further illustrated here, nor are other aspects of money supply, e.g. an interest rate linked monetary policy (instead of direct money aggregates) aimed at inflation targeting (ca. 2% in the US and Europe) [Jahan, 2017; Gali, 2008], as explicitly or implicitly followed by most major central banks (empirically relatively consistent with the Taylor rule [Hammond, 2012] and based on works such as [Hall, Sargent, 2018; Bernanke et al., 1997; Woodford, 2012]), which worked very well over the last 30 years. This was especially true during the "great moderation" period in the 1980s and 1990s [Woodford, 2004; 2013; Mishkin et al., 2012].

3. The VECM model linking debt to inflation

Linking debt (and deficits) and inflation, I will introduce a VECM model investigating the (cointegrating) relationship of these two variables. The aim of VECM models is to establish a long-run relationship between dependent (here inflation) and independent variables (here i.a. debt/GDP ratio) and to show short-run deviations and disturbance from them (and correct for the errors). Cointe gration means two or more integrated variables indicating a common long-run development.

The VECM model is a type of a VAR model, adding error correction possibilities and solving the problem of spurious regression. VAR is the multivariate (multi-dimensional) extension of well-known ARIMA (auto-regressive integrating moving average) models. In VAR, all variables can be treated as endogenous (hence also considering two-way relationships). A VECM model can be introduced as follows with the order (p – 1):

$$\Delta X_t = \mu + AB^T X_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta X_{t-i} + u_t \qquad [1]$$

where:

μ – deterministic shift-vector,

Γ_i – (k × k) parameter matrix of the lagged stationary differences,

B – (k × r) matrix of the k-dimensional cointegrating vectors,

A – (k × r) matrix of error correction coefficients (and u_t is the i.i.d. error).

The matrix hence illustrates the long-run relationship between the variables in X_t and Γ_i denotes the short-run coefficients. The vector X_t is assumed to be (vector-)integrated of order 1 (i.e. I(1)), hence ΔX_t is vector-stationary

4. Analysis overview

My empirical analysis starts with the unit root tests to show the effects of shocks on variables over time[9]. All tests are statistically significant at the 5% level (95% confidence interval). The Augmented Dickey-Fuller (ADF), Phillip Perron (PP), and Ng Perron (NP) tests can be used to confirm stationarity.

First, each variable is tested independently for integration and stationarity using the ADF. Then, if necessary, the differences (Δ) or lagged differences are brought to equal levels, but might lose interpretability; using another integration

[9] The tests are also quite useful for forecasting and testing whether a regression is spurious, cf. e.g. [Asteriou, Hall, 2011].

test later is not, however, necessary here. The test is done with a constant/intercept and with a constant plus trend (when necessary).

Afterward, an appropriate lag length selection is executed to obtain suitable homoscedastic, normally distributed error terms without autocorrelation. A standard comparer is also used as a lag length selection criterion – the Aikake Information Criterion (AIC) – in order to obtain the model with the lowest values. Alternatives are the SC or HQ test (cf. e.g. [Liew, 2004]).

The Johannsen cointegration test is then conducted. Its advantage e.g. compared to the Engle-Granger-test (not Granger-causality) is that it allows for the possibility of having more than one cointegrating relationship [Chang et al., 2011]. If a series is not co-integrated (i.e. that any shock to the system in the short-run quickly adjusts to the long-run, short-run model just to be estimated), a VAR model is used; if it is – VECM. Sims, Hanssen and Johanssen contributed to developing the theory of VECMs. In case the series (the single ones) are integrated in different orders or mutually cointegrated (I(0) and I(1) existing, not I(2)), a cointegration test is also required such as the Bounds test/ARDL test [Pesaran et al., 2001], after which one would continue depending on the result with ARDL or ECM. However, it is possible to use the Johanssen test in this case. The number of cointegrating vectors (rows in B^T) can be determined as the rank of the matrix AB^T. The test can take the form of maximum eigenvalue of Π or of the trace (sum of diagonal elements) of Π. After that, the model can be estimated (A, B, Γ) essentially by a maximum likelihood estimator (MLE, alternatively GLS). A diagnostic (and stability) analysis can be applied at the end.

Most standard statistical software (R language, STATA, SPSS, GRETL) can be used for VECM and the Johannsen test; some, like SPSS, need further extensions (based on R) or packages. I will use GRETL here.

5. Data sources

The data sources are official time series for economic research from the Federal Reserve of St. Louis. For inflation, it is the Consumer Price Index for All Urban Consumers: All Items Less Food and Energy in the U.S. City Average, hence Core Consumer Price Index (CPI, and for model purposes not the absolute values but ln-measures which means the inflation). The index is normalized with Index 1982 – 1984 = 100, and the monthly values (X-12 seas. ARIMA) are seasonally adjusted. Code is CPILFESL. For debt, I use the series with code GFDEGDQ188S, which is Federal Debt: Total Public Debt as Percent of Gross Domestic Product, Percent of GDP, quarterly data, seasonally adjusted. As the instrument for inflation targeting and central bank money control (IL-link), I add the federal funds rate (FFR). Its corresponding series is BOGZ1FL072052006A (code) named: Interest Rates and Price Indexes, Effective Federal Funds Rate (Percent), Level, Percent, annual, not seasonally adjusted (as the period is already annual). The first two series are filtered as annual and as they are absolute values with no (moving/adjusted) averages or (percentage) changes, 1 January of each year can be taken as the date (time-synchronized).

As FFR and thus an included "controlling" instrument of the Fed is added, the series begins with 1983 (after Volcker's "crackdown on inflation" by sudden rate hikes), covers the "great moderation" period, and includes the recent financial crises (1989, 9/11, 2008, euro crisis), and ends in 2018. COVID-19 is not included as available data might still be subject to revision. Hence the paper covers a full quarter-century.

6. Results

The steps described above are pursued for the variables l_CPIT, i.e., log of CPI-total –the inflation, DT/GDP (debt to GDP ratio), and FFR. ADF tests for the (single) variable series. The AIC criterion is used and goes down from 6 (difference) lags. The result is that for FFR (p = 0.02484 0.05 (LOS)) with constant and trend, a lag 1 describing a I(1) series is obtained, and for L_CIP (p-value 0.04917 0.05 (LOS)) with constant, a lag 1 describing a I(1) series is received. For DTGDP lag 1 is suggested by GRETL, but it is not clear from the p-value. Hence the KPSS test is done of the null-hypothesis of stationary with trend against a unit root (other than Dickey-Fuller where H0 suggest non-stationarity). For lag 1 H0 is clearly denied, with a unit root problem. The differentiated DTGDP, d_ DTGDP is used and KPSS done again, and then H0 is not denied (T036, p = 0.058), so trend-stationarity can be assumed. Trend 1 is received, and DTGDP as I(1) can be done. All processes are therefore integrated of order 1 (I(1)); alternatively, d_DTGDP or transformations as I(0) could be done, followed by the Bounce integration test.

Next, the appropriate common lag order is tested in GRETL via the AIC-criterion going down from 4 lags. Following AIC (or BIC, HQC), lag order 2 is the result (all criteria have the lowest score here). Hence the total (common) lag order is facilitated to perform the Johannsen test with lag order 2 and up to full rank. The trace and maximum eigenvalue test are used (T034, estimation period 34, lag order 2, number of equations 3, unrestricted/constrained constant), giving the results shown in Table 1.

Table 1. Trace and Eigenvalue test

Eigenvalue	Trace-test with p-value	Lmax-test with p-value
0.36505	16.337 [0.0356] [0.046 sample size corrected]	15.443 [0.0303]

Source: Own elaboration using GRETL.

For the cointegration vector, adjustment vector, and matrices like the long-term matrix, see Appendix A.

Rank order 0 and 1 ($p < 0.05$) are clearly denied; rank 2 is obtained as cointegration rank, giving a (2) cointegrated series as a result. Cointegration leads to VECM as a method, and with $p = 2$, p-1-VECM as VECM of lag order 1 and (cointegration) rank 2 are recommended as a model. The VECM model estimate (Johanssen procedure, ML estimator) is applied, and for the coefficients of the adjustment vectors, with a case of an unconstrained constant, produces the results presented in Table 2.

Table 2. Alpha (adjustment vectors)

l_CPIT	–0.036100	0.00022319
DTGDP	–8.8496	–0.0094076
FFR	–3.5603	–0.0051166

Source: Own elaboration using GRETL.

The exact data for d_l_CPIT, d_DTGDP, and d_FFR can be found in Appendix A. The overarching covariance matrix yields the results presented in Table 3.

Table 3. Covariance matrix

	l_CPIT	DTGDP	FFR
l_CPIT	2.3084e-005	–0.0041268	0.0021892
DTGDP	0.0041268	7.5984	–1.2057
FFR	0.0021892	–1.2057	–1.6500

Source: Own elaboration using GRETL.

Conclusions

Keeping in mind X=(l_CPIT, DTGDP, FFR) and alpha as coefficients of A, beta of B (beta cointegration vectors, alpha lt-adjustment vectors), AB^T as long-term trend, Γ_i as short-term effect parameters and the following equation, the values presented in Table 4 indicate a moderately fast adjustment of long-term equilibrium to shocks.

$$\Delta X_t = \mu + AB^T X_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta X_{t-i} + u_t$$

Table 4. Adjustment to long-term equilibrium – coefficients

DTGDP	–8.8496	–0.0094076
FFR	–3.5603	–0.0051166

Source: Own elaboration using GRETL.

The R^2 adjustment is very good for the first (single) equation above for l_CPI with nearly 80%. The other equations score satisfactorily (~20%).

The sign and strength of DTGDP and FFR show a positive versus a negative correlation for the variables with the inflation l_CPI (as heuristically feasible), with lower interest rates (FFR) leading to higher inflation and higher debts to higher inflation, yet the last is not highly significant. Nevertheless, especially during non-crisis times and in the long-run, lower debt seems to have a moderate constraining effect on inflation (0.4% for 1% debt), so deficit reduction measures should be enforced. We can therefore reject the null hypothesis H0 that there is no link between higher debt and rising inflation. The aim of the article was achieved and such a link established via the VEC-model. This becomes even more true as inflation is accelerating and considerably higher in nearly all forecasts. Yet FFR-interest rate policy and a trustworthy, credible central bank were even more critical in the US in the last 25 years.

The independence of central banks is an essential element that should be safeguarded and not lost in the current unconventional, crisis-mode driven situation. Therefore, joined with the modern inflation target policy framework [Balls et al., 2018], I would summarize – as Bernanke [2011] concludes in a speech for the Fed: "With respect to monetary policy, the basic principles of (flexible) inflation targeting-the commitment to a medium-term inflation objective, the flexibility to address deviations from full employment, and an emphasis on communication and transparency – seem destined to survive".

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Appendix A. Data series for the macro variables

Time	FFR	DT/GDP	CPIT	l_CPIT
1.01.1983	9.47	35.82911	97.6	4,580,877
1.01.1984	8.38	37.45447	102.5	4,629,863
1.01.1985	8.27	40.44121	107.1	4,673,763
1.01.1986	6.91	44.07415	111.9	4,717,606
1.01.1987	6.77	47.57835	115.9	4,752,728
1.01.1988	8.76	49.03151	120.9	4,794,964
1.01.1989	8.45	49.73276	126.5	4,840,242
1.01.1990	7.31	51.96856	132.1	4,883,559
1.01.1991	4.43	57.41652	139.5	4,938,065
1.01.1992	2.92	60.99679	145.1	4,977,423
1.01.1993	2.96	62.86657	150.1	5,011,302
1.01.1994	5.45	64.30709	154.5	5,040,194
1.01.1995	5.60	64.66271	159.0	5,068,904
1.01.1996	5.29	65.04171	163.7	5,098,035
1.01.1997	5.50	64.34428	167.8	5,122,773
1.01.1998	4.68	62.50988	171.6	5,145,166
1.01.1999	5.30	60.01334	175.6	5,168,209
1.01.2000	6.40	57.71743	179.3	5,189,060
1.01.2001	1.82	55.1304	183.9	5,214,392
1.01.2002	1.24	55.66835	188.7	5,240,158
1.01.2003	0.98	57.77057	192.4	5,259,577
1.01.2004	2.16	59.82355	194.6	5,270,946
1.01.2005	4.16	60.94141	199.0	5,293,305
1.01.2006	5.24	61.53482	203.2	5,314,191
1.01.2007	4.24	62.28400	208.6	5,340,419
1.01.2008	0.16	64.41587	213.771	5,364,905
1.01.2009	0.12	77.29970	217.346	5,381,491
1.01.2010	0.18	86.76598	220.633	5,396,501
1.01.2011	0.07	93.35519	222.803	5,406,288
1.01.2012	0.16	97.42044	227.877	5,428,806
1.01.2013	0.09	101.21783	232.229	5,447,724
1.01.2014	0.12	102.90374	235.961	5,463,667
1.01.2015	0.24	100.82572	239.811	5,479,851
1.01.2016	0.54	104.30307	245.075	5,501,564
1.01.2017	1.30	103.16562	250.519	5,523,535
1.01.2018	2.27	104.18644	255.106	5,541,679

Source: Federal Reserve of St. Louis.

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Development of decentralized finance and its impact on global financing structures

This article discusses decentralized finance, its development, and its impact on global financing structures. It elaborates on the changes that have occurred since the introduction of Bitcoin in 2009 and those due to the blockchain technology. Since Bitcoin, cryptocurrencies and blockchain technology have grown in popularity. Decentralized finance is a new revolution in the finance and payment structure sector, which has expanded in part because of the continued growth of the Internet and its association with social networking. The analysis compares the new financing structures with centralized, traditional financing structures, with banks being the primary flow regulators. Open data from the World Bank is used and a systematic literature review is conducted as the primary method. Decentralized finance threatens the existence of the Swiss financial center. The main driver of technological innovation is the Blockchain technology, which aims to revolutionize the global financial system. The steep rise of cryptocurrencies in recent years has made blockchain technology known, illustrating its economic implications for the banking system.

