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Design of a Covid-19 model for environmental impact: From the partial equilibrium to the Computable General Equilibrium model

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Abstract

The Covid-19 pandemic led to a loss of employment in many sectors of the economy around the world. This negatively affected the industry capacity of production of many countries. Linking the CO2 emissions to the production capacity, the total pollution is likely to decrease. We investigate this issue by designing a simple environmental model based on the partial equilibrium (PE). We test this theoretically and empirically using recent data on the total contamination for four regions and countries. Then, we link our model to the CGE model of Hosoe et al. (2010) to capture the impact on other sectors of the economy. The final model PE-CGE is therefore designed through the household consumption demand channel. Broadly, our findings show that the environmental impact of the pandemic depends on the structure of the economy. While the USA, China and Sub-Saharan Africa reduce their CO2 emissions, that of the EU rather increases.

Keywords: Partial Equilibrium, Computable General Equilibrium, Covid-19, CO2 emissions, Employment, Production

Jel Classification: C68, F14, Q51

1. Introduction

Since the occurrence of the coronavirus pandemic (covid-19), many studies have attempted to assess its impact on the economy (Lone and Ahmas, 2020; Daniel, 2020; Dashraath et al., 2020; Bai et al., 2020). The most important and difficult issue that economists have been facing to was how to build a model to control the pandemic evolution and their consequences on activities. Indeed, in many countries, the pandemic has led to a weakness of activities in industries. However, the environmental issue has not been addressed. In this study we develop an environmental model based on the covid-19 crisis. This model results from a connexion between a partial equilibrium (PE) and the Hosoe et al. (2010)'s standard CGE model. Indeed, Computable General Equilibrium (CGE) models have become a standard tool for empirical economic analysis (PwC, 2014). Their primary use is to assess the impacts of important policies such as changes in tax policy, government spending, import tax tariff policy, CO2 emissions etc. Since the Johannsen's (1960) empirical CGE analysis, many CGE models have been developed. Some CGE models have focused on financial flows and assets (see Lewis, 1985; Feltenstein, 1986; Rosensweig and Taylor, 1990; Bourguignon et al., 1992; Haqiqi and Mirian, 2015). Others like the Adelman-Robinson model of South Korea and Taylor-Lysy model of Brazil were designed to study the impact of alternative policy choices on the extend of poverty and the distribution of income (Robison, 1991). Most recently there are many other CGE models that focus on macroeconomic aspects (see Decaluwé et al., 2001; McDonald, 2007; Hosoe et al., 2010; Cardenete et al. 2017). Concerning the environmental aspect, some studies focus on national economies (see Bergman, 1991; Dellink et al., 1995; Naqvi, 1998; Parry and Williams, 1999; Fadali, 2013; Yahoo and Othman, 2017; Dellink, 2020). For example, Dellink (2020) constructed a dynamic applied general equilibrium model (AGEM) to assess the pollution and abatement policy for Netherland. Otherwise, there are studies that emphasise on global economy such as OECD's Green model (see Lee et al, 1994), MERGE model built by Manne and Richels (1999), DICI model built by Nordhaus (1994)[1]. In the US economy, Fadali (2013) highlighted three main encounter energy models: The National Energy Modeling System (NEMS) that focuses on the prediction of energy production, consumption and price in the USA; the HAIKU model that focuses solely on the electricity sector and the Regional Energy Deployment System (ReEDS) used to analyse electricity generation capacity saddle. Regarding the partial equilibrium, even though one may focus only on one market, there are common in the literature. Bouet et al. (2014) built a PE model to analyse the value chain under the differential export tax scenario. Fontagné et al. (2010) used a PE to measure the Economic Partnership Agreement focusing on the demand side. The linkage between the PE and CGE models have been discussed by Delzeit et al. (2020) who identified two methods of linkage: the one-way linkage and the two-way linkage.

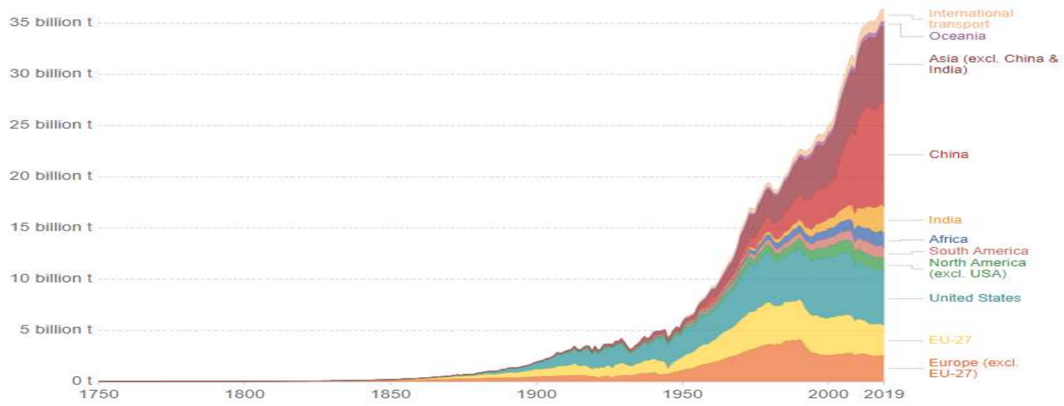
Therefore, the main research question of this study is: does the Coronavirus pandemic have an impact on the environment? More precisely, may the expected decrease in production lead to a decrease of CO2 emissions around the world? We analyse theoretically and empirically this question in our model (PE-CGE) using data on four regions in the world (the United States of America, USA; the European union, EU; China, CHN and the Sub-Saharan African countries, AFR). The choice of these regions is twofold: Indeed, O'Ryan et al. (2020) defended that energy-related CO2 emissions quadrupled reaching 80 MtCO2 over the past two decades and in the middle of years 1990s, China as well as the United States and the European union have become the world most populous countries and largest coal producers and

[1] For more studies see Abrell (2010)

consumers (Zhang, 1998). According to Global Carbon Project (2020) sources, data of Table 1 show that China contributed in average to 27.52 per cent of total CO2 emissions in the world between 2017 and 2019; the USA follow with 14.70 per cent then the EU with 9.43 per cent; India and Russia follow with 7.06 and 4.62 per cent respectively. That of Africa is 3.09 per cent. Therefore, we include the Sub-Saharan Africa region in our sample in order to have a balanced sample. Figure 1 summarizes the classification around the world and Table 2 presents the top 10 CO2 total emissions countries in 2018.

