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ECONOMETRIC MODELING OF CARBON DIOXIDE EMISSIONS

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Abstract

In this thesis autoregressive distributed lag (ARDL) models are analyzed on cointegration using the Bounds Test, firstly proposed by Pesaran et al. [2001]. The goal is to model the relation between CO_2 emissions per capita and GDP per capita and test the Environmental Kuznets Curve (EKC)-Hypothesis, which describes a particular shape of that dependence. Testing these models or more precisely the involved variables on a cointegration relationship is motivated by the fact that all involved variables are usually integrated. With this cointegrating relationship meaningful long-run developments can be estimated and scenario forecasts and Impulse Response functions can be estimated. The selection of those variables entering each country's model is done using Granger Causality, providing economic, demographic, energy and environmental variables. The countries involved are a heterogeneous set, as diverse as possible, constructed using economic, demographic, and geographical points of view. One further important point is a precise pre-testing of the used data, using unit root and cointegration tests. Moreover only countries, which do have a correct specified cointegrating polynomial regression (CPR)-relationship enter the model.
The analyzed models show an importance of demographic and economic variables over the others, the EKC-Hypothesis can be verified by about half of the analyzed countries.

In dieser Arbeit werden autoregressive distributed lag (ARDL)-Modelle auf Kointegration mittels des Bounds-Tests untersucht, der erstmals von Pesaran et al. [2001] publiziert wurde. Das Ziel ist es, die Beziehung zwischen Pro-Kopf-CO_2-Emissionen und Pro-Kopf-Bruttoinlandsprodukt zu modellieren und die Environmental Kuznets Curve (EKC)-Hypothese, welche eine spezielle Form dieser Abhängigkeit beschreibt, zu überprüfen. Diese Modelle, oder konkreter die involvierten Variablen, auf eine Kointegrationsbeziehung zu prüfen wird dadurch motiviert, dass alle involvierten Variablen in der Regel integriert sind. Mit dieser Kointegrationsbeziehung können aussagekräftig langfristige Entwicklungen geschätzt und Szenarienprognosen und Impulsantworten berechnet werden. Die Auswahl jener Variablen, die das jeweilige Modell eines Landes erweitern, erfolgt mittels Granger-Kausalität. Die zur Auswahl stehenden Variablen stammen aus drei Übergruppen, den ökonomischen, den demografischen, sowie den Energie- und Umweltvariablen. Die involvierten Länder stellen einen möglichst diversen Querschnitt dar, welcher unter Berücksichtigung von ökonomischen, demografischen und geografischen Gesichtspunkten erstellt wurde. Ein weiterer wichtiger Punkt ist die ausführliche Vorabprüfung des verwendeten Datensatzes, einerseits mit Unit-Root-Tests, andererseits mit Kointegrationstests. Weiters werden nur jene Länder genauer untersucht, bei denen eine korrekte cointegrating polynomial regression (CPR)-Beziehung festgestellt werden kann.
Die untersuchten Modelle zeigen eine relative Bedeutung von demografischen und ökonomischen Variablen, die oben angesprochene EKC-Hypothese kann von etwa der Hälfte der untersuchten Länder bestätigt werden.

Contents

1 Introduction and Motivation

We live in a time, where there are almost daily discussions about climate change in the media as well as among people on the street. Whenever there is a natural disaster such as a hurricane or flooding, whenever one day in winter is 'too warm', whenever some species becomes extinct, people wonder if there is a connection to climate change.
The hypothesis of climate change is one of the most proven scientific hypotheses, but still, many people do not really believe in it and do not see a necessity for change. One reason, that could contribute to this mood, could be the inability of world leaders to find bearing solutions and collective agreements. In December 2015, however, all participating countries of the 2015 United Nations Climate Change Conference agreed on the Paris Agreement, which aims to keep global temperature rise well below 2 degrees in this century. All parties emphasized the importance of the deal.

> *Today the world is united in the fight against climate change. Today the world gets a lifeline, a last chance to hand over to future generations a world that is more stable, a healthier planet, fairer societies and more prosperous economies. This robust agreement will steer the world towards a global clean energy transition.* [1]
>
> *- Jean-Claude Juncker, European Commission President, in 2015*

Although, in 2017, the U.S.-President Donald J. Trump announced that the U.S. will withdraw from the Paris Agreement, and commented critical on efforts against climate change. On Jan 10, 2018, he announced, that the U.S. could rejoin the Paris Agreement.

> *In the East, it could be the COLDEST New Year's Eve on record. Perhaps we could use a little bit of that good old Global Warming that our Country, but not other countries, was going to pay TRILLIONS OF DOLLARS to protect against. Bundle up!* [2]
>
> *- Donald J. Trump, current U.S. President, in 2017*

In this thesis I do not want to take part in these discussions, rather I want to provide reliable models for further scientific analysis. The answer science has to give to this corporate uncertainty is to provide even better, more exact and more reliable models, as a good and verified econometric model is the base for any forecast. More precisely, the goal is to determine the main sources for CO_2 emissions and to model the dependence between CO_2 and GDP per capita. These models can then be used to calculate forecasts and simulations.

[1] http://europa.eu/rapid/press-release_IP-15-6308_en.htm, accessed Jan 14, 2018
[2] Donald J. Trump (@realDonaldTrump), posted Dec 29, 2017 on Twitter

The basis of this work are autoregressive distributed lag (ARDL) models, which will be used to analyze an cointegrating behavior and an existing long-run relationship between the involved variables. With these long-run equations, the Environmental Kuznets Curve (EKC)-Hypothesis can be tested. Basically the EKC-Hypothesis describes the shape of the dependence of CO_2 emissions on GDP per capita. If the hypothesis is fulfilled, the relation between GDP per capita and CO_2 is described by an inverted U-shape or, in the more general case, a N-shape. These hypotheses were primarily designed for industrialized countries, commonly referred to as the first world. It will be interesting to see how poorer countries in the second and third world fulfill these hypotheses and how the numbers compare to those of the wealthier countries.
Prior to that, Granger-Causality will be used to decide which variables to include in each country's model. Variables from three basic categories, economy, demography, and energy/environment, will be provided. Usually the analyzed ARDL models include only very few determinants for CO_2 emissions, sometimes only GDP per capita. In this analysis the goal is to glean further variables that could be important. The inclusion of further variables and the selection of them is one decisive point for meaningful models, particularly keeping forecasting in mind.
Furthermore a discussion of including an energy consumption variable in those models and possible errors, that could arise, will be provided, mainly following Itkonen [2012]. As well, we will compare the results of the EKC-Hypothesis with and without the inclusion of the energy consumption variable and discuss differences. Also a detailed pre-testing will be provided, subsequent to the study of Wagner [2015].
The structure of this thesis is as follows: The next section discusses the theoretical background of the methods used in this thesis. Section 3 is devoted to data sources and variable selection, section 4 provides the Approach. Section 5 presents all results calculated and the last section summarizes and concludes.

2 Theory

2.1 The Kuznets Curve

The idea of the Kuznets curve was firstly brought up by Kuznets [1955]. In this study, Simon Kuznets connected income inequality with economic growth. His hypothesis was that during the development of a country the GDP per capita levels rise, which affects income inequality. At first, only a few people found companies and provide cheap (factory) jobs, which increases the income inequality. As the GDP per capita levels rise, the labor force becomes higher skilled and the profit margins for the companies decrease. Due to that, at some turning point, the inequality levels begin to fall. The result is an inverted U-shaped relationship between GDP per capita and income inequality.

For quite a long time countries were following this pattern, but starting in the late 1980s more and more OECD countries showed repeating rising income inequality numbers after initially confirming the theory of the Kuznets curve. Today the hypothesis is proven wrong by a number of studies.

2.1.1 The Environmental Kuznets Curve (EKC)

In 2004, the study of Dinda [2004] invented a similar hypothesis of an inverted U-shaped connected to GDP per capita. This time the relationship was postulated between GDP per capita and different pollutant emissions, for example CO_2, SO_2 or NO_x. Dinda explained, that an initial GDP per capita growth can be explained by a growing industry and agriculture. These sectors are responsible for many different pollutants and a large quantity of emissions. As a country is developing, however, more and more people shift to the services sector and therefore, at some turning point the emission levels start to fall.[3] This result was named the Environmental Kuznets Curve (EKC), and, if CO_2 is the pollutant, also Carbon Kuznets Curve (CKC). In the following thesis I will concentrate on CO_2, but most results can be easily applied to other pollutants as well.

An extension of the EKC-Hypothesis is the N-shaped EKC. This extension states that after performing the inverted U-shaped relationship, the emission levels start to rise again, forming an N shape. De Bruyn et al. [1998] argues that if at some point no more efficiency improvements are achieved or emission abatement has become too expensive, any further GDP per capita growth will result in an environmental degradation and thus higher emission levels.

Technically the EKC-Equation is formulated as

$$c_t = \alpha + \beta_1 y_t + \beta_2 y_t^2 + \beta_3 y_t^3 + \gamma Z_t + u_t \tag{1}$$

[3] Of course, assuming that the services sector produces in fact less emissions.

where t is time, c_t are CO_2 emissions per capita at time t, α is a constant, y_t describes GDP per capita and β_i denotes the coefficient of the i^{th} power of y_t, γ is the coefficient of all other variables Z_t and u_t is an error term. All variables are in logarithms and usually $u_t \overset{\text{i.i.d.}}{\sim} N(0, \sigma^2)$. Now Dinda [2004] differentiates several different cases.

(i) $\beta_1 = \beta_2 = \beta_3 = 0$: No relationship between y_t and c_t

(ii) $\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$: Monotonic increasing relationship between y_t and c_t

(iii) $\beta_1 < 0$ and $\beta_2 = \beta_3 = 0$: Monotonic decreasing relationship between y_t and c_t

(iv) $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$: Inverted U-Shape relationship between y_t and c_t

(v) $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 = 0$: U-Shape relationship between y_t and c_t

(vi) $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$: N-Shape relationship between y_t and c_t

(vii) $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 < 0$: Inverted N-Shape relationship between y_t and c_t

In literature, case (iv) of an inverted U-shaped curve is usually referred to the EKC-Hypothesis in a quadratic model, including y_t and y_t^2, in a cubic model with additionally y_t^3 added, the EKC-Hypothesis is said to be fulfilled if case (vi) of an N-shaped curve applies.
However, this characterization is neither complete nor correct since the shape of the curve does not only depend on the sign of the coefficients. That is why in this thesis, the following, slightly adapted, cases will be differentiated.

(i*) $\beta_1 = \beta_2 = \beta_3 = 0$: No relationship between y_t and c_t

(ii*) $\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$: Monotonic linearly increasing relationship between y_t and c_t

(iii*) $\beta_1 < 0$ and $\beta_2 = \beta_3 = 0$: Monotonic linearly decreasing relationship between y_t and c_t

(iv*) $\beta_1 \in \mathbb{R}$, $\beta_2 < 0$, $\beta_3 = 0$: Inverted U-Shape relationship between y_t and c_t: EKC-Hypothesis in quadratic model

(v*) $\beta_1 \in \mathbb{R}$, $\beta_2 > 0$ and $\beta_3 = 0$: U-Shape relationship between y_t and c_t

(vi*) $\beta_1, \beta_2 \in \mathbb{R}$, $\beta_3 > 0$, additionally $(\beta_2^2 - 3\beta_3\beta_1) \geq 0$: N-Shape relationship between y_t and c_t: EKC-Hypothesis in cubic model

(vii*) $\beta_1, \beta_2 \in \mathbb{R}$, $\beta_3 < 0$, additionally $(\beta_2^2 - 3\beta_3\beta_1) \geq 0$: Inverted N-Shape relationship between y_t and c_t

(viii*) $\beta_1, \beta_2 \in \mathbb{R}$, $\beta_3 > 0$, additionally $(\beta_2^2 - 3\beta_3\beta_1) < 0$: Monotonic non-linearly increasing relationship between y_t and c_t

(ix*) $\beta_1, \beta_2 \in \mathbb{R}$, $\beta_3 < 0$, additionally $(\beta_2^2 - 3\beta_3\beta_1) < 0$: Monotonic non-linearly decreasing relationship between y_t and c_t

2.1.2 Emissions-Energy-Output (EEO) Models

One quite popular choice of an additional variable in (1) is Energy Use per capita, first published in Ang [2007] [4]. With this, (1) transforms to

$$c_t = \alpha + \beta_1 y_t + \beta_2 y_t^2 + \beta_3 y_t^3 + \delta e_t + u_t \tag{2}$$

where e_t denotes Energy Use per capita. These models are also known as Emissions-Energy-Output (EEO) models.
Following this study, many other researchers analyzed similar models for different countries, not considering possible problems of including energy consumption into these kind of models. In 2012, however, Itkonen [2012] criticized the inclusion, stating a number of possible misinterpretations that could happen.

2.1.2.1 Itkonen-Critique

The first problem with including energy consumption into the EKC-Equation and treat it as a determinant for CO_2 emissions is that in fact both series are calculated from the same source. This happens because in reality emissions are not measured but are calculated from energy statistics. Itkonen [2012] provides the identity

$$C_t = E_t A_t + X_t \tag{3}$$

where C_t are CO_2 emissions per capita, E_t is energy consumption per capita, A_t is the carbon intensity[5] and X_t covers all emissions caused by gas flaring and cement manufacturing. Itkonen [2012] argues that X_t contributes only a very tiny fraction to (3), thus for simplification X_t is set to 0. Taking logarithms in (3) results in

$$c_t = e_t + a_t \tag{4}$$

Jaforullah and King [2017] note that unless a_t changes drastically over time, which would mean a significant change in a country's energy mix, carbon emissions and energy consumption are highly correlated by construction.
Secondly, Itkonen [2012] mentions a problem with the interpretation of the actual parameters. If we calculate the partial derivative of c_t with respect to y_t in (2), we get

$$\frac{\partial c_t}{\partial y_t} = \beta_1 + 2\beta_2 y_t + 3\beta_3 y_t^2 + \delta \frac{\partial e_t}{\partial y_t} \tag{5}$$

Usually the partial derivative of e_t with respect to y_t is not 0, i.e. there is a dependence between carbon emissions and energy consumption, but to formulate the EKC-Hypothesis, often one ignores this dependence and uses the simplified version

$$\frac{\partial c_t}{\partial y_t} = \beta_1 + 2\beta_2 y_t + 3\beta_3 y_t^2 \tag{6}$$

[4] A discussion of other variables that could enter the EKC-Equation (1) can be found in Section 3.2.
[5] The carbon intensity is the measure for the amount of emissions produced by one unit of energy, considering the whole energy mix.

In fact, this partial derivative (6) is correct if and only if energy consumption is held constant. Consequently, if one takes the derivative with respect to y_t in (4), we conclude that

$$\frac{\partial c_t}{\partial y_t} = \frac{\partial e_t}{\partial y_t} + \frac{\partial a_t}{\partial y_t} = \frac{\partial a_t}{\partial y_t} \tag{7}$$

and therefore the EEO-Model is in fact one analyzing the effect of output on carbon intensity, instead on emissions. The same result is got if one plugs equation (4) into the EEO-Model-Regression (2) and rearranges.
If we introduce a linear relationship between energy consumption and y_t

$$e_t = \beta_e y_t + v_t \tag{8}$$

and take the derivative

$$\frac{\partial c_t}{\partial y_t} = \beta_1 + 2\beta_2 y_t + 3\beta_3 y_t^2 + \delta\beta_e \tag{9}$$

we notice that the EKC-Hypothesis (6) is negatively biased by the term $-\delta\beta_e$. This misspecification bias, that arises through ignoring the dependence between energy consumption and GDP per capita, is the third problem Itkonen [2012] identifies. These adaptations imply that the turning point(s) is (are) at a higher level of GDP per capita and secondly, the shape itself of CKC changes, it grows faster and declines slower.
All mentioned points change the interpretation of the EKC-Hypothesis. If one includes any variable dependent on y_t, then y_t has a direct influence on c_t (via $\beta_1 y_t + \beta_2 y_t^2 + \beta_3 y_t^3$) as well as an indirect influence via the additional variable (in model (2) this would be δe_t), hence, the interpretation of the coefficients β_1, β_2 and β_3 changes. Therefore the inclusion of variables dependent on y_t is not wrong, but the right interpretation is crucial.
Another (structural) problem is the inclusion of GDP per capita and its power(s). Due to this approach the required normal distribution cannot be achieved. This problem is also discussed in the next section.

2.1.3 Cointegrating Polynomial Regressions (CPR)

Beside the problem with the normal distribution, Wagner [2015] argues, that a power of an integrated process is not necessarily an integrated process. Furthermore errors can happen by including a variable and its powers and treating them as "independent" variables. Wagner [2015] suggests using an FM-OLS based approach and careful pre-testing of the different models.
Let us first define a cointegrating polynomial regression (CPR), that is in the most general definition an equation including polynomial time trends up to power q, powers of integrated processes $x_{jt}, j = 1, .., m$ up to p_j and a stationary error term u_t

$$c_t = D_t'\theta_D + \sum_{j=1}^{m} X_{jt}'\theta_{X_j} + u_t \qquad t = 1, .., T \tag{10}$$

with $D_t := [1, t, t^2, .., t^q]'$, $x_t := [x_{1t}, .., x_{mt}]'$ and $X_{jt} := [x_{jt}, x_{jt}^2, .., x_{jt}^{p_j}]'$. The parameter vectors are $\theta_D \in \mathbb{R}^{q+1}$ and $\theta_{X_j} \in \mathbb{R}^{p_j}$. In the following, I will focus on a CPR with intercept and linear time trend as well as a single integrated process y_t up to power 2 i.e.

$$c_t = \gamma + \delta t + \beta_1 y_t + \beta_2 y_t^2 + u_t \qquad t = 1, .., T \tag{11}$$

The process y_t is an I(1)[6]-process with error terms v_t

$$y_t = y_{t-1} + v_t \tag{12}$$

and the error terms together with those from (11) fulfill

$$\xi_t = \begin{bmatrix} u_t \\ v_t \end{bmatrix} = C(L)\varepsilon_t = \sum_{j=0}^{\infty} C_j \varepsilon_{t-j} \tag{13}$$

with $\varepsilon_t = [\varepsilon_{t,u}, \varepsilon_{t,v}]'$ being a stationary ergodic martingale difference with positive definite conditional variance matrix Σ. We also define the long-run covariance matrix

$$\Omega = \begin{bmatrix} \Omega_{uu} & \Omega_{uv} \\ \Omega_{vu} & \Omega_{vv} \end{bmatrix} := \sum_{h=-\infty}^{\infty} \mathbb{E}(\xi_0 \xi_h') \tag{14}$$

as well as the one-sided long-run covariance matrix

$$\Delta = \begin{bmatrix} \Delta_{uu} & \Delta_{uv} \\ \Delta_{vu} & \Delta_{vv} \end{bmatrix} := \sum_{h=0}^{\infty} \mathbb{E}(\xi_0 \xi_h') \tag{15}$$

If we would aim to estimate CPRs as the one in (11) with OLS, the estimator would be consistent but would suffer from higher order bias terms. That is why in these cases a Fully-Modified OLS approach (FM-OLS) is chosen.
The first step is to replace the dependent variable c_t with $c_t^+ := c_t - v_t \hat{\Omega}_{vv}^{-1} \hat{\Omega}_{vu}$ and $c^+ := [c_1^+, .., c_T^+]'$. $\hat{\Omega}$ is denoting an consistent estimator for Ω.
A second step is to formulate the correction factor

$$A^* = \hat{\Delta}_{vu}^+ \begin{bmatrix} \mathbf{0}_{2\times 1} \\ T \\ 2\sum_{t=1}^{T} y_t \end{bmatrix} \tag{16}$$

with $\hat{\Delta}_{vu}^+ = \hat{\Delta}_{vu} - \hat{\Omega}_{uv} \hat{\Omega}_{vv}^{-1} \hat{\Delta}_{vv}$. The first two entries in this vector correspond to the intercept and the linear trend, the other two to the powers of the integrated process y_t.
Now, according to Hong and Wagner [2011] and Wagner [2015] and with $Z_t = [1, t, y_t, y_t^2]'$ and $Z = [Z_1, .., Z_T]'$ we can formulate the consistent FM-OLS estimator $\hat{\theta}^+$ of $\theta = [\gamma, \delta, \beta_1, \beta_2]'$ in (11) as

$$\hat{\theta}^+ := (Z'Z)^{-1}(Z'c^+ - A^*) \tag{17}$$

2.1.3.1 Test on a correct specified CPR-Relationship

Now, as we have developed an estimating technique for equations like (11), we can also think about testing these equations on a correct specified CPR-Relationship i.e. if all relevant powers of the deterministic trends and the integrated processes are included in the CPR. This is done

[6] An integrated process of order p is denoted as I(p).

by LM-Tests, which analyze the FM-OLS residuals

$$u_t^+ := c_t^+ - Z_t'\hat{\theta}^+ \tag{18}$$

There are 3 types of LM-Tests presented in Wagner [2015], later referenced as LM_I, LM_{II} and LM_{III}. The first one checks on higher orders of deterministic trends t^2 and t^3 in the errors, the second one on higher orders of the integrated process y_t i.e. y_t^3 and y_t^4 and the third one combines the first two. Subsequently the LM-Test LM_{III} is presented.
First of all, as mentioned, we define the auxiliary regressors $F_t = [t^2, t^3, y_t^3, y_t^4]'$ and $F = [F_1, .., F_T]'$. After orthogonalizing F to the regressors of (11), Z, i.e. $\tilde{F} = F - Z(Z'Z)^{-1}Z'F$ we can formulate the following regression

$$u_t^+ = \tilde{F}_t\theta_{\tilde{F}} + \psi_t \tag{19}$$

If the CPR is correctly specified, the estimator $\hat{\theta}_{\tilde{F}}$ should be insignificantly different from 0 i.e. the null hypothesis of a correct specified CPR is tested via $H_0 : \theta_{\tilde{F}} = 0$ in (19).
For that, $\theta_{\tilde{F}}$ is estimated with a modified FM-OLS with additional correction factors[7]

$$\hat{\theta}_{\tilde{F}}^+ = (\tilde{F}'\tilde{F})^{-1}(\tilde{F}'\hat{u}^+ - O^{F*} - A^{F*} + k^F A^*) \tag{20}$$

with $O^{F*} := -\tilde{F}'v\hat{\Omega}_{vv}^{-1}\hat{\Omega}_{vu}$, $v := [v_1, .., v_T]'$, $k^F := F'Z(Z'Z)^{-1}$ and

$$A^{F*} := \hat{\Delta}_{vu}^+ \begin{bmatrix} \mathbf{0}_{2\times 1} \\ 3\sum_{t=1}^T y_t^2 \\ 4\sum_{t=1}^T y_t^3 \end{bmatrix} \tag{21}$$

The first two entries of A^{F*} correspond to the deterministic trend and the latter two correspond to the higher powers of y_t. Under the H_0 and with $T \to \infty$, it holds that

$$T_{LM} = \frac{\theta_{\tilde{F}}^{+\prime}(\tilde{F}'\tilde{F})\theta_{\tilde{F}}^+}{\hat{\Omega}_{u.v}} \Rightarrow \chi_4^2 \tag{22}$$

with $\hat{\Omega}_{u.v} := \hat{\Omega}_{uu} - \hat{\Omega}_{uv}\hat{\Omega}_{vv}^{-1}\hat{\Omega}_{vu}$.

2.2 Granger-Causality

Granger-Causality was introduced by Granger [1969] and investigates, if one variable has a causal influence on another variable using forecasting methods. To be more specific, one variable is Granger-causal for another variable, if it improves the forecast of that variable.
To begin, let us take two variables x and y, and let us define $\mathbb{I}_t$ as the set of information available at time t without variable y and $\mathbb{Y}_t$ as the information set of variable y at time t. If we define the h-step-forecast of x_t given the information set $\mathbb{I}_t$ as $\hat{x}_{t+h|\mathbb{I}_t}$ and the h-step-forecast of x_t given the information set $\mathbb{I}_t \cup \mathbb{Y}_t$ as $\hat{x}_{t+h|\mathbb{I}_t\cup\mathbb{Y}_t}$, we say that y is Granger-non-causal for x, if

$$\hat{x}_{t+h|\mathbb{I}_t} = \hat{x}_{t+h|\mathbb{I}_t\cup\mathbb{Y}_t} \qquad \forall h > 0 \tag{23}$$

[7] For more details see Hong and Wagner [2011]

If (23) does not hold for one $h > 0$, we say that y is Granger-causal for x.
This simple approach can be expanded to multivariate Granger-Causality, including one or more variables Y being Granger-causal for one or more other variables X with additional control variables Z. In an obvious notation, Granger-non-Causality of Y for X given Z in this set-up would mean, that

$$\hat{X}_{t+h|\mathbb{I}_t \cup \mathbb{Z}_t} = \hat{X}_{t+h|\mathbb{I}_t \cup \mathbb{Y}_t \cup \mathbb{Z}_t} \quad \forall h > 0 \tag{24}$$

This can be easily tested using a VAR set-up. Following Barnett and Seth [2014], let us define the stochastic process

$$U_t = \begin{bmatrix} X_t \\ Y_t \\ Z_t \end{bmatrix} \tag{25}$$

that is sectioned into 3 parts X_t, Y_t and Z_t. Furthermore we assume, that U_t forms a VAR(p)-process

$$U_t = \sum_{i=1}^{p} A_i U_{t-i} + \varepsilon_t \tag{26}$$

considering

$$A_i = \begin{bmatrix} A_{xx,i} & A_{xy,i} & A_{xz,i} \\ A_{yx,i} & A_{yy,i} & A_{yz,i} \\ A_{zx,i} & A_{zy,i} & A_{zz,i} \end{bmatrix} \tag{27}$$

and

$$\varepsilon_t = \begin{bmatrix} \varepsilon_{x,t} \\ \varepsilon_{y,t} \\ \varepsilon_{z,t} \end{bmatrix} \tag{28}$$

with ε_t being a white-noise error term.
Now we want to know, if Y_t is Granger-causal for X_t, excluding additional effects of Z_t. First, we take a look at the h-step-forecast of X_t given the information set $\mathbb{I}_t \cup \mathbb{Y}_t \cup \mathbb{Z}_t$

$$\hat{X}_{t+h|\mathbb{I}_t \cup \mathbb{Y}_t \cup \mathbb{Z}_t} = \sum_{i=1}^{p} A_{xx,i}^{(h)} X_{t-i} + \sum_{i=1}^{p} A_{xy,i}^{(h)} Y_{t-i} + \sum_{i=1}^{p} A_{xz,i}^{(h)} Z_{t-i} \tag{29}$$

Technically, Y_t is now Granger-non-causal for X_t and therefore (24) is fulfilled if and only if

$$H_0 : A_{xy,i}^{(h)} = 0 \quad \forall i = 1, .., p \;\; \forall h > 0 \tag{30}$$

In applications[8], however, only the 1-step-forecast is considered i.e. Y_t is Granger-non-causal for X_t if (30) holds for $h = 1$ and the coefficients of the VAR-model are used.
If we want to test Granger-(non)-causality of Y_t for X_t given Z_t, we can compare the full equation

$$X_t = \sum_{i=1}^{p} A_{xx,i} X_{t-i} + \sum_{i=1}^{p} A_{xy,i} Y_{t-i} + \sum_{i=1}^{p} A_{xz,i} Z_{t-i} + \varepsilon_{x,t} \tag{31}$$

with the reduced one

$$X_t = \sum_{i=1}^{p} \tilde{A}_{xx,i} X_{t-i} + \sum_{i=1}^{p} \tilde{A}_{xz,i} Z_{t-i} + \tilde{\varepsilon}_{x,t} \tag{32}$$

[8] This is especially the case with annual data (which is analyzed in this thesis)

Now, if we want to test (30), according to Barnett and Seth [2014], Barnett et al. [2010] and Geweke [1982], we can formulate the variance-ratio test statistic

$$T = \ln\left(\frac{|\mathbb{V}(\varepsilon_{x,t})|}{|\mathbb{V}(\tilde{\varepsilon}_{x,t})|}\right) \tag{33}$$

which is asymptotically χ^2-distributed with $d = (p \cdot \dim(X) \cdot \dim(Y))$ degrees of freedom. Here, $\mathbb{V}(\tilde{\varepsilon})$ denotes the empirical variance-covariance-matrix of the estimated OLS-residuals and $|V|$ is the determinant of the (covariance) matrix V.

2.2.1 Case of Integrated Variables

One major condition in the definition above is stationarity[9]. In reality, many time-series, especially macroeconomic data, are integrated processes and therefore do not fulfill this condition. One solution would be calculating with the differences of these variables. During this process much information is lost, hence, this is not very fruitful in this appliance.
A different solution is provided by the result of Toda and Yamamoto [1995]. They proof, that adding d lags and estimating a VAR($p+d$) model (instead of a VAR(p)), where d is denoting the maximum order of integration of the variables involved, delivers promising results.
Let us first consider a process y_t generated by

$$y_t = \beta_0 + \beta_1 t + .. + \beta_q t^q + \eta_t \tag{34}$$

where η_t is described by an VAR(p)-system

$$\eta_t = J_1 \eta_{t-1} + .. + J_p \eta_{t-p} + \varepsilon_t \tag{35}$$

and integrated of order d. Combining (34) and (35) leads to

$$y_t = \gamma_0 + \gamma_1 t + .. + \gamma_q t^q + J_1 y_{t-1} + .. + J_p y_{t-p} + \varepsilon_t \tag{36}$$

or more compact

$$y_t = \Gamma \tau_t + \Phi x_t + \varepsilon_t \tag{37}$$

with $\Gamma = [\gamma_0, .., \gamma_q]$, $\tau_t = [1, t, .., t^q]'$, $\Phi = [J_1, .., J_p]$ and $x_t = [y'_{t-1}, .., y'_{t-p}]'$.
Let us now consider the hypothesis

$$H_0 : f(\phi) = 0 \tag{38}$$

where $\phi = \text{vec}(\Phi)^{10}$. $f : \mathbb{R}^{p\cdot(\dim y_t)^2} \to \mathbb{R}^m$ is a twice continuously differentiable function with

$$\text{rk}(F(\cdot)) = m \tag{39}$$

in a neighborhood $U(\phi)$ around the true parameter ϕ and $F(\theta) = \frac{\partial f(\theta)}{\partial \theta}$.