Keywords: decentralized finance, blockchain, cryptocurrency, Bitcoin, digital currency

JEL classification: B27, F65, G21, O16, P33

Introduction

Decentralized finance (DeFi) is technologically a blockchain structure. An autonomous organization and smart contracts play the decisive role here. Typical characteristics create a transparent ecosystem for financial services, the open-source orientation, and the freedom of permission. For Zetzsche et al. [2020], a central authority (to manage transactions) is not required; everyone has access to these financial markets. The interactions take place peer-to-peer and via various decentralized applications.

The prerequisite for implementing decentralized financial markets is that the underlying blockchain technology supports smart contracts. Smart contracts implement computer programs and have self-executable and self-enforceable conditions. The Bitcoin blockchain, e.g., only partially includes the required instruction sets for smart contracts. The control is decentralized, i.e., users interact through the system, and thus the DeFi market offers them autonomy. This is the decisive difference with the traditional financial markets with centrally acting financial intermediaries [Popescu, 2020a]. It should be noted that the decentralized model does not apply to banks and securities dealers. Over the past few years, DeFi has been developing exponentially and today it has a significant impact on the global financial markets.

1. Decentralized finance

DeFi aims to create a highly interoperable financial system with greater transparency, equal access rights, and less need for intermediaries, as intelligent contracts take over these roles. This implies that it is an alternative (open, transparent, and automated) financial system.

Centralized financial markets prevent fair access and are vulnerable to counterparty risk, censorship, lack of transparency, and manipulation. The recent GME and Robinhood events, ultimately driven by regulatory requirements, vividly illustrate these shortcomings. Long before GME, DeFi stepped in to address them and ensure that the infrastructure that supports the programmable asset markets is as decentralized as the underlying technology [Popescu, 2020b]. While the decentralized exchanges (DEXs) were a little over two years old, they hit USD 60 billion in total in Q4 2020, while DeFi outstanding loans hit USD 4.5 billion.

1.1. Yield

Implementing liquidity incentives over the summer drove a mostly speculative frenzy, complete with income from farming, fork wars, and grocery stamps. Admittedly, while speculation can be the primary driver, it also leads to increased productivity and technological advances. As a result, DeFi's focus has shifted from acquiring liquidity to maintaining liquidity. As virtually the entire DeFi ecosystem competes for resources on Ethereum, gas costs have been phased out by hand, and there are government channels, knowledge-free rollups, and optimistic rollups. However, as liquidity increases, more money invested in DeFi comes on the market, and the risk is reduced, current interest rates hardly seem sustainable.

Just as the introduction of interoperability in technology results in commercialized base layer protocols, more efficient/liquid markets also lead to tighter spreads and lower returns over time. DeFi is not immune to TradFi's fragile recoveries, such as re-mortgage and excessive leverage. By definition, composability leads to dependencies that cause a systemic risk. However, the transparency offered by DeFi changes the risk equation. The systemic breakdowns in the TradFi markets were partly the result of opacity (in 2008, no one knew who was bearing which risk), while DeFi's transparency enables real-time risk pricing and a verifiable collateral path. Protocols are also jointly owned and operated. This means that the fees are shared among users rather than with hedge fund managers. Both are important reasons to use DeFi even after returns normalize.

1.2. Financial inclusion

Cryptocurrencies are less regulated and cheaper than their traditional counterparts, removing barriers to entry for the 1.7 billion people worldwide without a bank account, many of which do not have it because they lack a legal form of identification, and the various under-banked currencies. The advantages here are supposed to include lower fee transfers, reduced banking, general adoption, and the use of digital IDs.

Starting with lower fee transfers, though there have been exciting advances, they remain challenging as regulatory barriers; capital controls and factors outside the banking system cause most of the friction and costs involved in making cross-border payments. While a portion of the population has been excluded from the financial system for decades, the pandemic has shown an urgent need for inclusion. Much of the US population can receive funds through direct deposit, but there is still a sizeable unbanked population who cannot. Stimulus checks were sent out to them in the mail, adding to inequality. Funding for SMEs has also been difficult due to lending practices that require loan officers, personal identification, and faxes. The proposal for a digital dollar was included in the original business cycle, and there is still an urgent need for better digital IDs and digital distribution channels.

It is important to note that depending on the design, digital currencies can potentially decrease financial inclusion. The Libra announcement raised concerns about the national sovereignty of developing countries at the risk of accidental dollarization [Le Maire, 2019]. It also seemed to create something very similar to a reserve bank that raised alarms about global financial stability. Shortly after that, the People's Bank of China raised concerns about the threat to existing reserve currencies [Goodell, Al-Nakib, 2021]. Whether or not these concerns were justified, they resulted in a massive surge in the central bank's R&D of digital currencies.

1.3. Mainstream adoption of DeFi

There have been significant developments in mainstream distribution towards a broader adoption of crypto payments. PayPal [2020] has introduced new features that allow its 346 million users and 26 million dealers to buy, hold, and sell cryptocurrency. Visa announced that it is connecting its network of 60 million merchants to USDC. Mastercard enables cardholders to carry out transactions in specific cryptocurrencies on their network [Dhamodharan, 2021]. Square generates over USD 1 billion in quarterly Bitcoin revenue. Coinbase has more than 43 million users [Gudgeon et al., 2020]. BlockFi has more than USD 5 billion in personal loans, liquidity events in the public market are on the way, and Coinbase is expected to go public on a valuation that ranks it among the top 10 financial institutions in the US [Li et al., 2019].

1.4. Web 3.0

Web 3.0 refers to the use of blockchain technology to create an alternative to our current Internet, which is dominated by large, centralized platforms supported by extractive business models [Khan et al., 2019]. Web 3.0 is supposed to grant users access to a stateful Web, thereby reducing platform risk, empowering users, enabling new business models, and aligning incentives between network participants.

1.5. Key advantages of DeFi systems

Since DeFi systems are built based on blockchain networks, they have the same security, decentralization, and other benefits.

Open systems are great equalizers in business. People who typically do not have access to financial services can easily participate in these unlicensed systems. Typically, legacy financial services are only available in middle- and high-income regions. DeFi platforms do not have such a tendency. Since they exist online, they are available in any part of the world with Internet access [Chohan, 2021]. In addition, open ecosystems are also censorship-resistant. With decentralized finance, no user can be excluded.

Traditional financial systems have arbitrators and centralized servers, both of which are common avenues of attack. For example, a server mainframe could be hacked, and system administrators could make mistakes or deliberately sabotage a system for their benefit. DeFi applications, on the other hand, run on a network made up of thousands of devices. This eliminates the single point of failure that typically exists with financial services. As a result, decentralized financial platforms are extraordinarily robust and hardly ever shut down.

In older financial systems, one would have to refer multiple lenders and compare their rates to get the best interest rates and fees. In addition, one would need to make extra effort to find hidden fees. In DeFi systems, not all of these problems have to arise. Important information is stored on the blockchain, which anyone can easily access. Therefore, users can easily search for the best DeFi services available and anticipate the risks involved, e.g. when a stable coin platform is critically under-collateralized.

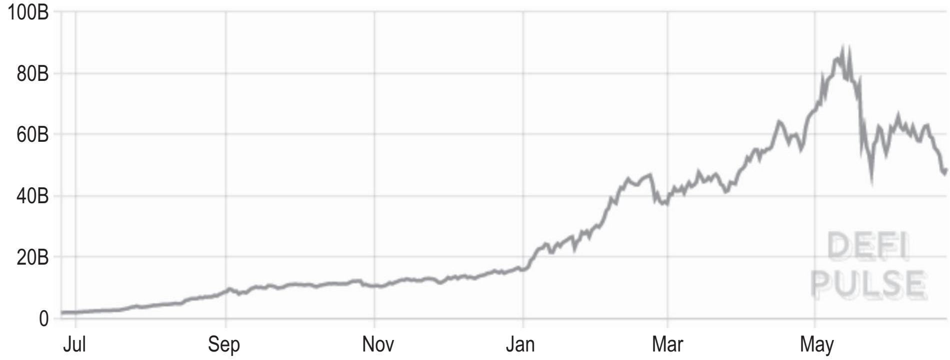

Figure 1. Total value locked in DeFi (USD)
Source: [DeFi Pulse, 2021].

Figure 1 shows the total value locked in DeFi, illustrating its growth as a result of the mentioned benefits.

2. DeFi use cases

While blockchain is still in its infancy, DeFi has only just been concieved. However, experts have already established use cases that have reformed the crypto space and are disrupting the financial world. Therefore, it can be assumed that in a few years DeFi technology will develop beyond even greater heights than before.

2.1. Lending and borrowing

Loan and credit platforms are some of the most popular types of applications in decentralized finance. These platforms allow anyone to borrow money provided they have enough assets to serve as collateral. Decentralized lending systems are generally cheaper than their traditional counterparts for several reasons. One can use DeFi platforms to secure digital assets such as cryptocurrencies and non-fungible tokens. Most finance apps also have instant transaction settlements, which is very convenient. In addition, they do not require any credit checks. For many people, these functions are more than sufficient to switch to decentralized lending platforms.

2.2. Limitless transactions

While cryptocurrencies like Bitcoin and Ethereum allow users to send and receive cross-border payments, they have never been stable enough to be used as cash. Most people would not like to use currencies that fluctuate regularly in value for their daily needs. Several DeFi systems give users stable coins that they can freely use as a means of payment. A platform called MakerDAO allows users to lock up their assets as security to generate a stable coin called DAI that can be used to top up Visa debit cards on Wirex.

2.3. Decentralized exchanges

A DEX is a platform that allows users to trade digital assets without the need for a custodian. Instead of letting an exchange take control, DEX users rely on smart contracts to bring buyers and sellers together and execute trades directly from their crypto wallets. As of 2020, centralized exchanges like OKEx and Binance still hold the vast majority of crypto assets in this space, but that could change in the future. DEXs such as Binance DEX, Kyber Network, and others have gained popularity over the past year. Ultimately, they give users more control and sovereignty over their wealth. In addition, they require less maintenance and have lower trading fees compared to centralized exchanges. Even so, they still have a long way to go in terms of liquidity, user interface, and advanced tools.

2.4. Decentralized marketplaces

Decentralized marketplaces like Open Bazaar are simply e-commerce applications built with a decentralized architecture – they can be thought of as Amazon without the Amazon company. People can buy or sell goods and services in digital currencies. Moreover, since there is no central authority, nobody has control over their items, unlike on eBay or Amazon. With this autonomy, one might wonder how buyer-seller disputes are resolved. Once a transaction has been recorded on a blockchain, it eventually becomes irreversible. The solution to that is a multi-signature escrow scheme. By creating a 2-3 Bitcoin address, a moderator can be added during a transaction if the buyer and seller disagree. In such a scenario, the moderator or a third party decides which one to give his vote to.

Moreover, decentralized insurance protocols allow users to purchase insurance coverage tied to smart contracts. Rather than relying on large insurance companies, a small group of government individuals could pool their funds to cover claims [Zetzsche et al., 2020]. This eliminates the need to pay high premiums as this becomes almost a zero-sum game. Smart contracts, unlike insurers, do not try to make a profit from users. To date, insurance is not DeFi's most popular applica-

Figure 2. DeFi index
Source: [Etheriumprice, 2021].

tion, but there are plenty of blockchain companies like Etherisc that are thriving in the crypto-insurance space.

3. The Swiss market

The bankruptcy of the American investment bank Lehman Brothers on 15 September 2008 shook the foundations of the global financial system with debts of USD 631 billion. Unsettled by the financial crisis, consumers and companies in the western industrialized countries steadily lost confidence in the reliability of the existing banking system, which led to a search for alternative financing and investment options. According to the World Bank, only 62% of the world's population had a bank account in 2014 [Underwood, 2016]. In developing countries, most of the population does not yet have access to financial services, hindering economic development and increasing prosperity in countries such as Bolivia, Nicaragua, and India [Li et al., 2019].

In 2008, a few weeks after the collapse of Lehman Brothers, Satoshi Nakomoto, whose identity is still unclear, published the white paper *Bitcoin: A peer-to-peer electronic cash system*. With the implementation of Bitcoin, he created the first global cryptocurrency and laid the foundation for a fundamental technology with undreamt-of technological and economic development potential with the blockchain. Since 2009, it has been possible to make digital payments on the Internet in a decentralized peer-to-peer network in which the transactions are legitimized by an autonomous consensus mechanism instead of a trustworthy central authority [Underwood, 2016]. The transparency, immutability, and efficiency of business transactions in the blockchain are of equal economic and social importance for industrialized and developing countries. As a result, the global financial system can be made more trustworthy, cost-effective, and accessible.

While Bitcoin has been viewed with suspicion since the beginning of its existence, the financial sector's interest in blockchain technology has steadily increased, which is evident in the form of an increase in the volume of investment in start-up companies. A total of USD 1.79 billion has flowed into blockchain projects in the financial sector in the form of venture capital since 2012 and USD 1.13 billion from Initial Coin Offerings over just twelve months [Ramos, Zanko, 2020]. The world's largest banks have also joined forces in the R3 consortium to create a standardized blockchain platform with Corda for smooth transaction processing between banks.

3.1. The impact of the pandemic on Bitcoin

The pandemic negatively impacted the crypto market. The Swiss Blockchain Federation carried out a broad survey of 203 startups in the Swiss blockchain ecosystem. A considerable majority (79.8%) stated that they would most likely go bankrupt in the next six months [Lahmiri, Bekiros, 2020]. A similarly high percentage (88.2%) will not survive the COVID-19 crisis without government help.

Interest rates are low, and the financial markets' situation is serious given the economic consequences of the crisis. Nevertheless, investors are still aiming for the highest possible profits [Garg, Prabheesh, 2021]. Some people think about alternatives to conventional investment products [Werner et al., 2021]. Currently, Bitcoin is increasingly coming into focus again. Internet money is met with deep suspicion by some and strong approval by others [Lahmiri, Bekiros, 2020]. Following the Bitcoin price roller coaster from mid-March to the end of April 2020, it rose again. In early May, the price was USD 9,000. Anyone who invests in Bitcoins should deal with the topic intensively – and arm themselves against fraudsters.