The remainder of the paper is organized as follows: Section 2 presents the partial equilibrium model; Section 3 summarizes the standard CGE model while Section 4 makes a link between the PE et CGE models; in Section 5 some empirical evidences are put in place before concluding in Section 6.

Figure 1: Annual total CO2 emissions by world region (production perspective)



Source: Our World in Data based on Global Carbon Project (2020)

Table 1: Total share of CO2 emissions by region in percentage

Region	2017	2018	2019	Average
Africa	3.86	3.88	3.94	3.89
China	27.32	27.34	27.92	27.52
EU-27	8.76	8.39	8.00	8.38
EU-28	9.85	9.43	9.02	9.43
India	6.88	7.12	7.18	7.06
Russia	4.61	4.64	4.61	4.62
United States	14.72	14.90	14.50	14.70

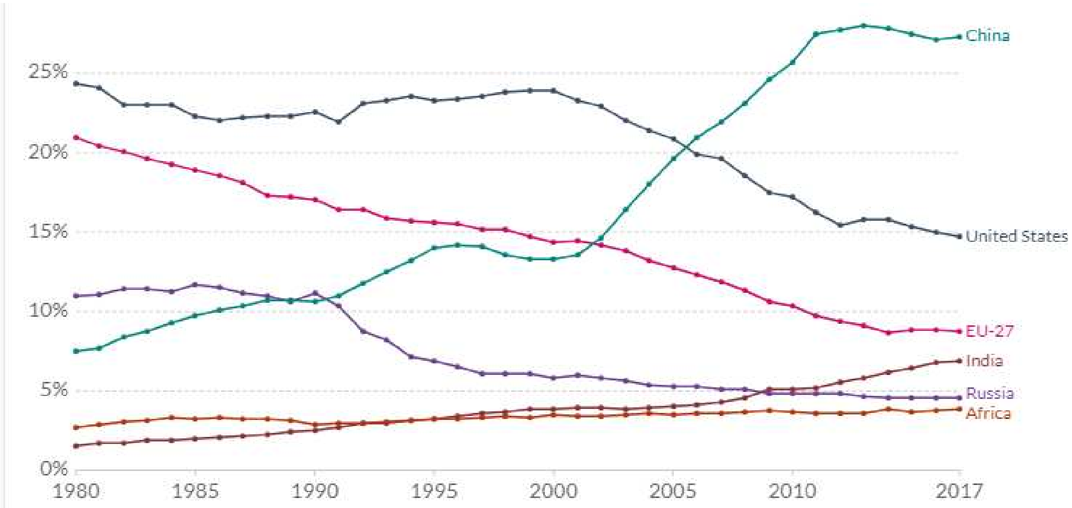
Source: Our World in Data based on Global Carbon Project (2020)

Table 2: Top 10 CO2 emissions countries in 2018

Rank	**Country**	**Total CO2 emissions**
1	China	10.06GT
2	United States	5.41GT
3	India	2.65GT
4	Russia Federation	1.71GT
5	Japan	1.16 GT
6	Germany	0.75 GT
7	Islamic Republic of Iran	0.72 GT
8	South Corea	0.65 GT
9	Saudi Arabia	0.62 GT
10	Indonesia	0.61 GT

Source: Our World in Data based on Global Carbon Project (2020)

Figure 2: Share of CO2 emissions by country



Source: Our World in Data based on Global Carbon Project (2020)

2. Partial equilibrium model of Covid-19 pandemic

The occurrence of the coronavirus pandemic has upset the habits in various sectors of activity: the demand of goods by households has increased because they had in mind to constitute as a preventive measure a large stock of products for a consumption over a long period. This resulted in a rise in food prices which was beneficial for firms at the beginning of the pandemic. However, after a few months, they began to suffer from the crisis consequences, seeing their profits decline substantially despite the support they received from governments and other partners and multinational organizations. This decline is due not only to a change in the prices of goods but also to declining production. The CO2 emissions strongly driven by production in the industrial sector is then likely to decrease. Also, almost all borders, especially air borders, have been closed to limit the spread of the pandemic, which has caused a considerable drop in imports and exports from one country to another. This work aims to assess the impact of Covid-19 on the environment. In order to achieve this objective, we first proceed to the construction of a partial equilibrium model (PE) for assessing the impact of Covid-19 on the environment; in the second step we expose the computable general equilibrium model (CGE) which comes from Hosoe et al. (2010). This model is finally related to the PE in a so-called PE-CGE model.

2.1. The partial equilibrium model of Covid-19 implementation

In this section, we first present the model assumptions, followed by the functional forms; then the equations are built, and we end with the saddle path of the different endogenous variables.

2.1.1 Basic hypotheses and equations of the model

We denote by r the set of regions and by i the set of goods. Taking into account the fact that the CO2 emissions are strongly due to the activities of the industrial sector and steadily the agricultural sector, i is made up of industrial and agricultural goods that is $i = \{IND, AGR\}$With IND, the industrial products and AGR, the agricultural products. Let EP_r be the level of employment in region r before the Covid-19 pandemic, which is assumed to be constant; Em_r the level of employment after the onset of the pandemic; Cov_r the total number of Covid-19 cases recorded in region r; $CO2_r$ the volume of CO2 emissions during the pandemic and $Xp_{i,r}$ the consumption demand of good i by households in region r.

- Under the representation agent hypothesis, we assume that there is only one economic agent, including the household;

- This agent owns the factors of production (capital and labor) which are sold to firms at the unit price Pf;
- All factors revenue is spent on its consumption. No savings are contemplated and there is no government intervention.

Suppose that Em_r is linked to Cov_r by a function of Cobb Douglas type respecting an isoelastic form (Bouet et al., 2014) defined by:

$$Em_r = EP_r Cov_r^{-\vartheta_r} \quad (1)$$

Where, $Em_r < EP_r$

$\vartheta_r > 0$ refers to the elasticity of job loss following the total number of contamination cases detected in region r at any given date.