[9] A VAR-process is a stationary solution of a VAR-equation-system
[10] vec(A) denotes a function of a matrix A, that stacks all rows of A one after one into a column vector.

If the maximum order of integration expected in the process is d_{max}, Toda and Yamamoto [1995] suggest estimating a VAR($p + d_{max}$)-model by OLS

$$y_t = \hat{\Gamma}\tau_t + \hat{\Phi}x_t + \hat{\Psi}z_t + \varepsilon_t \tag{40}$$

with $\hat{\Psi} = [\hat{J}_{p+1}, .., \hat{J}_{p+d_{max}}]$ and $z_t = [y'_{t-p-1}, .., y'_{t-p-d_{max}}]'$. With the estimated parameter $\hat{\phi} =$ vec($\hat{\Phi}$), a Wald-statistic W is constructed to test (38). It is proven that asymptotically W is χ^2-distributed with m degrees of freedom. That means that the additional coefficient matrices $\hat{\Psi}$ are simply ignored and just the first p coefficient matrices are used to test hypothesis (38).

2.3 Cointegration

Cointegration describes a relationship between two or more integrated variables, that do have a long-term equilibrium. Two integrated variables, say x_t and y_t, are called cointegrated if there exists a $\beta \neq 0$ (and a $\mu \in \mathbb{R}$) such that

$$u_t = y_t - \mu - \beta x_t \tag{41}$$

is stationary.

2.3.1 ARDL-Models

A simple Autoregressive Distributed Lag model with orders p and q i.e. ARDL(p, q) with variables x_t and y_t, an unrestricted intercept term and no trend[11] is a model of the form

$$y_t = \mu + a_1 y_{t-1} + .. + a_p y_{t-p} + b_0 x_t + .. + b_q x_{t-q} + u_t \tag{42}$$

where $\{u_t\}$ is a white-noise process. If we consider the lag polynomials

$$a(L) = 1 - a_1 L - .. - a_p L^p \tag{43}$$

$$b(L) = b_0 + b_1 L + .. + b_q L^q \tag{44}$$

we can simplify (42) to

$$a(L)y_t = \mu + b(L)x_t + u_t \tag{45}$$

Here L denotes the lag-operator $L(y_t) = Ly_t = y_{t-1}$.
Let us consider the identity

$$c(L) = c(1)L + \tilde{c}(L)(1 - L) \tag{46}$$

that holds for any lag polynomial $c(L)$. If we apply (46) to both lag polynomials $a(L)$ and $b(L)$ in (45), we get

$$a(1)y_{t-1} + \Delta y_t - \tilde{a}_1 \Delta y_{t-1} - .. - \tilde{a}_{p-1}\Delta y_{t-p+1} = \mu + b(1)x_{t-1} + \tilde{b}_0 \Delta x_t + .. + \tilde{b}_{q-1}\Delta x_{t-q+1} + u_t \tag{47}$$

[11] That is ARDL Case III, referring to Pesaran et al. [2001]

Rearranging gives

$$\Delta y_t = \mu - a(1)y_{t-1} + b(1)x_{t-1} + \tilde{a}_1\Delta y_{t-1} + .. + \tilde{a}_{p-1}\Delta y_{t-p+1} + \tilde{b}_0\Delta x_t + .. + \tilde{b}_{q-1}\Delta x_{t-q+1} + u_t \tag{48}$$

or alternatively

$$\Delta y_t = \mu - \underbrace{a(1)}_{\alpha} y_{t-1} + \underbrace{b(1)}_{\beta} x_{t-1} + \sum_{j=1}^{p-1} \underbrace{\tilde{a}_j}_{\tilde{\alpha}_j} \Delta y_{t-j} + \sum_{j=0}^{q-1} \underbrace{\tilde{b}_j}_{\tilde{\beta}_j} \Delta x_{t-j} + u_t \tag{49}$$

It is important to note that (49) is equal to (42) if and only if $p > 0$ and $q > 0$[12].
Finally if we consider more than one additional variable x_t, namely $x_{1,t}, .., x_{i,t}$, equation (49) transforms to[13]

$$\Delta y_t = \mu - \alpha y_{t-1} + \beta_1 x_{1,t-1} + .. + \beta_i x_{i,t-1} + \sum_{j=1}^{p-1} \tilde{\alpha}_j \Delta y_{t-j} + \sum_{j=0}^{q_1-1} \tilde{\beta}_{1,j} \Delta x_{1,t-j} + .. + \sum_{j=0}^{q_i-1} \tilde{\beta}_{i,j} \Delta x_{i,t-j} + u_t \tag{50}$$

and will be denoted as ARDL(p, q_1,.., q_i).
If this equation holds, we can rearrange and express the 'long-run' part $(\mu - \alpha y_{t-1} + \beta_1 x_{1,t-1} + .. + \beta_i x_{i,t-1})$ as a function of the 'short-run' part, which is a linear combination of the differences of the variables and the residuals u_t. If the involved variables are integrated of order 1, then $(\mu - \alpha y_{t-1} + \beta_1 x_{1,t-1} + .. + \beta_i x_{i,t-1})$ is stationary. Therefore we get a cointegrating relation between y_t and the $x_{i,t}$'s, if $\alpha \neq 0$ and $\beta_i \neq 0$ for at least one i. If $\alpha = 0$, then (50) would describe a cointegrating relation between the $x_{i,t}$ (which is not of interest here) and if $\alpha \neq 0$ and $\beta_i = 0$ for all i, y_t would be stationary. Pesaran et al. [2001] calls equation (50) an unconstrained ECM-Equation[14].
If we estimate (50)

$$\Delta y_t = \hat{\mu} + \hat{\alpha} y_{t-1} + \hat{\beta}_1 x_{1,t-1} + .. + \hat{\beta}_i x_{i,t-1} + \sum_{j=1}^{p-1} \hat{\tilde{\alpha}}_j \Delta y_{t-j} + \sum_{j=0}^{q_1-1} \hat{\tilde{\beta}}_{1,j} \Delta x_{1,t-j} + .. + \sum_{j=0}^{q_i-1} \hat{\tilde{\beta}}_{i,j} \Delta x_{i,t-j} + \hat{u}_t \tag{51}$$

and the Bounds-Test, which is described in Chapter 2.3.2.1 is rejecting its H_0 and is confirming a cointegrating relationship between the involved variables, we can formulate a long-run model by setting all short-run terms i.e. all differences in (51) to 0. After rearranging and shifting the time to t this results in

$$y_t = \hat{\gamma} + \hat{\delta}_1 x_{1,t} + .. + \hat{\delta}_i x_{i,t} + \zeta_t \tag{52}$$

with $\hat{\gamma} = \hat{\mu}/\hat{\alpha}$ and $\hat{\delta}_k = \hat{\beta}_k/\hat{\alpha}$.
For testing these parameters, but also applying impulse responses or other forecasting techniques to these results, it is important to calculate standard errors of these parameters. For that, Pesaran and Shin [1997] come up with the so-called Delta-Method.

[12] This is often ignored in recent literature.
[13] Note, that now $\beta_i = b_i(1)$, where b_i denotes the lag polynomial for variable $x_{i,t}$ and $\tilde{\beta}_{i,j} = \tilde{b}_{i,j}$ is the j^{th} coefficient of $\tilde{b}_i$
[14] See Engle and Granger [1987] for more information

The long-term coefficients $\hat{\theta}$ are a function of the short-run-coefficients

$$\hat{\theta} = \begin{bmatrix} \hat{\gamma} \\ \hat{\delta}_1 \\ \vdots \\ \hat{\delta}_i \end{bmatrix} = \frac{1}{\hat{\alpha}} \begin{bmatrix} \hat{\mu} \\ \hat{\beta}_1 \\ \vdots \\ \hat{\beta}_i \end{bmatrix} =: g \begin{pmatrix} \hat{\mu} \\ \hat{\alpha} \\ \hat{\beta}_1 \\ \vdots \\ \hat{\beta}_i \end{pmatrix} =: g(\hat{\psi}) \tag{53}$$

The variance of $\hat{\theta}$ can now be approximated by the Delta-Method via

$$\mathbb{V}(\hat{\theta}) = \left(\frac{\partial g(\hat{\psi})}{\partial \hat{\psi}}\right)' \mathbb{V}(\hat{\psi}) \left(\frac{\partial g(\hat{\psi})}{\partial \hat{\psi}}\right) \tag{54}$$

where $\psi = [\mu, \alpha, \beta_1, .., \beta_i]'$ and $\mathbb{V}(\hat{\psi})$ is the asymptotic covariance matrix of the estimate $\hat{\psi}$, which is obtained from (50).

2.3.2 Tests on Cointegration

2.3.2.1 Bounds-Test

The Bounds-Test, developed by Pesaran et al. [2001], analyzes if the variables in an ARDL-model are cointegrated and do have a long-term relationship. One central requirement of the test to work is that all variables are either I(0) or I(1). It cannot deal with higher orders of integration.

Key to this approach is the short-term unconstrained ECM-Equation (50). If we define the hypotheses $H_0^{\alpha} : \alpha = 0$, $H_1^{\alpha} : \alpha \neq 0$, $H_0^{\boldsymbol{\beta}} : \boldsymbol{\beta} = [\beta_1, .., \beta_i]' = [0, .., 0]' = \mathbf{0}$ and $H_1^{\boldsymbol{\beta}} : \boldsymbol{\beta} \neq \mathbf{0}$, we can differentiate 4 cases. The absence of any level relationship refers to fulfilling H_0^{α} and $H_0^{\boldsymbol{\beta}}$ and will be denoted as

$$H_0 = H_0^{\alpha} \cap H_0^{\boldsymbol{\beta}} \tag{55}$$

Correspondingly we can define the alternative hypothesis

$$H_1 = H_1^{\alpha} \cup H_1^{\boldsymbol{\beta}} \tag{56}$$

We notice, that the cases H_1^{α} combined with $H_0^{\boldsymbol{\beta}}$ as well as H_0^{α} combined with $H_1^{\boldsymbol{\beta}}$ are included in the H_1 as well. However, we are only interested in the subset $H_1^{\alpha} \cap H_1^{\boldsymbol{\beta}}$, which indicates a long-run cointegrating relationship.

The null hypothesis H_0 of no cointegration is evaluated with an F-Test, the distribution of the F-statistic is a non-standard one and does in general depend on the cointegration rank r of $\boldsymbol{x_t} = [x'_{1,t-1}, .., x'_{i,t-1}]'$. However, the polar cases $\boldsymbol{x_t} \sim I(0)$, which corresponds to $r = i$ and $\boldsymbol{x_t} \sim I(1)$, which corresponds to $r = 0$, can be simulated. Pesaran et al. [2001] show as well, that these simulated values provide upper and lower bounds for the general case of arbitrary combinations of $I(0)$ and $I(1)$ variables in $\boldsymbol{x_t}$. That is why, in some cases, the test is inconclusive and further testing is necessary, including the determination of the cointegration rank r.

The asymptotic critical values are calculated and listed in Pesaran et al. [2001] for different intercept and trend structures. With a lower number of observations, these critical values

sometimes turn out as not reliable. For this case different critical values are listed in Narayan [2005].
If the calculated F-statistic falls outside these critical bounds, a decision on whether a cointegration relationship exists or not can be made without knowing the actual cointegration rank r. If, however, it falls within these critical values, the test is inconclusive and further testing including the actual calculation of r may be necessary.

2.3.2.2 Phillips-Oularis-Test

The Phillips-Oularis-Test is a residual-based method to test on cointegration in an regression model

$$c_t = D_t'\theta_D + X_t'\beta + u_t \qquad t = 1, .., T \tag{57}$$

Under the null hypothesis H_0 of this test, that is non-cointegration, the regression above would be a spurious regression of two $I(1)$-processes i.e. $\{u_t\}$ is not stationary.
The starting point of the test is the first order regression of the error terms

$$\hat{u}_t = \rho\hat{u}_{t-1} + k_t \tag{58}$$

Now a Phillips-Perron style unit root test is applied to (58) and the H_0 of no cointegration translates into $H_0 : \rho = 1$ in (58). The test statistic of this test is

$$Z_\rho = T(\hat{\rho} - 1) - \frac{1}{2}(\hat{\omega}_k^2 - \hat{\sigma}_k^2)\left(\frac{1}{T}\sum_{t=1}^{T}\hat{u}_{t-1}^2\right)^{-1} \tag{59}$$

where $\hat{\omega}_k^2$ denotes a consistent estimator of the long-run variance of $\{k_t\}$ and $\hat{\sigma}_k^2$ denotes a consistent estimator of the variance of $\{k_t\}$.

2.3.2.3 Shin-Test

The Shin-Test flips the hypotheses of the Phillips-Oularis-Test and tests on H_0 of cointegration by extending the KPSS test. Starting point are the FM-OLS residuals u_t^+, calculated for example in (18). Now the test statistic is formulated as

$$\hat{\eta}_{\text{Shin}} = \frac{1}{\hat{\omega}^2}\left(\frac{1}{T^2}\sum_{t=1}^{T}S_t^2\right) \tag{60}$$

where $\hat{\omega}^2$ denotes the long-run-variance of the residuals $\{u_t^+\}$ and $S_t = \sum_{i=1}^{t}\hat{u}_i^+$.

2.4 Impulse Response

Impulse Responses are an important tool in econometrics to understand the dynamics of an equation (system). It shows the reaction of the involved variables to a shock, or more specifically, an innovation in one (or more) variables.

To begin, let us consider a VAR(1) equation system[15]

$$y_t = Ay_{t-1} + u_t \tag{61}$$

Let us now introduce a shock of one unit in the first variable $y_{1,t}$ at time 0, namely $u_0 = (1,0,0,..)'$. Furthermore, we assume that no more shocks occur i.e. $u_i = (0,0,..)' \quad \forall i \neq 0$ and that $y_t = (0,0,..)' \quad \forall t < 0$. Now we are able to calculate the reaction of the system by simply plugging in

$$\begin{array}{rcl} y_0 = & Ay_{-1} + u_0 & = u_0 = (1,0,0,..)' \\ y_1 = & Ay_0 + u_1 & = Au_0 \\ y_2 = & Ay_1 + u_2 & = A^2 u_0 \\ & ... & \end{array} \tag{62}$$

Note that the coefficient matrices A^i are exactly the coefficient matrices ϕ_i of the MA(∞)-representation of the process.

In our case, however, we cannot exactly apply this approach as we do not have a transition matrix A in an ARDL system as exogenous variables are involved as well. There are still different ways to get an impulse response function. For reasons of clarity, this analysis is only presented for an ARDL(p,q) model with a scalar variable y_t and one exogenous variable x_t

$$y_t = \mu + a_1 y_{t-1} + .. + a_p y_{t-p} + b_0 x_t + .. + b_q x_{t-q} + u_t \tag{63}$$

Extensions to more exogenous variables $x_{1,t}, .., x_{i,t}$ are obvious and follow exactly the same principle.

Let us start with a direct shock in the errors u_t. With this approach we take a look at the partial derivatives of y_{t+j} with respect to the variable the shock occurs in at the appropriate time, which will be $t = 0$ in this case. As before, we set $y_t = 0$ and $x_t = 0$ for $t < 0$ and furthermore we also set $\mu = 0$. We start with the calculation of the reaction of y_0.

$$\frac{\partial y_0}{\partial u_0} = a_1 \frac{\partial y_{-1}}{\partial u_0} + .. + a_p \frac{\partial y_{-p}}{\partial u_0} + b_0 \frac{\partial x_0}{\partial u_0} + .. + b_q \frac{\partial x_{-q}}{\partial u_0} + \frac{\partial u_0}{\partial u_0} = 1 \tag{64}$$

which obviously is 1. The further development is got by simply deriving the appropriate partial derivative.

$$\begin{array}{l} \frac{\partial y_1}{\partial u_0} = a_1 \frac{\partial y_0}{\partial u_0} + .. + a_p \frac{\partial y_{1-p}}{\partial u_0} + b_0 \frac{\partial x_1}{\partial u_0} + .. + b_q \frac{\partial x_{1-q}}{\partial u_0} + \frac{\partial u_1}{\partial u_0} = a_1 \\ \frac{\partial y_2}{\partial u_0} = a_1 \frac{\partial y_1}{\partial u_0} + .. + a_p \frac{\partial y_{2-p}}{\partial u_0} + b_0 \frac{\partial x_2}{\partial u_0} + .. + b_q \frac{\partial x_{2-q}}{\partial u_0} + \frac{\partial u_2}{\partial u_0} = a_1^2 + a_2 \\ \quad ... \\ \frac{\partial y_i}{\partial u_0} = a_1 \frac{\partial y_{i-1}}{\partial u_0} + .. + a_p \frac{\partial y_{i-p}}{\partial u_0} + b_0 \frac{\partial x_i}{\partial u_0} + .. + b_q \frac{\partial x_{i-q}}{\partial u_0} + \frac{\partial u_i}{\partial u_0} \end{array} \tag{65}$$

Exactly the same technique can be used for a shock in x_t at time 0. First, as before, we derive the reaction of y_0.

$$\frac{\partial y_0}{\partial x_0} = a_1 \frac{\partial y_{-1}}{\partial x_0} + .. + a_p \frac{\partial y_{-p}}{\partial x_0} + b_0 \frac{\partial x_0}{\partial x_0} + .. + b_q \frac{\partial x_{-q}}{\partial x_0} + \frac{\partial u_0}{\partial x_0} = b_0 \tag{66}$$

[15] Note, that every VAR(p) can be transformed to a VAR(1) system.

Once again, we just have to take a look at the appropriate partial derivative for the further aftermath.

$$\begin{aligned}
\frac{\partial y_1}{\partial x_0} &= a_1 \frac{\partial y_0}{\partial x_0} + .. + a_p \frac{\partial y_{1-p}}{\partial x_0} + b_0 \frac{\partial x_1}{\partial x_0} + .. + b_q \frac{\partial x_{1-q}}{\partial x_0} + \frac{\partial u_1}{\partial x_0} = a_1 b_0 + b_1 \\
\frac{\partial y_2}{\partial x_0} &= a_1 \frac{\partial y_1}{\partial x_0} + .. + a_p \frac{\partial y_{2-p}}{\partial x_0} + b_0 \frac{\partial x_2}{\partial x_0} + .. + b_q \frac{\partial x_{2-q}}{\partial x_0} + \frac{\partial u_2}{\partial x_0} = a_1^2 b_0 + b_1 a_1 + a_2 b_0 + b_2 \\
&... \\
\frac{\partial y_i}{\partial x_0} &= a_1 \frac{\partial y_{i-1}}{\partial x_0} + .. + a_p \frac{\partial y_{i-p}}{\partial x_0} + b_0 \frac{\partial x_i}{\partial x_0} + .. + b_q \frac{\partial x_{i-q}}{\partial x_0} + \frac{\partial u_i}{\partial x_0}
\end{aligned} \tag{67}$$

A special case in our analysis is GDP per capita, which is not only entering the model linearly, but also quadratically and cubically. In this case the actual value x_0 is necessary to know, as for example $\frac{\partial x_0^2}{\partial x_0} = 2x_0 \frac{\partial x_0}{\partial x_0} = 2x_0$.
Prediction intervals and standard errors for y_t can be calculated by bootstrapping.

3 Data

3.1 Countries and Sources

All data discussed and mentioned in this thesis is extracted from the World Development Indicators (WDI) database[16] from the World Bank, except the CO_2-dataset for Germany between 1960 and 1990, which is taken from the Carbon Dioxide Information Analysis Center[17]. Some minor modifications were applied to the dataset, for example a few missing data points were linearly interpolated. Also a missing Population Density dataset for Belgium has been calculated from the total population size dataset from the WDI database. Furthermore all data is annual and was logarithmized.

3.1.1 Countries entering the Model

The first countries entering the model are the Top 20 countries in GDP according to the International Monetary Fund (IMF) Estimation[18] for 2017 excluding the Russian Federation due to a lack of data. Additionally 0-8 countries per continent are added. As the goal is a cross section, as diverse as possible, proportionally more countries from Asia and Africa are added, as they are not reflected in the GDP Top 20.
Table 3.1 gives an overview of the chosen countries and time horizons and Figure 3.1 presents the different income groups graphically, which were taken from the provided Metadata of the World Bank. The variable of interest in this context is the Gross National Income (GNI) per capita. Here, the 'Low Income' group denotes countries with a GNI per capita of less than \$1005 in 2016, the 'Lower Middle Income' group is between \$1006 and \$3955, the 'Upper Middle Income' group is between \$3956 and \$12235 and the 'High Income' group are countries with a GNI per capita higher than \$12236.
As the EKC-Hypothesis is especially designed for developed countries, it will be interesting to see if the other countries will even make their way to the actual analysis, as they potentially do not meet the variable restrictions (see section 5.1) and in case they do, if they fulfill the hypothesis.

3.2 Possible Variables to enter the Model

In this section, possible variables to enter a CO_2 emission model are discussed, what possible relationship there could potentially be and finally if they were chosen to enter the set of

[16] http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators, accessed Jan 5, 2018

[17] See more at Boden et al. [2017]

[18] http://www.imf.org/external/datamapper/NGDPD@WEO/OEMDC/ADVEC/WEOWORLD, accessed Jan 5, 2018

Country	Begin	End	Length of dataset	Continent	Income Group
Algeria	1971	2014	44	Africa	Upper Middle Income
Argentina	1971	2014	44	South America	Upper Middle Income
Australia	1970	2014	45	Australia & Oceania	High Income
Austria	1970	2014	45	Europe	High Income
Bangladesh	1972	2014	43	Asia	Lower Middle Income
Belgium	1970	2014	45	Europe	High Income
Brazil	1971	2014	44	South America	Upper Middle Income
Bulgaria	1980	2014	35	Europe	Upper Middle Income
Canada	1970	2014	45	North & Central America	High Income
Chile	1971	2014	44	South America	High Income
China	1971	2014	44	Asia	Upper Middle Income
Congo, Dem. Rep.	1971	2014	44	Africa	Low Income
Cuba	1971	2014	44	North & Central America	Upper Middle Income
Denmark	1971	2014	44	Europe	High Income
Egypt, Arab Rep.	1971	2014	44	Africa	Lower Middle Income
France	1970	2014	45	Europe	High Income
Germany	1970	2014	45	Europe	High Income
Greece	1970	2014	45	Europe	High Income
Honduras	1971	2014	44	North & Central America	Lower Middle Income
India	1971	2014	44	Asia	Lower Middle Income
Indonesia	1971	2014	44	Asia	Lower Middle Income
Iran, Islamic Rep.	1971	2014	44	Asia	Upper Middle Income
Israel	1971	2014	44	Asia	High Income
Italy	1970	2014	45	Europe	High Income
Japan	1970	2014	45	Asia	High Income
Kenya	1971	2014	44	Africa	Lower Middle Income
Korea, Rep.	1971	2014	44	Asia	High Income
Mexico	1971	2014	44	North & Central America	Upper Middle Income
Mongolia	1985	2014	30	Asia	Lower Middle Income
Nepal	1971	2014	44	Asia	Low Income
Netherlands	1970	2014	45	Europe	High Income
Nigeria	1971	2014	44	Africa	Lower Middle Income
Norway	1970	2014	45	Europe	High Income
Pakistan	1971	2014	44	Asia	Lower Middle Income
Peru	1971	2014	44	South America	Upper Middle Income
Philippines	1971	2014	44	Asia	Lower Middle Income
Saudi Arabia	1971	2014	44	Asia	High Income
Senegal	1971	2014	44	Africa	Low Income
South Africa	1971	2014	44	Africa	Upper Middle Income
Spain	1970	2014	45	Europe	High Income
Switzerland	1980	2014	35	Europe	High Income
Thailand	1971	2014	44	Asia	Upper Middle Income
Turkey	1970	2014	45	Asia	Upper Middle Income
United Kingdom	1970	2014	45	Europe	High Income
United States	1970	2014	45	North & Central America	High Income

The 'Income Group' classification is taken from the provided Metadata of the World Bank.

Table 3.1: Selected Countries for the Analysis

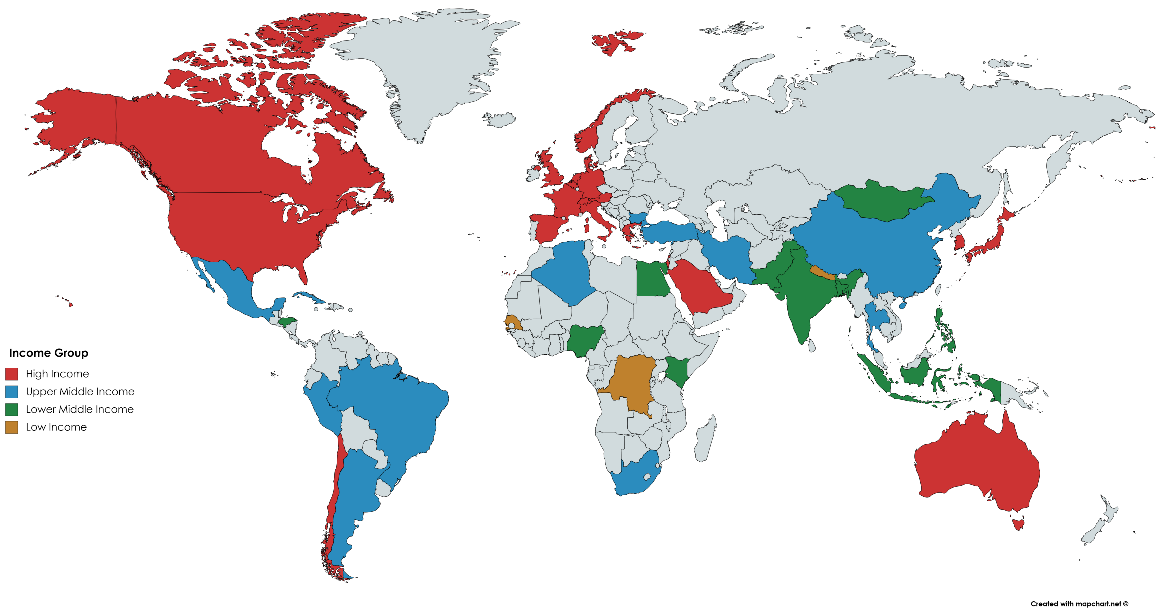


Figure 3.1: Overview of the Income Groups of the Selected Countries

possible variables. The variables are grouped in three thematic groups, economic variables, demographic variables and energy and environmental variables.

3.2.1 Economic Variables

The first variable discussed is an indicator for **Foreign Trade**, for example used in the studies of Halicioglu [2009], Jalil and Mahmud [2009], Jalil and Feridun [2011], Onafowora and Owoye [2014] or Kasman and Duman [2015]. In the last decades globalization progressed further and therefore also the total volume of world trade has risen dramatically. One way of connecting Foreign Trade to CO_2 emissions is of course via transportation. Otherwise a high Foreign Trade indicator could be a sign for a strong importing economy with a weak production industry, which could be a sign for low CO_2 emissions (per capita). The expectations for the effect of this variable are therefore mixed.
As this variable is not available in common datasets, the following approximation will be used

$$FT = \frac{EX + IM}{GDP} \tag{68}$$

where EX denotes the exports of goods and services, IM the imports and GDP the total gross domestic product.
One could also argue, that the Foreign Trade variable is calculated from GDP, therefore the same problems for a CO_2 emission model could arise as through the inclusion of Energy Consumption, as discussed in 2.1.2.1. That is partially true, as, of course, the inclusion changes the interpretation of the EKC-Hypothesis further. The main arguments, however, do not apply, as we will not include powers of this variable and also constructed dependence, as it was with energy consumption in (2), is not an issue here.
Another economic variable frequently used is **Financial Development**, for example in Jalil and Feridun [2011]. The main argument here is, that financial development may attracts foreign investments in a country, which potentially stimulate the local economy. On the one hand,

this could also lead to higher pollution levels. On the other hand, financial development could also give poorer countries access to environmental-friendly technologies, which could also lower their emissions. However, this variable is not used, as data is not widely available.

3.2.2 Demographic Variables

In times of a still strongly rising world population and population growth rates in some developing countries well over 3 %, demographic variables could also play a role in explaining different pollutants. It makes a structural difference for transportation networks and public transport, industrial development and production if people live in dense, big cities or in rural, thinly populated areas. This strongly rising behavior of demographic variables could, on the other hand, also cause some problems. Note, that a variable needs to be integrated with a maximum order of 1 to be feasible for this analysis. This assumption could be violated by these variables in some countries, which will be discussed later in section 5.1.

The first variable used in the analysis is **Urbanization**, also used for example by Kasman and Duman [2015]. In urban areas people tend to travel shorter distances to get to their workplace, for shopping and other services. As well, cities tend to have better public transport systems and in general more efficient structures, this could be a sign that countries with a higher Urbanization indicator have lower CO_2 emission rates.

A similar indicator is **Population Density**, which is used in many papers, for example Onafowora and Owoye [2014]. The implications could be similar to the urbanization variable. Dense areas tend to have a better and more efficient infrastructure. In thinly populated areas the distances are longer and are usually driven by car. Also between CO_2 emissions and population density a negative dependence is expected.

However, these variables seem similar, they could turn out pretty different in some cases. For an example, one thinks of a highly urbanized country with a large, sparsely populated, area. In this case the Urbanization indicator is quite high whereas the Population Density indicator is relatively small.

3.2.3 Energy and Environmental Variables

The last group are the energy and environmental variables. Especially energy related variables have to be chosen very carefully, referring to the discussion in section 2.1.2.1.

The first variable groups are the **total amounts of produced renewable** and **nuclear energy**, used for example in Apergis et al. [2010]. Obviously, these variables would be very tempting to include in the analysis, but similar problems to those of including Energy Use would arise.