The rapid pace of technological development is also significant for the Swiss financial center, which should not be underestimated. At the end of 2016, 261 banks were operating in Switzerland, generating CHF 32 billion of nominal gross value added and CHF 11.8 billion in profit in the same year [Auer, Tille, 2016]. With assets under management of CHF 6.6 billion, 48% of which come from abroad, the Swiss financial center is the frontrunner in the global wealth management business with a market share of 25%. Swiss asset managers maintained their market position during the financial crisis, but confidence in the banks there has also suffered, and increasing regulation has increased complexity and costs. The asset management business will not be able to escape the digital transformation.

Disruptive business models can shake the foundations of the Swiss wealth management business in the long term if blockchain technology succeeds in challenging the banks for the monopoly of trust [Casey et al., 2018]. However, the banks can deal with the development of decentralized finance in several ways. One of them is to wait and watch the market develop. The second option is to experiment with blockchain technology and new business models. Furthermore, the banks can take an active leadership role in the global democratization of the blockchain value network.

3.2. The impact of DeFi on the Swiss financial center

The digital transformation will not leave the Swiss financial center untouched. The main driver of technological innovation is the blockchain, which aims to revolutionize the global financial system. In recent years, the steep rise of Bitcoin has made blockchain technology known, illustrating its economic implications for the banking system [Bartoletti et al., 2021]. Payments in Bitcoin are made almost in real-time, directly, transparently, verifiably, and forgery-proof between sender and recipient, completely without bank accounts and central clearinghouses. The integrity of the financial transactions is made possible by a decentralized, publicly accessible general ledger consisting of cryptographically secured and verified blocks.

Blockchain innovation starts with the financial market infrastructure, the foundation of the global financial system. The closed, central financial systems may give way to an open, decentralized blockchain platform, which provides the basis for new data-based business models [Smith, 2021]. Through digitization and decentralization, the asset management value chain is transformed into a value network dynamically orchestrated via the blockchain. Since the contracting parties can directly exchange all types of digital assets, the existing settlement networks and depository offices in the decentralized value creation process become obsolete [Casey et al., 2018]. At the same time, the decentralized general ledger replaces the bank account, which means that it loses its importance as a customer interface.

In order to strengthen the Swiss financial market in the global competition between locations, the Federal Council lowered the market entry barriers in spring 2017 with the amendment of the Banking Act and the Banking Ordinance and created a technology-neutral innovation area. The relaxation of financial market regulation allows fintech companies to test new technologies and innovative business models in the Swiss market [Smith, 2021]. The attractiveness of the Swiss regulation is shown by the increasing number of fintech companies settling in Crypto valley in the canton of Zug [Auer, Tille, 2016]. As a result, the Swiss fintech ecosystem takes a top position in fintech funding in an international comparison of locations.

The blockchain and Switzerland are based on governance structures that represent transparency, integrity, stability, and create trust. Switzerland provides the social foundation for the technological trust protocol of the blockchain. In combination with the availability of capital, financial market, technological expertise, and business-promoting financial market regulation, the Swiss financial center offers ideal conditions for setting up a global, decentralized asset management platform.

Conclusions

The DeFi ecosystem offers a range of innovative financial services such as lending, token issuance, insurance, and banking in an open-source, permissionless, and transparent network. Users have complete control over their assets while connecting to a whole range of decentralized peer-to-peer applications. DeFi generally requires the execution of smart contracts, a digital agreement tied to computer code instead of legal documents. Smart contracts can, therefore, self-execute and automate a large number of business transactions that would have required manual effort. The proponents of the digital transformation predict that the disruptive potential of the DeFi technology will lead to a profound structural change in numerous industries.

The blockchain innovation starts with the financial market infrastructure, the foundation of the global financial system. The closed, central financial systems might give way to an open, decentralized blockchain platform, which provides the basis for new data-based business models. Through digitization and decentralization, the asset management value chain is transformed into a value network dynamically orchestrated via the blockchain. Since the contracting parties can directly exchange all types of digital assets, the existing settlement networks and depository offices in the decentralized value creation process become obsolete. At the same time, the decentralized general ledger replaces the bank account, which means that it loses its importance as a customer interface.

DeFi and traditional finance are based on governance structures that stand for transparency, integrity, and stability and create the basis for trust. Traditional finance provides the social foundation for the technological trust protocol of the blockchain. In combination with the availability of capital, financial market, technological expertise, and business-promoting financial market regulation, the Swiss financial center offers ideal conditions for setting up a global, decentralized asset management platform.

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Regional competitiveness of selected Sub-Saharan African economies – an application of stochastic production frontier analysis

This article evaluates the competitiveness of 44 selected Sub-Saharan African economies by modelling the efficient utilization of the factors of production. It deviates from the traditional approach and methods for a competitiveness study and opts to utilize the econometric methodology of stochastic production frontier, using Cobb-Douglas production function to estimate time-invariant and time-varying decay effects efficiency and panel data for 1980–2019. The results show that the selected SSA countries operated on an average score of 40% and 26% efficiency levels, when analyzing the data under time-invariant and time-varying decay models respectively. Highly competitive countries ranked higher with respect to efficiency, incl. Equatorial Guinea, Mauritius, South Africa, Eswatini, and Gabon. At the bottom of the scale were Congo, Liberia, Burundi, Central Africa, and Niger.

Keywords: technical efficiency, stochastic production frontier, Cobb-Douglas production function, time-varying decay model, truncated normal distribution

JEL classification: E23, H21, O55, P52

Introduction

Sub-Saharan Africa is a diverse economic region with abundant human and natural resources that can economically progress to improve the standard of living of its populace. More than 1 billion people live in the SSA region, with those under the age of 25 estimated to constitute half of the total population by 2050 [WB]. However, SSA countries are poor due to their underperforming economies, with high corruption, poor infrastructure and weak and inefficient public institutions causing lower productivity growth and impeding economic progress.

Figure 1 depicts GNI per capita in constant 2017 USD based on PPP of the world's developing regions in 2000–2018. It compares one of the key stylized facts of economic growth and improvement in the income level per capita of the SSA region with the rest of the world. The GNI per capita in SSA remains stagnant, which is a departure from the upwards growth trend of the major economic regions. The implications for the SSA countries are lower GDP and economic growth rates, which translate into higher poverty rates.

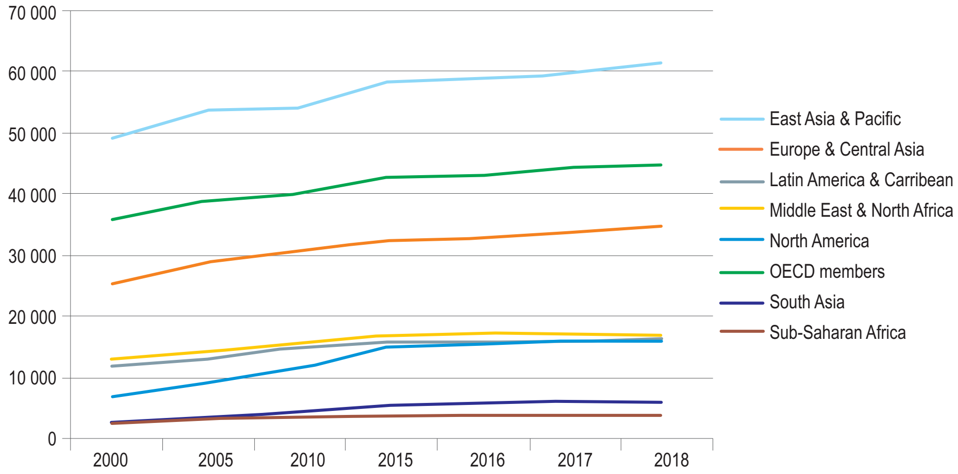

Figure 1. GNI per capita across world developing regions in 2000–2018 (constant 2017 USD, PPP)

Source: [WB].

Significantly, there have been poverty rates improvements globally, but SSA countries still have the highest poverty rates in the world. According to the World Population Review (poverty rate by country), which is based on the 2021 World Bank estimates, ca. 736 million people live in extreme poverty, surviving on less than USD 1.90 per day, and out of this number, it is estimated that 413 million live in Sub-Saharan Africa.

Many questions remain unanswered as to the cause of the lower economic growth and development within SSA. Therefore, the important task now is to evaluate the salient factors that determine the economic growth of SSA countries.

1. Objectives

This paper aims to analyze the competitiveness of SSA countries in their quest for economic growth and development. Many of them had recently enjoyed economic success, e.g. Rwanda, Ghana, Kenya, Uganda, Ivory Coast, and Ethiopia have ambitious plans to grow and develop and transform into upper-middle-income economies. The essence is an assessment of these countries' competitive use of their available resources to ensure economic growth that will transform their economies for the betterments of their citizenries. In short, this paper empirically evaluates the competitiveness of SSA countries based on the available factors of production, using the scale of efficiency. It deviates from the previous competitiveness studies, most of which are conducted and centered in advanced countries like Japan, the UK, Canada, Poland, Ireland, Germany, or Italy, at the disadvantage and neglect of developing countries, particularly within SSA. Secondly, because of the vast differences in economic structures between advanced and developing countries, the application of their findings may not be transferable. The need to evaluate the competitiveness of SSA countries in particular is therefore warranted.

2. Methodology and theoretical framework

Over the past few years, assessments of economic policies, growth, and development have gained recognition in attempts to compare the competitiveness of countries and sub-regions. The economic success and competitiveness of countries directly depict the efficiency of the factors of production. Over a decade ago, the importance of efficiency in economic growth and development was emphasized. There is a consensus that economic efficiency positively impacts economic growth and development. In other words, how effectively the resources of a country are combined and utilized significantly expedites that country's economic progress, which also improves its competitiveness.

The OECD [1994] defines competitiveness of a country as "the degree to which [it] can, under free and fair market conditions, produce goods and services which meet the requirements of international markets, while simultaneously maintaining and expanding the real incomes of its people over the long term". Competitiveness can be evaluated with the use of various methods. This means that there is no unique methodology for competitiveness assessment. This paper makes use of technical efficiency to evaluate the competitiveness of SSA countries.

Based on the fundamental theory of production, the growth of output is attributable to technical and economic efficiency, economies of scale in production, and specialization that tend to reduce costs and increase productivity. A country able to efficiently combine its factors of production in the production of goods and services tends to perform better competitively when compared with other countries [Fuente-Mella et al., 2020].

The concept of efficiency was first introduced in the 19th century by Pareto in his production and resource utilization analysis. After that, studies in efficiency were carried out in the 1950s by Koopmans and Debreu [Ouattara, 2012], but it was after the seminar work of Farrell [1957] that the concept gained momentum. The papers that add to Farrell's efficiency measures are discussed by Hjalmarsson [1978]. Efficiency can be technical or allocative [Farrell, 1957]. Their combination constitutes economic efficiency [Battese, Coelli, 1992; 1995; Battese, 1992; Coelli et al., 2005; Singh et al., 2000].

3. Measuring efficiency

Efficiency can be measured or estimated using data envelopment analysis, a method both deterministic and nonparametric, and the stochastic frontier method, a parametric method allowing for random shocks in its estimation [Fuente-Mella et al., 2020]. Typically, analysts measure efficiency with the use of a production function, which depicts the maximum output a firm or a country can produce given the available factors of production under the existing technology [Battese, Coelli, 1992].

This paper adopts the estimation method of stochastic frontier analysis (SFA) by using the Cobb–Douglas production framework. The stochastic frontier model can be formulated as [Mango et al., 2015]:

$$Y_{it} = f\left(X_{it}, \beta\right) + v_{it} - u_{it} = f\left(X_{it}, \beta\right) + \varepsilon_{it} \qquad [1]$$

where:

Y_{it} – scalar output of country in time T,

X_{it} – vector of factors of production in time T,

β – vector of parameters to be estimated,

ε_{it} – composed error term that measures the level of efficiency of country i at time T.

The error term ε_{it} breaks into two parts: v_i, which is defined as the effects of random shocks, which is beyond the control of country i and is assumed to be independently and identically distributed (*iid*), symmetric, and distributed independently from u_{it}; u_{it} are the nonnegative ($u_i \geq 0$) technical inefficiency effects, representing the economic and other factors under the control of country i. Therefore, the error term u_{it} captures the technical inefficiency component of the error term ε_{it}. The stochastic production frontier model is also based on the assumption that economic agent i, be it an individual, a firm, or a country, exploits the full or complete technological potential when the value of u_i comes close to zero [Mburu et al., 2014]. Thus, the higher the value of u_i, the higher the level of technical inefficiency. Because ($u_i \geq 0$), its subtraction from model 1 implies that $0 < \varepsilon_{it} \leq 1$, the assumption being that the combination of u_i and v_{it} should be between 0 and 1.

Kumbhakar and Lovell [2000] provided a detailed version of this derivation[1], and presented a similar approach in cost derivation [Sugarhouse, 2000].

This paper utilizes the unbalanced panel data from the Penn World Table, which is a set of national-accounts data developed and maintained by scholars at the University of California and the Groningen Growth and Development Centre at the University of Groningen to measure real GDP and other variables across countries and over time. The PWT panel data for 1980–2019 is considered this study [Feenstra et al., 2015].

