Trine Sommervold

An Empirical Analysis of Income Convergence Between EU-Regions

Bachelor's thesis in Economics
Supervisor: Hildegunn E. Stokke
May 2022

Bachelor's thesis

NTNU
Norwegian University of Science and Technology
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NTNU
Kunnskap for en bedre verden

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Preface

This thesis marks the end of my bachelor's degree in economics here at NTNU. Working on this project has been an exciting and educational process.

First and foremost, I would like to thank my supervisor, Hildegunn E. Stokke for thorough guidance and constructive criticism throughout this whole process. Further, I would like to thank my brother and earlier economics student, Eirik, for proofreading and discussions during the writing process. I would also like to thank my family for input when needed.

I am solely responsible for any errors and omissions that might be.

Trondheim, May 2022
Trine Sommervold

Abstract

This bachelor thesis explores income convergence between EU-regions in a macroeconomic perspective using econometric methods. I have investigated whether there is empirical evidence of less developed regions having a higher growth rate than more developed regions in EU in the period 2000-2019 focusing on NUTS 2 regions. I explored economic growth based on GDP per capita in the start of the period using simple linear regression. I then wanted to see if a multiple linear regression model would be a better fit when exploring economic growth by including education and population as control variables. The results from both models indicates that there has been income convergence between the EU regions in the given period. I also concluded that a model with more variables has a greater explanatory power, which is in accordance with the theory.

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1 Introduction

1.1 Motivation

In the last 200 years there has been an outstanding growth in the wealthy countries in the world. Their GDP (measured in fixed prices) has increased by 30-40 times what it was 200 years ago. In this bachelor thesis I will explore increase in GDP per capita in the EU-regions in the period 2000-2019.

The purpose of this study is to see whether there has been income convergence between EU-regions in the given time-period. Do poorer countries have a higher growth rate than richer countries, allowing them to catch up?

1.2 Presentation of Research Question

Based on the motivation for the thesis, I've formulated the following research question:

Will poorer regions have a higher growth rate than wealthier regions leading to income convergence over time?

1.3 Further Structure of the Thesis

So far, I've presented the motivation for thesis and the research question I'll explore. In chapter 2, I'll present the economic theories that will be used in the analysis. These are the Solow Model and the Nelson-Phelps Model which are the two main theories used to study income convergence. In chapter 3, I will present the data that will be used for the analysis, as well as the descriptive statistics related to the variables. In chapter 4, I will specify the econometric methods I will us to perform a regression analysis. The analysis will be performed in the software Stata. I will talk upon the results gathered from the analysis in this part as well. The last chapter will be a discussion on the analysis related to the research question.

2 Economic Theory

In this chapter I will present the economic theory that will be used to analyze the research question presented in the introduction. The analysis will be done in chapter 4. There are two main theories when it comes to income convergence, being neoclassical convergence and technological catch-up. The models are called, respectively, the Solow Model and the Nelson-Phelps Model.

2.1 The Solow Model – Neoclassical Convergence

The first theory for income convergence I'm going to present is the Solow Model. The Solow Model is a long-term economic growth model used to study the effects of increased saving and investment rates on GDP per capita. The model was developed by economist Robert Solow and is the basis for modern theory on economic growth.

Table 2.1.1 Overview of variables used in the Solow Model

Variable name	Definition
I	Gross investment in capital.
S	Saving.
N	Labor (number of workers).
$\bar{N}$	Constant number of workers.
K	Capital.
Y	Income.
MPK	Marginal productivity.
δK	Depreciation rate for capital.

Assumptions

We have five assumptions for the Solow Model:

1. We have a closed economy, meaning that there is no trading with other economies. This gives us equation $(3)\ S = I$.
2. The number of workers is constant, given by $N = \bar{N}$. This means that only a change in K can change Y.
3. There is no productivity growth.
4. We disregard human capital.
5. There is a decreasing return in capital, meaning $F'_K = MPK > 0, F''_K = MPK < 0$.