A different approach is not to use the total amounts, but the **share of renewable** and/or **nuclear energy**, as in Baek and Kim [2013], which will be also used in this thesis. These dimensionless indicators do not cause problems and shall not be confounded with carbon intensity, which measures the amount of emissions produced by one unit of energy. Different than energy consumption, the share of renewable or nuclear energy is correlated to GDP per capita and carbon intensity significantly less.

One problem does however occur with these indicators. As all the data is logarithmized and some of these indicators are 0 for some points in time, those shares are added and inverted to get the **share of fossil energy**. The implications of this variable for CO_2 emissions are fairly obvious in this context.

Another variable used is **Natural Resources Rents** as a share of a country's GDP, which can be used as a measure for environmental exploitation. This variable is also interesting, as dynamics with other variables could develop. A high Natural Resources Rents variable could be a sign for a high Foreign Trade variable as well (through exporting the raw materials as well as importing knowledge, machinery and more for the production). The same implication could be made with the share of fossil energy.

Therefore also the expected influence of Natural Resources Rents for CO_2 emissions is positive. One additional point is also an increased heavy traffic by trucks, ships and planes for further transportation of the raw materials.

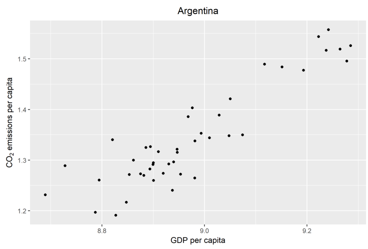
3.3 Data Preview

The descriptive statistics of all countries and all variables are shown in Table A.1. CO_2 emissions are measured in metric tons per capita, real GDP per capita is measured in constant 2010 US-$, Population Density is measured in people per square kilometer of land area and the remaining variables are percentage shares. All data has been logarithmized.

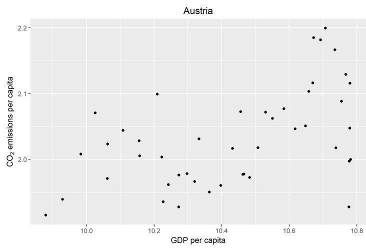
The lowest mean CO_2 emissions per capita are found in the Democratic Republic of Congo, with a log value of -2.73, the highest in the United States of America with a log value of 2.96. In general, not surprisingly, the more a country is developed, the higher the mean emission values. The mean value of all countries involved is 1.05.

The mean GDP per capita values range from 5.96 in Nepal and 11.08 in Switzerland. The mean Foreign Trade indicators vary from 2.98 to 4.79, Urbanization is between 2.25 and 4.57, Population Density is between 0.43 and 6.73, the mean share of fossil energy is between 1.78 and 4.60 and the mean natural resources rents are between -3.78 and 3.22.

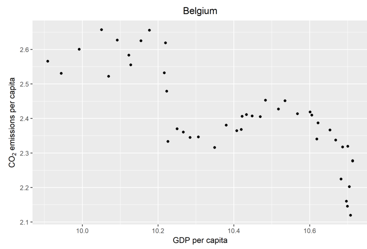
Furthermore Scatter Plots of GDP per capita against CO_2 emissions per capita of selected countries, more specific those countries which will be chosen to be analyzed further in section 5.1, will be presented in Figure 3.2. With those plots, the clear connection between GDP per capita and CO_2 emissions per capita is illustrated. It is especially considerable in the case of Brazil, Korea or Turkey, where a clear pattern can be seen.



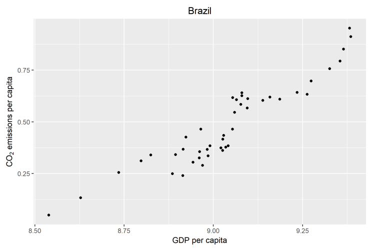
(a) Argentina



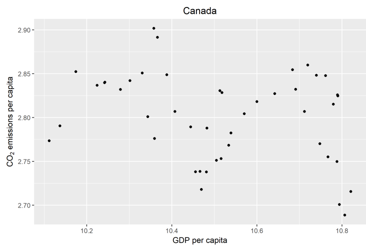
(b) Austria



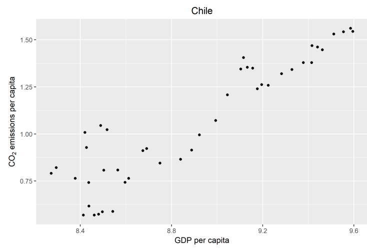
(c) Belgium



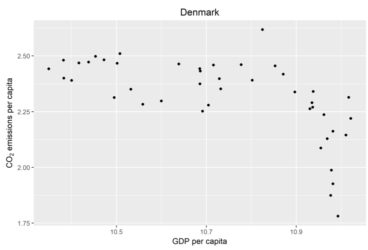
(d) Brazil



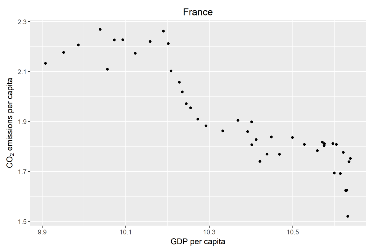
(e) Canada



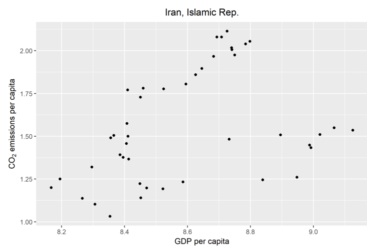
(f) Chile



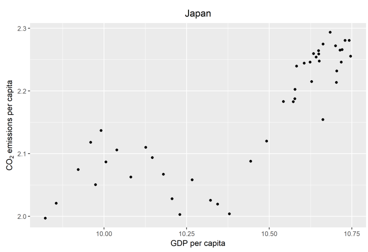
(g) Denmark



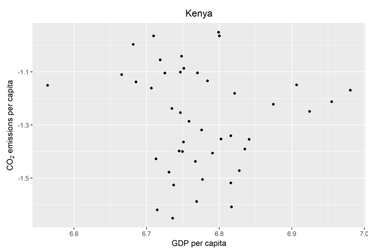
(h) France



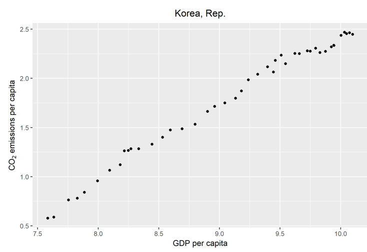
(i) Iran, Islamic Rep.



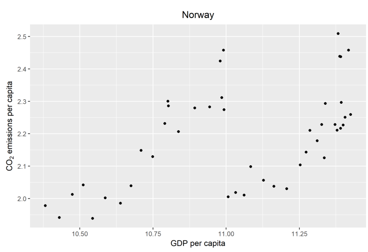
(j) Japan



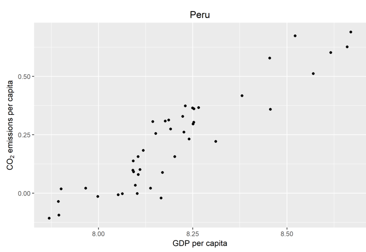
(k) Kenya



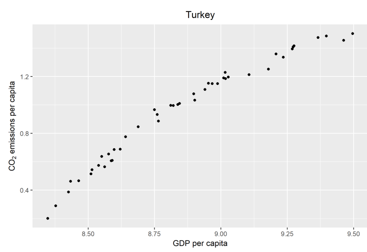
(l) Korea, Rep.



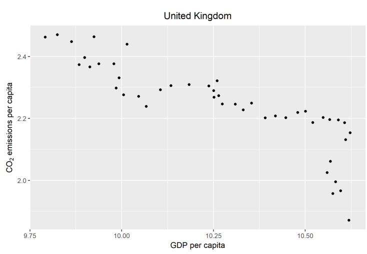
(m) Norway



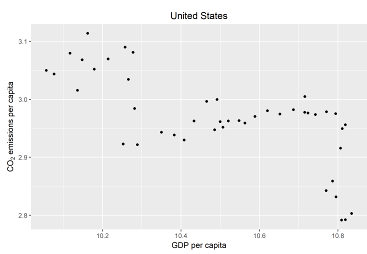
(n) Peru



(o) Turkey



(p) United Kingdom



(q) United States

Figure 3.2: Scatter Plots (CO_2 versus GDP) of Selected Countries

4 Approach

The approach of this thesis can be grouped into the following steps.

In a first step all countries, where the essential variables CO_2 emissions per capita and GDP per capita (and its powers) are integrated of order 2 or higher are excluded, as the later performed ARDL Bounds-Test cannot deal with integration orders higher than 1. The testing is done by two augmented Dickey-Fuller Tests, that are applied to the variables and their differences.

The next step is a pre-selection of countries which are analyzed more detailed in the following steps. First, unit root tests are executed and later cointegration tests, more specifically the Phillips-Oularis-Test and the Shin-Test, are performed. Also LM-Tests on a correct specified CPR-Relationship are executed. Those countries, where a majority of the LM-Tests state a correct specified CPR, proceed to the next step.
From here on, two models, Model 2 and Model 3, will be differentiated. Model 2 denotes an ARDL model as described in (42) with GDP per capita and its square included. Model 3 adds the third power additionally. Further variables to be added will be chosen in Step 3.
The chosen countries will now be analyzed deeper, also using powers of GDP per capita. Despite the criticism in section 2.1.3 those powers are treated as normal variables. This has been done in recent literature and furthermore only countries are included in the analysis, where the usual unit root tests accept the null of an I(1) process for the powers of GDP per capita. Therefore they show (at least in this dataset) a similar behavior. Note as well, that the models analyzed in this part include a linear trend. In the following analysis, the linear trend is excluded due to the inclusion of further variables.

After eliminating additional variables that are I(2) or higher for the countries chosen in steps 1 and 2, variable selection is done using Granger-Causality. First of all, for each country all remaining variables are included into a Granger-Causality model. Then, in each step, among the non-causal variables for CO_2 emissions the least causal is dropped out of the set of possible variables. This is done until all remaining variables are causal for CO_2 emissions per capita.

Step 4 is the actual cointegration testing using Pesaran et al. [2001]'s Case III of the Bounds-Test. First, the appropriate lag lengths p and q_i in (50) are determined using the Bayesian Information Criterion (BIC) and the errors are tested on serial correlation using the Breusch-Godfrey-Test and on heteroskedasticity using the Breusch-Pagan-Test. After that, the Bounds-Test is performed and (in case of cointegration) the long-run and the short-run-model are calculated. With those, we are able to check the EKC-Hypothesis. As well, a comparison with an included energy variable is provided to show the differences in results of this approach.

In the last step, different scenarios for the development of all explaining variables are created and their effect on the future CO_2 emissions is calculated. Also an Impulse Response analysis, as presented in section 2.4, is executed.

5 Results

In this chapter the results of the models, as described in Section 4, will be presented. Unless stated differently, the significance level of all tests is $\alpha = 0.05$. Some results were shifted to the Appendix for improved readability.

5.1 Pre-Testing

The first step of the analysis is the pre-testing. As described in Wagner [2015], a precise investigation of the given data is crucial for getting reliable results.
First, all countries, where one of the essential variables CO_2 emissions per capita or GDP per capita and its powers is integrated of order 2 or higher, are excluded, see Table 5.4 for the results and Table A.2 for details. The following extended testing is only done for the remaining countries.

Country	Phillips-Perron-Test				Augmented Dickey-Fuller-Test			
	CO_2	GDP	GDP^2	GDP^3	CO_2	GDP	GDP^2	GDP^3
Argentina	-7,927	-7,358	-7,277	-7,196	-1,422	-2,108	-2,106	-2,104
Austria	-14,986	-5,206	-5,28	-5,415	-1,587	-0,332	-0,34	-0,37
Belgium	-11,38	-5,244	-5,28	-5,347	-2,088	-0,239	-0,309	-0,403
Brazil	-11,091	-13,29	-12,848	-12,364	-2,135	-2,15	-2,078	-2,008
Canada	-11,178	-11,029	-11,163	-11,262	-1,948	-2,389	-2,421	-2,447
Chile	-6,395	-10,241	-9,618	-8,97	-2,722	-3,507	-3,41	-3,301
Denmark	-9,046	-2,856	-3,082	-3,33	-0,987	-0,698	-0,745	-0,795
Egypt, Arab Rep.	-7,802	-5,129	-5,882	-6,808	-2,809	-4,142*	-3,924*	-3,711*
France	-12,437	-3,837	-3,759	-3,696	-2,056	-0,242	-0,244	-0,258
Germany	-29,208*	-6,032	-6,633	-7,378	-3,584*	-1,363	-1,406	-1,463
Iran, Islamic Rep.	-4,938	-3,709	-3,73	-3,756	-2,129	-1,729	-1,743	-1,758
Japan	-10,55	-1,234	-1,206	-1,193	-1,961	-0,18	-0,224	-0,273
Kenya	-10,546	-10,723	-10,316	-9,914	-2,902	-0,9	-0,872	-0,843
Korea, Rep.	-1,91	0,332	0,414	-0,495	-1,024	0,177	0,17	-0,097
Norway	-18,212	-0,629	-0,455	-0,306	-2,054	-0,264	-0,217	-0,196
Peru	-2,085	-1,15	-0,98	-0,808	-0,617	-0,496	-0,432	-0,367
Senegal	-18,002	-3,415	-3,412	-3,41	-2,548	-0,767	-0,757	-0,746
Turkey	-16,202	-11,799	-10,142	-8,569	-2,602	-2,425	-2,114	-1,826
United Kingdom	-7,598	-5,612	-5,901	-6,19	-1,113	-1,445	-1,656	-1,861
United States	-8,317	-5,481	-5,869	-6,277	-2,088	-0,837	-0,985	-1,14

* is denoting a significance at the 5% level

Table 5.1: Results of the Unit Root Tests

Next, the essential variables, CO_2 emissions per capita and GDP per capita and its powers, will be tested on a unit root with the Phillips-Perron-Test and the Augmented Dickey-Fuller (ADF)-Test, both with a null hypothesis of a unit root. The results are presented in Table 5.1. We note, that in most cases both tests deliver consistent results except in two countries, Germany and Egypt. The null hypothesis is rejected in the case of Germany's CO_2 emissions for both tests and in the case of Egypt's GDP and its powers for the ADF-Test.
In all other countries we note that CO_2 emissions and GDP per capita do have a unit root. This is not surprising and verifies the clear trend, which can be found in all data.
The next tests will be cointegration tests of a quadratic and a cubic model using the Phillips-Oularis-Test of Chapter 2.3.2.2 and the Shin-Test of Chapter 2.3.2.3. The results are shown in Table 5.2.

Country	Quadratic Model		Cubic Model	
	Philips-Oularis-Test	Shin-Test	Philips-Oularis-Test	Shin-Test
Argentina	-24,333	0,051	-30,503	0,051
Austria	-32,532*	0,041	-32,561	0,019
Belgium	-15,509	0,106	-15,641	0,027
Brazil	-5,383	0,163	-5,287	0,056
Canada	-15,635	0,042	-16,957	0,036
Chile	-13,952	0,027	-15,051	0,023
Denmark	-25,256	0,032	-27,135	0,02
Egypt, Arab Rep.	-29,659	0,046	-31,054	0,022
France	-16,187	0,066	-29,712	0,027
Germany	-37,831*	0,027	-43,292*	0,039
Iran, Islamic Rep.	-20,912	0,033	-20,609	0,019
Japan	-16,89	0,087	-23,197	0,062
Kenya	-10,945	0,058	-10,997	0,026
Korea, Rep.	-14,531	0,05	-13,478	0,044
Norway	-19,512	0,081	-23,827	0,038
Peru	-30,511	0,048	-34,247	0,044
Senegal	-19,813	0,033	-19,821	0,039
Turkey	-31,313	0,156	-32,438	0,024
United Kingdom	-42,685*	0,035	-43,86*	0,021
United States	-11,08	0,128	-11,216	0,027

* is denoting a significance at the 5% level
Quadratic Model: $c_t = \mu + \alpha t + \beta_1 y_t + \beta_2 y_t^2 + u_t$
Cubic Model: $c_t = \mu + \alpha t + \beta_1 y_t + \beta_2 y_t^2 + \beta_3 y_t^3 + u_t$

Table 5.2: Results of the Cointegration Tests

The results show a cloudy picture. Only 3 countries, Austria, Germany and the UK, show consistency (on cointegration). In all other countries the tests both choose their null hypothesis and the results are conflicting.
The next tests will be on a correct specified CPR-relationship and will be presented in Table 5.3. All countries, where more than half of the LM-Tests in both models reject the null hypothesis are excluded. In case of two or more rejections in only one model, the countries are kept.

Country	Quadratic Model			Cubic Model		
	LM_I	LM_{II}	LM_{III}	LM_I	LM_{II}	LM_{III}
Argentina	2,981	12,175*	19,353*	2,33	0,074	2,531
Austria	3,976	2,589	5,323	5,17	6,271*	8,667*
Belgium	6,291*	4,958	6,943	6,17*	0,035	6,248
Brazil	5,26	0,14	8,979	5,938	0,241	6,439
Canada	6,593*	4,013	7,716	6,489*	0,57	6,508
Chile	6,135*	4,391	11,541*	1,831	1,793	5,687
Denmark	2,458	1,545	2,644	2,069	0,099	2,136
Egypt, Arab Rep.	9,182*	17,217*	19,02*	8,838*	18,835*	21,244*
France	4,507	6,064*	7,25	11,002*	1,529	14,632*
Germany	11,591*	3,862	12,793*	15,219*	1,8	17,084*
Iran, Islamic Rep.	5,803	0,138	6,164	5,877	0,001	5,885
Japan	1,275	9,428*	9,706*	2,488	1,688	3,655
Kenya	3,955	0,776	4,562	3,732	0,173	3,792
Korea, Rep.	2,705	2,974	8,98	3,584	1,937	8,114*
Norway	2,692	3,81	3,874	1,228	1,361	2,711
Peru	2,729	3,958	5,368	1,659	2,779	3,789
Senegal	33,606*	0,505	44,522*	44,142*	0,342	45,814*
Turkey	1,581	0,875	1,826	0,869	0,833	2,488
United Kingdom	3,347	0,825	6,333	6,096*	0,015	6,213
United States	1,726	4,027	5,764	2,387	0,105	2,551

LM_I-LM_{III} are denoting the different LM-Tests, described in Chapter 2.1.3.1.
* is denoting a significance at the 5% level
Quadratic Model: $c_t = \mu + \alpha t + \beta_1 y_t + \beta_2 y_t^2 + u_t$
Cubic Model: $c_t = \mu + \alpha t + \beta_1 y_t + \beta_2 y_t^2 + \beta_3 y_t^3 + u_t$

Table 5.3: Results of the LM-Tests

We note, that Egypt, Germany and Senegal drop out. Argentina, Chile and Japan (Quadratic Model) as well as Austria and France (Cubic Model) show rejections in only one model, however, are taken into the group of analyzed countries.
In Table 5.4, all countries that proceed to the actual analysis and the excluded countries plus the reason for their exclusion are summarized. We observe some interesting behavior. Only one of the 13 countries of the poorer half of the countries (with Income Group 'Low Income' or 'Lower Middle Income'), Kenya, is taken for further analysis. Furthermore the classical boom countries in Asia and Africa, for example Bangladesh, China, Indonesia, Philippines, Saudi Arabia or Thailand, are excluded as well as many newly industrialized countries, such as South Africa, Mexico, India or Pakistan. As the variables have to be I(1) at most, this is not surprising at all. Especially the GDP (per capita) variables from booming countries do normally have a quadratic or even an exponential trend included, which does not meet the conditions.
Concluding we note, that from a set of countries which was quite diverse at the beginning, we end up with a selection of 17 countries, where Europe and North America contribute almost half.

Country	Acceptance	Description
Algeria	✗	GDP, GDP^2 and GDP^3 are I(2)+
Argentina	✓	
Australia	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Austria	✓	
Bangladesh	✗	GDP, GDP^2 and GDP^3 are I(2)+
Belgium	✓	
Brazil	✓	
Bulgaria	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Canada	✓	
Chile	✓	
China	✗	GDP, GDP^2 and GDP^3 are I(2)+
Congo, Dem. Rep.	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Cuba	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Denmark	✓	
Egypt, Arab Rep.	✗	Not correct specified CPR-Relationship
France	✓	
Germany	✗	Not correct specified CPR-Relationship
Greece	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Honduras	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
India	✗	CO_2 is I(2)+
Indonesia	✗	GDP, GDP^2 and GDP^3 are I(2)+
Iran, Islamic Rep.	✓	
Israel	✗	CO_2 is I(2)+
Italy	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Japan	✓	
Kenya	✓	
Korea, Rep.	✓	
Mexico	✗	CO_2 is I(2)+
Mongolia	✗	CO_2 is I(2)+
Nepal	✗	GDP, GDP^2 and GDP^3 are I(2)+
Netherlands	✗	GDP, GDP^2 and GDP^3 are I(2)+
Nigeria	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Norway	✓	
Pakistan	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Peru	✓	
Philippines	✗	CO_2 is I(2)+
Saudi Arabia	✗	GDP, GDP^2 and GDP^3 are I(2)+
Senegal	✗	Not correct specified CPR-Relationship
South Africa	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Spain	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Switzerland	✗	GDP, GDP^2 and GDP^3 are I(2)+
Thailand	✗	CO_2, GDP, GDP^2 and GDP^3 are I(2)+
Turkey	✓	
United Kingdom	✓	
United States	✓	

✓= Acceptance, ✗= Drop-Out

Table 5.4: Overview of the Accepted and Dropped-Out Countries

5.2 Variable Selection with Granger-Causality

In this section, the variables chosen to enter each country's Model 2 and Model 3 are presented. If a variable is not feasible in this context, it means that it was excluded, because it was I(2) or higher.
The results of Model 2 are shown in Table 5.5.

Country	Foreign Trade	Population Density	Urbanization	Fossil Energy	Resources Rents
Argentina	✓	✓	⊘	×	×
Austria	×	×	⊘	⊘	✓
Belgium	✓	⊘	×	×	⊘
Brazil	✓	×	⊘	×	⊘
Canada	⊘	✓	⊘	⊘	✓
Chile	×	×	×	×	×
Denmark	×	⊘	⊘	✓	×
France	✓	✓	✓	⊘	×
Iran, Islamic Rep.	✓	⊘	×	×	×
Japan	✓	✓	⊘	⊘	×
Kenya	×	×	✓	×	×
Korea, Rep.	×	⊘	⊘	⊘	×
Norway	✓	⊘	⊘	✓	✓
Peru	⊘	⊘	⊘	×	×
Turkey	✓	×	⊘	×	×
United Kingdom	×	⊘	⊘	⊘	×
United States	✓	⊘	⊘	⊘	×

✓= Causal, ×= Not causal, ⊘ = Not feasible

Table 5.5: Chosen Variables in Model 2

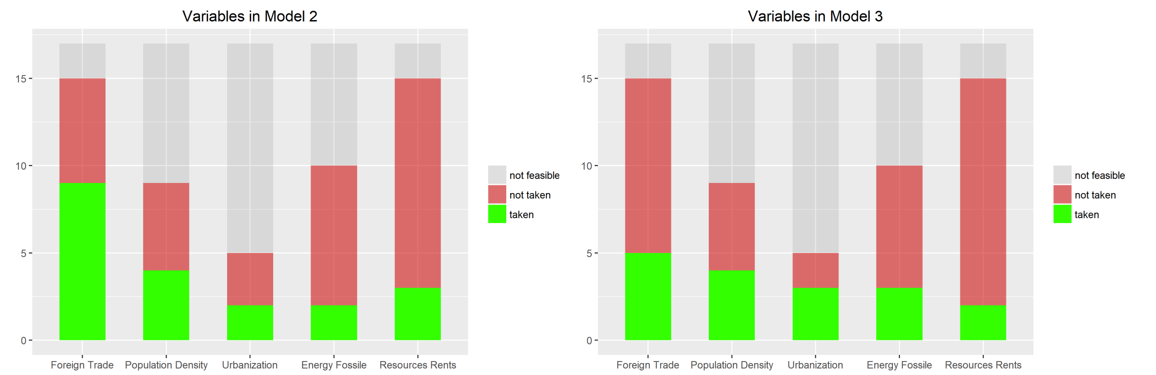
We note that the Foreign Trade variable is taken the most. Furthermore it is not feasible in only 2 countries (Canada and Peru). Both demographic variables, Population Density and Urbanization, are quite often integrated of order 2 or higher, especially the latter one. In the remaining countries, they were taken by about half. Surprisingly, the last group of variables, which consists of Fossil Energy and Resources Rents, is only taken in very few countries. The Fossil Energy variable is only chosen by the two Scandinavian countries, Denmark and Norway, and Resources Rents only by Austria, Canada and Norway. Other than the previous group of variables, the energy and environmental variables are feasible in most countries. We notice no clear pattern in the variable selection, but it can be seen that nearly all countries choose further variables and only 4 countries, Chile, Korea, Peru and the UK, stay with their basic model, only consisting of CO_2 emissions per capita and GDP per capita.
Next, all results of Model 3 are presented in Table 5.6.

Country	Foreign Trade	Population Density	Urbanization	Fossil Energy	Resources Rents
Argentina	✓	✗	⊘	✗	✗
Austria	✗	✗	⊘	⊘	✗
Belgium	✓	⊘	✓	✓	⊘
Brazil	✗	✓	⊘	✗	⊘
Canada	⊘	✓	⊘	⊘	✗
Chile	✗	✗	✓	✓	✗
Denmark	✗	⊘	⊘	✓	✗
France	✗	✗	✓	⊘	✗
Iran, Islamic Rep.	✗	⊘	✗	✗	✗
Japan	✗	✓	⊘	⊘	✗
Kenya	✗	✗	✗	✗	✗
Korea, Rep.	✗	⊘	⊘	⊘	✗
Norway	✓	⊘	⊘	✗	✗
Peru	⊘	⊘	⊘	✗	✗
Turkey	✓	✓	⊘	✗	✗
United Kingdom	✓	⊘	⊘	⊘	✓
United States	✗	⊘	⊘	⊘	✓

✓= Causal, ✗= Not causal, ⊘ = Not feasible

Table 5.6: Chosen Variables in Model 3

Qualitatively, a similar picture to the one in Model 2 is got. Foreign Trade is the most chosen variable, behind are the demographic and the energy and environmental variables. Quantitatively we note, that the models got smaller and additional variables are chosen less often, due to the inclusion of the third power of GDP per capita. If we take a look at the variable Foreign Trade for example, we note that only 5 countries chose it as an additional variable, in Model 2 it were with 9 almost double the amount. Also the number of plain models rose from 4 in Model 2 to 5 in Model 3.
An overview of the number of inclusions of the provided variables is shown in Figure 5.1.



(a) Model 2 (b) Model 3

Figure 5.1: Observed Frequency of Occurrence of the Involved Variables in the Models

5.3 Bounds-Testing

In this section, all results of the ARDL Bounds-Test as well as the short-run and long-run models are found.
First of all, the lower and upper bounds of the Bounds-Test at the 10% level are presented in Table 5.7. The values are those calculated in Narayan [2005] and are only calculated for observation numbers divisible by 5, in case of an observation number not divisible by 5, the critical bounds of the next higher suitable number are chosen. As well the critical values are only calculated till a variable number of $k = 7$. If the variable number is larger, according to Jordan and Philips, the critical values from the case $k = 7$ will be chosen[19].

	obs = 30		obs = 35		obs = 40		obs = 45	
	LB	UB	LB	UB	LB	UB	LB	UB
k = 2	3,437	4,47	3,393	4,41	3,373	4,377	3,33	4,347
k = 3	3,008	4,15	2,958	4,1	2,933	4,02	2,893	3,983
k = 4	2,752	3,994	2,696	3,898	2,66	3,838	2,638	3,772
k = 5	2,578	3,858	2,508	3,763	2,483	3,708	2,458	3,647
k = 6	2,457	3,797	2,387	3,671	2,353	3,599	2,327	3,541
k = 7	2,384	3,728	2,3	3,606	2,26	3,534	2,238	3,461
k = 8	2,384	3,728	2,3	3,606	2,26	3,534	2,238	3,461
k = 9	2,384	3,728	2,3	3,606	2,26	3,534	2,238	3,461

k = Number of Variables, obs = Number of Observations, LB = Lower Bound, UB = Upper Bound

Table 5.7: Critical Values (10% level) for the Bounds-Test

Now, we can calculate the short-run and the long-run models and perform the Bounds-Test. Here, the appropriate short-run model is chosen from all possible models with $1 \leq p \leq 2$ and $1 \leq q_i \leq 2$ for all i, using the Bayesian Information Criterion (BIC). Models with heteroskedastic or serially correlated errors are excluded.
The long-run results of Model 2 can be found in Table 5.8 and those of Model 3 in Table 5.9. The corresponding short-run models are in Tables A.3 and A.4 and were moved to the Appendix. Furthermore GDP per capita was demeaned and standardized to prevent collinear behavior, which some countries showed in prior analysis.