Following Battese and Coelli [1992], the time-varying stochastic production frontier model in the Cobb–Douglas production function framework in logarithm form for technical inefficiency could be specified as:

$$In(RGDPO_{it}) = \alpha_i + \beta_1 In(EMP_{it}) + \beta_2 In(Year_{it}) + (v_{it} - u_{it}) \qquad [2]$$

where:

$$u_{it} = \exp([-\eta(t - T_i]u_i) \qquad [3]$$

$In(RGDPO_{it})$ – log of output-side real GDP at chained PPPs (in million 2017 USD) i, for period t,
$In(EMP_{it})$ – number of persons engaged (in millions) in country i, for period t,
$In(CNit)$ – capital stock at current PPPs (in million 2017 USD) of country i, for period t,
$Year_{it}$ – trend variable, which is a proxy for technological progress,
T_i – the last period in the i^{th} panel, η = is the decay parameter,
α_i – the country i specific constant term,
v_{it} – two-sided random error component beyond the control of the country i, for period t.
u_{it} – one-sided inefficiency component.

The combination of v_{it} and u_{it} gives ε_{it} in (1) and $i = 1..., N, t = 1..., T$.

The econometric model in equation 3 assumes that the efficiency of each country within the sub-region might have changed over the time period 1980–2019, since there has been a structural and institutional transformation, leading to economic progress in most of the countries, and thus potential efficiency gains.

It should be noted that without model 3, the equation reduces to model 2, which is the time-invariant model at the base level, as described by Battese and Coelli [1988].

Model 2 is estimated assuming that the economies of these countries are diverse due to the differences in economic structures, the factors affecting their economies, and the way they are efficiently combining their factors of production, leading to variations of efficiency. True fixed effects (TFE) are assumed since each

[1] Analogous derivation in the dual cost function was used in the process.

country may have time-invariant characteristics such as language, culture and political system that can influence predictor variables. In this case, heterogeneity means that $\alpha = \alpha_i$ and time-varying country inefficiency u_i are considered [Rashidghalam et al., 2016]. Model 2 is also estimated under the assumption of maximum likelihood and under the assumption that one-sided inefficiency u_{it} has truncated normal distribution with v_{it} having a normal distribution with a mean and a standard deviation of (0, 1). Thus, using maximum likelihood requires that the parametric assumptions of the error terms v_{it} and u_{it} should be $v_{it} \sim iid\, N(0, \sigma_v^2)$ and $u_{it} \sim iid\, N^+$ (0, σ_v^2) under truncated normal distribution. The error terms v_{it} and u_{it} are also distributed independently of each other and the covariates in model 2.

Model 2 could also be estimated under other distributions [Newton et al., 2010; Ahmadzai, 2017] and gamma distributions [Kumbhakar et al., 2015].

As proposed by Battese and Coelli [1992], the output-oriented technical efficiency scores can be predicted after estimating model 2, using the conditional expectation predictor:

$$TE_i = \exp(-u_i) = \frac{y_i}{\exp(x_i, \beta) + v_i} = \frac{y_i}{\bar{y}} \quad [4]$$

Efficiency scores are useful for assessing policy implications, and there is a need to investigate factors that cause inefficiencies [Jones, Mygind, 2008]. Inefficiency can be affected by the time trend, and we incorporate T as the time-varying inefficiency variable [Battese, Coelli, 1992]. In time-decaying specification, u_{it} is stipulated in model 3 as [Sugarhouse, 2000; Baten et al., 2009]:

$$u_{it} = \exp(\eta[t - T_i]u_i) \quad [5]$$

where:

η – unknown scalar parameter to be estimated, which determines whether inefficiencies are time-varying or time-invariant.

When $\eta > 0$, the degree of inefficiency decays over time; when $\eta < 0$, the degree of inefficiency shifts upwards over time. Because $t = T_i$ in the last period, the last period for country would contain the base level of inefficiency for that country. If $\eta > 0$, the level of inefficiency reduces toward the base level. If $\eta < 0$, the level of inefficiency increases to the base level [Baten et al., 2009; Sugarhouse, 2000]. Models 2 and 3 are estimated simultaneously to avoid possible downward biased [Ahmadzai, 2017; Kumbhakar et al., 2015]. The frontier parameters to be estimated are β_1, β_2 and β_3. The frontier estimates or output also brings out the reports for the following items: (σ_v^2, σ_u^2; $\sigma_s^2 = (\sigma_v^2 + \sigma_u^2)$, $\gamma = (\sigma_u^2 / \sigma_s^2)$, lambda ($\lambda = \sigma_u / \sigma_v$) and η (time decaying parameter).

4. Results and discussion

Table 1 presents the summary statistics of the variables under study, which show significant differences. Their means and the standard deviations vary, indicating a statistical difference.

Table 1. Statistical summary of output and input variables

Variable	Mean	SD	Min.	Max.	Observation
logrgdpo	9.6216	1.4034	5.8883	13.8297	1,472
logemp	0.6984	1.5484	–3.3749	4.2907	1,472
logcn	10.4514	1.6372	5.9952	15.3396	1,472
year	–	–	1980	2019	39 years

Source: Own elaboration.

In the selected SSA countries, the mean value 0.6984 of the log of the number of persons engaged (in millions), which is represented by , is the lowest with a minimum value of –3.3749 and a maximum value of 4.2907, compared with the rest of the means of the other variables. The log of output-side real GDP at chained PPPs (in million 2017 USD) has a mean of 9.6216, a standard deviation of 1.4034, and maximum and minimum values of 13.8297 and 5.8883, respectively, indicating that there are variations of output-side real GDP among the selected SSA countries. The standard deviation of the log of capital stock at current PPPs (in million 2017 USD), represented by *logcn*, is the highest with the value of 1.6372 and the minimum and maximum years of 5.9952 and 15.3396, respectively, indicating how comprehensive the series of this variable is.

Table 2 presents the results of the SFA as defined in model 2. The results of Cobb–Douglas stochastic production frontier of efficiency analysis of the 44 selected SSA countries are discussed or undermentioned. The results are obtained using Stata 11.

The coefficients of employment, capital, and technological progress are significantly different from zero at 1% for truncated normal distribution in both models. Employment and capital have the expected signs, indicating that these inputs significantly impact the economic progress of the selected SSA countries. These variables promote the countries' GDP, making them more competitive. Technology, measured in the model by the trend variable (year), has an unexpected negative sign in both models, indicating technological regression, delayed economic progress, and lower competitiveness. In fact, there has been no technological development, R&D, or innovation in SSA countries. "Innovation drives that process, it underlies economic growth, and it is a crucial element in how countries achieve prosperity" [Schumpeter, 1942].

Table 2. Maximum likelihood estimates of technical efficiency for SSA countries

Variable	Parameter	Time-invariant model	Time-varying decay model
logemp	β_1	0.689*** (0.0946)	0.690*** (0.0893)
logcn	β_2	0.456*** (0.0144)	0.472*** (0.0182)
year	β_3	–0.00555* (0.00232)	–0.00886** (0.00303)
_cons	α_i	17.02*** 4.780)	23.49*** (6.075)
mu	μ	1.515*** 0.244)	1.499*** (0.233)
sigma_u	σ_u^2	0.4369	0.4314
sigma_v	σ_v^2	0.0574	0.0572
sigma2	$\sigma_s^2 = (\sigma_v^2 + \sigma_u^2)$	0.4943	0.4886
gamma	$\gamma = (\sigma_u^2 / \sigma_s^2)$	0.8839	0.8829
lambda	$\lambda = (\sigma_u / \sigma_v)$	2.7589	2.7460
eta	η	–	0.0015
log likelihood	–	–103.0317	–101.9282
observations	N	1472	1472

Source: Own elaboration.

With the discussion of the variabilities, the results return positive values of sigma2δ_S^2), which are ca. 48% and ca. 49% for time-invariant and time-varying decaying inefficiency models, respectively. These values suggest that within the time frame under consideration, technical inefficiencies accounted for the differences between the actual output (real GDP at chained PPPs) and the production frontier (potential output and not random shocks alone). On a yearly basis, this translated to an average efficiency score of ca. 40% and 26%, respectively, meaning that SSA countries had 60% and 74% chance to reach their maximum output potential. The maximum likelihood results also return ratios of gamma (γ), which are ca. 88% and ca. 88%, respectively. The interpretation of these ratios is that, 88% of random variability of the outputs of these countries, is due to technical inefficiency when analyzing the data under the truncated normal distribution. Furthermore, we initially made the assumptions of differences in economic structures and policies. The lambda values of 2.7589 and 2.7460, respectively, indicate differences in actual production or output due to differences in economic structures, resources, and other factors such as economic policies and managerial abilities rather than random variability. The estimator of the parameter of time-varying decay η of ca. 0 indicates that the model reduces to the time-invariant model, making it not warranted when considering this data in applying stochastic production frontier analysis under the truncated normal distribution to analyze the efficiency of the selected SSA countries.

Efficiency scores were also estimated to compare the competitiveness of the selected SSA countries. Table 3 presents their mean technical efficiencies under the time-invariant model. Appendix A and B also contain information on the technical efficiency of the selected SSA countries.

Table 3. Efficiency results for selected SSA countries in 1980–2019

Rank	Country	Technical efficiency	Rank	Country	Technical efficiency
1	Equatorial Guinea	0.93	23	Mauritania	0.36
2	Mauritius	0.77	24	Congo	0.36
3	South Africa	0.73	25	Ghana	0.36
4	Eswatini	0.65	26	Uganda	0.36
5	Gabon	0.65	27	Zambia	0.36
6	Sudan	0.61	28	Lesotho	0.36
7	Botswana	0.61	29	Cabo Verde	0.33
8	Namibia	0.55	30	Burkina Faso	0.31
9	Seychelles	0.55	31	Benin	0.31
10	Zimbabwe	0.55	32	Chad	0.29
11	Guinea	0.49	33	Mozambique	0.29
12	Djibouti	0.46	34	Madagascar	0.28
13	Côte d'Ivoire	0.45	35	Malawi	0.27
14	Gambia	0.41	36	Togo	0.25
15	Mali	0.41	37	Nigeria	0.25
16	Cameroon	0.40	38	Guinea-Bissau	0.23
17	Angola	0.38	39	Ethiopia	0.21
18	Senegal	0.38	40	D.R. of the Congo	0.20
19	Sao Tome and Principe	0.38	41	Liberia	0.20
20	Rwanda	0.37	42	Burundi	0.20
21	Kenya	0.37	43	Central African	0.18
22	Sierra Leone	0.37	44	Niger	0.18

Source: Own elaboration.

The efficiency scores indicate the average potential output of these countries. The average realized potential output for all 44 SSA countries was 0.40 with a standard deviation of 0.17 for the time-invariant model. This score indicates that the selected countries can improve their efficiency levels by 60%, all things being equal. Equatorial Guinea, Mauritius, South Africa, Eswatini, and Gabon were found to be highly competitive, while Congo, Liberia, Burundi, Central Africa, and Niger were at the bottom of the ranking.

Conclusions

This study utilized the estimation method of the stochastic frontier model through the framework of Cobb-Douglas production function to evaluate the competitiveness of 44 selected SSA countries. The results show that Equatorial Guinea, Mauritius, South Africa, Eswatini, and Gabon are highly competitive. In contrast, Congo, Liberia, Burundi, Central Africa, and Niger were found to be less competitive based on their efficiency scores when utilizing the data under the truncated normal distribution.

On average, SSA countries realized potential outputs of 40% based on model 2 under truncated normal distribution. The interpretation of these efficiency scores is that, on average, SSA countries have the potential to improve their efficiency levels by 60% and thus increase their competitiveness.

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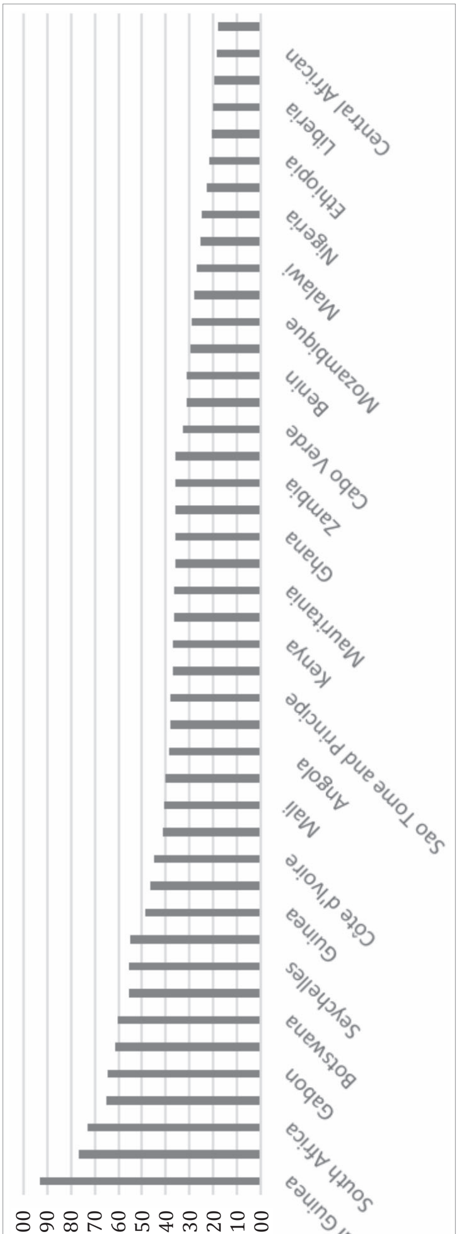
Appendix A. Average technical efficiency for selected SSA countries in 1980–2019



Source: Own elaboration.

Appendix B. Average yearly technical efficiency for SSA countries in 1980–2019

Source: Own elaboration.

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Strategy for the sustainable development of aquaculture in the European Union

This article aims to evaluate the state of aquaculture in the European Union and its contribution to the development and life of the local community. It identifies EU standards and policy measures promoting aquaculture and suggests how to increase its production. Descriptive statistics are used to analyze the development of fish and shellfish farming in EU countries and reports describing fish and other marine organisms in farming are referenced. Over the past 20 years, the EU has been making attempts to unlock production potential by issuing strategy papers and establishing the Aquaculture Advisory Council in 2016. It trusts that environmentally sustainable aquaculture has excellent potential for development. It can create new products of high value for a growing world population and reduce the problem of fisheries collapse and overfishing, becoming an alternative source of raw material for the fish industry. Increasing fish production would create new jobs and secure the economic development of local communities.