Applying the logarithmic to relation (1), we have:

$Log(Em_r) = Log(EP_r Cov_r^{-\vartheta_r}) = Log(EP_r) - \vartheta_r Log(Cov_r)$ Which leads to:

$$\vartheta_r = \frac{Log(EP_r/Em_r)}{Log(Cov_r)} \quad (2)$$

Let δ_r be the rate of job loss following the Coronavirus in region r. Then we have:

$$\delta_r = \frac{Ep_r}{Em_r} - 1 \quad (3)$$

We suppose that the rate δ_r is negatively related to the CO2 emissions according to the relation:

$$Co2_r = \frac{1}{1+\delta_r} t_r \sum_i Xd_{i,r} \quad (4)$$

With t_r a parameter which represents the rate of CO2 emissions in region r.

Relations (1) to (4) form a system of $4r$ equations with $6r + 2$ endogenous variables [2] $(Em_r, CO2_r, Xd_{i,r}, \delta_r, \vartheta_r, Cov_r)$.However, the fact that ϑ_r is an elasticity makes it a parameter rather than a variable in the model. We will see later that equation (2) will serve more as a calibration of ϑ_r which leads us to exclude this equation from the system. This means that we have exactly $3r$ equations and $5r + 2$ unknown variables. So, the system is not square. We must therefore exogenize $2r + 2$ variables. Since we are looking for the impact of covid-19 on the environment, the variable Cov_r must be exogenous. We further assume that the demand $Xd_{i,r}$ is constant, which makes it possible to re-establish equality between the number of equations (3r) and the number of endogenous variables $(5r + 2 - 2r - 2 = 3r)$ namely: $Em_r, CO2_r, \delta_r$.

As ϑ_r is known, we can express δ_r as a function of ϑ_r.

Equation (3) becomes:

[2] +2 because the set i in $Xd_{i,r}$ has 2 elements (IND, AGR)

$\delta_r = \frac{Ep_r}{Em_r} - 1 = {Cov_r}^{-\vartheta_r} - 1$ because from equation (1) we have

$\frac{Ep_r}{Em_r} = {Cov_r}^{-\vartheta_r}$.

In sum, the model is as follows:

Equations:

$$Em_r = EP_r {Cov_r}^{-\vartheta_r} \quad (1)$$

$$\delta_r = {Cov_r}^{-\vartheta_r} - 1 \quad (3)$$

$$Co2_r = \frac{1}{1+\delta_r} t_r \sum_i Xd_{i,r} \quad (4)$$

Endogenous variables: $Em_r, CO2_r, \delta_r$

Exogenous variables: $COV_r, Xd_{i,r}$

Parameters: $t_r,\ \vartheta_r$

2.1.2. Calibration of the model

In order for each equation to fit perfectly the baseline values of the different endogenous variables we must calibrate the parameters or each equation of the model. Note that the endogenous variables used in the calibration process end with the number "0" which is a conventional notation. Thus, for the system presented previously, the initial values of the parameters $Em0_r$ and EP_r, COV_r, $Xd_{i,r}$ and $t_{i,r}$, are known. The calibration of equation (1) is done by determining the value of the parameter ϑ_r according to the equation

$$\vartheta_r = \frac{Log(EP_r/Em0_r)}{Log(Cov_r)} \quad (2)$$

Once ϑ_r has been determined, we can calculate the initial value of δ_r given by:

$$\delta0_r = {Cov_r}^{-\vartheta_r} - 1 \quad (5)$$

Then, that of $Co20_r$ is given by:

$$Co20_r = \frac{1}{1+\delta0_r} t_r \sum_i Xd_{i,r} \quad (6)$$

2.1.3. Saddle path of variables

By implementing an increase in Coronavirus cases, we must be able to quantify the impact on the various endogenous variables, especially CO2.

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2.1.3.1 Saddle path of employment

Let's start from equation (1)

$Em_r = EP_r Cov_r{}^{-\vartheta_r}$

We have:

$$\Delta Em_r = EP_r \Delta Cov_r{}^{-\vartheta_r} = EP_r(Cov1_r{}^{-\vartheta_r} - Cov_r{}^{-\vartheta_r}) \quad (7)$$

Let's $Cov1_r = k_r Cov_r$ (8)

$Cov1_r$ represents the level of shock on Covid-19. As the Covid-19 contamination is increasing, we have $k_r > 1$. By replacing (8) in (7) we get:

$$\Delta Em_r = EP_r Cov_r{}^{-\vartheta_r}\left(k_r{}^{-\vartheta_r} - 1\right) = Em_r(k_r{}^{-\vartheta_r} - 1)$$

$$\frac{\Delta Em_r}{Em_r} = \frac{Em_r(k_r{}^{-\vartheta_r} - 1)}{Em_r}$$

Hence,

$$\frac{\Delta Em_r}{Em_r} = k_r{}^{-\vartheta_r} - 1 \quad (9)$$

Given that the level of employment after Covid-19 i.e. Em_r remains quite close to EP_r, we will generally have $0 < \vartheta_r < 1$. However, even in the case where the pandemic comes to the end, if the level of employment rises and exceeds Ep_r, then we will have $\vartheta_r > 1$. This shows that this model could be applied to post-Covid-19 studies when activities have resumed their normal ascension.

Equation (9) which represents the saddle path of the employment level shows for this purpose, that $\frac{\Delta Em_r}{Em_r} < 0$, which means that an increase of k_r percent of the level of Covid-19 contamination in region r results in job loss of $(k_r{}^{-\vartheta_r} - 1)$ percent. For simplification let's call:

$$\boldsymbol{g_r = k_r{}^{-\vartheta_r} - 1} \quad (10)$$

2.1.3.2 Saddle path of the rate of employment loss

In order to establish the saddle path of the job loss rate due to Covid-19, let's start from the following relation:

$\delta_r = \frac{Ep_r}{Em_r} - 1$

We have $\delta 0_r = \frac{Ep_r}{Em0_r}$ and $\delta 1_r = \frac{Ep_r}{Em1_r}$ which implies that:

$\Delta\delta_r = \delta 1_r - \delta 0_r = -Ep_r \frac{Em1_r - Em0_r}{Em1_r.Em0_r}$