First, we note that in Model 2 no feasible combination is found for France and in Model 3 for Belgium. That means that all combinations do either show serial correlation or heteroskedastic behavior in the errors. Moreover, not many countries do have many significant variables. Especially the additional variables with the exception of Foreign Trade are not significant in any model.
Some countries, as Brazil, Iran and Kenya in Model 2 and Brazil, Chile, France, Iran, Peru and the United States in Model 3 show an explosive and unrealistic behavior in the coefficients, even after GDP per capita was demeaned and standardized.
We note, that the variables partly fulfill the expected algebraic signs. The Foreign Trade coef-

[19] This could theoretically happen in the presented models with the presented additional variables, as the largest possible model has 9 variables. Practically the largest model in this analysis has 5 variables. Therefore, this is only a theoretical statement.

ficients are slightly more positive than negative, but almost the same quantity, which confirms the mixed expectancy we had in section 3.2.1. This variable is also the only additional variable, which shows significance in some countries.
The signs of the Population Density coefficients are also mixed, which does not meet our expectations. On the other hand Urbanization has a negative, the share of Fossil Energy a positive and Natural Resources Rents a negative impact on CO_2 emissions per capita, except the latter one this is well inline with our assumptions.
The Error-Correction-Model (ECM)-Parameter is between -1 and 0 and therefore in the right range for every country except the UK. In Model 2 six countries show cointegrating behavior and the Bounds-Test rejects its H_0, in Model 3 there are four. Furthermore, in the case of Denmark in Model 2 and in the case of Argentina, Austria, Japan, Korea and the United States in Model 3, the Bounds-Test is inconclusive.
Next, the fitted values versus the original values are presented in Figure 5.2 for Model 2 and in Figure 5.3 for Model 3. Those estimated values were calculated by deriving the estimated coefficients of the ARDL-Polynomials (43) and (44) for all variables and plugging them into the ARDL-Equation (45). The estimated coefficients are found in Tables A.5 and A.6.
In general, we note an excellent fit in both models and in all countries. Only in some models, a few short time periods cannot be modeled completely right, as in Austria's, Kenya's or Norway's Models.
The addition of the third power of GDP per capita enhances nearly all models, especially in Brazil, Kenya or Peru, a clearly improved fit is achieved and the variance of CO_2 is explained much better.
Overall, the best fit is gained in Brazil, Chile, Denmark, France (Model 3), Korea, Turkey and the United States. Especially in Denmark, the accuracy of the predictions is remarkable, keeping the volatility of the CO_2 emissions in mind. Also in Korea and Turkey, the fit is extraordinary, but for the sake of fairness, the complexity of CO_2 emissions is much lower in those countries and a good degree of explanation was also expected from the data inspection in the Scatter Plots, provided in Figures 3.2(l) and 3.2(o).

Country	ARDL-Combination	Intercept	GDP	GDP^2	FT	POD	URB	FO	RR	ECM	SC	HS	F-Statistic
Argentina	(2,1,1,2,1)	1,99***	0,06**	0,02	0,1**	-0,33				-0,84	0,08	0,42	6,13*
Austria	(1,1,1,1)	1,91***	0	0,01					-0,06	-0,42	0,09	0,5	2,61
Belgium	(1,1,1,1)	8,51***	0,13	-0,01	-1,29					-0,38	0,07	0,72	6,24*
Brazil	(1,1,1,1)	157,16	6,76	6,42	-53,8					-0,08	0,26	0,57	4,22*
Canada	(1,1,1,1,1)	3,96***	0,11	0		-0,99			-0,01	-0,33	0,61	0,61	1,53
Chile	(1,1,1)	0,97***	0,28***	-0,05						-0,14	0,18	0,09	1,37
Denmark	(1,1,1,1)	-6,94***	0,06	0,01				2,06		-0,43	0,26	0,95	3,39†
France	-												
Iran, Islamic Rep.	(1,1,2,1)	16,19	1,22	-0,09	-3,63					-0,02	0,06	0,18	0,68
Japan	(1,1,1,1,1)	0,54	0,1	0,07	-0,2	0,37				-0,37	0,1	0,3	5,77*
Kenya	(1,1,1,1)	-1,32	0,15	-0,07			-0,08			-0,29	0,19	0,27	2,3
Korea, Rep.	(1,1,1)	1,75***	0,5***	-0,02						-0,27	0,25	0,46	2,39
Norway	(1,1,1,2,1,1)	-8,96	-0,14	0,03	1,18			1,5	0,11	-0,32	0,17	0,05	1,76
Peru	(1,1,1)	0,24***	0,23***	0						-0,5	0,3	0,56	5,35*
Turkey	(1,1,1,1)	0,71***	0,32***	-0,05***	0,09***					-0,79	0,6	0,46	6,97*
United Kingdom	(2,1,1)	2,59***	-0,1*	0,12						0,07	0,25	0,11	1,19
United States	(1,1,1,1)	5,41***	0,21*	-0,03	-0,9**					-0,08	0,69	0,25	2,44

*, ** and *** are denoting significance at the 10%, 5% and 1% level.
In the column F-statistic, * is denoting significance at the 10% level and † is denoting, that the Bounds-Test is inconclusive at the 10 % level.
GDP = GDP per capita, FT = Foreign Trade, POD = Population Density, URB = Urbanization, FO = Fossil Energy, RR = Resources Rents
ECM is denoting the estimated Error-Correction Parameter, SC is denoting the p-values of the Breusch-Godfrey-Test on Serial Correlation and HS is denoting the p-values of the Breusch-Pagan-Test on Heteroskedasticity.

Some coefficients appear as 0 in the table above. These results arise due to rounding the values.

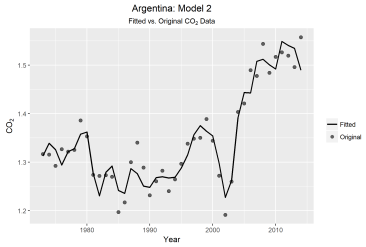
Table 5.8: Long-Run Coefficients of Model 2

Country	ARDL-Combination	Intercept	GDP	GDP^2	GDP^3	FT	POD	URB	FO	RR	ECM	SC	HS	F-Statistic
Argentina	(1,1,1,1,1)	$1,15^{***}$	0,05	0	0,01	$0,06^{*}$					-0,59	0,14	0,85	$2,81^{\dagger}$
Austria	(1,1,1,2)	$2,07^{***}$	$0,13^{**}$	-0,02	$-0,09^{**}$						-0,41	0,23	0,46	$3,61^{\dagger}$
Belgium	-													
Brazil	(1,1,1,1,1)	-4,67	-0,51	0,03	0,18		1,75				-0,12	0,46	0,76	1,52
Canada	(1,1,1,1,1)	$3,98^{***}$	$0,17^{*}$	0,01	$-0,03^{*}$		-1,07				-0,32	0,71	0,38	1,95
Chile	(1,1,1,1,1,1,1)	32,59	0,61	0,02	-0,05			-8,32	1,28		-0,34	0,46	0,43	2,24
Denmark	(1,1,1,1,1)	$-7,05^{**}$	0,04	0	0,01				2,09		-0,42	0,28	0,48	2,42
France	(2,2,2,1,2)	414,8	8,29	-0,98	-1,13			-95,73			-0,1	0,09	0,63	$4,13^{*}$
Iran, Islamic Rep.	(1,1,2,1)	$2,01^{***}$	0,63	0,14	-0,23						-0,05	0,13	0,72	0,58
Japan	(1,1,1,2,1)	-13,09	0,06	-0,01	-0,09		2,62				-0,29	0,13	0,07	$3^{\dagger}$
Kenya	(1,1,1,1)	$-1,32^{***}$	-0,04	-0,06	0,04						-0,21	0,31	0,58	1,07
Korea, Rep.	(1,1,1,1)	$1,88^{***}$	$0,39^{***}$	$-0,15^{***}$	$0,05^{**}$						-0,26	0,29	0,96	$3,67^{\dagger}$
Norway	(1,1,1,1,1)	$3,72^{***}$	-0,07	0,06	0,09	-0,35					-0,68	0,6	0,06	$4,03^{*}$
Peru	(1,1,1,2)	$0,25^{***}$	$0,37^{***}$	$0,05^{**}$	$-0,03^{*}$						-0,56	0,1	0,31	$6,63^{*}$
Turkey	(1,1,1,1,1,1)	$1,87^{**}$	$0,32^{*}$	-0,04	0,01	0,13	-0,27				-0,81	0,5	0,54	$4,76^{*}$
United Kingdom	(2,1,1,1,1,2)	$5,27^{***}$	-0,12	0,12	0,03	$-0,75^{*}$				-0,02	0,12	0,14	0,07	1,07
United States	(1,1,1,1,1)	$2,71^{***}$	-0,46	-0,2	0,21					-0,61	-0,06	0,16	0,95	$2,92^{\dagger}$

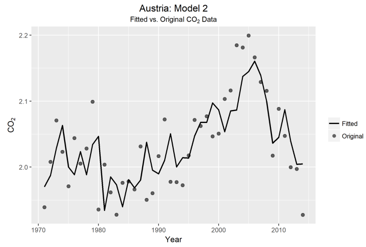
*, ** and *** are denoting significance at the 10%, 5% and 1% level.
In the column F-statistic, * is denoting significance at the 10% level and † is denoting, that the Bounds-Test is inconclusive at the 10 % level.
GDP = GDP per capita, FT = Foreign Trade, POD = Population Density, URB = Urbanization, FO = Fossil Energy, RR = Resources Rents
ECM is denoting the estimated Error-Correction Parameter, SC is denoting the p-values of the Breusch-Godfrey-Test on Serial Correlation and HS is denoting the p-values of the Breusch-Pagan-Test on Heteroskedasticity.

Some coefficients appear as 0 in the table above. These results arise due to rounding the values.

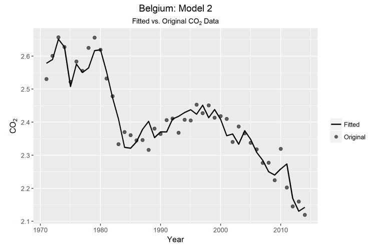
Table 5.9: Long-Run Coefficients of Model 3



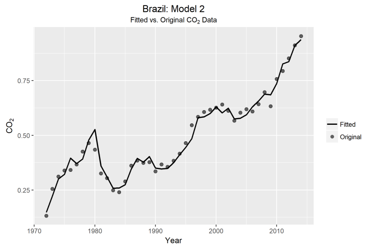
(a) Argentina



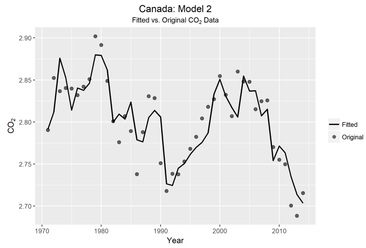
(b) Austria



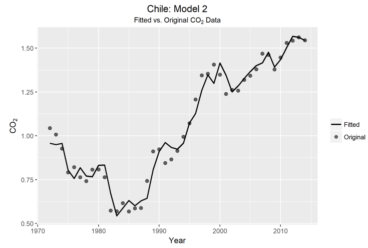
(c) Belgium



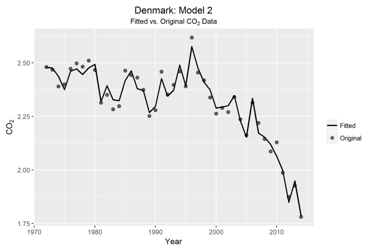
(d) Brazil



(e) Canada

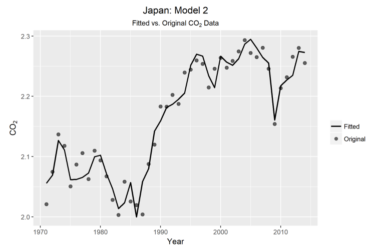


(f) Chile

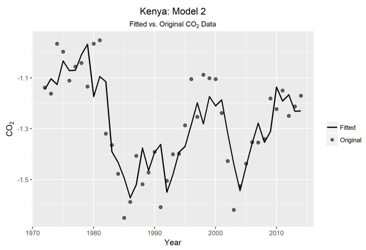


(g) Denmark

(h) Iran, Islamic Rep.

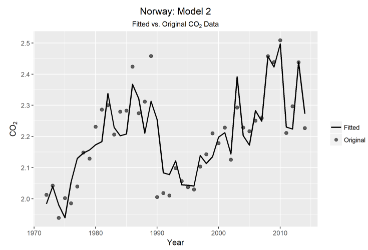


(i) Japan

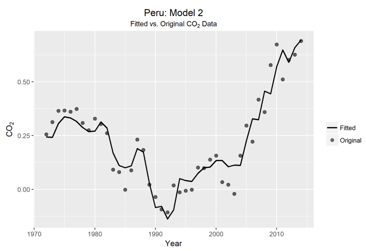


(j) Kenya

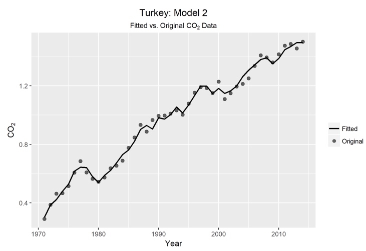
(k) Korea, Rep.



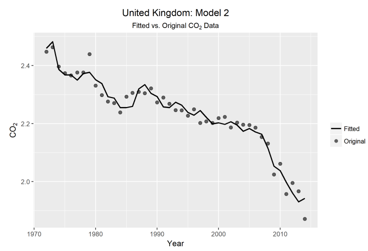
(l) Norway



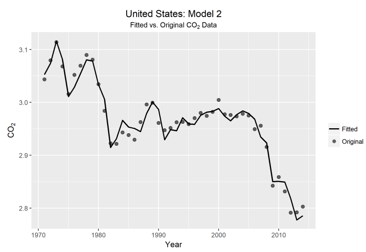
(m) Peru



(n) Turkey

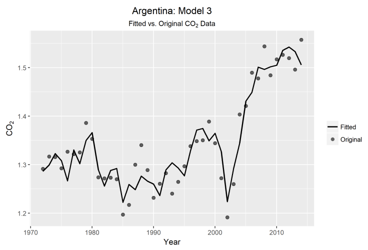


(o) United Kingdom

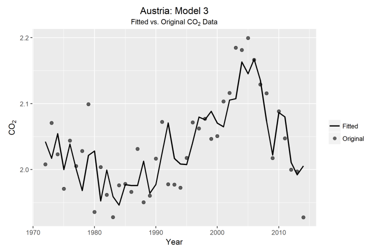


(p) United States

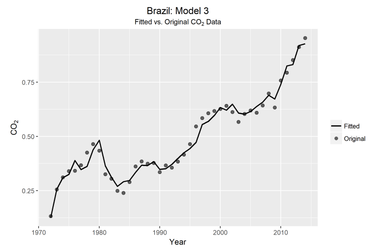
Figure 5.2: Plots of the Fitted Values in Model 2



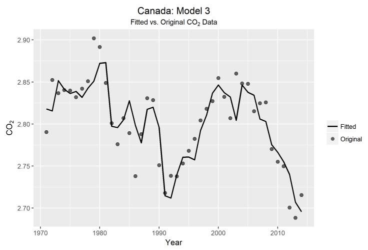
(a) Argentina



(b) Austria

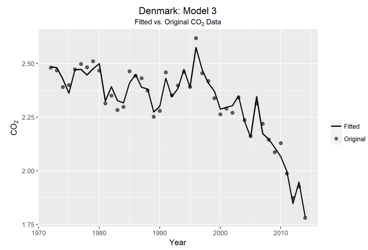


(c) Brazil

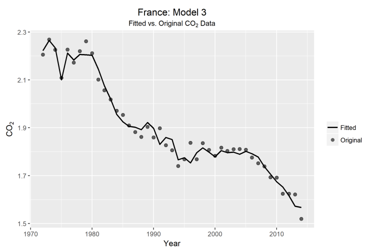


(d) Canada

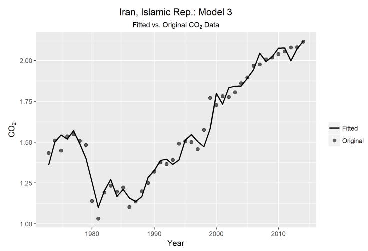
(e) Chile



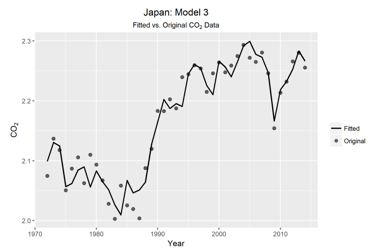
(f) Denmark



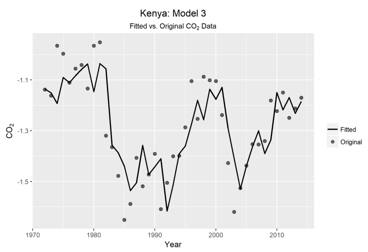
(g) France



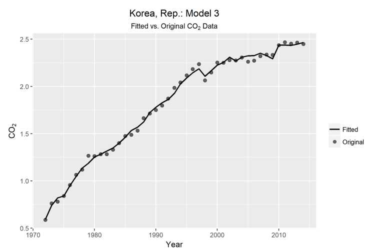
(h) Iran, Islamic Rep.



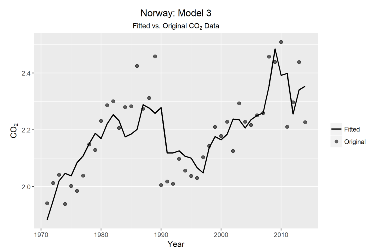
(i) Japan



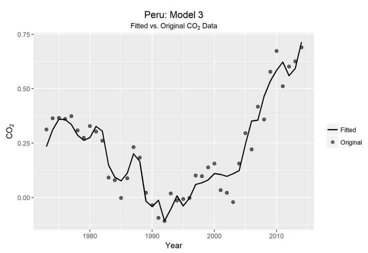
(j) Kenya



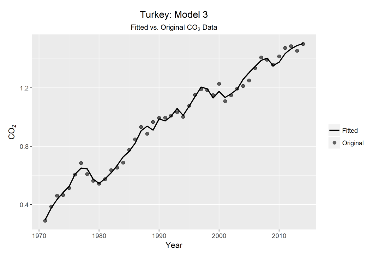
(k) Korea, Rep.



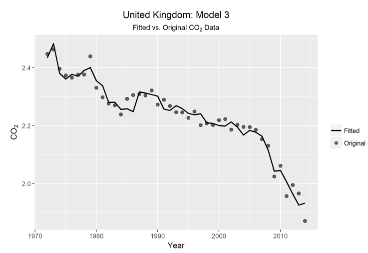
(l) Norway



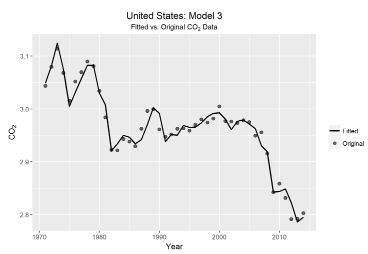
(m) Peru



(n) Turkey



(o) United Kingdom



(p) United States

Figure 5.3: Plots of the Fitted Values in Model 3

5.4 EKC-Hypothesis

In this section we will try to verify the EKC-Hypothesis for the long-run models presented in the previous section. As already stated at some points of this thesis, the results have to be interpreted carefully as some modifications were made to the underlying equation of the EKC-Hypothesis[20]. The results of Model 2 are shown in Table 5.10 and those of Model 3 in Table 5.11. In Model 2, the hypotheses to be tested are cases (iv*) and (v*) of Chapter 2.1.1, in Model 3 cases (vi*) - (ix*).

Country	Without Energy Use				With Energy Use			
	EKC	GDP	GDP^2	Turning Point	EKC	GDP	GDP^2	Turning Point
Argentina	U	0,06	0,02	-1,49	U	-0,06	0	6,41
Austria	U	0	0,01	-0,08	U	-0,22	0,02	7,01
Belgium	inv U	0,13	-0,01	5,96	U	-0,16	0	40,61
Brazil	U	6,76	6,42	-0,53	U	-1,34	0,12	5,65
Canada	U	0,11	0	-14,7	U	-0,01	0,04	0,08
Chile	inv U	0,28	-0,05	3,07	-			
Denmark	U	0,06	0,01	-2,11	inv U	-0,02	-0,01	-0,97
Iran, Islamic Rep.	inv U	1,22	-0,09	6,59	U	0,23	0,03	-4,38
Japan	U	0,1	0,07	-0,74	U	-0,05	0,1	0,24
Kenya	inv U	0,15	-0,07	1,07	-			
Korea, Rep.	inv U	0,5	-0,02	10,67	-			
Norway	U	-0,14	0,03	2,04	inv U	-0,19	-0,01	-9,05
Peru	inv U	0,23	0	84,27	-			
Turkey	inv U	0,32	-0,05	3,16	inv U	0,14	-0,03	2,36
United Kingdom	U	-0,1	0,12	0,42	U	-0,05	0,19	0,14
United States	inv U	0,21	-0,03	3,27	U	0	0,01	-0,11

inv U = inverted U-Shaped relationship, referring to case (iv*)
U = U-Shaped relationship, referring to case (v*)
The Turning Point has been calculated by $-\frac{\hat{\beta}_1}{2\hat{\beta}_2}$, where $\hat{\beta}_i$ is denoting the estimated coefficient of GDP^i.
Some coefficients appear as 0 in the table above. These results arise due to rounding the values.

Table 5.10: EKC-Hypothesis and Turning Point in Model 2

We note, that 50 % of the countries in Model 2 fulfill the EKC-Hypothesis of an inverted U-shaped relationship. In Model 3 there are 5 countries fulfilling the EKC-Hypothesis of an N-shaped relationship, further 4 do show the so-called N* shape of a monotonic non-linearly increasing relationship. It is interesting to note, that no real conclusions can be drawn from the result on the wealth of a country, as for example Norway, with one of the highest GDP per capita of the chosen countries is not fulfilling the EKC-Hypothesis in Model 2, but Kenya, with the lowest GDP per capita in the selection, is. As well in Model 3, rich countries like Austria or Canada do not fulfill the N-shaped relationship, but Kenya is once again.
Furthermore, some examples for each shape have been plotted in Figure 5.4. In Turkey's case, we can see a pretty smooth and wide inverted U-shape, the highest GDP per capita value is also the last one from 2014. Also in Japan, the development is interesting, starting at medium CO_2 emissions in the 1970s and reaching its turning point in the 1980s at a GDP per

[20]There are additional variables, that are dependent on GDP, included in the model and GDP per capita was demeaned and standardized.

capita value of -0.74, the emissions started to rise again with a growing economy and GDP per capita values. In Canada's example, the next years will decide if the inverted N-shaped path is confirmed, as the highest GDP per capita value from 2014 is exactly at the second expected turning point.

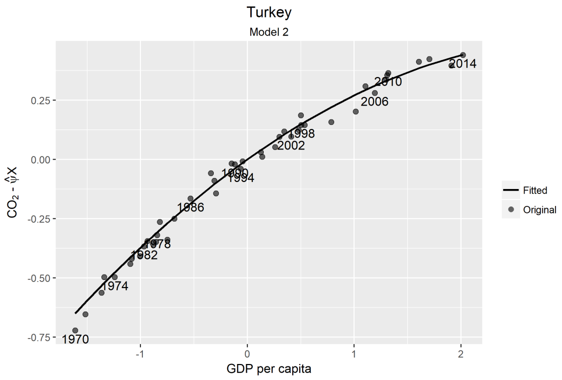
Country	Without Energy Use					With Energy Use				
	EKC	GDP	GDP^2	GDP^3	Turning Points	EKC	GDP	GDP^2	GDP^3	Turning Points
Argentina	N*	0,05	0	0,01	-	N*	0,02	0,02	0,01	-
Austria	inv N	0,13	-0,02	-0,09	-0.74, 0.62	inv N*	-0,12	-0,04	-0,04	-
Brazil	N	-0,51	0,03	0,18	-1.03, 0.92	N	-0,32	-0,55	0,32	-0.24, 1.41
Canada	inv N	0,17	0,01	-0,03	-1.29, 1.56	inv N	0,03	0,05	-0,02	-0.28, 2
Chile	inv N	0,61	0,02	-0,05	-1.82, 2.12	inv N	0,1	0,06	0	-0.76, 11.23
Denmark	N*	0,04	0	0,01	-	N	-0,03	-0,01	0,01	-1.06, 1.57
France	inv N	8,29	-0,98	-1,13	-1.88, 1.3	N	-0,15	0,02	0,17	-0.59, 0.51
Iran, Islamic Rep.	inv N	0,63	0,14	-0,23	-0.77, 1.18	inv N	0,21	0,07	-0,04	-0.9, 2.12
Japan	inv N	0,06	-0,01	-0,09	-0.51, 0.43	N	0	0,05	0,03	-1.18, -0.03
Kenya	N	-0,04	-0,06	0,04	-0.27, 1.22	-				
Korea, Rep.	N*	0,39	-0,15	0,05	-	-				
Norway	N	-0,07	0,06	0,09	-0.76, 0.33	N	-0,3	0,17	0,1	-1.75, 0.6
Peru	inv N	0,37	0,05	-0,03	-1.55, 2.69	-				
Turkey	N*	0,32	-0,04	0,01	-	N	-0,02	-0,02	0,02	-0.41, 0.96
United Kingdom	N	-0,12	0,12	0,03	-3.46, 0.45	N	-0,23	0,12	0,12	-1.21, 0.53
United States	N	-0,46	-0,2	0,21	-0.59, 1.23	N	-0,08	0,01	0,03	-1.07, 0.82

N = N-Shaped relationship, referring to case (vi*)
inv N = inverted N-Shaped relationship, referring to case (vii*)
N* = Monotonic non-linearly increasing relationship, referring to case (viii*)
inv N* = Monotonic non-linearly decreasing relationship, referring to case (ix*)
The Turning Points have been calculated by solving $\hat{\beta}_1 + 2\hat{\beta}_2 x + 3\hat{\beta}_3 x^2 = 0$, where $\hat{\beta}_i$ is denoting the estimated coefficient of GDP^i.
Some coefficients appear as 0 in the table above. These results arise due to rounding the values.

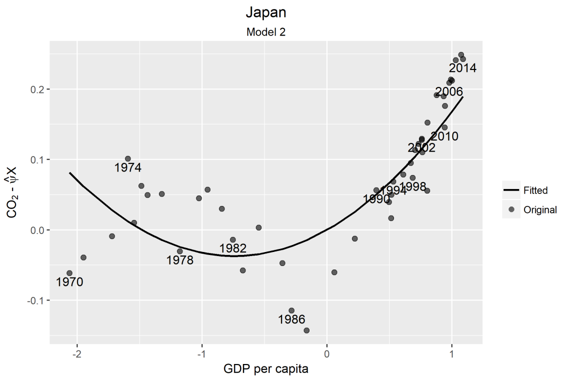
Table 5.11: EKC-Hypothesis and Turning Points in Model 3

5.4.1 Comparison with included Energy Use Variable

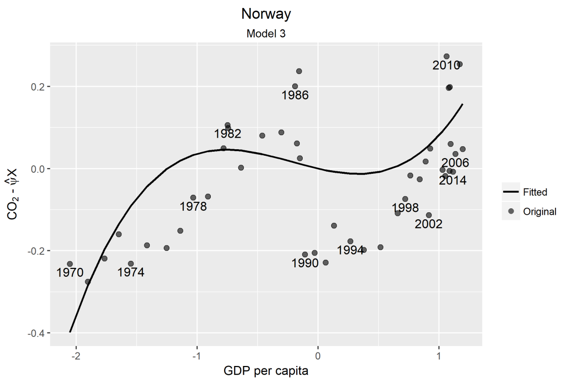
The results of the models with an additional Energy Use variable are shown as well in Tables 5.10 and 5.11. The inverted U-shaped relationship between GDP per capita and CO_2 emissions per capita is shown by 3 countries, Denmark, Norway and Turkey. Furthermore we see, that the results on the shape of the curve change in nearly 50 % of the analyzed countries.
In Model 3, the N or N*-shaped relationship applies in 9 of 13 cases and in 11 of 13 cases the shape stays, apart from changes in the existence of the turning points, the same.
We note also some interesting values, for example Peru's turning point of 84.27 or Korea's of 10.67 in Model 2 without Energy Use, where especially the former one seems quite inaccurate. In general, in about 2/3 of the countries in Model 2 and in about half of the countries in Model 3, however, the turning points rise, for example in the case of Belgium the turning point increases more than sixfold. This result is interesting, keeping the theoretical discussion of section 2.1.2.1 in mind, as we expected the turning points to fall in a model with an included Energy Use variable.
It should be noted, that in 3 countries, Kenya, Korea and Peru, the Energy Use variable is I(2) or higher and therefore a model with Energy Use included cannot be presented. Moreover in Chile's Model 2 no feasible ARDL-Model is found with an included Energy Use variable.



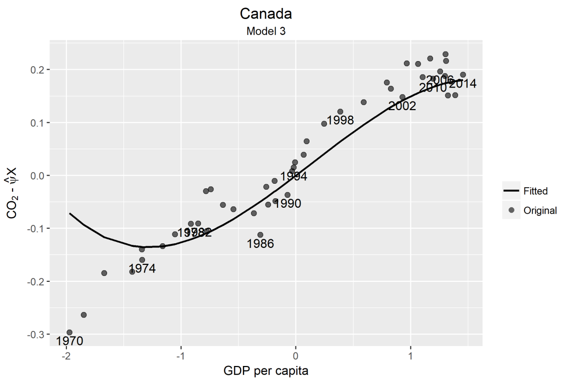
(a) Inverted U-Shaped Relationship (case (iv*)) in Turkey's Model 2



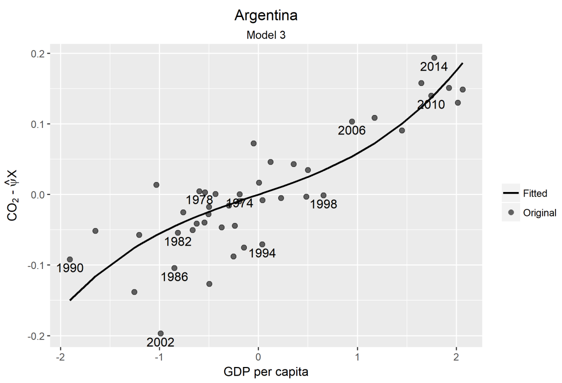
(b) U-Shaped Relationship (case (v*)) in Japan's Model 2



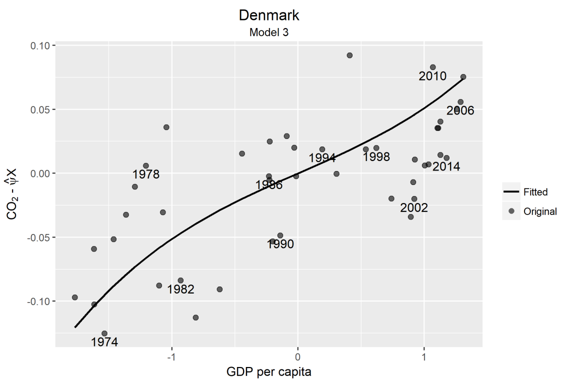
(c) N-Shaped Relationship (case (vi*)) in Norway's Model 3



(d) Inverted N-Shaped Relationship (case (vii*)) in Canada's Model 3



(e) Monotonic non-linearly increasing Relationship (case (viii*)) in Argentina's Model 3



(f) Monotonic non-linearly increasing Relationship (case (viii*)) in Denmark's Model 3

Note, that the CO_2 emissions per capita have been adjusted in these plots by the effects of the additional variables and the intercept, whose estimated coefficients have been summarized in $\hat{\psi}$. X is a matrix, consisting of one row with only 1-entries (for the intercept) and the further rows cover the values of the additional variables.