Keywords: aquaculture, sustainable development

JEL classification: Q22, Q01

Introduction

Nowaways, fish and seafood as natural resources are common goods. The main objective of the European Union's Common Fisheries Policy (CFP) is to ensure that, in the long term, aquaculture, sea fishing, and fish market organisation balance the environment, at the same time leading to economic success, creating jobs, providing high-quality food, and keeping fishing traditions alive. Aquaculture, unlike fisheries, is not an exclusive EU competence, but due to its importance for the food security, sustainable economic growth, and employment, it was considered that to coordinate the policies of the member states, a system of EU guidelines was needed. It is up to individual countries to adapt them to local circumstances and implement them, but they have an incentive to do that – resources from the future European Maritime, Fisheries and Aquaculture Fund and other EU aquaculture development funds.

1. Determinants of aquaculture development

1.1. Overfishing of natural resources

Using data provided by the Food and Agriculture Organization of the United Nations (FAO), we can see that the last 50 years of more intense fishing brought a shortage of fish in the sea. According to a FAO report, 33% of fish stocks are overfished, three times more than in the mid-1970s. Over 50% could be fully fished. According to scientists, a catastrophic situation is taking place in the Mediterranean and Black seas, where this problem affects over 62% of fish stocks; the same goes for south-east Pacific Ocean (61%) and south-west Atlantic Ocean (58.8%) [FAO, 2020]. There is still a threat to the cod population in the Baltic Sea. Growing fishing pressure is observed in oceans and seas. Most European fish resources are managed in an incorrect way. There is fishing on a massive scale to produce fishmeal, which is food for farmed fish [Draganik, 2017, p. 4]. This interferes with the food system in the food chains of Baltic fish, including cod. As a result of overfishing, certain species of fish have suffered more than others, causing biodiversity to decline, which creates further challenges to the ecosystem. All these developments can lead to loss of employment for people who work in the fishing industry [Hojrup, Schriewer, 2012, p. 70].

1.2. Consumption of fresh fishery and aquaculture products and consumer preference

Fish are a source of valuable nutrients for the human body, including omega acids. Consumption of fish around the world has grown exponentially. In the 1960s, an average person ate 9 kg of fish per year, in the 1990s – above 14 kg, and nowadays up to 20 kg. The Chinese eat the most fish and seafood in the world – 40 kg per year. In 2016, global fish consumption amounted to 171 million tonnes, with aquaculture accounting for 47% [FAO, 2018].

The EU is one of the biggest players in the global fish market, but the per capita level of fish consumption in its member states varies, from nearly 86 kg in Malta to just 5.6 kg the Czech Republic. Total per capita consumption of seafood in the EU averages just below 24 kg per year. On the continent, the record holders are undoubtedly the Portuguese, who eat 57 kg of fish per year. Fish are also an essential part of Lithuanian, Spanish, Finnish, French, and Swedish diets. Polish consumers, although aware of their health benefits, do not reach for them very often – they eat on average 13 kg of fish per year, perhaps discouraged by their high prices compared to other food products [Szlinder-Richert, 2019, pp. 11–25]. This is still twice as much as in Hungary, Romania, and Bulgaria, where the per capita fish consumption is 6 kg per year.

EU households spend yearly on fish and seafood somewhat more than EUR 100 per capita – one-fourth of what they spend on meat. The EU is the 6th largest producer of fish products and aquaculture globally, accounting for 3% of global production in 2018 (1.2% of aquaculture and 5.5% of catches). Food production is an essential element of the Polish economy. Poland is the 6th largest food producer in the EU. Over the last 40 years, the value of trade in fish and fish products increased 18 times, reaching USD 143 billion in 2016. Catches provide almost 80%, and aquaculture below 20% of fish supply in the EU [EUMOFA, 2020].

Fish consumers are interested in a balanced sector of fishing, its impact on the environment and well-being of fish, and the quality of farms. According to the Eurogroup for Animals [2018], purchase decisions are influenced by factors such as freshness, quality, overfishing, and aquaculture's environmental impact. The well-being of fish is categorised in: clear water (95%), the health of the fish (94%), the environment (93%), minimal pain (89%). 40% of consumers in Europe declare that they are ready to pay up to 10% more for balanced seafood. The aspects related to ethical, balanced growth can be found in the records of the EU Parliament Resolution [OJEU, 2020].

2. Concept of aquaculture in the theory of sustainable development

According to EU laws, aquaculture is part of the fishing economy, and it is defined as a means to produce aquatic organisms through developed techniques to increase the production of the natural environmental performance, in a situation when these organisms stay as property of a physical or legal person throughout the entire period of farming and breeding to catching [EP, 2013]. Aquaculture covers the breeding and farming of fish, shellfish, mollusks, and seaweed. The production occurs in ponds, pools, fairways, baffles and seats, cages, and recirculation systems [EP, 2008].

European aquaculture, which uses diverse technological production techniques, is one of the most innovative in the world. According to EU standards, it is divided as follows: 1) raising and breeding of aquatic organisms (e.g. carp, whitefish, pike-perch), fed naturally at low densities, in earthen ponds which play an important and beneficial role in landscape and water management, and are biodiversity-friendly [Gil, 2009]; 2) growing and breeding aquatic organisms (e.g. rainbow trout, European eel, sturgeon, tilapia) in flow systems, which, although expensive due to energy costs, allow for better control of water quality (temperature, oxygenation) and combining aquaculture with hydroponic plant production [Czarkowski, 2010, p. 6]; 3) extensive aquaculture in brackish waters (e.g. sole, sea bream, shrimp, clams are often carried by sea currents and are kept in lagoons prepared for this purpose, *vide* Spanish esteros, Italian vallicultura, which play a vital role in preserving the natural coastal heritage); 4) mariculture, most developed in island or seaside states, is a method of breeding marine animals and plants (e.g. Atlantic salmon, sea bass, sea bream, algae; oyster and mussel farming account for 90% of European production) in sea water in tanks on land or in cages on the seabed; 5) lastly, hatchery and larval culture [Czarkowski, 2010, p. 8], where fry or caviar are produced, are also classified as aquaculture.

Sustainable development has long been a priority within the European integration process, including the CFP. The EU is committed to a development that meets the needs of today without reducing the ability to meet the needs of the future. The essence of sustainable development is a dignified life for everyone on our planet, consisting of prosperity, efficient economy, and environmental responsibility. Since 2010, sustainable development has been included in the Europe 2020 strategy [EC, 2010]. The new global framework for sustainable development has been set out by the UN 2030 Agenda for Sustainable Development, signed by world leaders on 25 September 2015. It established 17 sustainable development goals to achieve sustainable development worldwide by 2030, including life under water.

The sources of the concept of sustainable development are often found in the criticism of traditional theories of growth and prosperity. Current production and consumption patterns, as well as technological progress, resulted in increased anthropopression due to the demand for natural resources. The global interest in the effects of human economic activity on the environment dates back to the 1960s and 1970s [Meadows et al., 1972]. Sustainability means combining material development with the long-term existence of the human population, efficient use of natural resources, environmental responsibility and equal opportunities for present and future generations [Roosa, 2009, p. 44]. It is essential to balance environmental protection with the need for development [Tladi, 2007, p. 74]. A report by the World Commission on Environment and Development [1987] defines the following policy objectives: restoring economic growth and changing its quality, meeting human needs in the areas of food, hygiene, work, and energy, stabilizing the population, preserving natural resources and innovation.

3. Evolution of the EU strategy for the sustainable development of aquaculture

The first EU document supporting aquaculture was the Strategy for the sustainable development of European aquaculture [EC, 2002]. Its objectives included employment growth in the aquaculture sector of between 8,000 and 10,000 new jobs in the period 2003–2008, environmentally friendly aquaculture and farming, healthy high-quality aquaculture products, and high welfare standards for farmed fish and seafood. The specified targets have not been achieved, although environmental sustainability and quality have been ensured. In addition, EU aquaculture faced the difficulties related to increased competitiveness of goods from developing countries and the economic crisis of 2007. By contrast, aquaculture worldwide was booming.

Next came the communication "Building a sustainable future for aquaculture: A new impetus for the strategy for the sustainable development of European aquaculture" [EC, 2009]. A number of steps were taken to maintain the EU as an essential partner in global aquaculture. The priority was to support the competitiveness of EU aquaculture production by technical means and the promotion of development and high performance. Over the next four years, it became clear that past efforts had failed to produce the desired results. The Advisory Committee for Aquaculture concluded that the main reasons were insufficient implementation and that critical issues were not resolved.

In 2013, the EC issued Strategic guidelines for the sustainable development of aquaculture, which were intended to help meet aquaculture targets. The EU member states submitted national strategic plans to develop aquaculture in their territories for 2014-2020, which mostly envisaged increasing the production of fish and other aquatic organisms, increasing their value, expanding the number of farmed species, and introducing innovative breeding technologies. Carp producers who have a significant surface potential of fish ponds (incl. in Poland) do not expect a significant increase in carp production but diversify revenues from pond farms e.g. by enhancing the environmental role of ponds and developing agritourism. National aquaculture strategies of Italy, Germany, and Poland introduce innovative, intensive technologies for the farming of salmonids (incl. trout), European eel, and sturgeon. The essential elements for the competitiveness of European freshwater aquaculture are the expansion of the range of new fish species and the development of fish processing. The Advisory Committee for Aquaculture proposed focusing on three priority areas: ensuring the sustainable growth of aquaculture by optimizing licensing procedures, increasing the competitiveness of EU aquaculture, and promoting a level playing field. It was accepted that EU aquaculture must be innovative and environmentally sustainable, and products must be competitive compared to imports from third countries. Significant levels of seafood imported into the EU come from aquaculture in third countries. Countries that produce food imported to EU markets should meet EU production and environmental standards. Expanding an existing farm or setting up a new fishing farm requires access to the so-called environmental space that must align with the objectives set out in the WFD, the Marine Strategy Framework Directive, the Nature 2000 directives, and the Blue Growth Guidelines. The ability of aquaculture to meet future food needs depends on the availability of space.

The Strategic guidelines for a more sustainable and competitive aquaculture in the EU for 2021-2030 [EC, 2021] present new trends in the development of aquaculture. The EU fisheries sector must be competitive. Access to space and water and a transparent and effective regulatory and administrative framework is designed to assist planning. Coordinated spatial planning should cover marine, freshwater, and terrestrial aquaculture (recirculating aquaculture systems). Lower environmental impact (e.g. combining certain types of farming to reduce nutrient and organic matter emissions) and ecosystem services to protected areas should be a priority. The sustainable growth of EU aquaculture is more critical today than ever. It is also vital to rebuild it in the aftermath of the pandemic and ensure its long-term resilience.

Aquaculture production is expected to increase by 37% compared to 2016 and reach 109 million tonnes in 2030. Per capita global fish consumption is expected to reach 21.5 kg in 2030, compared to 20.3 kg in 2016. "Increasing global aquaculture production is predicted to fill the supply and demand gap. Aquaculture has great potential to create value and short supply chains locally, contributing to the environmentally, economically, and socially sustainable food production process. It will continue to be one of the fastest-growing sectors of livestock production" [FAO, 2018].

4. Structural aid to EU aquaculture

The main objective of the structural policy in the fisheries sector is to provide financial resources to implement the CFP and ensure the sustainable development of fisheries and aquaculture areas. Structural assistance covered sustainable aquaculture activities intended to preserve species biodiversity, satisfy food needs, and develop local communities connected with fish farming in lakes, ponds, or in special fish farming facilities. The EU fisheries policy, initially financed in 2002–2006 by the Financial Instrument for Fisheries Guidance, was financed by the European Fisheries Fund in 2007–2013 (EUR 3.8 billion for all EU countries, incl. EUR 600 million for Poland), and is now financed by the new European Maritime and Fisheries Fund. The European Court of Auditors concluded in 2014 that the European Fisheries Fund did not effectively support aquaculture and, despite subsidies, it did not bring the expected growth. At the European level, the support measures were not well designed and insufficiently supervised, and they did not provide a clear framework for aquaculture development. At the level of the member states, they were not properly applied, and national strategic plans and operational programs did not provide a basis for promoting aquaculture. In Poland, PLN 979 million was allocated to the Operational Program "Sustainable Development of the Fisheries Sector and Coastal Fishing Areas 2007–2013" for priorities 1 and 3 concerning aquaculture and sustainable development of areas dependent on fisheries [Obwieszczenie…, 2016]. The value of support for EU countries in 2014–2020 is EUR 6.4 billion, including EUR 4.3 billion for implementing planned investments in sustainable aquaculture and rural development [EP, 2014]. Poland was granted EUR 531 million, which together with the contribution from the national budget (ca. EUR 179 million) amounted to over PLN 2.8 billion. PLN 1.8 billion was allocated to priorities 1 and 2, promoting environmentally sustainable, resource-efficient, innovative, competitive, and knowledge-based fisheries [NIK, 2020].

5. Development prospects for aquaculture

Aquaculture, especially in freshwater bodies, has been present in Europe for a very long time. The farming of pond fish and oysters in the Mediterranean was well developed as far back as in Roman times, when "native breeding" systems were very popular among the wealthier families. After the "green revolution" of the 1960s, when agricultural production grew enormously through the use of improved seeds, fertilizers, and pesticides, aquaculture also received a powerful stimulus. Scientists fully domesticated and improved fish species such as salmon, sea bass, and sea bream, increasing their production to an industrial level. However, EU aquaculture has stagnated in recent years compared to world production, increasing by mere 6% since 2007. Negative experiences resulting from past mistakes made by the global agriculture and fisheries sectors necessitate changes in ecosystems.

In 2018, world aquaculture production was almost 82.1 million tonnes – 45% of total fish production. The largest fish and aquatic organisms producer is Asia. The overall trend shows that EU aquaculture production decreased by 2.2% between 2000 and 2019, compared to a 20% decrease in marine catches. EU aquaculture has stagnated over the years [FAO, 2020].