Given that $g_r = \frac{Em1_r - Em0_r}{Em0_r}$, we get to $\Delta\delta_r = -Ep_r \frac{g_r}{Em1_r} = -Ep_r \frac{g_r}{Em0_r(1+g_r)}$

that is $$\Delta\delta_r = -\frac{Ep_r}{Em0_r}\frac{g_r}{(1+g_r)} \qquad (11)$$

Now, we know that $\delta_r = \frac{Ep_r}{Em0_r} - 1$ which implies that $\frac{Ep_r}{Em0_r} = 1 + \delta_r$. Equation (11) becomes:

$\Delta\delta_r = -(1+\delta_r)\frac{g_r}{1+g_r}$

And then dividing the previous expression by δ_r, we obtain the expected rate of δ_r given by:

$$\frac{\boldsymbol{\Delta\delta_r}}{\boldsymbol{\delta_r}} = -\frac{\boldsymbol{g_r(1+\delta_r)}}{\boldsymbol{\delta_r(1+g_r)}} \qquad (12)$$

Equation (12) shows that there is a negative relationship between Em_r growth and δ_r growth. So, since Em_r decreases, δ_r will rather increase.

2.1.3.3 Saddle path of CO2 emissions

Recall the equation (4):

$Co2_r = \frac{1}{1+\delta_r} t_r \sum_i Xd_{i,r}$

For simplification, since $t_r \sum_i Xd_{i,r}$ is constant, let's call $A_r = t_r \sum_i Xd_{i,r}$. We get: $Co2_r = \frac{1}{1+\delta_r} A_r$

Let's call $Co21_r$, the level of CO2 emissions after simulation. We have:

$Co21_r = \frac{1}{1+\delta 1_r} A_r$

Hence, $\Delta CO2_r = Co21_r - Co2_r = \left(\frac{1}{1+\delta 1_r} - \frac{1}{1+\delta_r}\right) A_r = -\frac{\Delta\delta_r}{(1+\delta_r)(1+\delta 1_r)} A_r$

As, $\Delta\delta_r = -(1+\delta_r)\frac{g_r}{1+g_r}$,

$\Delta CO2_r = -\frac{-(1+\delta_r)\frac{g_r}{1+g_r}}{(1+\delta_r)(1+\delta 1_r)} A_r = \frac{g_r}{(1+g_r)(1+\delta 1_r)} A_r$

$$\frac{\Delta CO2_r}{Co2_r} = \frac{g_r}{(1+g_r)(1+\delta 1_r)} A_r \frac{(1+g_r)}{A_r} = \frac{g_r(1+\delta_r)}{(1+g_r)(1+\delta 1_r)} \qquad (13)$$

Given that $\Delta\delta_r = -\frac{g_r(1+\delta_r)}{1+g_r} = \delta 1_r - \delta_r$ we can write

$$\delta 1_r = \delta_r - \frac{g_r(1+\delta_r)}{1+g_r}$$

Equation (13) becomes:

$$\frac{\Delta CO2_r}{Co21_r} = \frac{g_r(1+\delta_r)}{(1+g_r)\left(1+\delta_r - \frac{g_r(1+\delta_r)}{1+g_r}\right)} = \frac{\boldsymbol{g_r(1+\delta_r)}}{\boldsymbol{(1+g_r)(1+\delta_r)-g_r(1+\delta_r)}} = \frac{\boldsymbol{g_r(1+\delta_r)}}{\boldsymbol{(1+\delta_r)(1+g_r-g_r)}}$$

$$\frac{\boldsymbol{\Delta CO2_r}}{\boldsymbol{CO2_r}} = \boldsymbol{g_r} \tag{14}$$

Equation (14) shows that the saddle path of CO2 emissions is the same with that of the employment.

3. The CGE model

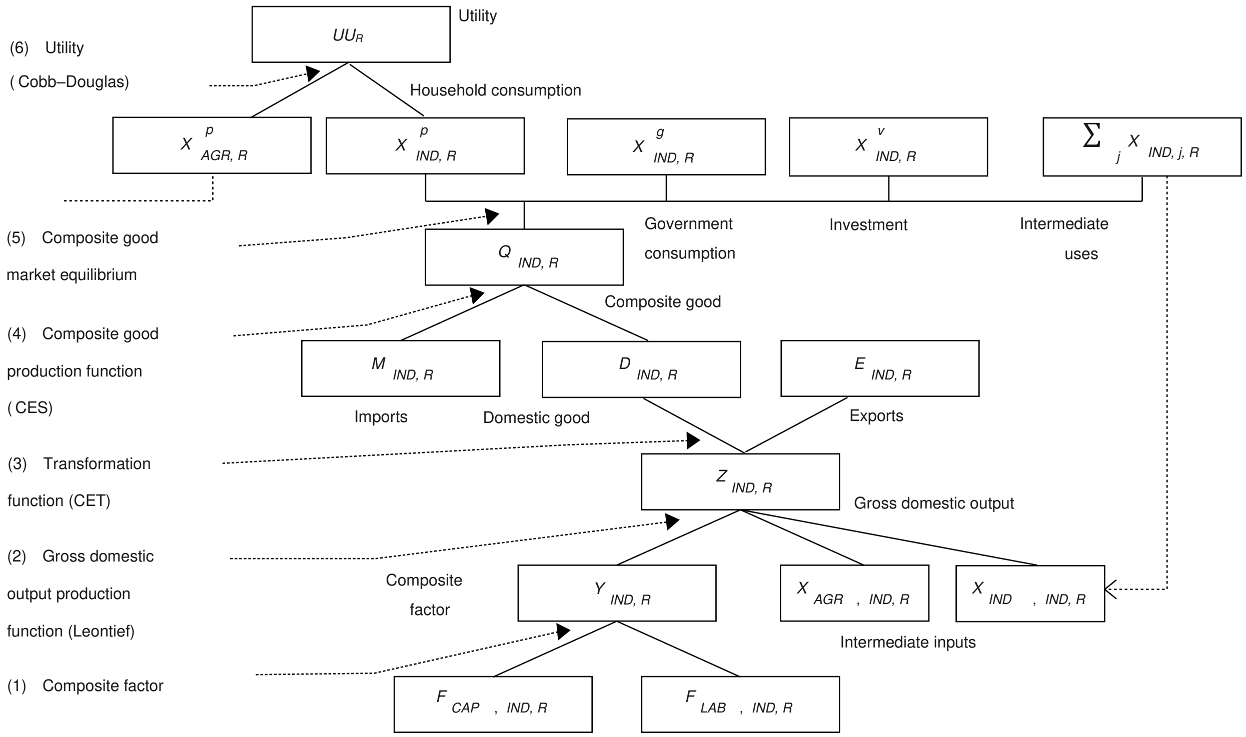
In order to appreciate the impact of Covid-19 on all sectors of the economy, it is important to connect the above PE to a computable general equilibrium model (CGE). Therefore, we use the static CGE model constructed by Hosoe et al. (2010). This model has a remarkable advantage over others. First, almost all parameters of that model are calibrated with the exception for the elasticity parameters (elasticity of substitution and elasticity of transformation)[3]. This offers a way around the difficulties linked to the acquisition of elasticities such as the elasticity of demand for goods by households or of factor demand by firms in the industrial and agricultural sectors. Secondly, this model has a rather simplified structure thus offering the possibility of carrying out a study on several regions of the world. Indeed, with this model, the data we need for designing the social accounting matrix (SAM) of a country or region are easy to access. In this section, we first present the CGE model in question; then we take into account a few amendments with the PE presented above; Finally, we justify the linkage between the both PE and CGE models.