The fitted values have been calculated by $(\hat{\beta}_1\text{GDP} + \hat{\beta}_2\text{GDP}^2)$ in Model 2 and by $(\hat{\beta}_1\text{GDP} + \hat{\beta}_2\text{GDP}^2 + \hat{\beta}_3\text{GDP}^3)$ in Model 3.

Figure 5.4: Selected Adjusted Relationships between CO_2 emissions and GDP per capita

5.5 Forecasts

In this last section, the results of the previous sections will be used to estimate forecasts, analyzing different scenarios and calculate Impulse Response functions.

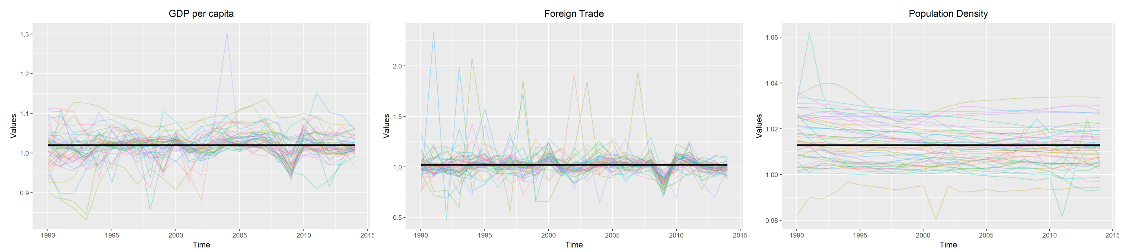
5.5.1 Scenario Analysis

The scenarios presented in Table 5.12 are based on estimations of the mean average growth rates over the past 25 years of the involved variables, which are presented in Figure 5.5. The result of GDP per capita is well inline with official forecasts, which predict the total GDP growth rate worldwide at about 3.5 % and population growth at about 1.15 %[21], which results in a growth rate of GDP per capita of 2.3%. The other estimated growth rates cannot be compared to official forecasts, as official estimates are not widely available.

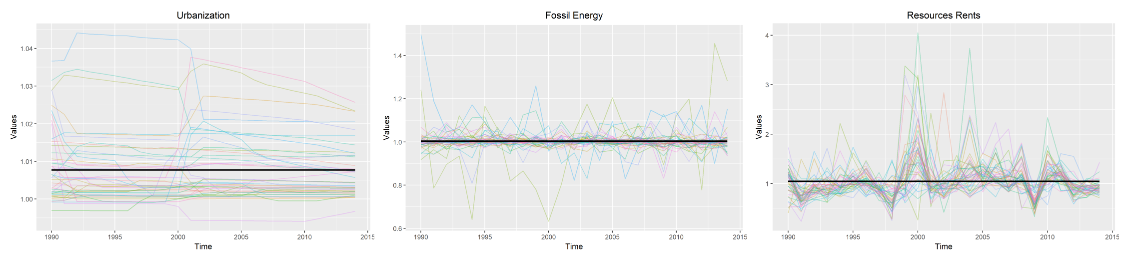
Scenarios	GDP	FT	POD	URB	FO	RR	Description
Scenario 1	0.02	0.02	0.013	0.008	0.004	0.005	Base Scenario
Scenario 2	0.04	0.02	0.013	0.008	0.004	0.005	High GDP
Scenario 3	0.02	0.02	0.033	0.028	0.004	0.005	Population Growth
Scenario 4	0.02	0.02	0.013	0.008	0.024	0.025	Mining and Fossil Energy
Scenario 5	0.02	0.02	0.013	0.008	-0.016	-0.005	Green Scenario
Scenario 6	-0.01	-0.01	0.013	0.008	0.004	0.005	Crisis Scenario
Scenario 7	0.03	0.04	0.013	0.008	0.004	0.005	High Trade Scenario

GDP = GDP per capita, FT = Foreign Trade, POD = Population Density, URB = Urbanization, FO = Fossil Energy, RR = Resources Rents

Table 5.12: Scenarios



(a) GDP per capita (b) Foreign Trade (c) Population Density



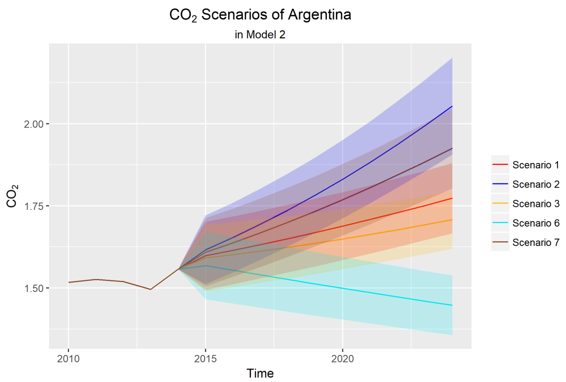
(d) Urbanization (e) Fossil Energy (f) Resources Rents

Figure 5.5: Estimating the Average Growth Rates

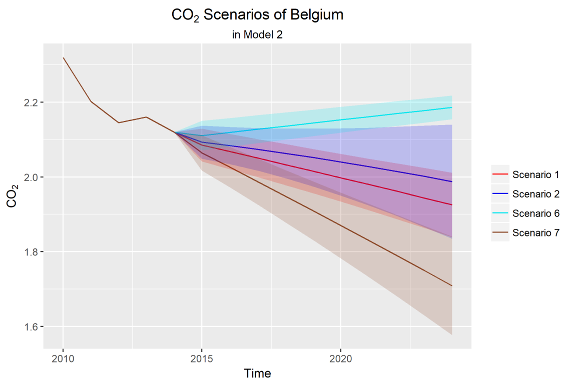
[21]These growth rates are taken from the World Bank.

Those estimated growth rates[22] form Scenario 1, which will be called the 'Base Scenario' in this analysis. The other scenarios are modifications of Scenario 1, where one or more growth rates have been adapted.
The scenario analysis of the cointegrating countries in Model 2 is presented in Figure 5.6 and the one of Model 3 in Figure 5.7. The scenario analysis of all other countries are shown in Figures A.1 and A.2 and were shifted to the Appendix. The confidence region is calculated by adding ± 1 Standard Density, which was derived by bootstrapping. Furthermore, if duplicated scenarios occur due to the exclusion of the variable which differentiated them, those scenarios will be removed for reasons of clarity. Note, that the scenarios of those countries without a cointegrating relationship have to be interpreted very carefully, as the results are not very meaningful. Furthermore, in some cases, the autoregressive part of the ARDL-Polynomial does not fulfill the stability condition, as for example in the case of the United Kingdom.
First, we note that the 'Mining and Fossil Energy Scenario' (Scenario 4) and the 'Green Scenario' (Scenario 5) are not applicable, as the corresponding variables are only chosen by a few countries in total and in none of the countries with an cointegrating relationship. Furthermore we note a quite large discrepancy between Brazil's real CO_2 emission values and their long-run estimates in Model 2, which can be seen by the 'jump' in 2015. The consequences of collinearity are seen in France's Model 3, the explosive behavior can also be explained by a nearly instable autoregressive part of the ARDL-Polynomial, as in Brazil's Model 2 as well, see Tables A.5 and A.6 for details.
Generally, we can identify GDP per capita and Foreign Trade as the main drivers for CO_2 emissions per capita in all countries except Belgium in Model 2 and Peru in Model 3. In the corresponding scenarios, where those variables show disproportionately high growth rates compared to the 'Base Scenario' (Scenario 2 and 7), CO_2 emissions per capita show significantly the highest increase rates. The 'Population Growth Scenario' (Scenario 3) leads to slightly less increase of CO_2 emissions than the 'Base Scenario'. The 'Crisis Scenario' (Scenario 6) is the only scenario, where CO_2 emissions per capita start to somewhat fall.
Belgium on the other hand shows the complete opposite behavior, here the 'Crisis Scenario' is the only scenario with slightly increasing CO_2 emissions, the highest reduction is achieved in the 'High Trade Scenario'.
In Model 3, the behavior of Norway and Turkey is very similar to the one described above, Peru is similar to Belgium in Model 2, with the only difference, that here, the 'High GDP Scenario' leads to the highest reduction.

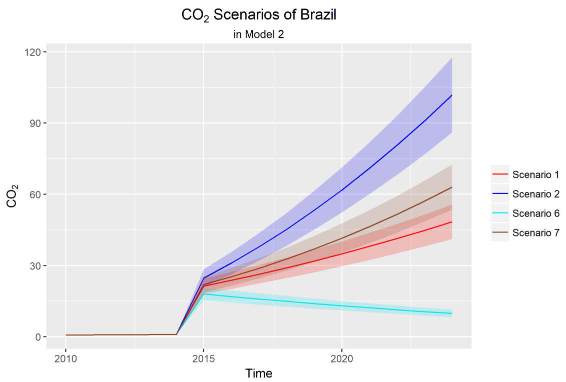
[22]Note, that these growth rates refer to the non-logarithmized data.



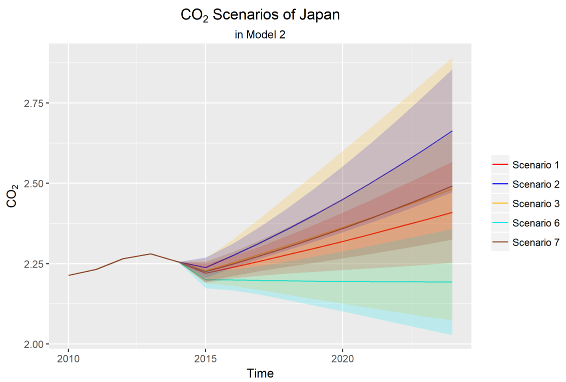
(a) Argentina



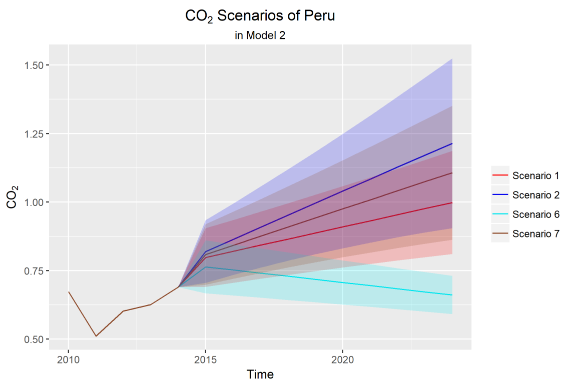
(b) Belgium



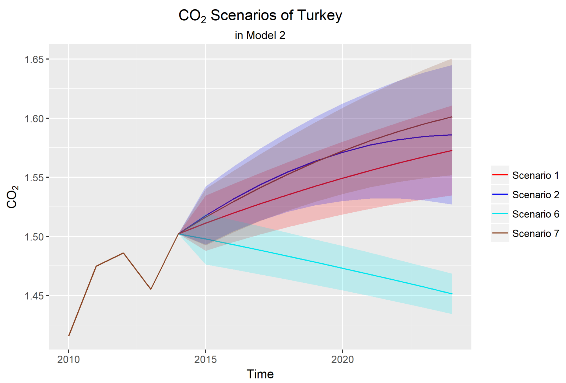
(c) Brazil



(d) Japan

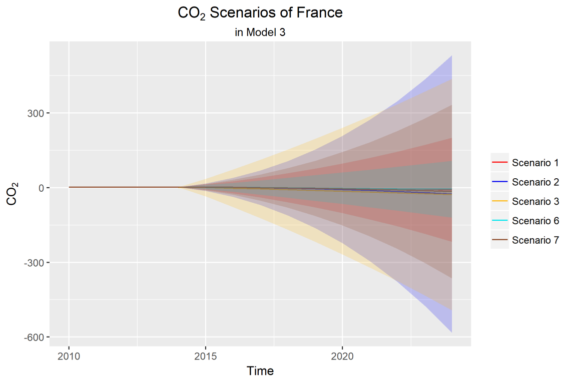


(e) Peru

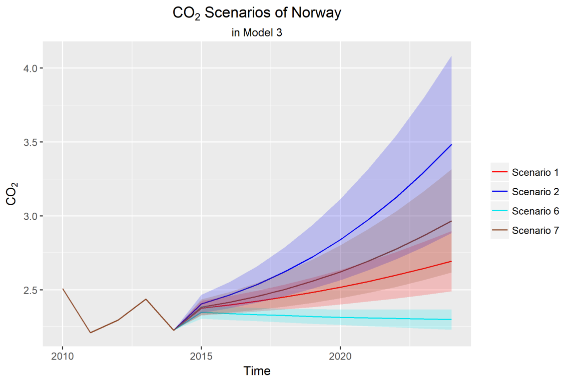


(f) Turkey

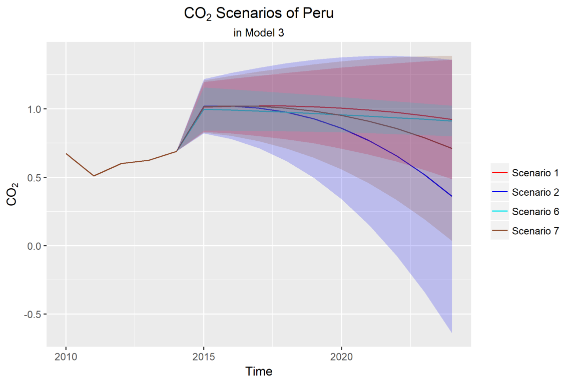
Figure 5.6: Scenarios of the Countries in Model 2 with Cointegrating Relationship



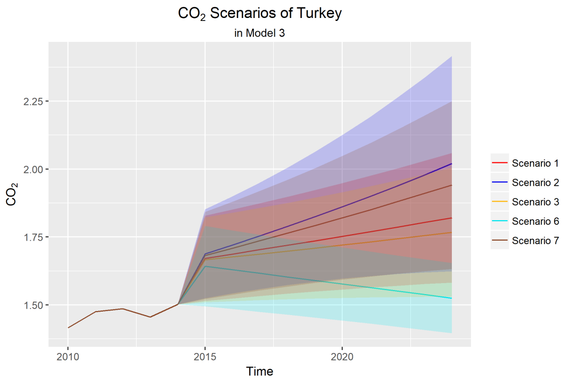
(a) France



(b) Norway



(c) Peru



(d) Turkey

Figure 5.7: Scenarios of the Countries in Model 3 with Cointegrating Relationship

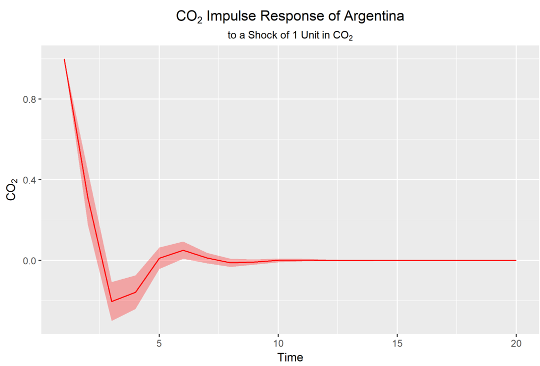
5.5.2 Impulse Response Analysis

In this section, all Impulse Response functions of those countries, which show a cointegrating relationship in Model 2 or Model 3 are presented. The other Impulse Response functions can be seen in Figures A.3 - A.24 and were shifted to the Appendix. The confidence region is calculated by adding ± 1 Standard Density, which was derived by bootstrapping. Note, that the Impulse Response functions of those countries without a cointegrating relationship have to be interpreted very carefully, as the results are not very meaningful. Furthermore, in some cases, the autoregressive part of the ARDL-Polynomial does not fulfill the stability condition, as for example in the case of the United Kingdom, which results in an explosive behavior of the confidence areas.

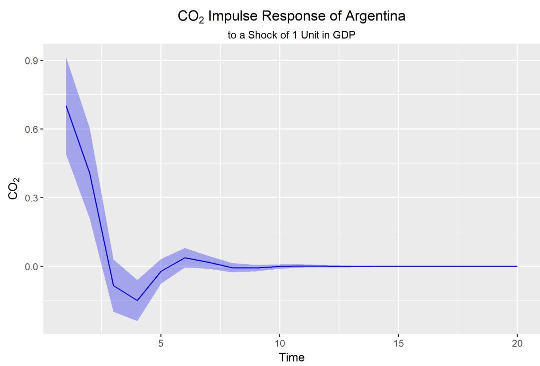
First of all, the results of Model 2, which can be seen in Figures 5.8 - 5.13, are discussed. In the case of Argentina, the Impulse Response to a shock in population density is remarkably high, as the the coefficient b_0 of the corresponding ARDL-Polynomial is quite large. Comparatively, the coefficient of population density is with -0.33 relatively small. In Belgium, a shock in Foreign Trade leads to a reduction of CO_2 emissions, as expected from the scenario analysis of the previous section.

In Brazil's Impulse Response functions, we note an explosive behavior in the confidence areas, as they expand over time instead of becoming more narrow. This can be explained one more time by a nearly instable autoregressive part of the ARDL-Polynomial. Interestingly though, a shock in any variable has a lasting impact, none of the variables returns to zero in a time span of 20 periods.

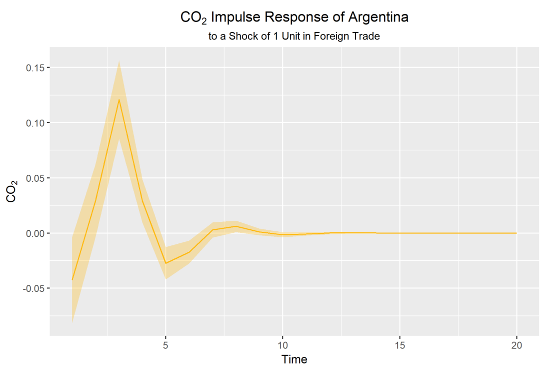
The opposite can be seen in Peru's or Turkey's model, a shock in any variable has a non-sustainable effect and the CO_2 emissions go back to zero relatively fast, it needs only 5-7 periods.
At last, the Impulse Response functions of the countries with cointegrating relationships in Model 3 are shown in Figures 5.14 - 5.17.
We notice an oscillating behavior in France's model with all variables, but especially with Urbanization. Furthermore the high values in Figure 5.14(c), which result from the high coefficients of the urbanization ARDL-Polynomial as well as the estimated urbanization parameter (-95.73) and the collinearity in the model, make it unreliable.
In Norway's case an increase of the Foreign Trade indicator leads to a reduction of CO_2 emissions, as in Belgium's Model 2, but the confidence area is too wide, that this can be said without fail.
Once more, in Peru's and Turkey's model the variables return to steady state level relatively fast, in only 5-6 periods.



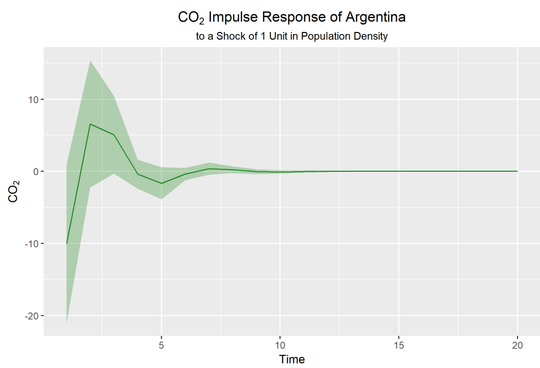
(a) Shock in CO_2



(b) Shock in GDP

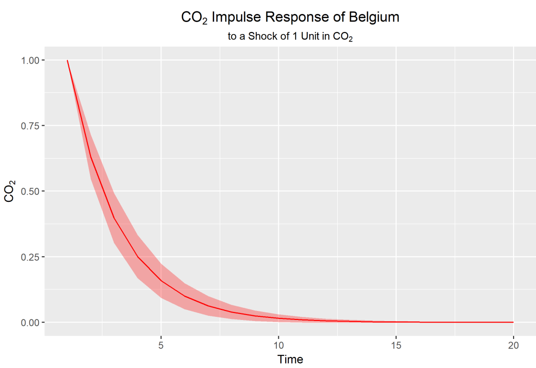


(c) Shock in Foreign Trade

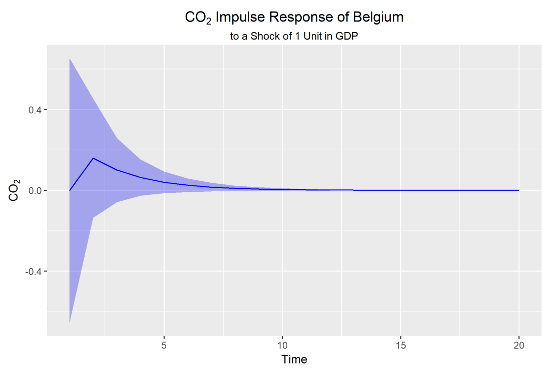


(d) Shock in Population Density

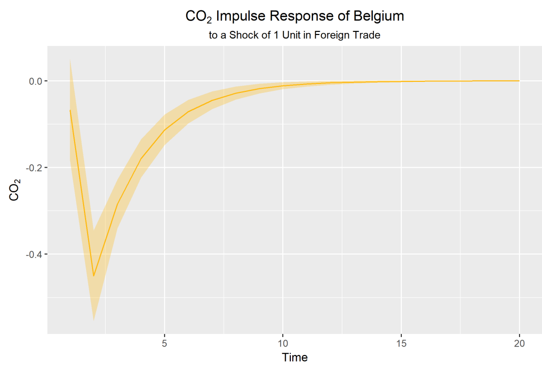
Figure 5.8: Impulse Response Functions for Argentina's Model 2



(a) Shock in CO_2

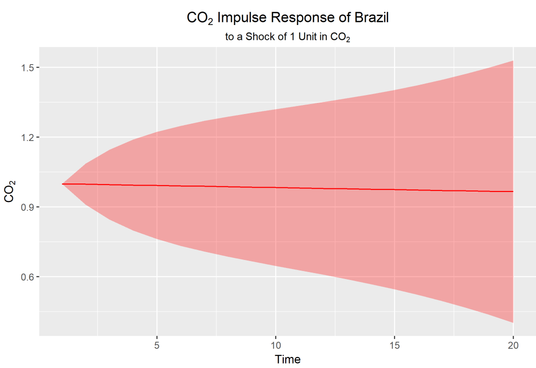


(b) Shock in GDP

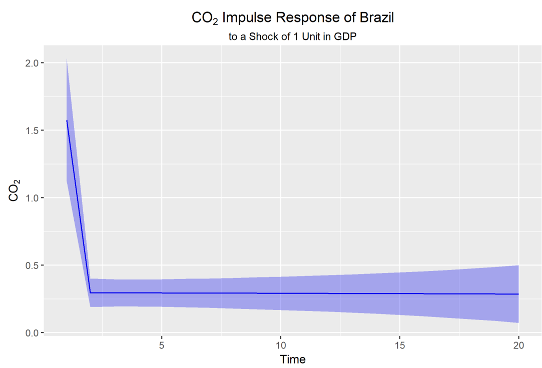


(c) Shock in Foreign Trade

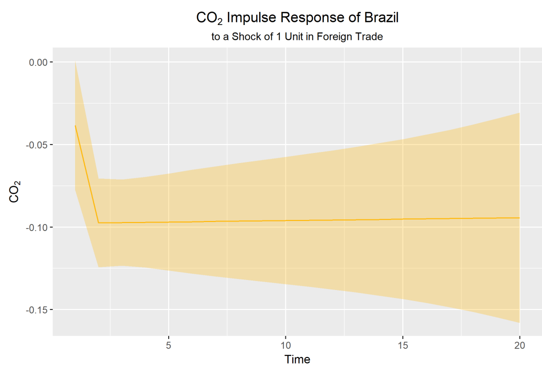
Figure 5.9: Impulse Response Functions for Belgium's Model 2



(a) Shock in CO_2

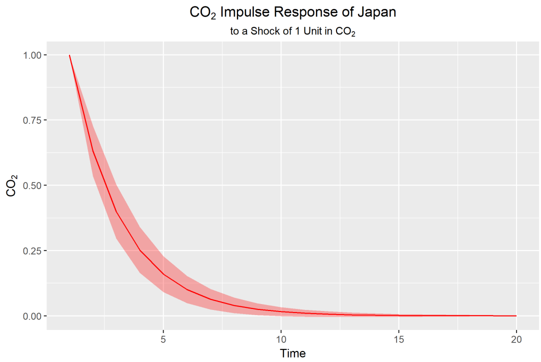


(b) Shock in GDP

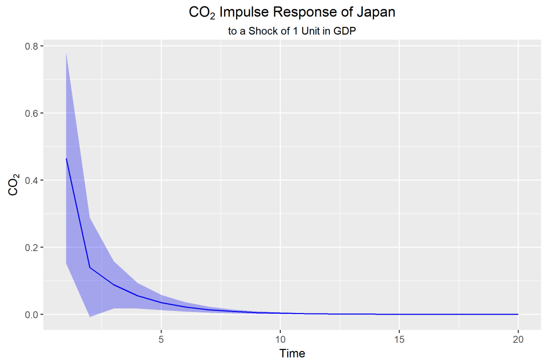


(c) Shock in Foreign Trade

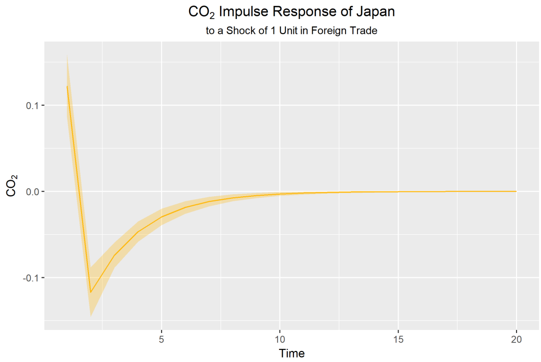
Figure 5.10: Impulse Response Functions for Brazil's Model 2



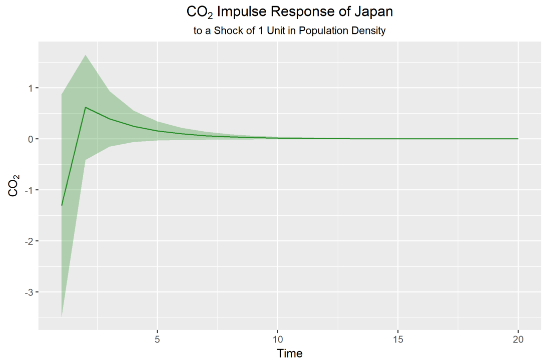
(a) Shock in CO_2



(b) Shock in GDP

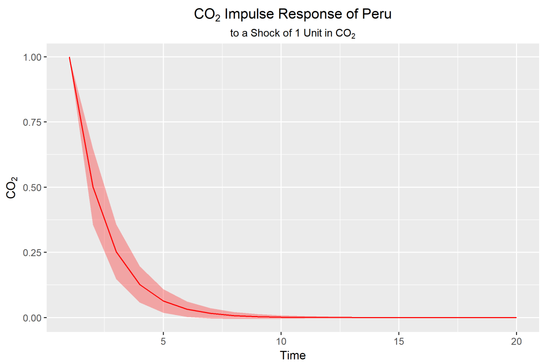


(c) Shock in Foreign Trade

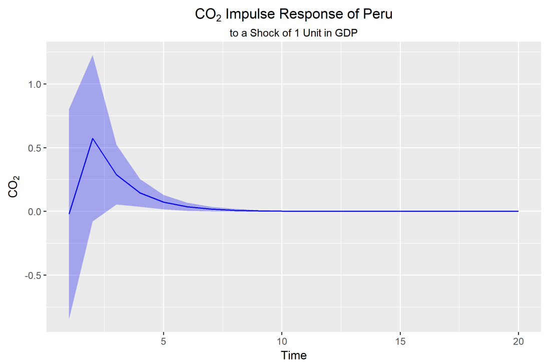


(d) Shock in Population Density

Figure 5.11: Impulse Response Functions for Japan's Model 2

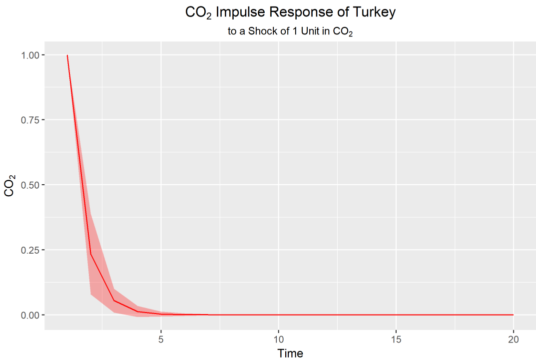


(a) Shock in CO_2

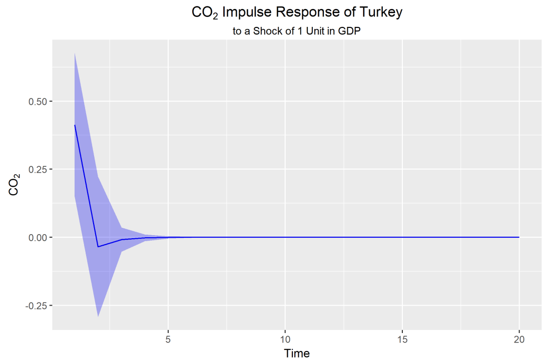


(b) Shock in GDP

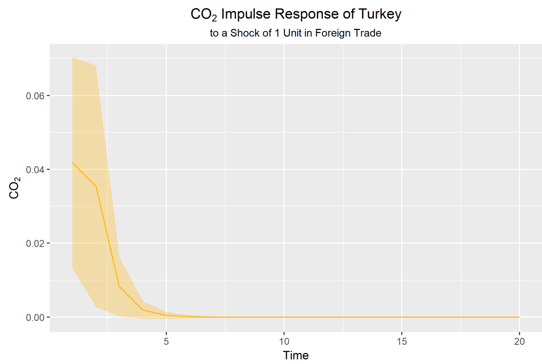
Figure 5.12: Impulse Response Functions for Peru's Model 2