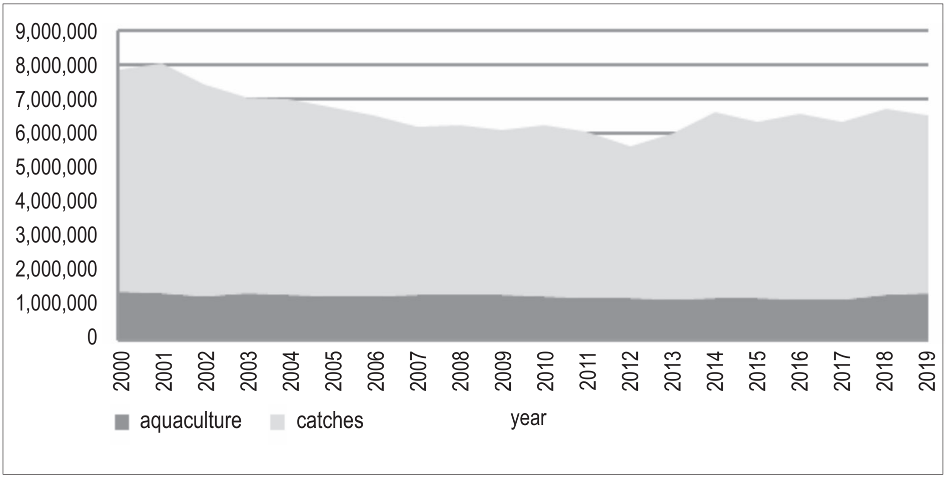

Figure 1. EU total fish production in 2000-2019 (million tonnes of live weight)
Source: Own elaboration based on: [Eurostat, 2011; STECF, 2018].

This general lack of growth in the aquaculture sector is explained, at least partially, by strict environmental regulations and a heavy bureaucratic burden that does not facilitate economic development [Guillen et al., 2019]. The EU imports over 70% of the seafood it consumes. Total aquaculture products (incl. imports) account for 25% of EU seafood consumption, while EU aquaculture products only account for 10%. Considering its exports (which in the case of aquaculture account for less than 2% of world production), the 2018 self-sufficiency rate[1] for EU fishery and aquaculture sector was ca. 42%.

Table 1. Characteristics of the EU aquaculture sector

Country	2011	2019	Share in 2019 total, %	Employment in 2018	
	Production (tonnes live weight)			Total employees	Number of enterprises
total	1,228,773	1,366,682	100.0	74,634	12,389
Spain	274,223	306,507	22.4	17,794	2,990
France	193,672	194,328	14.2	16,265	2,700
Italy	164,127	125,777	9.2	5,456	711
Poland	34,246	39,731	2.9	8,731	1,242

Source: Own elaboration based on: [Eurostat, 2019; STECF, 2019].

[1] Self-sufficiency is defined as the ability of EU member states to meet demand from their own production and can be calculated as the ratio of domestic production to domestic consumption.

In 2019, EU aquaculture production amounted to 1.36 million tonnes and increased by 11% in 2019 compared to 2011, with a total value of EUR 4.9 billion compared to EUR 3.6 billion in 2011. It was mainly concentrated in three countries: Spain (22.4%), France (14.2%), and Italy (9.2%). In 2018, 74,600 people were employed in the aquaculture sector by 2,400 companies, mostly in Spain and France. Freshwater production on land, where trout and carp dominate, increased by 12% in 2019 compared to 2000. In the same period, there was an increase of almost 12% in salmonids and of 27% in other sea fish, i.a. seabass and seabream. The most valuable fish was the bluefin tuna. EU aquaculture production stagnates mainly when it comes to mussel production in Spain and oysters in France, which increased by mere 3.5% in 9 years, as well as cephalopod breeding, which decreased the most in the analysed period.

Table 2. Main species in EU acquaculture

Commodity group	Volume (t)	Value (EUR million)	Volume (t)	Value (EUR million)
	2011		2019	
flatfish	11,338	76.838	12,994	105.124
cephalopods	3	0.100	1	0.007
other marine fish	153,622	817.077	195,677	1,076.394
bivalves and other molluscs and aquatic invertebrates	600,908	1,031.923	622,190	1,105.709
freshwater fish	97,243	262.340	109,404	316.891
miscellaneous aquatic products	86	1.002	569	11.994
crustaceans	242	5.902	414	4.915
tuna and tuna-like species	5,155	93.302	22,434	308.195
salmonids	360,176	1,320.387	403,000	2,056.321
total	1,228,773	3,608.870	1,366,682	4,985.551

Source: Own elaboration based on: [EUMOFA, 2020].

EU aquaculture is very diverse and highly specialized. The variety of activities makes it difficult to link environmental policy with the economics of production, which is a reason of the growing concern about the environmental impact of this sector. On the other hand, it is subsidized precisely to increase the level of environmental protection. The EU guidelines present a vision of the development of this sector consistent with the concept of the European Green Deal. They are also expected to help implement the farm-to-fork strategy, which is the transition of EU countries to a sustainable food system, healthy for people and less harmful to the environment than land-based farming. Major aquaculture producers, especially China and other Asian countries, need to bring food safety legislation into line with EU legislation. Still, less restrictive environmental protection regulations, therapeutic treatments, and labor laws mean that production costs in Asian aquaculture are much lower. Pursuing profitable aquaculture production must not lead to the renunciation of product quality improvement, production optimization, or environmental achievements. Undoubtedly, these are the reasons for EU's lower competitiveness. We could intensify production and increase the economies of scale, but the environmental protection regulations in the EU are very restrictive. Too often, the EU regulations interfere with the sector, creating obstacles to its development. Another limitation may be finding new places for farming and breeding fish and aquatic organisms. Therefore, it is essential that the science and aquaculture sectors cooperate in the implementation of new production technologies in order to combine three aspects of production: economic profitability, environmental impact, and production acceptable to the consumer.

Aquaculture depends on the cleanliness and pristine condition of marine and freshwater areas. EU legislation sets high health, consumer protection, and environmental sustainability standards that must be respected in aquaculture activities. Undoubtedly, they affect the costs incurred by producers, but they may contribute to gaining a competitive advantage as consumer awareness increases. The reform of the CFP is based on these high standards. The new labeling rules proposed in the Single CMO regulation can help distinguish EU aquaculture products. An essential element is the development of short food supply chains that will help people appreciate high-quality fresh local produce. In addition, sustainability certification was introduced in the EU to create market incentives for farmers to use responsible aquaculture to be more competitive. In 2005–2011, the FAO developed guidelines for a certification system to eco-label fish and seafood. The standards are closely related to the Code of Responsible Fisheries [FAO, 1995]. Compared to other countries, EU aquaculture is subject to some of the strictest quality, health, and environmental regulatory requirements. Nevertheless, it can further improve its environmental performance and thus contribute to meeting the objectives of the European Green Deal and related strategies [EC, 2021]. The FAO has developed the climate-friendly agriculture concept, covering aquaculture for food security in a changing climate [FAO, 2018]. Fish farmers are already looking at the concept of climate-friendly agriculture as an alternative and innovative practice. Fish, plants, and animals' aquatic litter are to remove solids and dissolved waste from fish farming and thus provide a self-sufficient source of food.

The EC's Blue Growth Policy for the Baltic Sea Region [Beyer, 2017] identifies aquaculture as one of the most promising sector of the maritime economy in terms of growth and employment potential. However, in the Southern Baltic, including

Poland, marine aquaculture is still underdeveloped, which may indicate its untapped potential. In the development of innovative mariculture in Poland, the increase in knowledge at the local level is of key importance, as there is a great demand for highly qualified personnel[2].

Local fisheries groups are being created with the support of the EU FLAG, as it is unlikely that aquaculture will meet all the labor and income needs of the local communities [Freeman et al., 2021]. Complementary activities are needed. The groups' strategies envisage a wide range of such complementary activities, ranging from tourism and gastronomy to the processing of by-products. Sometimes fish farms themselves create valuable landscapes and habitats (e.g. carp ponds in Central Europe). The aquaculture sector can increase the region's attractiveness, leading to the development of tourism and strengthening of local social ties.

Conclusions

There is a growing global demand for fish, not only due to population growth, but also health benefits. Unfortunately, intensive exploitation of natural resources and human activity have disrupted ecosystems' natural balance, which manifests itself in dramatic declines in the population of many fish species. Therefore, it is necessary to develop aquaculture to satisfy local demand for fish and seafood through its production in the EU. Rural fisheries make a significant contribution to preserving the biodiversity of these water resources, and their protection is a condition for sustainable economic and social development. The preservation of natural values undoubtedly shapes tourist attractiveness and improves the quality of life in areas dependent on aquaculture. Aquaculture has great potential. It supplies raw materials to fish processing plants, becoming an alternative to sea fishing. It must bridge the growing gap between aquatic food supply and the demand of a more affluent population. Support from CFP aims to improve food security and economic development in line with the EU Blue Growth strategy and the potential of creating sustainable growth and jobs in marine sectors.

Aquaculture is the fastest-growing global food production sector, the most efficient producer of animal protein with the lowest carbon footprint. Even so, it remains surprisingly little known among those outside the industry. It has been

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[2] From January 2020, the AquaVIP project coordinated by the Science and Technology Park in Klaipeda, with the participation of the University of Rostock, the University of Gdańsk and the University of Klaipeda, has been conducted for 3 years. Virtual platform for career development in aquaculture for the South Baltic region (South Baltic Interreg program), which aims to strengthen the marine aquaculture sector in the region. The AquaVIP project partners have diverse competences in innovative aquaculture, including fish and shellfish farming in recirculating water systems, experience in aquaponics and microalgae cultivation.

perceived as a development industry for many years. However, when analyzing the production results, it can be expected that its success will be determined by the consumer and nutritional trends.

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Developing an evaluation framework for smart countries with a focus on sustainability as a basis for comparative analysis

The concept of smart cities based on the principles of sustainable development and the approaches to their comparative assessment have been extensively studied. However, with both analysis and, above all, implementation concerned predominantly with matters of economy, there is not much research that combines a macro-level view with a focus on social and environmental issues. The article addresses this gap, proposing to develop a sustainability index for macro-level comparison of countries and regions. Based on a comprehensive review of printed and online sources, a set of indicators was selected and applied to 14 countries from different regions of the world. The compiled data were then normalized to generate a comparative ranking. An analysis of the results reveals regional differences in the emphasis placed on sustainability in general as well as its environmental and social aspects in particular. It also shows that if the government takes concrete regulatory measures for insreasing sustainability, with time quality of life improves, and the economy benefits. By identifying potential problem areas, systematic and ongoing assessment of sustainability indicators would make it possible to address them, thus supporting the efforts to meet climate strategy targets. For this reason, efforts should be made to elaborate the index further and include more countries, so that better recommendations may be made on its basis.

Keywords: climate change, smart country, sustainable development, quality of life

JEL classification: D01, O18, R41, Q01

Introduction

In December 2018, the European Union and 196 other countries met at the 24th United Nations Climate Change Conference and agreed on the Katowice Climate Package implementing the Paris Agreement towards a sustainable global climate policy [UN, 2018]. In October 2018, in preparation for the conference, the Intergovernmental Panel on Climate Change published a special report (IPCC 2018) [IPCC, 2018]. Its key finding was that it is still possible to limit the temperature increase to 1.5°C above pre-industrial levels, but further reductions in greenhouse gas emissions and human-caused CO_2 emissions would be necessary. The climate strategy set key targets for the use of renewable energy, cuts in GHG emissions, and improved energy efficiency.

The EU has paid great attention to climate change in recent years. With the latest major update in November 2018, the European Commission presentedthe European Green Deal, its ambitious long-term strategy with for a climate-neutral Europe by 2050 [EC, 2019; 2020]. More precisely, the key objective is to achieve a GHG reduction of 50–55% by 2030 and climate neutrality in terms of GHG net emissions by 2050 (instead of the original aim of a 60% reduction).

Science has already sufficiently described the adverse effects of global warming with regard to human health and mortality (one example being the negative impact of air pollution on mental health) and its historical ramifications for the present and future of humanity as a whole [Dai, 2013; Hansen et al., 2006; US GCRP, 2018; Vitousek, 1994; Mathioudakis et al., 2020; Solanas et al., 2014; Turan, Beşirli, 2008].

At the same time, a year-by-year trend of movement from rural areas to cities can be recognized. OECD countries show a steady increase of urbanization, whose level rose from 62.5% in 1960 to 80.6% in 2018, and it is expected to reach 86% by 2050 [WB, 2018]. There is a particular threat to the more vulnerable populations in developing countries, because increasing urbanization with its negative effects is particularly evident in the emerging markets [Patz et al., 2005; Berry, 2008; Sadorsky, 2014].

Ultimately climate change and urbanization present some of the most significant challenges facing humanity in the coming decades, which shows the necessity for a closer look at these topics. A smart country should set the course for the urban regions of tomorrow to make a significant contribution to counteracting global climate change. Initial approaches to a smart country have already been examined in the literature from various perspectives.

There are a number of ways to evluate the performance of cities or urban regions. In addition to productivity and infrastructure improvements, they increasingly focus on social aspects such as quality of life, equity, inclusion, and environmental sustainability [Ruso et al., 2019]. The measures differ for particular regions, depending on their individual characteristics and needs [Antwi-Afari et al., 2021; Sourav et al., 2020]. Adamik and Sikora-Fernandez [2021] emphasize the importance of Industry 4.0 and technological innovation for performance results on three levels: (1) smartness, (2) competitiveness, and (3) sustainability.

However, to set a country on a path of sustainable development, a prerequisite is an efficient political and economic environment. A holistic approach to performance assessment must therefore be adopted, which prioritizes the “health” of the economy, acknowledges all stakeholders, systematically solves the challenges it faces, and thus strives to align social behaviors and habits with the ethos of sustainability.