3.1. The CGE model implementation

The basic CGE model used in this study is that of Hosoe et al. (2010)[4]. Figure 3 shows how the different flows operate in the studied economy.

Figure 3: Model design

[3] One can find the estimation technique in Okagawa and Ban (2008)
[4] For more details, see chapter 6 of the book



The household that owns the capital and labor factors ($F_{h,\ i}$) sells them to companies and their transformation yields a composite factor for each sector (value added). This value added is combined with the intermediate inputs used by each sector to produce the domestic output according to a Leontief-type production function. One part of the domestic output is sold on the domestic market and the other part is exported to the international market. The mechanism used to determine the quantities of domestic output and the foreign output follows a CET (constant elasticity of transformation function) specification. The final demand or composite demand is the result of the domestic and import demand, the respective quantities of which are determined via a production function of the CES type respecting the Armington (1969) hypothesis. The resulting intermediate output is used to satisfy the consumption demand of households whose quantities demanded (X_i^p) are determined according to a function of the Cobb Douglas type, government demand (X_i^g), investment demand (X_i^v) of different branches, and the total demand for intermediate goods $\sum_j X_{i,j}$ of the branches. The total household utility is finally given by UU.

3.2 Data and their sources

The data used for the construction of the various social accounting matrices (SAMs) come from various sources. These data are collected for four countries and regions for the empirical verification purpose: The United States of America (USA), the European Union (EU), China (CHN), and the Sub-Saharan Africa

(AFR). The choice of these countries is made according to the objective of this article, which is to assess the impact of the Coronavirus pandemic on the environment. Indeed, in terms of industrial development, the United States of America (USA), the European Union (EU), China (CHN) are included in the sample due to their high degree of environmental pollution in the world. In contrast, the Sub-Saharan Africa region is recognized as the least polluting industries in the world. Therefore, it is consistent to have a balanced sample.

Hence, Data on intermediate inputs, private consumption and public consumption come from the OECD database (2018) and relate to the year 2015. Data on Covid-19 come from the Our database World in Data (Hasell et al., 2020). The rates of direct, indirect taxes and import tariffs relative to GDP are taken from ICTDWIDERGRD (2020). Imports and exports come from the WTO (2021)[5]. Table 3 shows how these data are aggregated according to the industrial and agricultural sectors. Finally, the factors of production are taken from the ILO database (2021).

Table 3: Group of products

Industrial products	**Agricultural products**
Fuels and mining products	Agricultural products
Fuels	Food
Manufactures	
Iron and steel	
Chemical	
Pharmaceuticals	

3.3. Social accounting matrix

A social accounting matrix is built from the data whose sources have just been presented for each region (USA, EU, CHN, AFR). Figure 4 shows how the different accounts in the matrix are broken down.

Figure 4: Structure of the SAM

[5] Data used represent an average over the period 2016-2019

		Activity	Factor	In.tax	Tariff	Hoh.d	Gov.d	Acc	External	Total
		Act	Fac	IDT	TRF	HOH	GOV	INV	EXT	
Activity	Act	$P_i^{q0} X_{i,j}^0$				$P_i^{q0} X_i^{p0}$	$P_i^{q0} X_i^{g0}$	$P_i^{q0} X_i^{v0}$	$P_i^{e0} E_i^0$	
Factor	Fac	$P_h^f F_{h,j}^0$								
Indirect Tax	IDT	T_j^{z0}								
Tariff	TRF	T_j^{m0}								
Hoh. demand	HOH		$p_h^{f0} FF_h^0$							
Gov. demand	GOV			$\sum_j T_j^{z0}$	$\sum_j T_j^{m0}$	T^{d0}				
Accumulation	INV					S^{p0}	S^{g0}		$\varepsilon^0 S^f$	
External	EXT	$p_j^{m0} M_j^0$								
Total										

Source: Authors from Hosoe et al. (2010)

Meaning of SAM's entries

$P_i^{q0} X_{i,j}^0$:	Value of intermediate input used in branches
$P_h^f F_{h,j}^0$:	Value of factor h used in sector j
T_j^{z0} :	Value of indirect tax revenue collected on output j
T_j^{m0} :	Value of customs duties on imported good j
$p_j^{m0} M_j^0$:	Import value in good j
$p_h^{f0} FF_h^0$:	Household revenue yield from the factor h sold
$\sum_j T_j^{z0}$:	Value of the total indirect tax on good j
$\sum_j T_j^{m0}$:	Import tariff revenue on good j
$P_i^{q0} X_i^{p0}$:	Total expenses of household in the purchasing good i
T^{d0} :	Value of direct tax on household revenue
S^{p0} :	Value of household saving
$P_i^{q0} X_i^{g0}$:	Government expenditure in good i
S^{g0} :	Government saving
$P_i^{q0} X_i^{v0}$:	Value of investments in good i
$P_i^{e0} E_i^0$:	Value of exports in good i
$\varepsilon^0 S^f$:	Foreign saving