(a) Shock in CO_2

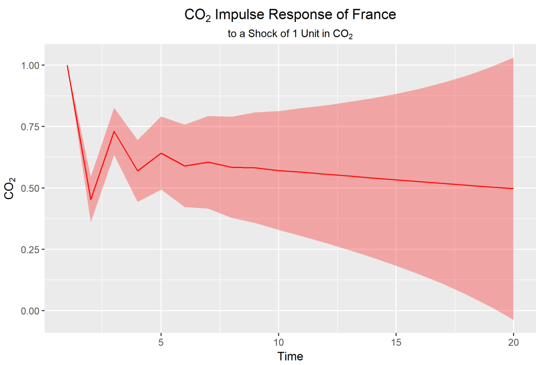


(b) Shock in GDP

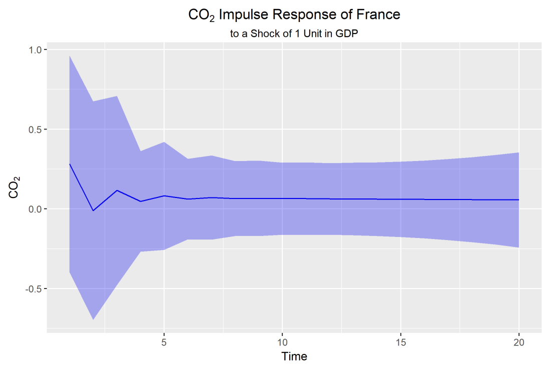


(c) Shock in Foreign Trade

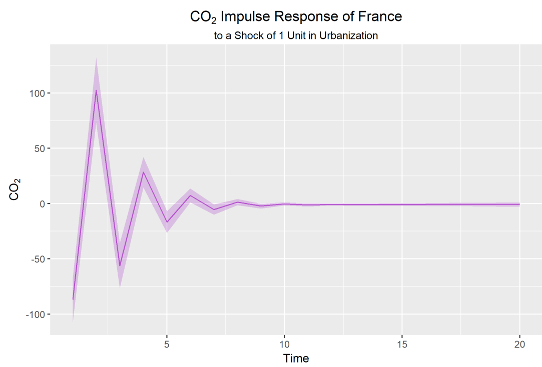
Figure 5.13: Impulse Response Functions for Turkey's Model 2



(a) Shock in CO_2

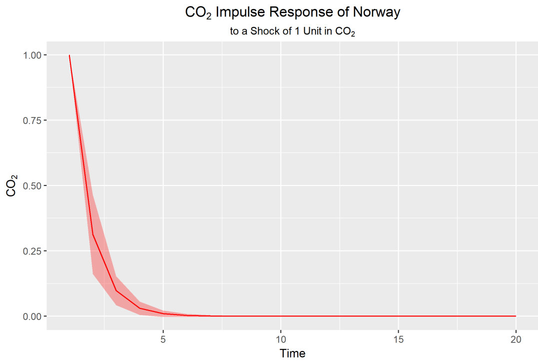


(b) Shock in GDP

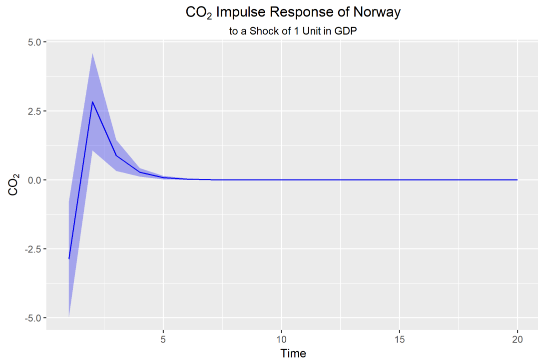


(c) Shock in Urbanization

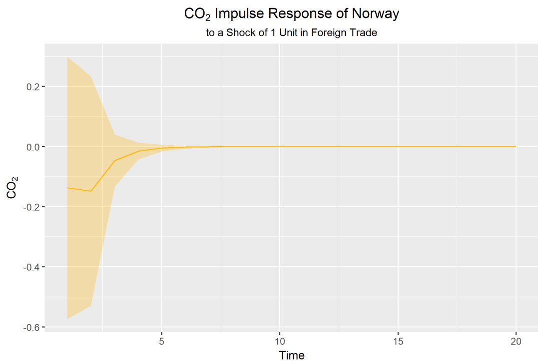
Figure 5.14: Impulse Response Functions for France's Model 3



(a) Shock in CO_2

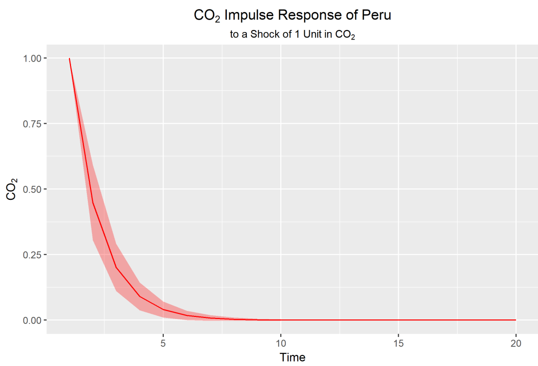


(b) Shock in GDP

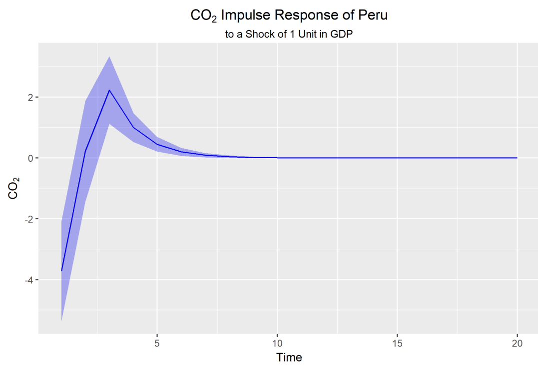


(c) Shock in Foreign Trade

Figure 5.15: Impulse Response Functions for Norway's Model 3

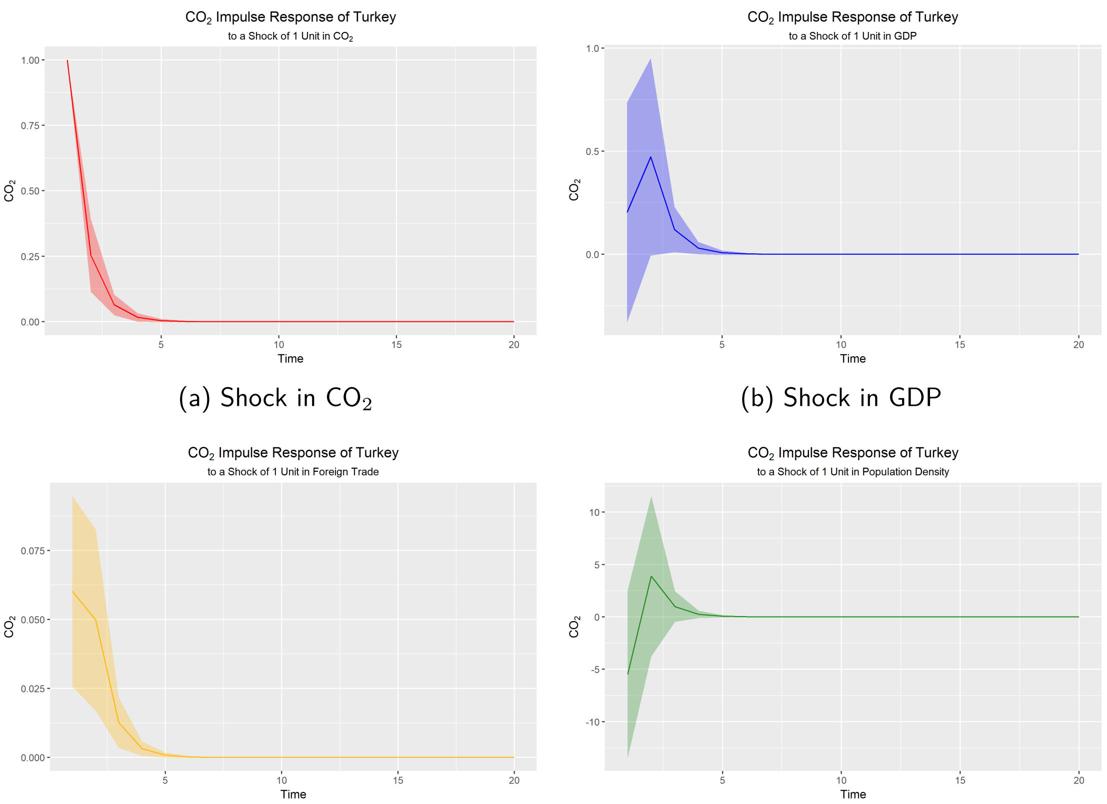


(a) Shock in CO_2



(b) Shock in GDP

Figure 5.16: Impulse Response Functions for Peru's Model 3



(a) Shock in CO_2

(b) Shock in GDP

(c) Shock in Foreign Trade

(d) Shock in Population Density

Figure 5.17: Impulse Response Functions for Turkey's Model 3

6 Conclusion

We have discussed ARDL-Models and the analysis on a cointegrating relationship using the Bounds-Test. With the resulting long-run models a slightly adapted EKC-Hypothesis has been tested. Using the gained knowledge, scenarios and Impulse Response functions have been analyzed.
Many interesting observations were made.

- Many seemingly obvious variables for CO_2 emissions per capita, as the share of Fossil Energy or Natural Resources Rents, are not included in the models of almost all countries. On the other hand, Foreign Trade and Population Density play a far more decisive role.
- Urbanization and Natural Resources Rents have a negative, the share of Fossil Energy has a positive effect on CO_2 emissions. The implications of Foreign Trade and Population Density are mixed.
- Cointegration, contradictively to other studies, is not the case in many countries, as only 6 out of 16 countries in Model 2 and only 4 out of 16 countries in Model 3 showed corresponding behavior. Maybe this result can be explained by the quite diverse set of countries used.
- Collinearity is the case in a few countries, even after demeaning and standardizing GDP per capita. This makes the results of the referring countries hard to interpret and not reliable.
- The EKC-Hypothesis in Model 2 of an inverted U-shape does apply in about half of the analyzed countries. The one in Model 3 of an N-shape, applies in an adapted formulation in slightly more than 50 % of the analyzed countries. The results, however, have to be interpreted with care, as some variables dependent on GDP per capita, as Foreign Trade, Fossil Energy or Resources Rents, have been added to the analysis and may have changed the interpretation as well as the values of the coefficients of GDP per capita and its powers.
- A strong connection between GDP per capita and CO_2 is found. It has been identified as the main driver for CO_2 emissions per capita.
- Newly industrialized and development countries could not enter the analysis (unless a few exceptions) as their data did not fulfill the requirements for this approach.
- The inclusion of Energy Use distorts the results significantly and changes the shape of the relationship between GDP per capita and CO_2 emissions per capita as well as the position and the existence of the turning points.

It will be interesting to see in further studies, if the EKC-Hypothesis can be verified, especially in those countries which could not enter the analysis in this thesis, as well as which variables are Granger-causal in other countries and how these variables react to different scenarios. The importance of Foreign Trade and Population Density, however, should be recognized by further work.
Moreover, in a few years, a comparison can be made, if the countries analyzed in this thesis do in reality follow the calculated patterns or if they show some different behavior.

Appendix

Descriptive Statistics

Country	Variable	Mean	Standard Deviation	Minimum	Maximum
Algeria	CO_2	1.04594	0.22166	0.22146	1.31303
	GDP	8.20291	0.14612	7.7499	8.45017
	EN	6.60894	0.43463	5.44493	7.18622
	FT	4.05009	0.20542	3.4869	4.3397
	POD	2.38149	0.2862	1.83756	2.79863
	URB	3.97179	0.187	3.68047	4.25034
	FO	4.602	0.00309	4.59031	4.60495
	RR	2.40369	0.999	-0.98435	3.44718
Argentina	CO_2	1.34456	0.09959	1.19136	1.55747
	GDP	8.97572	0.15008	8.68942	9.28545
	EN	7.35684	0.11769	7.21573	7.60847
	FT	3.01703	0.42447	2.44631	3.73177
	POD	2.49717	0.16982	2.18646	2.75402
	URB	4.4611	0.04344	4.3735	4.51747
	FO	4.49161	0.02174	4.45206	4.53661
	RR	0.6242	0.94186	-2.16572	1.77699
Australia	CO_2	2.73674	0.12215	2.46834	2.90143
	GDP	10.52297	0.24258	10.16663	10.90402
	EN	8.52264	0.11215	8.29145	8.69361
	FT	3.53479	0.17248	3.21223	3.80483
	POD	0.81201	0.176	0.48737	1.11641
	URB	4.46139	0.0148	4.44576	4.49188
	FO	4.53681	0.01015	4.51281	4.55923
	RR	1.30639	0.54613	0.47572	2.35711
Austria	CO_2	2.03139	0.07311	1.91528	2.19946
	GDP	10.4343	0.26873	9.87893	10.78207
	EN	8.10388	0.14867	7.79078	8.31522
	FT	4.29591	0.20641	3.99403	4.64913
	POD	4.55667	0.04171	4.50449	4.63962
	URB	4.18437	0.00326	4.17835	4.18843
	FO	4.36962	0.08626	4.17279	4.50203

Table A.1: Descriptive Statistics of all Countries and all Variables

Country	Variable	Mean	Standard Deviation	Minimum	Maximum
	RR	-1.38645	0.57222	-2.44112	-0.40498
Bangladesh	CO_2	-1.81536	0.60659	-2.95815	-0.7784
	GDP	6.14652	0.30465	5.76111	6.82672
	EN	4.86673	0.26455	4.46452	5.40367
	FT	3.21499	0.35681	2.3975	3.87351
	POD	6.7346	0.2728	6.25248	7.11036
	URB	2.97494	0.37721	2.10669	3.51202
	FO	3.82802	0.36708	3.03044	4.30094
	RR	-0.37637	0.5414	-1.33838	0.91166
Belgium	CO_2	2.40927	0.13584	2.11964	2.65714
	GDP	10.40306	0.24321	9.90873	10.71355
	EN	8.5045	0.09718	8.31873	8.64283
	FT	4.78733	0.18664	4.43768	5.10361
	POD	5.81621	0.04172	5.7648	5.91399
	URB	4.56726	0.01242	4.54162	4.58311
	FO	4.39356	0.11505	4.25256	4.60411
	RR	-3.03165	1.00664	-4.16055	-1.34419
Brazil	CO_2	0.48248	0.20148	0.04899	0.95335
	GDP	9.0391	0.18512	8.53875	9.38531
	EN	6.92614	0.17255	6.57094	7.30312
	FT	2.98416	0.21821	2.66659	3.39041
	POD	2.89059	0.22353	2.45896	3.19593
	URB	4.29918	0.12431	4.04119	4.44773
	FO	3.97206	0.06772	3.7763	4.07953
	RR	0.85666	0.48174	0.12577	1.80424
Bulgaria	CO_2	1.96491	0.22344	1.67298	2.32408
	GDP	8.43298	0.26675	8.07832	8.89557
	EN	7.91572	0.14704	7.71005	8.15717
	FT	4.51276	0.19266	4.19564	4.87495
	POD	4.31132	0.06773	4.19785	4.39672
	URB	4.22146	0.04769	4.12875	4.299
	FO	4.36469	0.07745	4.25147	4.51484
	RR	0.50289	0.41087	-0.58257	1.12928
Canada	CO_2	2.8012	0.05025	2.68857	2.90193
	GDP	10.51994	0.2068	10.11169	10.82112
	EN	8.9454	0.06127	8.77592	9.04088
	FT	4.04669	0.19976	3.70074	4.41712
	POD	1.12614	0.1477	0.85227	1.36323
	URB	4.35444	0.02685	4.32417	4.40244
	FO	4.34	0.0489	4.27247	4.43867
	RR	1.23277	0.38029	0.5657	2.19866
Chile	CO_2	1.06052	0.32154	0.56833	1.56148

Table A.1: Descriptive Statistics of all Countries and all Variables

Country	Variable	Mean	Standard Deviation	Minimum	Maximum
	GDP	8.89146	0.42184	8.27231	9.59574
	EN	7.08627	0.36873	6.59492	7.70337
	FT	3.97657	0.28035	3.1233	4.39185
	POD	2.8996	0.18168	2.57312	3.16503
	URB	4.42864	0.04431	4.32919	4.49263
	FO	4.28767	0.04982	4.18834	4.3722
	RR	2.27228	0.40054	1.59226	3.06527
China	CO_2	0.93324	0.58865	0.04137	2.0225
	GDP	6.92231	1.0377	5.47149	8.71739
	EN	6.7784	0.46636	6.14189	7.71277
	FT	3.23947	0.70479	1.59348	4.18386
	POD	4.79351	0.14583	4.49526	4.97892
	URB	3.36556	0.37989	2.84398	3.99655
	FO	4.32669	0.11489	4.09267	4.48562
	RR	1.55378	0.77149	-0.21619	2.9446
Congo, Dem. Rep.	CO_2	-2.73682	0.75277	-4.05842	-1.88883
	GDP	6.23669	0.50118	5.57205	6.98455
	EN	5.77455	0.06287	5.68836	5.96504
	FT	3.76707	0.43266	3.01735	4.55391
	POD	2.8206	0.38124	2.20501	3.48183
	URB	3.46177	0.16264	3.21274	3.7371
	FO	1.79162	0.68671	0.49453	2.61773
	RR	2.88067	0.57897	1.87368	3.70361
Cuba	CO_2	1.01943	0.15592	0.79324	1.24741
	GDP	8.23471	0.2728	7.78302	8.72952
	EN	7.09059	0.18985	6.79922	7.46531
	FT	3.90898	0.41937	3.20799	4.36535
	POD	4.58715	0.0784	4.41387	4.70027
	URB	4.27526	0.0677	4.11048	4.34342
	FO	4.27282	0.11636	4.00626	4.49853
	RR	-0.03019	0.8112	-1.52466	1.93211
Denmark	CO_2	2.31858	0.17835	1.78099	2.61846
	GDP	10.73571	0.21839	10.34951	11.02149
	EN	8.18373	0.07242	7.96296	8.33573
	FT	4.2978	0.19148	3.97446	4.65232
	POD	4.81931	0.03622	4.76335	4.90082
	URB	4.43821	0.02015	4.38501	4.47166
	FO	4.49481	0.09377	4.22734	4.59676
	RR	-0.9212	1.15295	-2.93339	0.66781
Egypt, Arab Rep.	CO_2	0.36738	0.40127	-0.45454	0.92749
	GDP	7.35797	0.36149	6.6686	7.86648
	EN	6.2462	0.4238	5.36418	6.79882

Table A.1: Descriptive Statistics of all Countries and all Variables

Country	Variable	Mean	Standard Deviation	Minimum	Maximum
	FT	3.92803	0.23983	3.48068	4.40887
	POD	4.07682	0.28232	3.58428	4.52431
	URB	3.76589	0.01185	3.73381	3.78314
	FO	4.52989	0.03559	4.4539	4.56867
	RR	2.07907	0.97305	-1.13956	3.33594
France	CO_2	1.90883	0.20088	1.51997	2.26868
	GDP	10.37193	0.21875	9.90802	10.63818
	EN	8.22151	0.10929	7.98857	8.36677
	FT	3.81428	0.17047	3.43826	4.09087
	POD	4.67817	0.06908	4.55419	4.79696
	URB	4.31652	0.02903	4.26345	4.3731
	FO	4.13383	0.22874	3.83317	4.50278
	RR	-2.38042	0.61133	-3.24214	-1.39989
Germany	CO_2	2.38738	0.1127	2.17686	2.57465
	GDP	10.36299	0.24369	9.88455	10.71492
	EN	8.34121	0.05687	8.23734	8.45218
	FT	3.9161	0.30547	3.42863	4.45289
	POD	5.43598	0.02291	5.40497	5.46644
	URB	4.29315	0.00916	4.27951	4.31874
	FO	4.47122	0.06735	4.37652	4.58557
	RR	-1.63126	0.83902	-3.07759	-0.00914
Greece	CO_2	1.85503	0.29433	1.01099	2.19509
	GDP	9.93587	0.19523	9.50244	10.31078
	EN	7.56309	0.29424	6.77169	7.92047
	FT	3.74663	0.24625	3.14026	4.20692
	POD	4.37032	0.07505	4.22265	4.45758
	URB	4.26895	0.04818	4.16231	4.35257
	FO	4.53931	0.02192	4.45502	4.57089
	RR	-1.69276	0.87176	-4.01462	-0.46391
Honduras	CO_2	-0.40103	0.31324	-0.86972	0.13008
	GDP	7.40028	0.11442	7.18726	7.63021
	EN	6.23461	0.08244	6.12782	6.41087
	FT	4.44552	0.31276	3.88752	4.91625
	POD	3.8387	0.35167	3.21919	4.36604
	URB	3.7168	0.17415	3.38673	3.99152
	FO	3.6281	0.27424	3.2913	4.03391
	RR	1.09808	0.56967	0.01969	2.11661
India	CO_2	-0.29756	0.46541	-1.01175	0.54812
	GDP	6.44201	0.47385	5.8628	7.40658
	EN	5.92341	0.25455	5.59129	6.45744
	FT	3.05323	0.57896	2.04804	4.02166
	POD	5.70524	0.25205	5.24936	6.07575

Table A.1: Descriptive Statistics of all Countries and all Variables

Country	Variable	Mean	Standard Deviation	Minimum	Maximum
	URB	3.25339	0.13329	2.99528	3.47711
	FO	3.97239	0.24666	3.55876	4.29679
	RR	1.00076	0.46179	-0.22145	2.01772
Indonesia	CO_2	-0.03882	0.53073	-1.10678	0.93991
	GDP	7.48436	0.42887	6.69014	8.21418
	EN	6.29498	0.3714	5.69441	6.78436
	FT	3.87924	0.18731	3.37327	4.50357
	POD	4.61613	0.227	4.17583	4.94758
	URB	3.46906	0.35773	2.8529	3.97035
	FO	3.94791	0.26506	3.20585	4.207
	RR	2.18832	0.46525	1.38204	3.49256
Iran, Islamic Rep.	CO_2	1.55945	0.3222	1.03219	2.11421
	GDP	8.59431	0.24767	8.1672	9.12539
	EN	7.28612	0.47444	6.29432	8.01417
	FT	3.70778	0.33056	2.64935	4.33225
	POD	3.48804	0.3076	2.88913	3.87415
	URB	4.05433	0.16083	3.74029	4.28847
	FO	4.59309	0.00558	4.57789	4.60182
	RR	2.69765	0.98326	-0.74826	3.55122
Israel	CO_2	1.99965	0.22302	1.66665	2.29019
	GDP	10.02057	0.23405	9.59904	10.39395
	EN	7.78972	0.19912	7.45757	8.04851
	FT	4.24193	0.11365	4.06065	4.50885
	POD	5.46898	0.29912	4.95456	5.93926
	URB	4.49911	0.0222	4.44017	4.52261
	RR	-3.58386	1.89227	-7.04586	-0.68123
Italy	CO_2	1.93727	0.11046	1.66219	2.10614
	GDP	10.27575	0.23486	9.77866	10.55155
	EN	7.84958	0.14342	7.57515	8.07548
	FT	3.75979	0.17006	3.40755	4.02865
	POD	5.2659	0.02596	5.20948	5.33111
	URB	4.20349	0.01526	4.16312	4.23151
	FO	4.50919	0.04354	4.3642	4.54908
	RR	-2.32375	0.43681	-3.49552	-1.59084
Japan	CO_2	2.16195	0.09721	1.99716	2.29346
	GDP	10.42687	0.29331	9.82203	10.74648
	EN	8.1283	0.15423	7.80725	8.31479
	FT	3.1307	0.22839	2.77332	3.62591
	POD	5.80678	0.06137	5.65091	5.86175
	URB	4.37954	0.0712	4.27496	4.53283
	FO	4.46496	0.06745	4.37461	4.57827

Table A.1: Descriptive Statistics of all Countries and all Variables

Country	Variable	Mean	Standard Deviation	Minimum	Maximum
	RR	-3.26817	1.09697	-4.7068	-1.47323
Kenya	CO_2	-1.27717	0.19303	-1.65115	-0.95143
	GDP	6.77431	0.07656	6.56363	6.98067
	EN	6.11365	0.03081	6.06499	6.24111
	FT	4.05715	0.11214	3.86499	4.31178
	POD	3.7568	0.41077	3.01958	4.3928
	URB	2.87183	0.21907	2.37751	3.22672
	FO	2.8744	0.12069	2.56172	3.07792
	RR	1.38463	0.24994	0.85807	1.98591
Korea, Rep.	CO_2	1.76723	0.58518	0.57808	2.46835
	GDP	9.05757	0.7906	7.58357	10.0992
	EN	7.67634	0.74721	6.24632	8.57344
	FT	4.13653	0.25755	3.57573	4.70048
	POD	6.09572	0.12528	5.83157	6.25495
	URB	4.22575	0.20905	3.74386	4.4111
	FO	4.4812	0.07591	4.38884	4.60077
	RR	-2.71969	1.34823	-4.49153	-0.29883
Mexico	CO_2	1.30138	0.16076	0.85521	1.47091
	GDP	8.93673	0.15572	8.56388	9.15831
	EN	7.21663	0.18263	6.68456	7.41428
	FT	3.58357	0.44934	2.7948	4.19582
	POD	3.79927	0.24229	3.31904	4.15735
	URB	4.2633	0.07956	4.09065	4.36908
	FO	4.48019	0.02087	4.42115	4.51149
	RR	1.33031	0.71045	-0.62755	2.47646
Mongolia	CO_2	1.50645	0.34997	1.14135	2.6032
	GDP	7.57518	0.29695	7.21792	8.26921
	EN	7.19592	0.23166	6.85054	7.51656
	FT	4.64812	0.20217	4.07111	4.91708
	POD	0.43359	0.10867	0.21276	0.63237
	URB	4.09961	0.08154	4.00806	4.2658
	FO	4.55774	0.01655	4.53024	4.58292
	RR	2.51371	0.75149	1.17008	3.76561
Nepal	CO_2	-2.71335	0.76596	-4.12441	-1.26041
	GDP	5.9694	0.2763	5.60873	6.5158
	EN	5.78655	0.08894	5.69958	6.02278
	FT	3.59584	0.38426	2.60852	4.15944
	POD	4.91567	0.26613	4.44993	5.28615
	URB	2.25075	0.46705	1.38754	2.90378
	FO	1.7762	0.66129	0.50312	2.75771
	RR	0.49897	0.54358	-0.23227	2.21628
Netherlands	CO_2	2.39721	0.07351	2.23909	2.59366

Table A.1: Descriptive Statistics of all Countries and all Variables

Country	Variable	Mean	Standard Deviation	Minimum	Maximum
	GDP	10.51679	0.24216	10.10107	10.86127
	EN	8.42332	0.07577	8.23365	8.53422
	FT	4.69582	0.16228	4.42026	5.03882
	POD	6.10282	0.07632	5.95639	6.2158
	URB	4.28154	0.12107	4.12168	4.49881
	FO	4.56263	0.02655	4.51026	4.60492
	RR	-0.45574	0.8199	-3.00298	0.9481
Nigeria	CO_2	-0.48224	0.32336	-1.12277	0.00997
	GDP	7.40301	0.23893	7.0485	7.84897
	EN	6.54023	0.07844	6.36147	6.68249
	FT	3.83418	0.3502	3.12516	4.40443
	POD	4.70786	0.33356	4.14168	5.26656
	URB	3.39449	0.28717	2.89873	3.84891
	FO	2.84867	0.30709	1.78637	3.12872
	RR	3.17282	0.62869	0.6834	4.15137
Norway	CO_2	2.18547	0.15335	1.93872	2.50907
	GDP	11.04143	0.32117	10.38209	11.42538
	EN	8.51736	0.18929	8.13573	8.84428
	FT	4.27649	0.05727	4.18217	4.41154
	POD	2.47695	0.07549	2.36193	2.6437
	URB	4.29335	0.05655	4.18046	4.38462
	FO	4.03008	0.05692	3.94702	4.14488
	RR	1.47732	0.97551	-1.08074	2.4619
Pakistan	CO_2	-0.50499	0.37297	-1.17571	-0.00901
	GDP	6.60249	0.27734	6.11764	7.01319
	EN	5.98565	0.19705	5.65311	6.26104
	FT	3.49702	0.11571	2.99234	3.66124
	POD	4.96531	0.34556	4.34934	5.48353
	URB	3.43869	0.11869	3.22223	3.64553
	FO	3.9211	0.19407	3.56374	4.14407
	RR	0.14899	0.62587	-1.72897	1.1024
Peru	CO_2	0.22578	0.21203	-0.10723	0.68988
	GDP	8.20263	0.19654	7.86921	8.66974
	EN	6.2968	0.17711	6.01233	6.64339
	FT	3.61957	0.23946	3.11515	4.06789
	POD	2.84251	0.24383	2.37085	3.18627
	URB	4.23957	0.08222	4.06896	4.36036
	FO	4.19148	0.08346	4.05653	4.37646
	RR	1.48834	0.87681	-0.36321	2.68656
Philippines	CO_2	-0.23855	0.16432	-0.66101	0.05397
	GDP	7.40614	0.15957	7.16054	7.82637
	EN	6.1207	0.05512	6.0076	6.23979