The main aim of this article is to develop a sustainability evaluation framework and on its basis analyze and compare selected countries. Whereas typically such efforts focus primarily on financial considerations, this one offers a more comprehensive view, placing stronger emphasis on social and environmental aspect. This is all too rare not just in research, but above all in practice, making it a contribution of special value for macro-level decision-making.

1. Selected countries – overview

The research focuses on Europe (the EU), two regions of Asia (the Gulf and the Far East), and the United States. It includes countries that reached the stage of economic maturity (Austria, Germany, the US, South Korea), newly industrialized countries (China, India, Malaysia), and developing countries (United Arab Emirates, Qatar, Saudi-Arabia). Although the sample is not generally representative, it is heterogenous in terms of sizes, economic power, cultures, and political systems. The 14 countries analyzed in the article are presented in Table 1.

Table 1. Selected countries – population and CO_2 emissions

Country (region)	Population (total / world share in %)	CO_2 emissions (total in Mt / world share in % / per capita in tonnes)
Austria (EU)	9,006,398 / 0.12	68.50 / 0.19 / 7.61
China (Far East)	1,439,323,776 / 18.47	10,174,68 / 27.92 / 7.07
France (EU)	65,273,511 / 0.84	323.75 / 0.89 / 4.96
Germany (EU)	83,783,942 / 1.07	701.96 / 1.93 / 8.38
India (Far East)	1,380,004,385 / 17.70	2,616 / 7.18 / 1.90
Malaysia (Far East)	32,365,999 / 0.42	250.09 / 0.69 / 7.73
Poland (EU)	37,846,611 / 0.49	322.63 / 0.89 / 8.52
Qatar (Gulf)	2,881,053 / 0.04	109.34 / 0.30 / 39.95
Saudi Arabia (Gulf)	34,813,871 / 0.45	582.15 / 1.60 / 16.72
Singapore (Far East)	5,850,342 / 0.08	38.94 / 0.11 / 6.66
South Korea (Far East)	51,269,185 / 0.66	611.26 / 1.68 / 11.92
Spain (EU)	46,754,778 / 0.60	252.68 / 0.69 / 5.40
UAE (Gulf)	9,890,402 / 0.13	190.68 / 0.52 / 19.28
US (North America)	331,002,651 / 4.50	5,524.70 / 14.50 / 16.97

Source: Population: [Worldometer]; CO_2 emissions: Own elaboration based on: [GCA].

Together, these countries have a population of more than 3.5 billion, and thus represent almost 46% of the global population. They also own ca. 65% of the world's wealth (USD 234.5 trillion) and are responsible for nearly 60% of global CO_2 emissions (China and the US alone account for 42.5%).

2. Sustainability indicators

When conceptualizing a smart country, there are many criteria, challenges, and risks to be taken into consideration, all of which should first be listed and analyzed [Kitchin, 2016]. As proposed by Shen et al. [2010], sustainability of development of a smart country can be then evaluated in the following dimensions: 1) environmental, 2) economic, 3) social, and 4) governance, which are divided into further 37 categories and contain as many as 115 indicators. This comprehensive International Urban Sustainability Indicator List is based on sets of indicators used by different international and regional organizations [UN, 2007; UN-Habitat, 2004; WB, 2009; EF, 1998; EC, 2000]. This article is based on a set of indicators belonging to four dimensions: 1) general, 2) environmental, 3) social, and 4) economic.

As part of the Agenda 2030, the UN and its 193 member states agreed on 17 sustainable development goals related to environmental sustainability, peace, justice, good governance and partnership, and social inclusion [Gigliotti et al., 2018; UN, 2018a; 2019b]. This means that decisions about the future of any country should take into account not only economic parameters, but also, and primarily, social and sustainability issues – and at every stage involve all stakeholders [SDSN, 2015]. With that in mind, the human development index was included in the general dimension, as was the democracy index [EIU], since any real involvement of residents in the decision-making processes rests on the political system they live in. Its inclusion also serves to promote the interests of residents, fulfil their basic needs, and eliminate corruption. The last general indicator, gross national income per capita, shows the total income generated by all residents of a country.

The environmental dimension groups indicators of particular importance from the point of view of sustainability. The first three focus on areas crucial for the conservation of the Earth: share of renewables in energy sources, volume of CO_2 emissions, and environmental protection. A shift from fossil fuels to "green" energy is one of the main steps on the path to climate neutrality [Johnsson et al., 2019; Salvia et al., 2021]. The last two indicators concern various impacts on mortality rates [Balakrishnan et al., 2019; WHO, 2016].

The social dimension contains a single indicator describing the proportion of the elderly in the population. This ratio is an indication of economic development, but at the same time the higher it is, the greater the burden (fiscal and otherwise) on the rest of the society, and the more difficult it will be to achieve sustainability.

The first indicator in the last, economic dimension, measures the volume of a country's investments in fixed assets (infrastructure, machinery, valuables, etc.) and goods held by firms. The second indicator measures the volume of investments in research and development, which are a crucial factor of innovation and efficiency.

The complete set used in the comparative analysis consists of the following 12 sustainability indicators[1]:

O: General
- O1: Human development index
- O2: Democracy index
- O3: Gross national income per capita

ES: Environmental
- ES1: Environmental parameters
  - ES1.1: Renewable energy consumption
  - ES1.2: Carbon dioxide emissions
  - ES1.3: Natural resource depletion
- ES2: Environmental threats
  - ES2.1: Mortality rate – air pollution
  - ES2.2: Mortality rate – sanitation

SS: Social
- SS1: Old-age dependency ratio

E: Economic
- E1: Gross capital formation
- E2: Research and development expenditure

3. Evaluation methodology

The values of sustainability indicators for the 14 selected countries were carefully analyzed. In order to achieve comparable results, various rules and assumptions were applied, which led to some limitations in the evaluation, but had only slightly negative effect on the significance of the results. The most recent available data were always used, and for some indicators – an average from several years. The values were correlated in each case with either the highest (e.g. democracy index, renewable energy consumption) or the lowest value (e.g. HDI, natural resource depletion). Cluster analysis was performed under different threshold

[1] Detailed description of the indicators can be found in Appendix A.

distances in order to define an optimal cutting level for grouping the countries into three clusters: (very) well, moderately, or (very) poorly developed[2].

4. Sustainability indicators – data

The next sections present the results from the sustainability factors are shown. The evaluation of the general dimension shows that Germany has the highest score when measured on the HDI of the countries considered, followed by Singapore. India, ranked 124th in the world, is by far in last place. Regarding the democracy index, again Germany is at the top, followed by Austria and Spain. Concerning the countries compared, the governments of the UAE, China, and Saudi Arabia are considered the most authoritarian. Looking at GNI per capita, the picture is somewhat different, with Qatar in first place, followed by Singapore and the UAE. However, it should be emphasized that the first two, in particular, represent very small countries with quite a few inhabitants. Even though India and China have been growing strongly in economic terms for years, the prosperity does not reach the broad masses, and the GNI per capita is relatively low.

Table 2. Sustainability indicators – general dimension

Country	O1: Human development index (from 0 worst to 1 best)	O2: Democracy index (from 0 worst to 10 best)	O3: Gross national income per capita (USD)
Austria	0.922	8.29	46,231
China	0.761	2.26	16,127
France	0.901	8.12	40,511
Germany	0.947	9.58	46,946
India	0.645	6.90	6,829
Malaysia	0.810	7.16	27,227
Poland	0.880	7.35	27,626
Qatar	0.848	3.19	110,489
Saudi Arabia	0.854	1.93	49,338
Singapore	0.938	6.02	83,793
South Korea	0.916	8.00	36,757
Spain	0.904	8.29	35,041
UAE	0.890	2.76	66,912
US	0.926	7.96	56,140

Source: Own elaboration based on IMF, OECD, WB, and UN figures.

2 Threshold values can be found in Appendix B.

The next, environmental dimension (cf. Table 3), focuses on the environment-related factors on which this analysis places a particular emphasis. For example, the relationship between energy consumption from fossil fuels and renewable energies is examined. Unfortunately, the picture is still very negative; only Austria and India have a renewable energy consumption of more than 30%.

The type of energy generation impacts CO_2 emissions, which are considered separately concerning economic output. Singapore is particularly strong here, followed by France and Spain. Only France can show a value of less than 50% for energy generation based on fossil fuels. However, for France, it is mainly not due to a high share of renewable energies, but to the high share of nuclear energy, which does not emit any CO_2, but is now viewed critically from an environmental and social point of view due to the nuclear waste and the increased risk [Prăvălie, Bandoc, 2018]. China and South Korea are economically very strong, but the high CO_2 emissions indicate that the processes to achieve this economic performance are not very sustainable.

Policymakers in many countries still do not consider that processes detrimental to the environment resulting from a lack of regulation, e.g. for the emission of CO_2 and other pollutants, also directly affect the economy to a great extent. While these effects are not immediately perceptible, they will be as they progress.

Table 3. Sustainability indicators – environmental dimension – parameters

Country	ES1.1: Renewable energy consumption (% of total final energy consumption)	ES1.2: Carbon dioxide emissions (kg per GDP unit in 2010 USD)	ES1.3: Natural resource depletion (% of GNI)
Austria	34.4	0.17	0.1
China	12.4	0.47	0.9
France	13.5	0.12	0.0
Germany	14.2	0.21	0.0
India	36.0	0.26	1.0
Malaysia	5.2	0.28	3.1
Poland	11.9	0.31	0.4
Qatar	0.0	0.27	7.4
Saudi Arabia	0.0	0.33	7.9
Singapore	0.7	0.10	0.0
South Korea	2.7	0.33	0.0
Spain	16.3	0.16	0.0
UAE	0.1	0.31	4.0
US	8.7	0.29	0.2

Source: Own elaboration based on IMF, OECD, WB, and UN figures.

The last factor of the Environmental parameters compares the country regarding the monetary valuation of energy, mineral, and forest depletion. Compared with the other countries evaluated, the UAE, Qatar, and Saudi Arabia, in particular, have a very high and thus negative value.

The second part of the environmental sustainability factors reflects the environmental threats. It shows that the mortality rate attributable to household and ambient air pollution is still relatively high. Policies in the EU and increasingly in other countries are introducing more and more regulations to reduce air pollution [EC, 2021; Krämer, 2020]. In recent years, the economies of China and India have grown rapidly, but their high mortality rates are an indicator that this has been at the expense of human health. In addition, in India in particular, a high percentage of the population does not have access to clean water, and thus a high mortality rate is caused by unsafe water, sanitation, and hygiene services.

Table 4. Sustainability indicators – environmental dimension – threats

Country	ES2.1: Mortality rate – air pollution (per 100,000 population)	ES2.2: Mortality rate – sanitation (per 100,000 population)
Austria	15	0.1
China	113	0.6
France	10	0.3
Germany	16	0.6
India	187	18.6
Malaysia	47	0.4
Poland	38	0.1
Qatar	47	0.1
Saudi Arabia	84	0.1
Singapore	26	0.1
South Korea	20	1.8
Spain	10	0.2
UAE	55	0.1
US	13	0.2

Source: Own elaboration based on IMF, OECD, WB, and UN figures.

In the assessment dimension "SS: Social sustainability", it is evident that the population, especially in Europe, is becoming increasingly older on average. As a result, there is a lack of young and well-educated citizens. However, these play a crucial role in driving innovations and developing the economy adequately, especially in the long term, to meet climate challenges. It is noticeable that Saudi Arabia, the UAE, Singapore, and India have an exceptionally high proportion of working-age people.

Table 5. Sustainability indicators – social dimension

Country	SS1: Old-age dependency ratio (% of people aged 65 and more per 100 people aged 15–64)
Austria	38.5
China	25.0
France	40.4
Germany	44.0
India	12.5
Malaysia	38.2
Poland	14.7
Qatar	37.0
Saudi Arabia	5.7
Singapore	8.3
South Korea	34.5
Spain	39.8
UAE	6.4
US	32.5

Source: Own elaboration based on IMF, OECD, WB, and UN figures.

In the last, economic dimension, the indicators are considered that have a concrete connection to social and environmental sustainability. For example, within the gross capital formation, different factors to improve the infrastructure such as construction of roads, railways, schools, hospitals, and private residential dwellings and business offices are considered. In addition, inventories are included, which compensate for fluctuations in production or sales and thus make the economy more robust. It is evident that Middle Eastern and Asian countries such as Saudi Arabia, China, India, and Malaysia perform better than European countries. One indicator for this may be the strong dependence of Western countries on the Asian market based on just-in-time delivery of goods and raw materials.

Investment in research and development is essential for creating innovative products and processes for sustainable economic change [WEF, 2019].

Malaysia, Austria, and Germany have a quite good rate in terms of GDP. On the other hand, India and Saudi Arabia Certain countries are trying to compensate for this by investing in innovative products and commissioning foreign companies.

Table 6. Sustainability indicators – economic dimension

Country	E1: Gross capital formation (% of GDP)	E2: Research and development expenditure (% of GDP)
Austria	25.3	3.1
China	44.3	2.1
France	23.5	2.2
Germany	21.3	2.9
India	31.0	0.6
Malaysia	30.2	4.2
Poland	23.6	1.3
Qatar	20.7	1.0
Saudi Arabia	44.6	0.5
Singapore	25.9	0.8
South Korea	26.6	2.2
Spain	21.9	1.2
UAE	22.4	1.0
US	20.6	2.7

Source: Own elaboration based on IMF, OECD, WB, and UN figures.

5. Sustainability index – comparative analysis

Since the values of raw data obtained in the previous step were measured on different scales, they had to be normalized using the following formula:

$$z\ value = \frac{(raw\ scale - mean\ (raw\ scale)}{sd\ (raw\ scale)} \quad [1]$$

The score value was calculated based on the z-transformed factor scores as a simple average over all factors, taking the pre-defined directions, plus for stimuli and minus for penalties, into account. The total normalized average scores were then used to rank the countries and obtain the sustainability index. Thus, Austria, with a score of 0.532, is in first place, ahead of Singapore with a score of 0.310, followed closely by Germany with a score of 0.308.