3.4 SAM balancing

In general, the basic SAM is unbalanced due to the use of various data sources. In order to obtain a balanced SAM, the data whose sources have been mentioned above are entered first. The only missing data relate to the accumulation account, in particular investment ($\boldsymbol{X_i^{v0}}$), and savings ($\boldsymbol{S^{p0}}, \boldsymbol{S^{g0}}, \boldsymbol{S^{f}}$). We first balance the activity accounts by determining the amounts of the investments given as the difference between the total of the column and the total of the row of the same account. Once the activity accounts are balanced, the rest of the world account (EXT) is balanced by determining the value of the current account balance ($\boldsymbol{S^{f}}$) which is the difference between the sum of exports and the sum of imports. The household account is then balanced by determining the household savings ($\boldsymbol{S^{p0}}$) given by the difference between the total household receipts (total of the line of the HOH account) and its expenses (total of the column HOH account). We end the balancing by government saving ($\boldsymbol{S^{g0}}$) which is the difference between its total revenue (total of the GOV row) and its expenditure (total of the GOV column).

The macroeconomic equilibrium after balancing the SAM is given by the equality:

$$GDP^0 = \sum_f \sum_j P_h^f F_{h,j}^0 + \sum_j \left(T_j^{z0} + T_j^{m0}\right)$$

$$= \sum_i (P_i^{q_0} X_i^{p0} + P_i^{q_0} X_i^{v0} + P_i^{q_0} X_i^{g0} + P_i^{e0} E_i^0) - \sum_j p_j^{m0} M_j^0$$

One can check this for the SAMs given in appendix.

4. PE-CGE linkage

Delzeit et al. (2020) proposed a method of linking global CGE models with sectoral models to generate the baseline scenarios. They identify two methods generally used in the literature: the one-way and the two-way linkage methods. In the one-way linkage, they contend that the top-down approach is used to link the CGE model to the PE model where some endogenous variables of the CGE model become exogenous in the global model which is on the other hand desegregated. Contrary to the top-down approach, the bottom-up approach that we adopt in this article consists of connecting the PE to the CGE model where functional forms and elasticities remain constant. Thus, in order to assess the impact of Covid-19 on the environment and in the background on other sectors of activity, we adopt the bottom up approach in our PE-CGE model connexion followed by the presentation of the different scenarios.

4.1 From Covid-19 to macroeconomic indicators

The model is formulated as a system of non-linear equations that can be solved simultaneously (Ginburgh and Keyser, 2002). The PE is a system of $3r$ equations with 3r unknown variables, i.e. $3 \times 4 = 12$ equations and 12 variables $(Co2_r, Em_r, \delta_r)$. On the other hand, the CGE used is a square system that consists of 27 blocks of equations including $18 \times 2r + 2 \times 2 \times 2r + 6r + 1 = 201$ equations and 201 endogenous variables[6]. The set of the two systems forms a square system of 213 equations and 213 endogenous variables. However, the private demand variable $(X_{i,r}^{p})$ is endogenous throughout the model. This means we need to modify an assumption in the PE. Indeed, the value of CO2 no longer depends only on δ_r but also on $(X_{i,r}^{p})$. Therefore, through this variable the impact of Covid-19 is generalized throughout the economy.

4.2 Macro closure

As with any CGE analysis, the model is built in such a way as to obey the variation in the value of an exogenous variable. Before presenting the exogenous variables of the model, we first list the endogenous variables.

List of endogenous variables:

$Y_{j,r}, F_{h,j,r}, X_{i,j,r}, Z_{j,r}, Xp_{i,r}, Xg_{i,r}, Xv_{i,r}, E_{i,r}, M_{i,r}, Q_{i,r}, D_{i,r,}, p_{h,f,r}, py_{j,r,}, pz_{j,r}, pq_{i,r}, pe_{i,r},$

$pm_{i,r}, pd_{i,r}, Tim_{i,r}, Tz_{i,r}, \varepsilon_r, Sp_r, Sg_r, Td_r, GDP_r, UU_r, CO2_r, Em_r, \delta_r, walras$

List of exogenous variables:

$Cov_r, FF_{h,r}, Sf_r, Pwe_{i,r}, \tau d_r, \tau z_{i,r}, \tau m_{i,r}$

Thus, as a main scenario, we use to simulate the behavior of endogenous variables especially the CO2 emissions following an increase in cases of Covid-19 contamination. To do this, we first calculate the average rates of increase in pandemic contamination over a series of 415 daily observations over the period from 22 January 2020 to 12 march 2021. This rate is an arithmetic average weighted by the number of new cases recorded each day. Let $\bar{\tau}cov_i$ be the rate of contamination recorded from one day

[6] Recall that $r = \{USA, EU, CHN, AFR\}$, $i = \{IND, AGR\}$ et $h = \{CAP, LAB\}$

to the following day, n_i the number of new cases, and N the total number of cases recorded between the date T_0 and the date T_n. The average rate $\overline{tcov}$ is given by:

$$\overline{tcov} = \frac{1}{N}\sum_{i=1}^{n} \overline{tcov}_i \,.\, n_i \qquad (15)$$

where $\overline{tcov}_i = \frac{N_i}{N_{i-1}} - 1$

Note that N_i is the cumulative number of cases registered up to date i and N_{i-1} the cumulative number of cases registered up to date $i - 1$. After the calculations, we get the following rates in Table 4:

Table 4: Average increase rate of Covid-19 per day

	USA	**EU**	**CHN**	**AFR**
$rate$	0.15	0.1	0.28	0.02

In the simulation process from equation (8) we can establish the relationship between k_r and $\overline{tcov}_k$ as follows:

$$k_r = 1 + \overline{tcov}_k$$

5. Empirical evidence

Let's start with our basis PE model.

5.1 Empirical evidence for the partial equilibrium

This section is subdivided into three subsections: firstly, we present the baseline scenario; secondly, the contrafactual is applied and we terminate with the changes in variables.

5.1.1 The baseline scenario

Table 5 gives a summary of the initial data that we need for calculations. Following equation (2) in the calibration section, we can calculate the baseline for the elasticity ϑ_r in each region using the formula:

$$\vartheta_r = \frac{Log(EP_r/Em_r)}{Log(Cov_r)}$$

Hence, for the USA for example, we will have:

$$\vartheta_{'USA'} = \frac{Log(EP_{'USA'}/Em_{'USA'})}{Log(Cov_{'USA'})} = \frac{Log(157538/155761)}{Log(29347338)} = 0.00065973$$

As interpretation for the USA, we can say that a discovering of a new Coronavirus infection leads to a 0.00066 units loss of employment in compagnies that is about 0.066 per cent.