Table A.1: Descriptive Statistics of all Countries and all Variables

Country	Variable	Mean	Standard Deviation	Minimum	Maximum
	FT	4.16764	0.30941	3.66739	4.68445
	POD	5.36763	0.3037	4.81667	5.81628
	URB	3.76816	0.12091	3.51134	3.88342
	FO	3.93022	0.1532	3.54389	4.12703
	RR	0.67279	0.7101	-0.88479	1.94129
Saudi Arabia	CO_2	2.67303	0.17612	2.2827	2.97191
	GDP	9.99581	0.28577	9.65559	10.57453
	EN	8.20316	0.55878	6.88512	8.84466
	FT	4.34504	0.16245	4.02693	4.79264
	POD	1.98437	0.47692	1.04313	2.66143
	URB	4.2913	0.13655	3.92569	4.41795
	FO	4.60507	7e-05	4.60493	4.60514
	RR	3.21521	1.26387	-1.8849	4.34857
Senegal	CO_2	-0.81282	0.18488	-1.17656	-0.46341
	GDP	6.81251	0.0718	6.67267	6.92598
	EN	5.53336	0.10608	5.33211	5.72035
	FT	4.1793	0.14571	3.90473	4.46548
	POD	3.72829	0.35663	3.12648	4.32483
	URB	3.64723	0.08756	3.42491	3.7703
	FO	3.80657	0.12635	3.51339	4.01032
	RR	1.16451	0.3427	0.47181	1.85911
South Africa	CO_2	2.14876	0.10503	1.95414	2.305
	GDP	8.76154	0.0916	8.61555	8.93942
	EN	7.80987	0.10627	7.57361	7.99408
	FT	3.94327	0.14917	3.62401	4.28861
	POD	3.43076	0.25619	2.94696	3.79853
	URB	3.98597	0.09907	3.86847	4.16353
	FO	4.47042	0.01971	4.43371	4.50542
	RR	1.69538	0.45791	0.76754	2.71224
Spain	CO_2	1.75136	0.19015	1.24068	2.0915
	GDP	10.01726	0.26511	9.51362	10.38776
	EN	7.70281	0.28284	7.02385	8.08684
	FT	3.72396	0.27953	3.25231	4.14308
	POD	4.37973	0.09229	4.21448	4.53805
	URB	4.31101	0.04696	4.19023	4.37393
	FO	4.42357	0.07858	4.27013	4.54363
	RR	-2.21833	0.8261	-3.34849	-0.7804
Switzerland	CO_2	1.7343	0.09749	1.4613	1.87224
	GDP	11.08239	0.10713	10.9045	11.24388
	EN	8.13533	0.05315	8.00109	8.20884
	FT	4.54967	0.14558	4.34319	4.88126
	POD	5.18923	0.07574	5.07437	5.3338

Table A.1: Descriptive Statistics of all Countries and all Variables

Country	Variable	Mean	Standard Deviation	Minimum	Maximum
	URB	4.25866	0.07502	4.04452	4.30195
	FO	4.03943	0.08155	3.88644	4.22538
	RR	-3.7789	0.45898	-4.46761	-2.80859
Thailand	CO_2	0.54489	0.74669	-0.67925	1.5308
	GDP	7.82641	0.57274	6.85313	8.62868
	EN	6.70937	0.57344	5.88771	7.59671
	FT	4.33942	0.45902	3.54967	4.94476
	POD	4.68908	0.17456	4.30826	4.89722
	URB	3.43518	0.21736	3.06535	3.89537
	FO	4.16175	0.23765	3.74576	4.40742
	RR	0.31405	0.53823	-0.65222	1.20952
Turkey	CO_2	0.95702	0.35961	0.20098	1.50218
	GDP	8.85787	0.31647	8.34783	9.49642
	EN	6.87558	0.30482	6.25805	7.36859
	FT	3.43084	0.51276	2.20825	4.00679
	POD	4.25404	0.23312	3.81365	4.60605
	URB	4.02593	0.20924	3.64373	4.28897
	FO	4.38398	0.09018	4.1844	4.50617
	RR	-0.65676	0.57712	-2.09369	0.35851
United Kingdom	CO_2	2.24674	0.13763	1.87141	2.47005
	GDP	10.26408	0.27034	9.79146	10.62256
	EN	8.17727	0.07622	7.92907	8.26376
	FT	3.93102	0.1003	3.70187	4.13613
	POD	5.48573	0.0426	5.43843	5.58752
	URB	4.36803	0.01713	4.34419	4.41092
	FO	4.50506	0.04189	4.41442	4.56954
	RR	-0.30581	0.9402	-2.66033	1.10864
United States	CO_2	2.96829	0.07671	2.79141	3.11399
	GDP	10.50306	0.2495	10.05662	10.83531
	EN	8.94494	0.04866	8.83483	9.04055
	FT	3.00853	0.26857	2.37308	3.43028
	POD	3.33526	0.13614	3.10853	3.55035
	URB	4.34026	0.03702	4.29867	4.39995
	FO	4.47645	0.04122	4.41805	4.5635
	RR	0.31585	0.59702	-0.60233	1.75031

All values are in logarithms. Israel's Fossil Energy data is not included due to data unavailability.
CO_2 = CO_2 emissions per capita, GDP = GDP per capita, EN = Energy Use per capita, FT = Foreign Trade, POD = Population Density, URB = Urbanization, FO = Fossil Energy, RR = Resources Rents

Table A.1: Descriptive Statistics of all Countries and all Variables

Test on I(2)

Country	CO_2	ΔCO_2	GDP	ΔGDP	GDP^2	ΔGDP^2	GDP^3	ΔGDP^3
Algeria	0,201	0,014*	0,641	0,61	0,641	0,612	0,645	0,613
Argentina	0,803	0,08*	0,532	0,042*	0,532	0,042*	0,532	0,043*
Australia	0,98	0,371	0,508	0,184	0,508	0,197	0,508	0,21
Austria	0,738	0,022*	0,985	0,018*	0,985	0,021*	0,983	0,024*
Bangladesh	0,259	0,01*	0,99	0,169	0,99	0,275	0,99	0,383
Belgium	0,539	0,025*	0,986	0,033*	0,986	0,043*	0,982	0,053*
Brazil	0,52	0,065*	0,543	0,094*	0,543	0,093*	0,571	0,092*
Bulgaria	0,751	0,28	0,739	0,37	0,739	0,376	0,743	0,383
Canada	0,594	0,083*	0,407	0,072*	0,407	0,074*	0,397	0,075*
Chile	0,288	0,086*	0,068*	0,01*	0,068*	0,01*	0,084*	0,01*
China	0,574	0,031*	0,553	0,285	0,553	0,238	0,886	0,163
Congo, Dem. Rep.	0,91	0,41	0,901	0,574	0,901	0,546	0,902	0,516
Cuba	0,462	0,33	0,556	0,43	0,556	0,434	0,57	0,437
Denmark	0,929	0,01*	0,959	0,016*	0,959	0,018*	0,955	0,02*
Egypt, Arab Rep.	0,254	0,073*	0,022*	0,044*	0,022*	0,043*	0,035*	0,043*
France	0,552	0,044*	0,989	0,01*	0,989	0,013*	0,988	0,016*
Germany	0,045*	0,01*	0,809	0,01*	0,809	0,01*	0,787	0,01*
Greece	0,99	0,448	0,322	0,318	0,322	0,297	0,281	0,276
Honduras	0,655	0,237	0,543	0,146	0,543	0,146	0,568	0,146
India	0,472	0,41	0,99	0,01*	0,99	0,01*	0,99	0,01*
Indonesia	0,091*	0,091*	0,365	0,169	0,365	0,167	0,367	0,168
Iran, Islamic Rep.	0,523	0,021*	0,675	0,027*	0,675	0,028*	0,67	0,029*
Israel	0,987	0,592	0,39	0,025*	0,39	0,027*	0,357	0,03*
Italy	0,99	0,599	0,99	0,18	0,99	0,222	0,99	0,261
Japan	0,59	0,068*	0,99	0,052*	0,99	0,055*	0,988	0,059*
Kenya	0,217	0,056*	0,947	0,075*	0,947	0,078*	0,951	0,081*
Korea, Rep.	0,923	0,081*	0,99	0,04*	0,99	0,058*	0,99	0,082*
Mexico	0,241	0,178	0,172	0,083*	0,172	0,082*	0,177	0,081*
Mongolia	0,99	0,289	0,773	0,016*	0,773	0,011*	0,856	0,01*
Nepal	0,488	0,043*	0,869	0,17	0,869	0,169	0,95	0,177
Netherlands	0,487	0,031*	0,642	0,166	0,642	0,174	0,621	0,182
Nigeria	0,66	0,224	0,911	0,181	0,911	0,184	0,913	0,188
Norway	0,552	0,045*	0,99	0,061*	0,99	0,066*	0,99	0,072*
Pakistan	0,99	0,498	0,495	0,142	0,495	0,142	0,423	0,142
Peru	0,97	0,01*	0,98	0,01*	0,98	0,01*	0,983	0,01*
Philippines	0,454	0,347	0,956	0,079*	0,956	0,084*	0,963	0,089*
Saudi Arabia	0,403	0,031*	0,564	0,351	0,564	0,359	0,562	0,367
Senegal	0,357	0,01*	0,958	0,03*	0,958	0,028*	0,959	0,026*
South Africa	0,283	0,217	0,922	0,219	0,922	0,218	0,923	0,218
Spain	0,74	0,358	0,44	0,302	0,44	0,315	0,39	0,328
Switzerland	0,965	0,014*	0,25	0,206	0,25	0,201	0,26	0,196
Thailand	0,862	0,29	0,61	0,172	0,61	0,179	0,492	0,182
Turkey	0,335	0,097*	0,529	0,01*	0,529	0,01*	0,643	0,01*
United Kingdom	0,91	0,082*	0,71	0,04*	0,71	0,045*	0,629	0,049*
United States	0,539	0,061*	0,93	0,011*	0,93	0,013*	0,906	0,016*

* is denoting significance at the 10% level.

Table A.2: Results of the ADF-Test on a Unit Root for CO_2 and GDP and its powers

Short-Run Results in Model 2

Country	Intercept	$CO2_{-1}$	GDP_{-1}	GDP^2_{-1}	FT_{-1}	POD_{-1}	URB_{-1}	FO_{-1}	RR_{-1}	$\Delta CO2_{-1}$	ΔGDP	ΔGDP^2	ΔGDP^2_{-1}	ΔFT	ΔFT_{-1}	ΔPOD	ΔURB	ΔFO	ΔRR
Argentina	1.97	-0,99	0,06	0,02	0,1	-0,33				0,3	0,05	0,01		-0,04	-0,1	-10,05			
Austria	0.77	-0,4	0	0,01					-0,03		0,15	0,02							0,02
Belgium	3.14	-0,37	0,05	0	-0,47						0,14	-0,05		-0,07					
Brazil	0.28	0	0,01	0,01	-0,1						0,19	0,03		-0,04					
Canada	1.18	-0,3	0,03	0		-0,3			0		0,1	0				-1,82			0,03
Chile	0.13	-0,14	0,04	-0,01							0,44	0,09							
Denmark	-2.82	-0,41	0,02	0,01				0,84			0,12	-0,03						2,73	
France	-																		
Iran, Islamic Rep.	0.37	-0,02	0,03	0	-0,08						0,19	-0,01	0,02	0,01					
Japan	0.2	-0,37	0,04	0,02	-0,07	0,14					0,15	-0,01		0,12		-1,31			
Kenya	-0.39	-0,29	0,05	-0,02			-0,02				0,11	0					4,25		
Korea, Rep.	0.51	-0,29	0,14	-0,01							0,81	0,13							
Norway	-2.94	-0,33	-0,05	0,01	0,39			0,49	0,03		-0,25	0,23		0,42	-0,85			2,2	-0,02
Peru	0.12	-0,5	0,11	0							0,13	-0,03							
Turkey	0.55	-0,77	0,25	-0,04	0,07						0,27	-0,03		0,04					
United Kingdom	-0.23	0,09	0,01	-0,01						-0,54	0,27	-0,01							
United States	0.42	-0,08	0,02	0	-0,07						0,23	-0,01		0,05					

GDP = GDP per capita, FT = Foreign Trade, POD = Population Density, URB = Urbanization, FO = Fossil Energy, RR = Resources Rents
Some coefficients appear as 0 in the table above. These results arise due to rounding the values.

Table A.3: Short-Run Coefficients of Model 2

Short-Run Results in Model 3

Country	Intercept	$CO2_{-1}$	GDP_{-1}	GDP^2_{-1}	GDP^3_{-1}	FT_{-1}	POD_{-1}	URB_{-1}	FO_{-1}	RR_{-1}	$\Delta CO2_{-1}$	ΔGDP	ΔGDP_{-1}	ΔGDP^2	ΔGDP^2_{-1}	ΔGDP^3	ΔGDP^3_{-1}	ΔFT	ΔPOD	ΔURB	ΔURB_{-1}	ΔFO	ΔRR	ΔRR_{-1}
Argentina	0.56	-0,49	0,02	0	0	0,03						0,07		0		0		-0,04						
Austria	0.76	-0,37	0,05	-0,01	-0,03							-0,11		0,04		0,06	-0,06							
Belgium	-																							
Brazil	-0.37	-0,08	-0,04	0	0,01		0,14					0,11		0,02		0,03			0,15					
Canada	1.35	-0,34	0,06	0	-0,01		-0,36					0,22		0,02		-0,03			-0,64					
Chile	10.79	-0,33	0,2	0,01	-0,02			-2,75	0,42			0,4		0,09		0,01				-20,06		1,3		
Denmark	-2.91	-0,41	0,02	0	0				0,86			0		-0,01		0,04						2,75		
France	8.86	-0,02	0,18	-0,02	-0,02			-2,04			-0,53	0,06	0,33	-0,14	-0,14	0,08				-86,82	57,08			
Iran, Islamic Rep.	0.1	-0,05	0,03	0,01	-0,01							0,23		0,01	0,01	-0,02								
Japan	-4.2	-0,32	0,02	0	-0,03		0,84					0,13		0,1		0,02	0,03		-1,3					
Kenya	-0.25	-0,19	-0,01	-0,01	0,01							0,11		-0,01		0								
Korea, Rep.	0.67	-0,35	0,14	-0,05	0,02							0,27		0,33		0,25								
Norway	2.56	-0,69	-0,05	0,04	0,06	-0,24						-0,52		-0,17		0		-0,14						
Peru	0.14	-0,55	0,2	0,03	-0,02							0,17		-0,06		-0,04	-0,02							
Turkey	1.39	-0,75	0,24	-0,03	0,01	0,09	-0,2					0,28		-0,01		-0,02		0,06	-5,47					
United Kingdom	-1.27	0,24	0,03	-0,03	-0,01	0,18				0	-0,63	0,16		-0,04		0,04		0,11					0,01	-0,01
United States	0.08	-0,03	-0,01	-0,01	0,01					-0,02		0,14		-0,01		0,03							0	

GDP = GDP per capita, FT = Foreign Trade, POD = Population Density, URB = Urbanization, FO = Fossil Energy, RR = Resources Rents
Some coefficients appear as 0 in the table above. These results arise due to rounding the values.

Table A.4: Short-Run Coefficients of Model 3

ARDL-Polynomials

Country	CO_2		GDP		GDP^2			Added Variable 1			Added Variable 2		Added Variable 3	
	a_1	a_2	b_0	b_1	b_0	b_1	b_2	b_0	b_1	b_2	b_0	b_1	b_0	b_1
Argentina	0,31	-0,3	0,05	0,01	0,01	0,01		-0,04	0,04	0,1	-10,05	9,72		
Austria	0,6		0,15	-0,15	0,02	-0,02		0,02	-0,05					
Belgium	0,63		0,14	-0,09	-0,05	0,05		-0,07	-0,41					
Brazil	1		0,19	-0,18	0,03	-0,02		-0,04	-0,06					
Canada	0,7		0,1	-0,07	0	0		-1,82	1,52		0,03	-0,03		
Chile	0,86		0,44	-0,4	0,09	-0,09								
Denmark	0,59		0,12	-0,1	-0,03	0,03		2,73	-1,9					
Iran, Islamic Rep.	0,98		0,19	-0,16	-0,01	0,03	-0,02	0,01	-0,09					
Japan	0,63		0,15	-0,12	-0,01	0,03		0,12	-0,19		-1,31	1,44		
Kenya	0,71		0,11	-0,06	0	-0,02		4,25	-4,27					
Korea, Rep.	0,71		0,81	-0,67	0,13	-0,14								
Norway	0,67		-0,25	0,21	0,23	-0,21		0,42	-0,88	0,85	2,2	-1,71	-0,02	0,05
Peru	0,5		0,13	-0,01	-0,03	0,03								
Turkey	0,23		0,27	-0,02	-0,03	-0,01		0,04	0,03					
United Kingdom	0,55	0,54	0,27	-0,26	-0,01	0								
United States	0,92		0,23	-0,21	-0,01	0,01		0,05	-0,12					

The CO_2 ARDL-Polynomial is of the form $(1 - a_1L - a_2L^2)$ and the other ARDL-Polynomials are of the form $(b_0 + b_1L + b_2L^2)$.
Some coefficients appear as 0 in the table above. These results arise due to rounding the values.

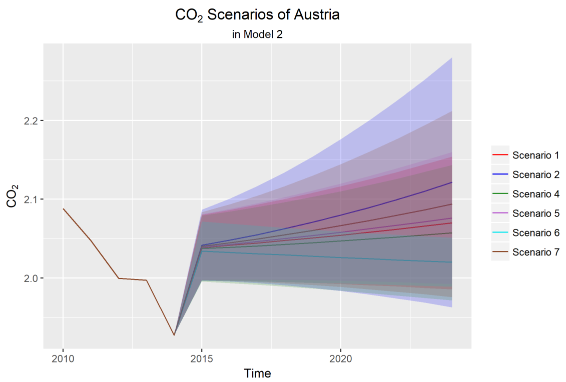
Table A.5: ARDL-Polynomials in Model 2

Country	CO_2		GDP			GDP^2			GDP^3			Added Variable 1			Added Variable 2		
	a_1	a_2	b_0	b_1	b_2	b_0	b_1	b_2	b_0	b_1	b_2	b_0	b_1	b_2	b_0	b_1	b_2
Argentina	0,51		0,07	-0,05		0	0		0	0,01		-0,04	0,07				
Austria	0,63		-0,11	0,16		0,04	-0,05		0,06	-0,16	0,06						
Brazil	0,92		0,11	-0,15		0,02	-0,01		0,03	-0,01		0,15	-0,01				
Canada	0,66		0,22	-0,16		0,02	-0,01		-0,03	0,02		-0,64	0,28				
Chile	0,67		0,4	-0,2		0,09	-0,08		0,01	-0,03		-20,06	17,3		1,3	-0,88	
Denmark	0,59		0	0,02		-0,01	0,01		0,04	-0,03		2,75	-1,89				
France	0,45	0,53	0,06	0,44	-0,33	-0,14	-0,02	0,14	0,08	-0,1		-86,82	141,85	-57,08			
Iran, Islamic Rep.	0,95		0,23	-0,2		0,01	0,01	-0,01	-0,02	0,01							
Japan	0,68		0,13	-0,12		0,1	-0,1		0,02	-0,01	-0,03	-1,3	2,14				
Kenya	0,81		0,11	-0,12		-0,01	0		0	0,01							
Korea, Rep.	0,65		0,27	-0,14		0,33	-0,38		0,25	-0,23							
Norway	0,31		-0,52	0,47		-0,17	0,21		0	0,07		-0,14	-0,1				
Peru	0,45		0,17	0,03		-0,06	0,09		-0,04	-0,01	0,02						
Turkey	0,25		0,28	-0,05		-0,01	-0,02		-0,02	0,02		0,06	0,03		-5,47	5,27	
United Kingdom	0,61	0,63	0,16	-0,13		-0,04	0,01		0,04	-0,05		0,11	0,07		0,01	-0,01	0,01
United States	0,97		0,14	-0,15		-0,01	0,01		0,03	-0,02		0	-0,02				

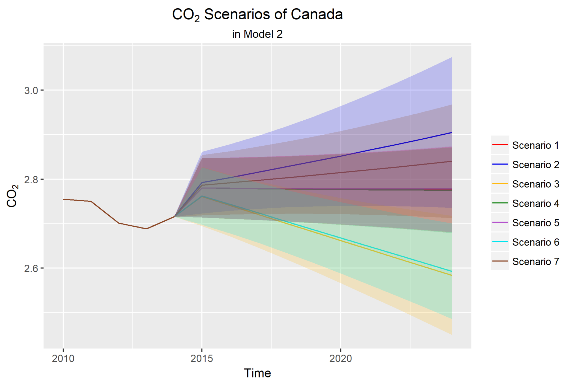
The CO_2 ARDL-Polynomial is of the form $(1 - a_1L - a_2L^2)$ and the other ARDL-Polynomials are of the form $(b_0 + b_1L + b_2L^2)$.
Some coefficients appear as 0 in the table above. These results arise due to rounding the values.

Table A.6: ARDL-Polynomials in Model 3

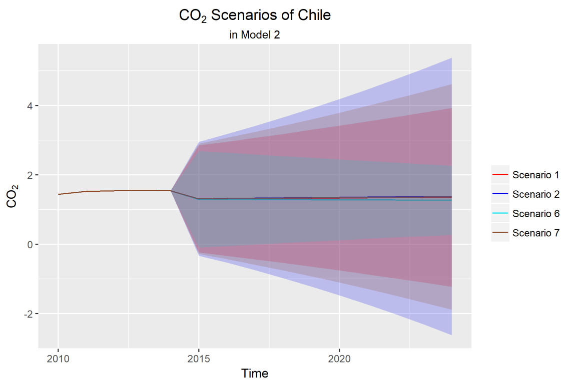
Additional Scenario Analysis



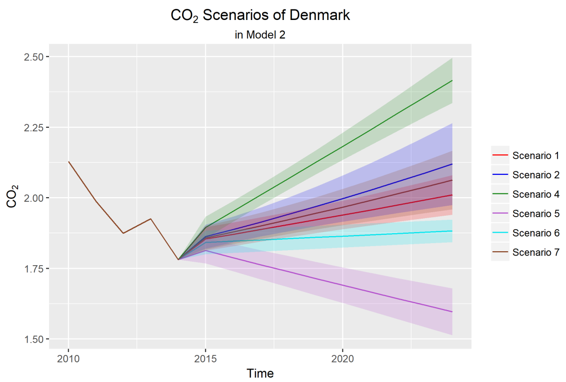
(a) Austria



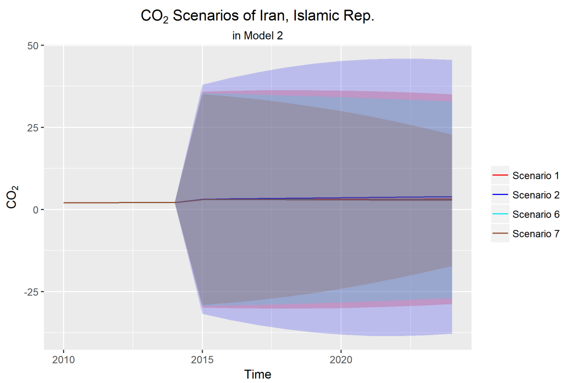
(b) Canada



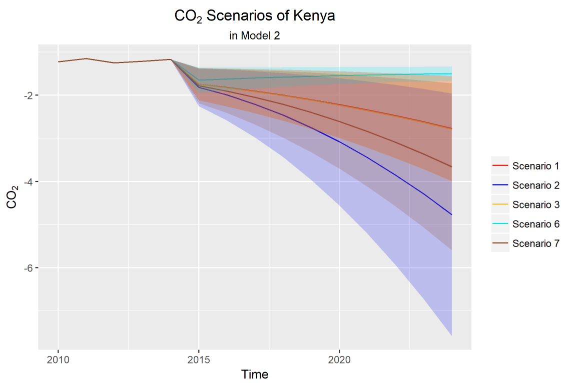
(c) Chile



(d) Denmark

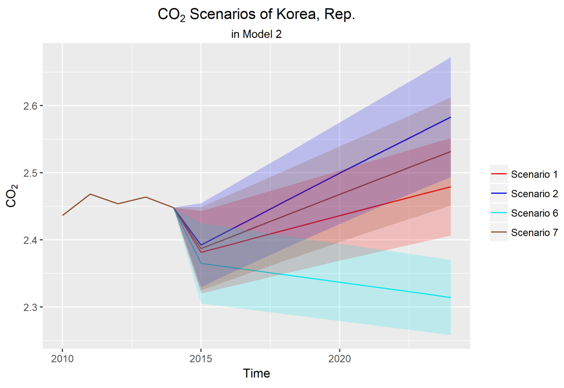


(e) Iran, Islamic Rep.

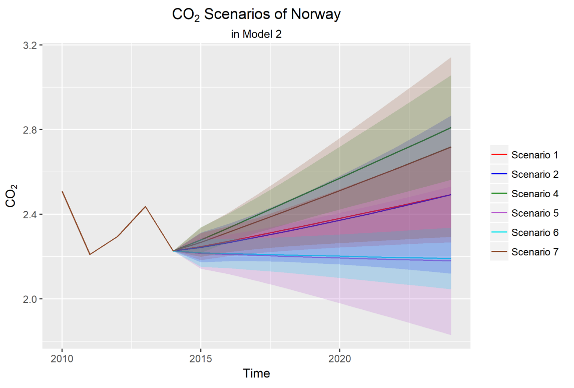


(f) Kenya

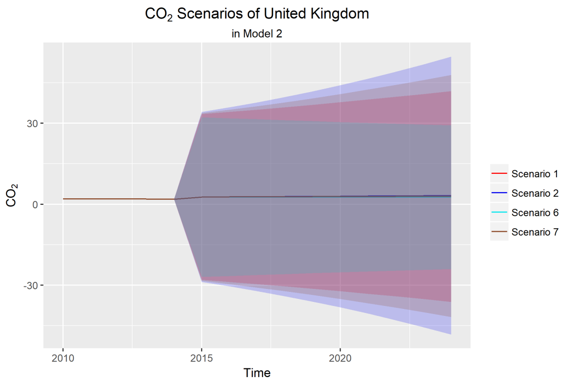
Figure A.1: Scenarios of the Countries in Model 2 with no Cointegrating Relationship



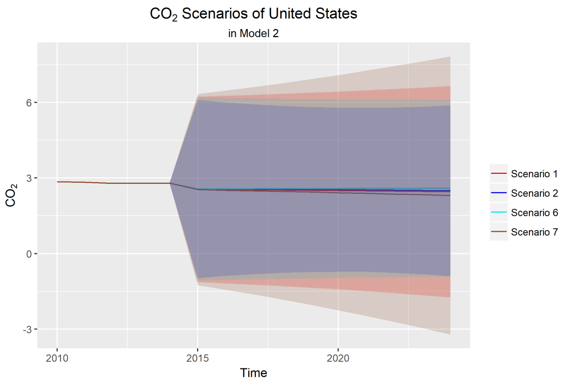
(g) Korea, Rep.