In addition, the results are allocated into three categories based on the raw values according to the defined thresholds and color coded: green = (very) well developed, yellow = moderately developed, red = (very) poorly developed, yields the result, shown in Table 7.

Table 7. Sustainability index – comparative analysis

Country	O1	O2	O3	ES 1.1	ES 1.2	ES 1.3	ES 2.1	ES 2.2	SS1	E1	E2	NAS	Rank.
	+	+	+	+	–	–	–	–	–	+	+		
Austria	0.67	0.78	-0.01	1.98	0.89	0.61	0.67	0.32	-0.94	-0.25	1.14	0.532	1
China	-1.29	-1.55	-1.12	0.11	-2.15	0.32	-1.29	0.22	0.22	2.14	0.23	-0.379	13
France	0.41	0.71	-0.22	0.20	1.40	0.64	0.77	0.28	-1.28	-0.48	0.32	0.252	4
Germany	0.97	1.27	0.02	0.26	0.49	0.64	0.65	0.22	-1.34	-0.75	0.96	0.308	3
India	-2.70	0.24	-1.47	2.12	-0.02	0.28	-2.77	-3.46	0.76	0.47	-1.12	-0.698	14
Malaysia	-0.70	0.34	-0.71	-0.51	-0.22	-0.47	0.03	0.26	0.73	0.37	2.13	0.114	7
Poland	0.15	0.42	-0.70	0.06	-0.53	0.50	0.21	0.32	-0.72	-0.46	-0.49	-0.112	9
Qatar	-0.23	-1.19	2.37	-0.95	-0.12	-2.02	0.03	0.32	1.44	-0.83	-0.76	-0.177	10
Saudi Arabia	-0.16	-1.67	0.11	-0.95	-0.73	-2.20	-0.71	0.32	1.17	2.18	-1.22	-0.352	12
Singapore	0.86	-0.10	1.38	-0.89	1.60	0.64	0.45	0.32	0.25	-0.17	-0.94	0.310	2
South Korea	0.59	0.67	-0.36	-0.72	-0.73	0.64	0.57	-0.03	-0.18	-0.09	0.32	0.063	8
Spain	0.45	0.78	-0.42	0.44	0.99	0.64	0.77	0.30	-1.02	-0.68	-0.58	0.152	6
UAE	0.28	-1.35	0.76	-0.94	-0.53	-0.80	-0.13	0.32	1.46	-0.61	-0.76	-0.210	11
US	0.71	0.65	0.36	-0.21	-0.33	0.57	0.71	0.30	-0.56	-0.84	0.78	0.196	5

Source: Own elaboration.

The distribution of results depends on the evaluation criteria. Since all countries are quite highly developed, all HDI and GNI per capita values are relatively high. However, there are clear outliers when it comes to the democracy index – Qatar, the UAE, Saudi Arabia, and China are considered authoritarian. Environmental parameters are quite negative, especially in industrialized countries. The consequences this has for human health and life are most dire in India and China. This underscores the need for urbanized areas to position themselves better based on environmentally friendly initiatives implemented jointly by politicians, private companies, educational institutions, scientific institutes, and the residents.

On another note, most of the countries do well in terms of economic sustainability, which means a high number of well-educated specialists, large research investments, and relative prosperity. However, low gross capital formation relative to GDP suggests that Germany, the US, Spain, and Qatar may be suffering from infrastructure deficits. But, since GDP varies and is a relative value, additional parameters are necessary for a more detailed analysis.

6. Reliability analysis

The quality of data used to calculate the index was tested using confirmatory factor analysis (dimensional test) supplemented by the reliability coefficient Cronbach's alpha. Multidimensional scaling had to be applied since not all factors show high loadings (> 0.6) in the score dimension – e.g. O3 and ES1.1 show particularly low factor loadings (Table 8).

Table 8. Goodness-of-fit test

Factor	Factor loading	Encoding alpha	Alpha item excluded
O1	–0.796	invers	0.775
O2	–0.801	invers	0.774
O3	–0.142	invers	0.839
ES1.1	–0.091	invers	0.842
ES1.2	0.647	–	0.788
ES1.3	0.623	–	0.796
ES2.1	0.874	–	0.764
ES2.2	0.460	–	0.814
SS1	–0.813	invers	0.773
E2	0.716	–	0.781
E4	–0.487	invers	0.808
alpha total	0.813	–	–

Source: Own elaboration.

However, since the score is by definition intended to represent entirely different dimensions, and since it was previously included in the macroeconomics for domain-specific reasons, these do not necessarily have to be in a robust correlative relationship and are therefore not removed from the score. The reliability coefficient nevertheless reaches a good, if somewhat lower value of 0.813 (removing factor O3 would boost it to 0.839, and ES1.1 – to 0.842)

To check the robustness of the normalized average scores, a simulation was performed by removing one country from the sample and calculating z-scores and normalized average scores for the remaining countries based on the reduced sample, and repeating this step 14 times, ech time removing a different country. As a result only minor deviations from the simulated mean can be observed, and a ranking based on the simulated values is identical to the original one, which confirms the robustness of the normalized average scores. The distribution of the simulated values is shown in Table 9.

Table 9. Robustness score values

Country	Normalized average scores		Simulated normalized average scores					
	Value	Rank.	Mean	Rank.	Med.	SD	Min.	Max.
Austria	0.532	1	0.534	1	0.530	0.028	0.504	0.607
China	–0.379	13	–0.385	13	–0.365	0.074	–0.623	–0.330
France	0.252	4	0.253	4	0.253	0.021	0.224	0.295
Germany	0.308	3	0.305	3	0.307	0.024	0.277	0.352
India	–0.698	14	–0.673	14	–0.669	0.031	–0.733	–0.600
Malaysia	0.114	7	0.106	7	0.112	0.042	–0.009	0.154
Poland	–0.112	9	–0.110	9	–0.102	0.025	–0.159	–0.068
Qatar	–0.177	10	–0.180	10	–0.172	0.040	–0.285	–0.137
Saudi Arabia	–0.352	12	–0.350	12	–0.344	0.032	–0.436	–0.323
Singapore	0.310	2	0.312	2	0.316	0.020	0.277	0.341
South Korea	0.063	8	0.045	8	0.073	0.082	–0.218	0.094
Spain	0.152	6	0.154	6	0.157	0.023	0.123	0.199
UAE	–0.210	11	–0.209	11	–0.203	0.034	–0.283	–0.181
US	0.196	5	0.198	5	0.200	0.025	0.148	0.233

Source: Own elaboration.

Conclusions

Urbanization, bringing with it problems such as traffic congestion, air pollution, and the resulting physical and psychological stressors, causes an increasing need for sustainable urban development. However, previous research considered the different aspects of building a sustainable country in relative isolation. This article offers a more comprehensive approach. Based on an extensive literature review, a set of sustainability indicators was compiled, which could be used as an argument for urban development programs to prioritize ecological and social factors over economic ones.

Moreover, based on those indicators, a sustainability index was developed, allowing to evaluate and rank countries in terms of sustainability in four different dimensions. It was applied to 14 countries and showed that countries such as China, India, Saudi Arabia, and the UAE, economically strong but also marked by pronounced inequalities, are straggling behind the EU in terms of environmental and social sustainability. Hence, the importance of a socially-oriented economic policy. The EU, in turn, is dealing with problems related to CO_2-emitting raw materials, infrastructure, and aging society.

Overall, three EU countries – Austria, France, and Germany – are at the top of the ranking in all four dimensions, accompanied by the a city-state of Singapore in the second place. South Korea tends to rank in the middle due to low social and environmental sustainability.

Neither was the analyzed sample of countries representative, nor the chosen set of indicators necessarily best suited to evaluate those countries, and it is possible that using different indicators would yield a different ranking. The sample was relatively small, overrepresented Europe and Asia, and comprised predominantly economically strong countries. Including developing countries with more extreme factor values would likely affect the mean and the standard deviation. However, as the robustness analysis revealed no relevant biases, it can be assumed that even if only European and Asian countries were selected for analysis, they would maintain their relative positions in the ranking.

This article should be treated as an element of a broader discussion and an alternative to the propositions of other researchers [Kitchin, 2016; Shen et al., 2010]. The evaluation framework it presents can be used by others for the purpose of examining other countries and include different indicators, e.g. to put more emphasis on social and environmental sustainability. In this regard, considering their mutual dependency, city-level solutions should be adapted to a country-wide macroeconomic level. This way policies promoting sustainability can positively affect the values of established environmental, social, and economic indicators. When implementing a holistic solution, it is important to measure its impact, to make sure that in practice it really is a sustainable, iterative and continuous process of improvement.

A significant contribution to managing climate change can only be made if long-term thinking is applied and the environmental and social factors (quality of life) are given priority. Environmentally harmful processes are still prevalent, especially in industry and in urban areas, due to the dominance of individual motorized transport. Moreover, as a result of increasing urbanization, cities shoulder more and more responsibility for climate change. Therefore, concrete measures based on international agreements must be broken down to country level and ultimately to the level of cities and municipal councils. This also means that policymakers must focus on long-term sustainability rather than on short-term profit maximization even if it means making disruptive decisions [EC, 2020].

This paper shows that a systematized evaluation framework for urban development sustainability is an effective way to address climate change substantially. The next step should therefore be to elaborate it further and use it in practice as a tool for an ongoing progress assessment, so that it can help ensure prosperity for present and future generations and sustainability in all dimensions of social life.

Countries around the world should adopt a more holistic view of sustainability, assessing economic health based on natural and human capital rather than financial measures such as GDP and GNI, which do not take into account long-term negative impacts on the environment, people, and other living organisms [Lange et al., 2018].

A stronger focus on sustainability indicators can facilitate the implementation of development strategies that can take us one step closer to global climate neutrality. Many countries are already making progress on the road to sustainability, demonstrating that it stores great potential, and with practices of shared learning and experience exchange – maybe even a promise of greater efficiency. Ultimately, the processes of today will have to be put to the test and reorganized with a view to sustainability, if we are to achieve the climate neutrality turnaround in the coming decades.

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Appendix A. Description of the sustainability indicators

Indicator	Description
O1: Human development index	A composite index measuring average achievement in three basic dimensions of human development: long and healthy life, knowledge, and decent standard of living.
O2: Democracy index	Countries scored on a 0–10 scale, with higher scores indicating higher level of democracy (x > 8 = full democracy; 8 ≤ x 6 = flawed democracy; 6 ≤ x > 4 = hybrid regime; x ≤ 4 = authoritarian).
O3: Gross national income per capita	Aggregate income of an economy generated by production and ownership of factors of production, less the incomes paid for the use of factors of production owned by the rest of the world, converted to international dollars using PPP rates, divided by midyear population.
ES1.1: Renewable energy consumption	Share of renewable energy (incl. hydroelectric, geothermal, solar, tidal, and generated by wind, biomass, and biofuels) in total final energy consumption.
ES1.2: Carbon dioxide emissions	Anthropogenic CO_2 emissions due to burning fossil fuels, gas flaring, and cement production, incl. forest biomass emissions caused by deforestation.
ES1.3: Natural resource depletion	Monetary valuation of energy and mineral and forest depletion.
ES2.1: Mortality rate – air pollution	Deaths resulting from exposure to ambient (outdoor) air pollution (generated by transport and industrial and household activity) and household (indoor) air pollution (from using solid fuel for cooking).
ES2.2: Mortality rate – sanitation	Deaths resulting from unsafe water, sanitation and hygiene services, focusing on inadequate wash services.
SS1: Old-age dependency ratio	Ratio of people aged 65 and more (i.e., generally economically inactive) to 100 people aged 15–64.
E1: Gross capital formation	Total volume of investments in fixed assets of the economy (land improvements, machinery, equipment, valuables, construction of infrastructure, etc.) plus net changes in inventories (work in progress and finished goods held by firms).
E2: Research and development expenditure	Public and private current and capital expenditures on creative work (basic research, applied research, experimental development, etc.) undertaken systematically to increase knowledge (incl. knowledge of humanity, culture, and society) and the scope of its application.

Source: Own elaboration based on: [UN, 2019a; 2019c, pp. 342, 346, 347; EIU; Lange et al., 2018].

Appendix B. Thresholds for sustainability indicators

Indicator	Data for	Formula	(Very) well developed	Moderately developed	(Very) poorly developed
O1: Human development index	2019	0–1 scale	x ≥ 0.8	0.8 > x ≥ 0.7	x < 0.7
O2: Democracy index	2020	0–10 scale	x ≥ 8	8 > x ≥ 6	x < 6
O3: Gross national income per capita	2019	USD	x ≥ 30,000	30,000 > x ≥ 10,000	x < 10,000
ES1.1: Renewable energy consumption	2015	% of total final energy consumption	x ≥ 40	40 > x ≥ 15	x > 15
ES1.2: Carbon dioxide emissions	2016	kg per GDP unit in 2010 USD	x ≤ 0.15	0.15 > x ≤ 0.25	x > 0.25
ES1.3: Natural resourcedepletion	2018 (av. 2012–2017)	% of GNI	x ≤ 0.5	0.5 > x ≤ 5	x > 5
ES2.1: Mortality rate – air pollution	2016	cases per 100,000 population	x ≤ 20	20 > x ≤ 60	x > 60
ES2.2: Mortality rate – sanitation	2016	cases per 100,000 population	x ≤ 0.5	0.5 > x ≤ 4	x > 4
SS1: Old-age dependency ratio	2018	% of people aged 65 and more per 100 people aged 15–64	x ≤ 10	10 ≥ x ≤ 25	x > 25
E1: Gross capital formation	2015–2018	% of GDP	x ≥ 30	30 > x > 22	x ≤ 22
E2: Research and development expenditure	2018	% of GDP	x ≥ 2.5	2.5 > x ≥ 1.5	x < 1.5

Source: Own elaboration.