Now, look at the value of δ_r which represents the rate of job loss following the Coronavirus pandemic in each region. Its initial value can be calculated through equation (5) given by:

$$\delta 0_r = Cov_r^{-\vartheta_r} - 1$$

For the USA economy, we get:

$\delta 0_{'USA'} = 29347338^{-0.00065973} - 1 = 0.0114085$ [7]

This value indicates that a unit of Coronavirus infection augments the rate of employment loss by 0.0114.

Regarding the CO2 initial emissions, we apply the equation (6) given by:

$$CO20_r = \frac{1}{1+\delta 0_r} t_r \sum_i Xd_{i,r}$$

For the USA, we get $CO20_{'USA'} = \frac{0.15(2562697.3)}{1+0.0114085} = 380068.581$

Since the consumptions $Xd_{i,r}$ are expressed in $US million, the CO2 value is also given in $US million.

The remainder results for other regions (EU, CHN, AFR) are given in Table 6.

5.1.2 Contrafactual scenario

When we applying the simulation of an increase in Coronavirus infection, the variable COV_r in which we focus on becomes $COV_r(1 + tcov_r)$. So, the effect of that simulation starts from equation (1):

$Em_r = EP_r Cov_r^{-\vartheta_r}$

For the USA, we have:

[7] See Table 5 for the summary

$$Em1_{'USA'} = EP_{'USA'}(Cov_{'USA'})(1 + tcov_{'USA'})^{-\vartheta_{'USA'}}$$
$$= 157538((29347338)(1 + 0.014))^{0.00065973} = 155759.5713$$

Then, we can find the value of $\delta 1_{'USA'}$ from equation (3) given by:

$$\delta_r = \frac{EP_r}{Em_r} - 1$$

So, $\delta 1_{'USA'} = \frac{157538}{155759.5713} - 1 = 0.011417781$

Finally, $CO2_r$ can be computed through equation 4 by:

$$CO21_r = \frac{0.15(2562697.3)}{1 + 0.011417781} = 380065.095$$

We summarise these results in table 7.

5.1.3 Percentage growth of variables

In this section, we are capable to check empirically the saddle path of variables presented at section 3.1.3. By doing so, we first calculate the growth of employment. Consider the formula with Tables 5 and 6, we can compute for the USA, the following growth in percentage:

$$g_{'USA'} = 100\left(\frac{Em1_{'USA'}}{Em_{'USA'}} - 1\right) = 100\left(\frac{155759.5713}{155761} - 1\right) = -0.00091722\%$$

Let's check that the rate percentage change in CO2 emission is the same with that of employment. We have

$$\frac{\Delta CO2_{'USA'}}{CO2_{'USA'}} = 100\left(\frac{380068.581}{380065.095} - 1\right) = -0.00091722\%$$

Now, the growth of the employment loss is

$$\frac{\Delta\delta_{'USA'}}{\delta_{'USA'}} = -100\left(\frac{0.011417781}{0.0114085} - 1\right) = 0.081315551\% = -\frac{-0.00091722(1 + 0.0114085)}{0.0114085(1 - 0.00091722)}$$

Table 5: Baseline situation

	USA	EU	CHN	AFR
EP	157538	195185	67240	94505
Em	155761	192206	66640	92206
Cov	29347338	23852650	6786564	1252016

t	0.15	0.1	0.28	0.02
tcov	0.014	0.0176	0.163	0.013
		Consumption demand Xd(i.r)		
IND	2453007	8304219	1377551	1869696
AGR	109690	429833	438725	137716
Total	2562697	8734052	1816276	2007412

Table 6: Summary of variables

	USA	**EU**	**CHN**	**AFR**
ϑ	0.00065973	0.00090538	0.00056981	0.00175407
$\delta 0$	0.0114085	0.015499	0.0090036	0.0249333
$CO20$	380068.581	860074.883	504019.208	39171.5636

Table 7: Contrafactual values

	USA	**EU**	**CHN**	**AFR**
Em1	155759.5713	192202.964	66634.2664	92203.911
$\delta 1$	0.011417781	0.01551504	0.00909042	0.02495652
$CO21$	380065.095	860061.297	503975.843	39170.6761

Table 8: Percentage growth

	USA	**EU**	**CHN**	**AFR**
Em	-0.00091722	-0.0015796	-0.00860387	-0.00226556
δ	0.081315551	0.10349764	0.96428965	0.09313267
$CO2$	-0.00091722	-0.0015796	-0.00860387	-0.00226556

5.2 Effect where the consumption demand becomes endogenous

By setting the demand of good **Xd(I,r)** endogenously, we extend the model to our PE-CGE model where the CGE is taken into account. So, our PE model cannot longer be solved since it is not square. As the side of the model becomes very large, we used the GAMS software for our computations. Besides, it is now possible to know about the impact of coronavirus on the other sectors of the economy. But we simplify it to a few variables namely the imports, exports, GDP and well-being.

Table 9 shows that as the households' consumption becomes endogenous, the impact of the pandemic becomes large. The percentage changes for the USA is now established at -0.70394824 per cent. Those of China and Sub-Saharan-Africa are -4.04341331 per cent and -0.08727469 per cent respectively. The novel here is the impact on the EU which is positive instead (0.28902175 per cent). As explanation for that result, Table 10 shows that the consumption demand by EU households is positively affected while the other regions rather has a negative impact on the both industrial and agricultural sectors. This is the main raison of the positive environmental impact mentioned above. Regarding the international trade, Table 11 shows that imports as well as exports are decreasing. However, an exception comes from the USA and the EU exports which are increasing instead. The difference comes fundamentally from the social accounting matrix data of each region (see the appendix). We terminate the interpretation of Table 9 which shows the welfare and the Gross Domestic Product impacts. Regarding the GDP, the Coronavirus pandemic has a negative impact on three regions (the EU, China and Sub-Saharan-Africa) apart from the USA economy where the impact is positive. To explain this result, let go to the formula:

$$GDP = C + I + G + E - M$$

Where C represents the households' consumption, I the total investment, G the public consumption, E the exports and M the imports.