(h) Norway

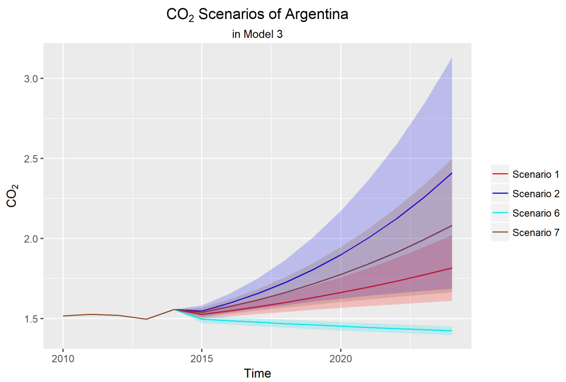


(i) United Kingdom

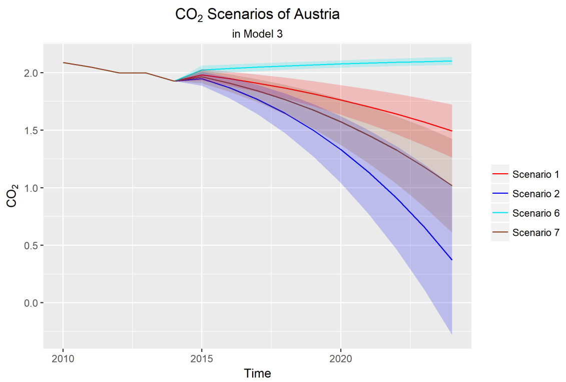


(j) United States

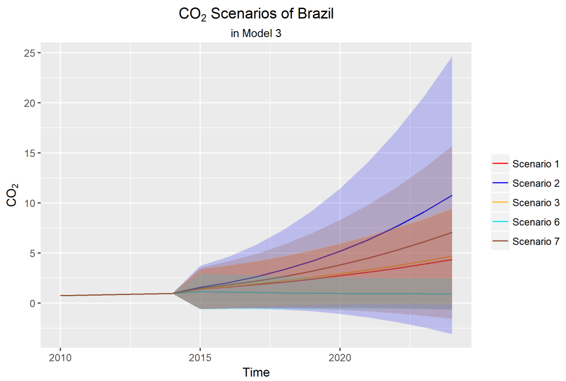
Figure A.1 (cont.): Scenarios of the Countries in Model 2 with no Cointegrating Relationship



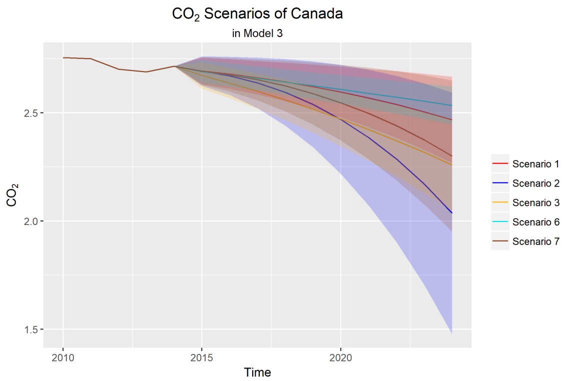
(a) Argentina



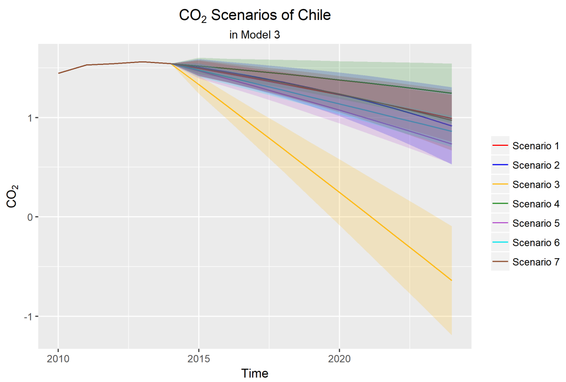
(b) Austria



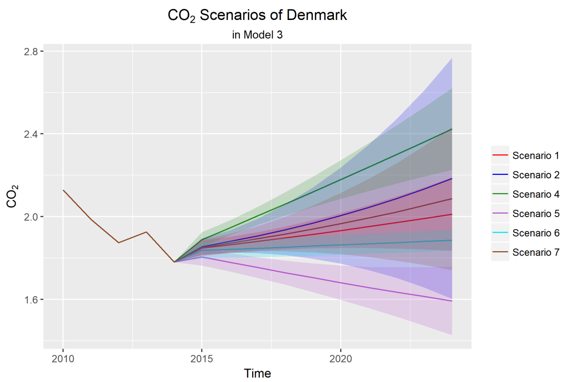
(c) Brazil



(d) Canada

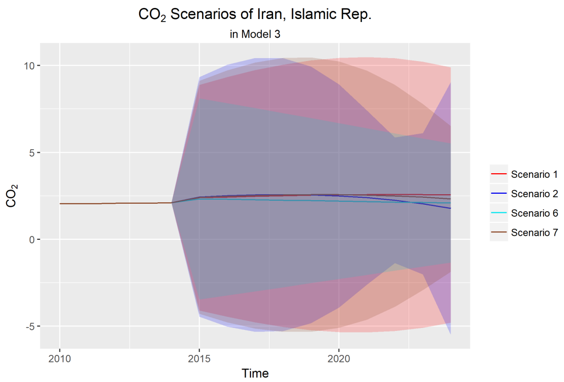


(e) Chile

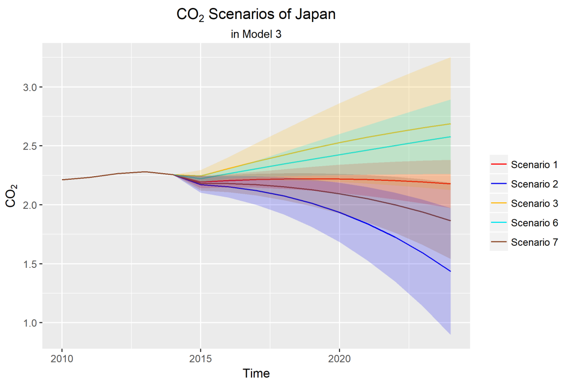


(f) Denmark

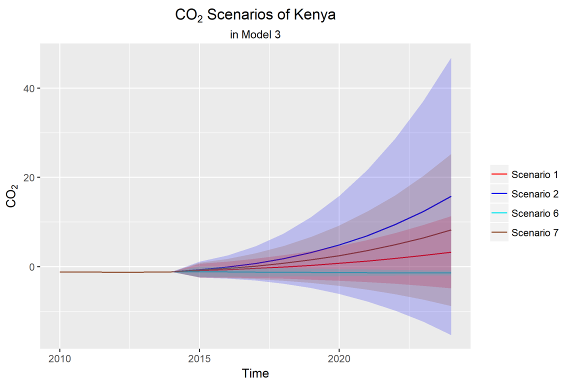
Figure A.2: Scenarios of the Countries in Model 3 with no Cointegrating Relationship



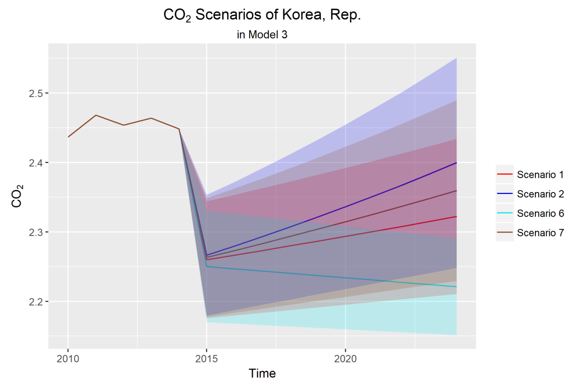
(g) Iran, Islamic Rep.



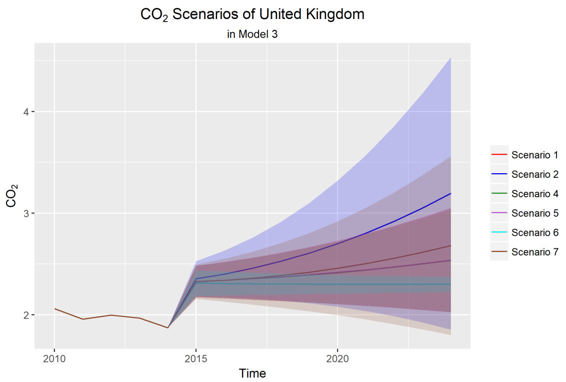
(h) Japan



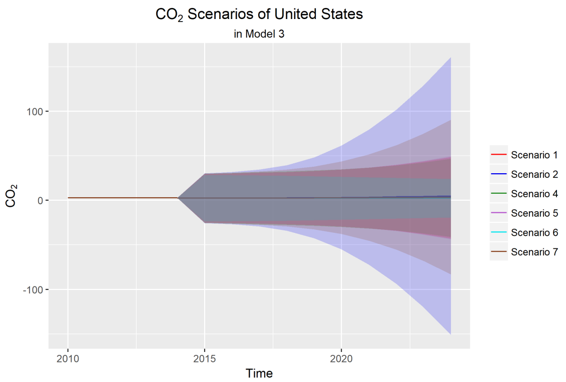
(i) Kenya



(j) Korea, Rep.



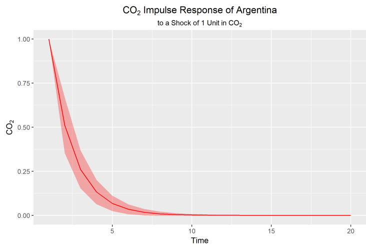
(k) United Kingdom



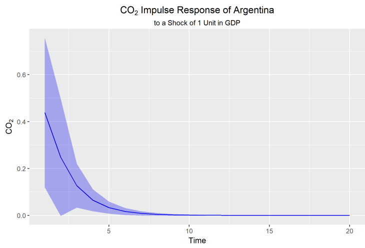
(l) United States

Figure A.2 (cont.): Scenarios of the Countries in Model 3 with no Cointegrating Relationship

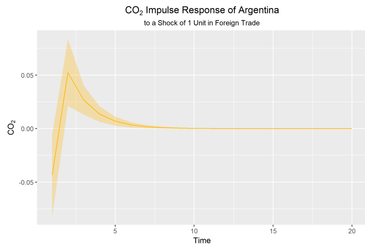
Additional Impulse Response Functions



(a) Shock in CO_2

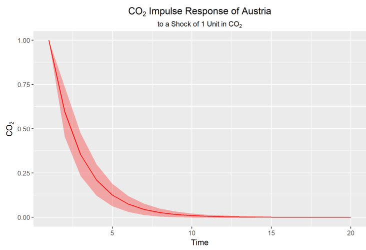


(b) Shock in GDP

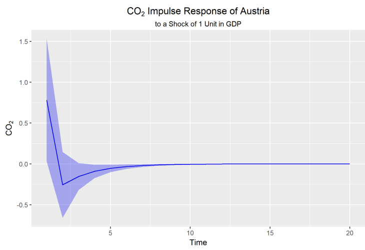


(c) Shock in Foreign Trade

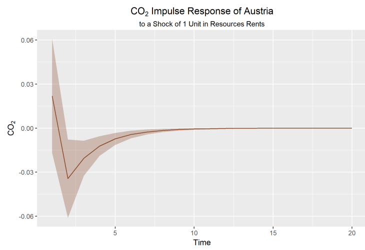
Figure A.3: Impulse Response Functions for Argentina's Model 3



(a) Shock in CO_2

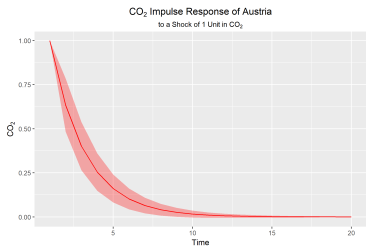


(b) Shock in GDP

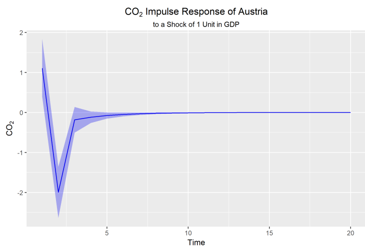


(c) Shock in Resources Rents

Figure A.4: Impulse Response Functions for Austria's Model 2

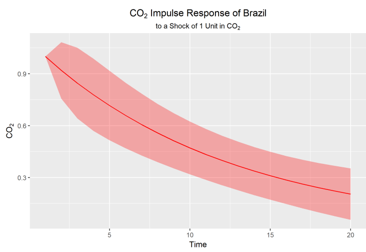


(a) Shock in CO_2

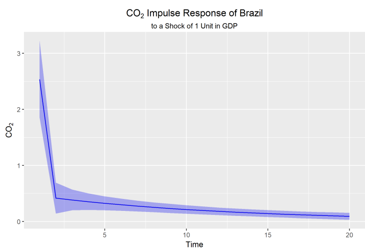


(b) Shock in GDP

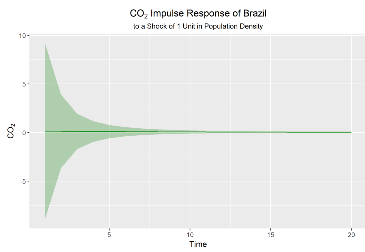
Figure A.5: Impulse Response Functions for Austria's Model 3



(a) Shock in CO_2

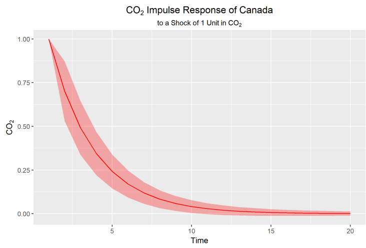


(b) Shock in GDP

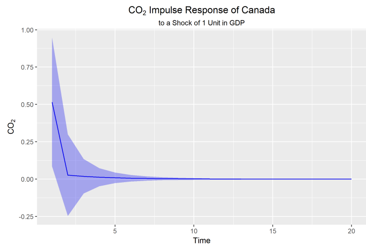


(c) Shock in Population Density

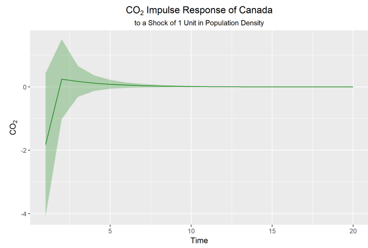
Figure A.6: Impulse Response Functions for Brazil's Model 3



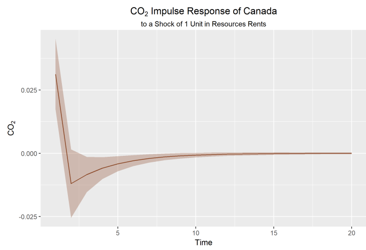
(a) Shock in CO_2



(b) Shock in GDP

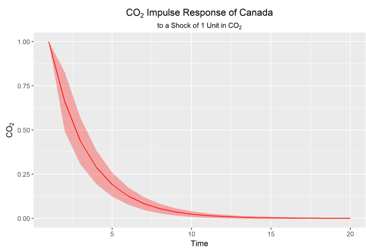


(c) Shock in Population Density

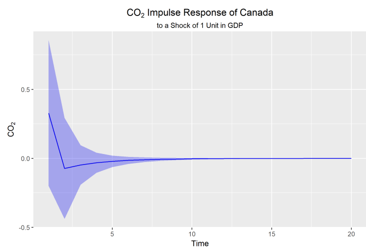


(d) Shock in Resources Rents

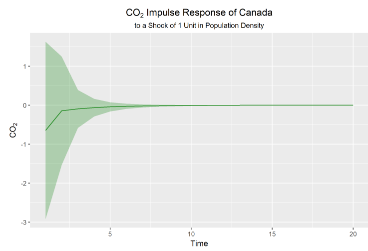
Figure A.7: Impulse Response Functions for Canada's Model 2



(a) Shock in CO_2

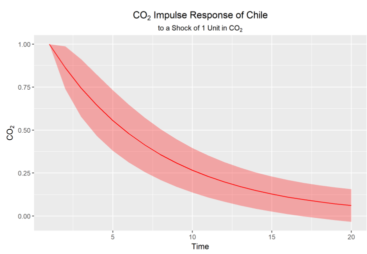


(b) Shock in GDP

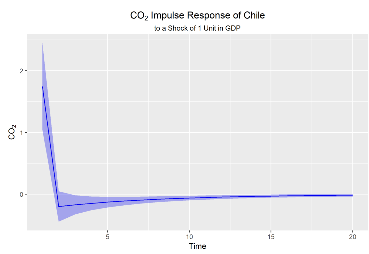


(c) Shock in Population Density

Figure A.8: Impulse Response Functions for Canada's Model 3

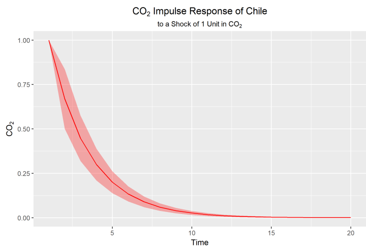


(a) Shock in CO_2

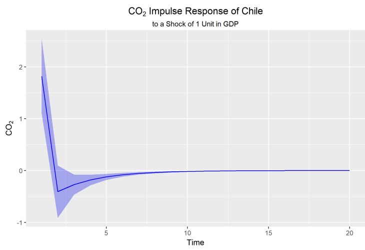


(b) Shock in GDP

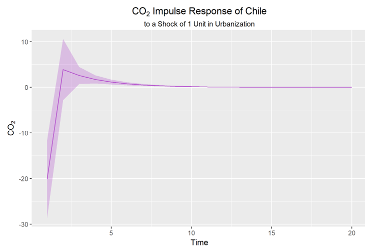
Figure A.9: Impulse Response Functions for Chile's Model 2



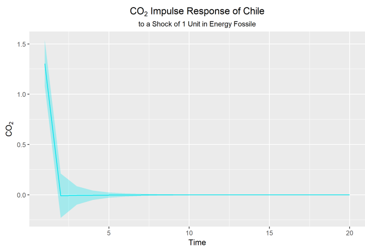
(a) Shock in CO_2



(b) Shock in GDP

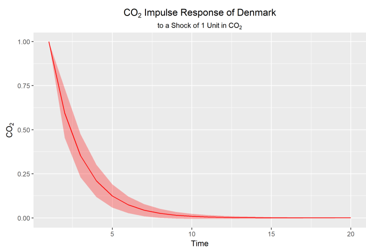


(c) Shock in Urbanization

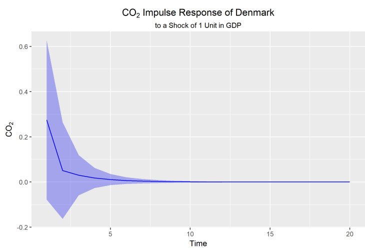


(d) Shock in Fossil Energy

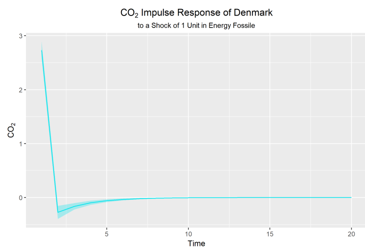
Figure A.10: Impulse Response Functions for Chile's Model 3



(a) Shock in CO_2

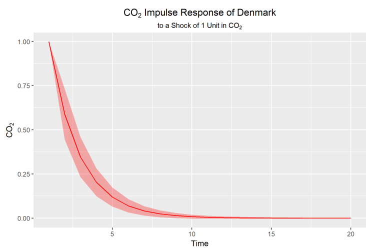


(b) Shock in GDP

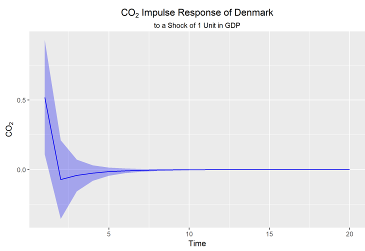


(c) Shock in Fossil Energy

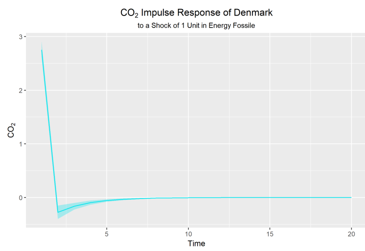
Figure A.11: Impulse Response Functions for Denmark's Model 2



(a) Shock in CO_2

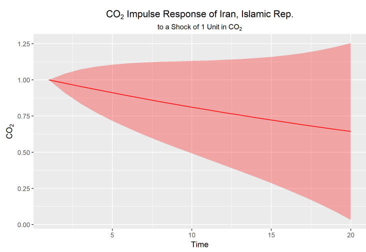


(b) Shock in GDP

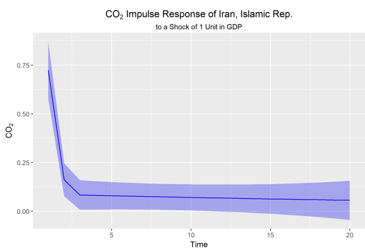


(c) Shock in Fossil Energy

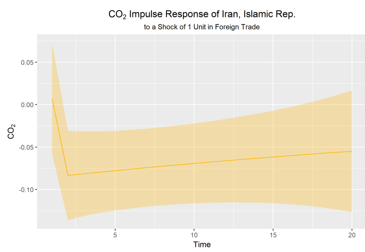
Figure A.12: Impulse Response Functions for Denmark's Model 3



(a) Shock in CO_2

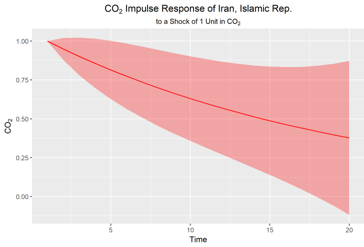


(b) Shock in GDP

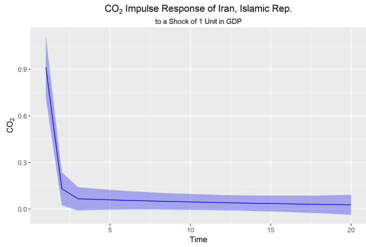


(c) Shock in Foreign Trade

Figure A.13: Impulse Response Functions for Iran, Islamic Rep.'s Model 2

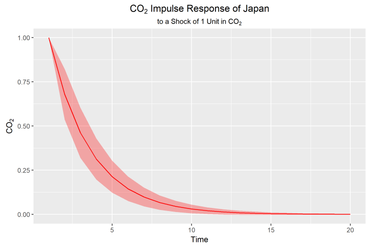


(a) Shock in CO_2

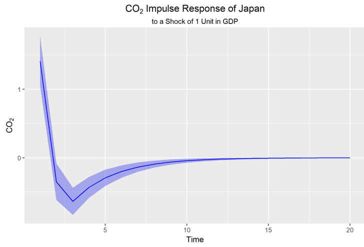


(b) Shock in GDP

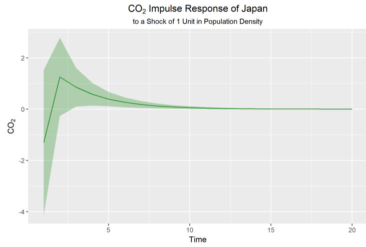
Figure A.14: Impulse Response Functions for Iran, Islamic Rep.'s Model 3



(a) Shock in CO_2

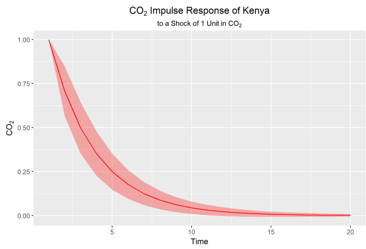


(b) Shock in GDP

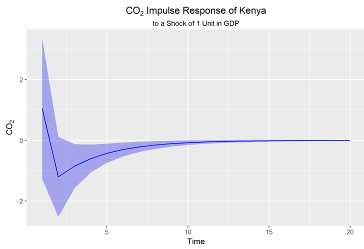


(c) Shock in Population Density

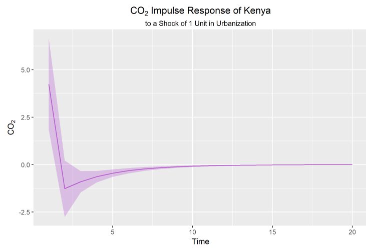
Figure A.15: Impulse Response Functions for Japan's Model 3



(a) Shock in CO_2

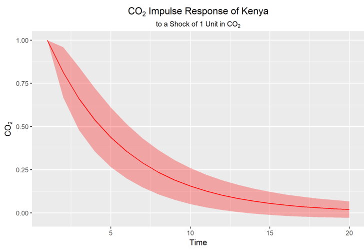


(b) Shock in GDP

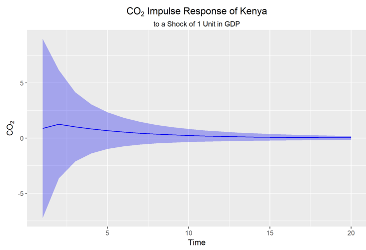


(c) Shock in Urbanization

Figure A.16: Impulse Response Functions for Kenya's Model 2

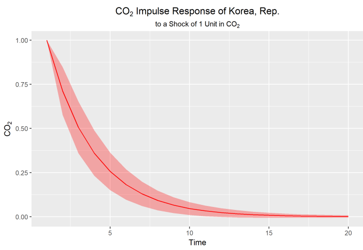


(a) Shock in CO_2

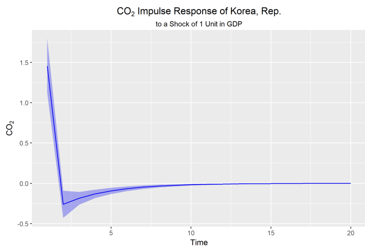


(b) Shock in GDP

Figure A.17: Impulse Response Functions for Kenya's Model 3

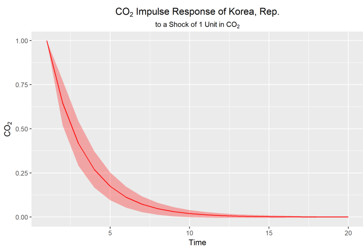


(a) Shock in CO_2

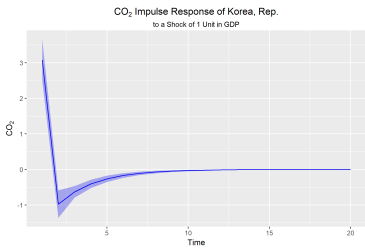


(b) Shock in GDP

Figure A.18: Impulse Response Functions for Korea, Rep.'s Model 2

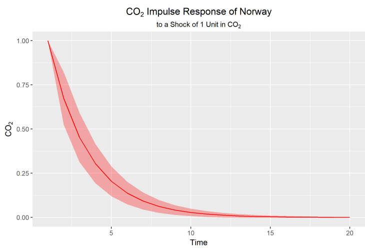


(a) Shock in CO_2

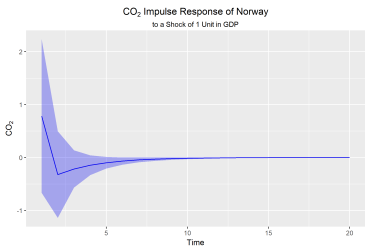


(b) Shock in GDP

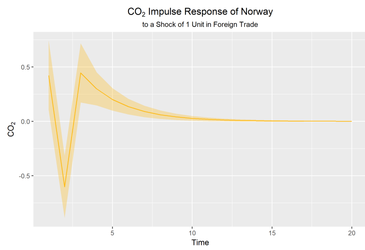
Figure A.19: Impulse Response Functions for Korea, Rep.'s Model 3



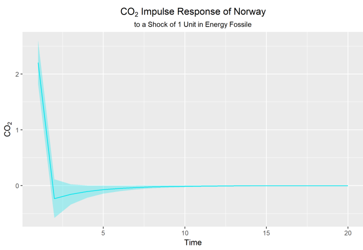
(a) Shock in CO_2



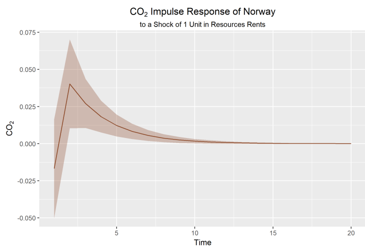
(b) Shock in GDP



(c) Shock in Foreign Trade

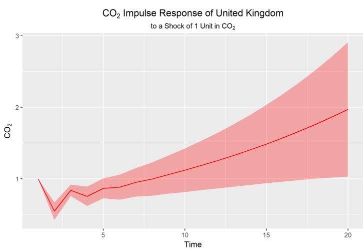


(d) Shock in Fossil Energy

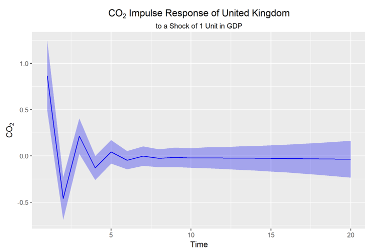


(e) Shock in Resources Rents

Figure A.20: Impulse Response Functions for Norway's Model 2

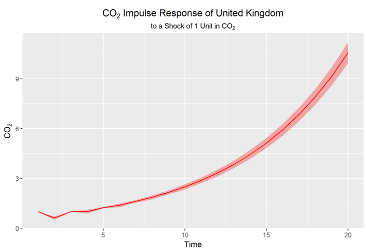


(a) Shock in CO_2

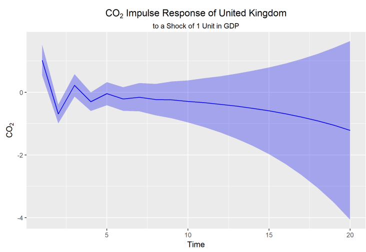


(b) Shock in GDP

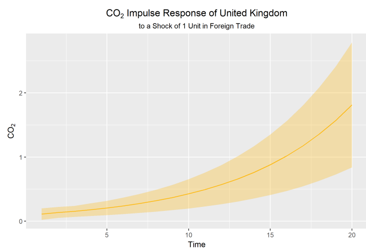
Figure A.21: Impulse Response Functions for United Kingdom's Model 2



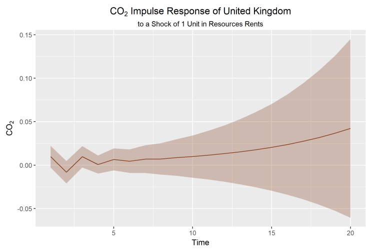
(a) Shock in CO_2



(b) Shock in GDP

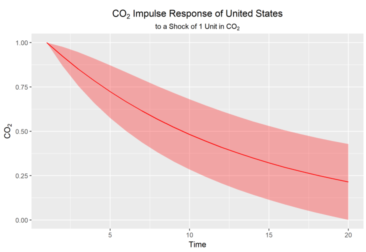


(c) Shock in Foreign Trade

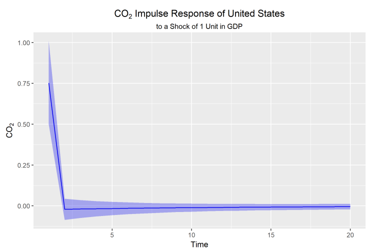


(d) Shock in Resources Rents

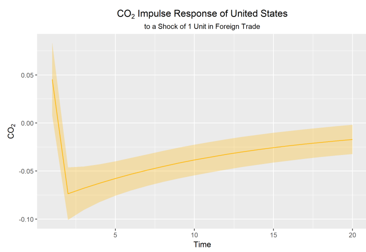
Figure A.22: Impulse Response Functions for United Kingdom's Model 3



(a) Shock in CO_2

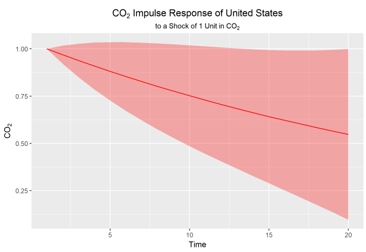


(b) Shock in GDP

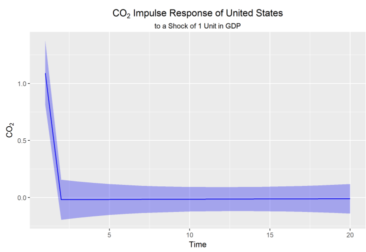


(c) Shock in Foreign Trade

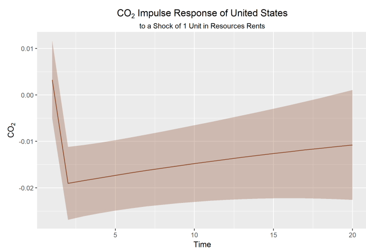
Figure A.23: Impulse Response Functions for United States' Model 2



(a) Shock in CO_2



(b) Shock in GDP



(c) Shock in Resources Rents

Figure A.24: Impulse Response Functions for United States' Model 3

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