Regarding the results of Table 10, we note that the positive impact of the GDP for the USA is related to the positive impact on the investment demand which increases for the both industrial and agricultural sectors while the impact is reversed for the other regions. Indeed, the capacity for the investment sector to impact the economic growth is greater than the other component according to the SAM data (see appendix). Otherwise, agricultural exports for the USA are increasing while imports are decreasing (see Table 11). This tends to positively impact the trade balance.

According to the welfare aspect, Table 9 shows that the Coronavirus infection reduces the welfare in the USA, China and Sub-Sahara Africa. In contrary, the European Union habitant see their well-being improving. This result can be explained by the households' consumption which is increasing solely for the EU for the both industrial and agricultural products.

Table 9: Percentage growth in PE-CGE model

	USA	**EU**	**CHN**	**AFR**
GDP	0.01539142	-0.01016296	-2.37996108	-0.01971666
CO2 emissions	-0.70394824	0.28902175	-4.04341331	-0.08727469

δ	0.08131555	0.10349764	0.96428965	0.09313267
Employnment	-0.00091722	-0.0015796	-0.00860387	-0.00226556
Welfare	-0.70304039	0.29060497	-4.04564013	-0.08507969

Table 10: Internal components of the GDP

	USA	EU	CHN	AFR
Households' consumption demand				
IND	-0.70813689	0.28743126	-4.84041465	-0.05326885
AGR	-0.58899849	0.35193957	-1.50672820	-0.51595775
Investment demand				
IND	0.69726921	-0.06279680	-4.16177393	-0.03448406
AGR	0.81809409	0.00148624	-0.80431435	-0.49726275
Government demand				
IND	0.03426969	0.13846295	-4.30673472	0.63847556
AGR	0.15429905	0.20287545	-0.95435350	0.17258148

Table 11: Impact on international trade in percentage

	USA	EU	CHN	AFR
Imports				
IND	-0.63235939	-0.72582546	-4.72436952	-1.24542277
AGR	-0.39421269	-0.78976029	-7.38707709	-0.88453924
Exports				
IND	-0.05267716	-0.0297899	-4.58862579	-0.00962359
AGR	0.3816299	0.00223677	-0.64311728	-0.20146462

6. Concluding remarks

This study tried to address the environmental impact of the Coronavirus pandemic through a combination of two types of model: we first built a partial equilibrium model which constitutes the main outcome of this study. This Model is then coupled to the CGE model of Hosoe et al. (2010). Therefore, we constructed four social accounting matrices (SAM) corresponding to the USA, the EU, the China and the Sub-Saharan Africa economies. Two observations are highlighted with respect to the consumption demand by households: firstly, from the PE model where we set the household demand exogenous, we noted that each country or region reduces its impact on the environment whether it is a developed or a developing country. This results from the fall in production capacity of firms since the level of employment is decreasing especially in the industry sector. Secondly, setting the consumption demand endogenous in the PE-CGE model permit us to capture the impact on other sectors of the economy. Therefore, the result on the environment through the CO2 emissions becomes mitigated: while we noted a decline in the USA, the China and the Sub-Saharan Africa economies, the impact for the EU were rather positive. This means that the effect depends on the structure of each economy regarding the data of the social accounting matrices.

Conflict of statement declaration

There is no conflict of interest to declare for this article

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Appendix

Social accounting matix for China

	IND	AGR	CAP	LAB	IDT	TRF	HOH	GOV	INV	EXT	TOTAL
IND	8012977	323709					1377551	167574	143011	2509375	12534197
AGR	93169	757350					438725	26340	1996545	149220	3461349
CAP	11789	70266									82055
LAB	211456	1260245									1471701
IDT	927036	599615									1526651
TRF	1088211	149453									1237664
HOH			82055	1471701							1553756
GOV					1526651	1237664	1510749				4275064
INV							-1773269	4081150		-168325	2139556
EXT	2189559	300711									2490270
TOTAL	12534197	3461349	82055	1471701	1526651	1237664	1553756	4275064	2139556	2490270	

Social accounting matix for Sub-Saharan Africa

	IND	AGR	CAP	LAB	IDT	TRF	HOH	GOV	INV	EXT	TOTAL
IND	3838460	91092					1869696	358128	6857549	319884	13334809
AGR	229112	54880					137716	13464	13117	77121	525410
CAP	389898	20480									410378
LAB	8145674	41984									8187658
IDT	345299	223343									568642
TRF	78995	19143									98138
HOH			410378	8187658							8598036
GOV					568642	98138	330812				997592
INV							6259812	626000		-15146	6870666
EXT	307371	74488									381859
TOTAL	13334809	525410	410378	8187658	568642	98138	8598036	997592	6870666	381859	

Social accounting matix for the USA										
	IND	AGR	CAP	LAB	IDT	TRF	HOH	GOV	INV	EXT	TOTAL
IND	2265135	86024					2453007	6548	2110983	1647423	8569120
AGR	243098	67013					109690	71	478395	304357	1202624
CAP	771354	102682									874036
LAB	1894374	252186									2146560
IDT	546673	353593									900266
TRF	78994	19143									98137
HOH			874036	2146560							3020596
GOV					900266	98137	4106898				5105301
INV							-3648999	5098682		1139695	2589378
EXT	2769492	321983									3091475
TOTAL	8569120	1202624	874036	2146560	900266	98137	3020596	5105301	2589378	3091475	

Social accounting matix for the EU											
	IND	AGR	CAP	LAB	IDT	TRF	HOH	GOV	INV	EXT	TOTAL
IND	15465690	301806					8304219	1114506	95226160	6592800	127005181
AGR	691520	113053					429833	2016	190239464	1150269	192626155
CAP	53512656	7123536									60636192
LAB	43059120	180520632									223579752
IDT	4488711	2903336									7392047
TRF	3419570	581299									4000869
HOH			60636192	223579752							284215944
GOV					7392047	4000869	19744496				31137412
INV							255737396	30020890		-292662	285465624
EXT	6367914	1082493									7450407
TOTAL	127005181	192626155	60636192	223579752	7392047	4000869	284215944	31137412	285465624	7450407	