Solving the Model

Solow assumed a production function where GDP depended on capital and labor. The production function can be formulated as follows:

$$(1)\ Y = F(K, N)$$

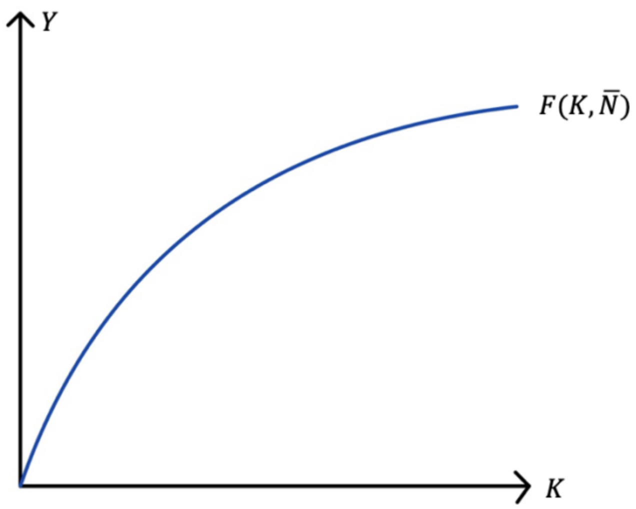

Figure 2.1.1 Production function with decreasing marginal productivity.

Equation (2) shows how change in capital is equal to $I - \delta K$, where I is the gross investment in capital and δK is the depreciation rate for capital which is called consumption of fixed capital. Consumption of fixed capital is the decline in value of fixed assets as a result of normal wear and tear, obsolescence, and accidental damage (SSB, 2014).

$$(2)\ \Delta K = I - \delta K$$

From the first assumption, we know that we're looking at a closed economy; we can't trade with other countries. We also look at the country as a whole, not dividing it into public and private sectors. From the national account definitions for a closed economy, we have that the country's savings equals their investments being equation (3).

$$(3)\ S = I$$

We assume that the country uses a constant share, s, of the income, Y, for savings.

$$(4)\ S = sY \qquad\qquad (= (I - c)Y)$$

This also involves that consumption is proportional with income:

$$[Y = C + I\ and\ Y = C + S, since\ C = cY \rightarrow Y = cCY + S \rightarrow S = (I - c)Y]$$

Now we put equation (3), (4) and (1) into equation (2):

$$(2)\ \Delta K = I - \delta K = \ sY - \delta K = sF(K, \overline{N}) - \delta K$$

We let K^* be the level of capital that makes K constant ($\Delta K = 0$):

$$\Delta K = 0 \rightarrow \ sF(K, \overline{N}) - \delta K = 0 \rightarrow sF(K, \overline{N}) = \delta K$$

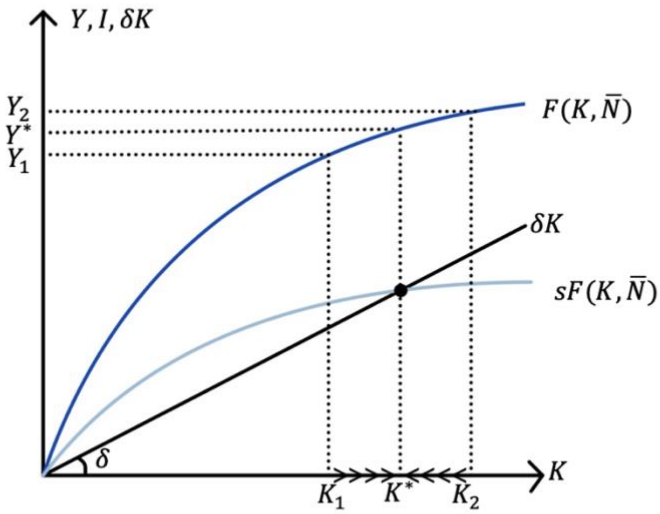

Figure 2.1.2 Equilibrium in capital (K) and income (Y).

Now the question is, is $K = K^*$ a stable equilibrium? If $K_1 < K^*$, then $I > \delta K$ and we have a positive change in capital ($\Delta K > 0$). If it was opposite with $K_2 > K^*$, then $I < \delta K$ and we have a negative change in capital ($\Delta K < 0$). We have that the solution K^* and Y^* is a stable steady state equilibrium. In a steady state the investment rate matches the depreciation rate of capital.

Implications of the Model

How do we interpret these results for the connection between saving, investing and economic growth? There are three key conclusions we can draw from the model presented, being:

1. There is an equilibrium for capital that keeps the economy in a steady state, and we don't have economic growth. This is when K and Y is constant.
2. If $K < K^*$, we'll have a period with economic growth. As stated in the second assumption, only a change in K can change Y and when capital increases, income will increase as well.
3. The lower K is compared to K^*, the stronger the growth rate. This is due to decreasing marginal productivity of capital. This is called classical convergence:

poorer countries, being countries with little capital, will have strong growth for a period.

Increased Saving and Investment Rate

What's the consequence of increased saving and investment rates? We assume that the savings rate (s) increases from s_1 to s_2:

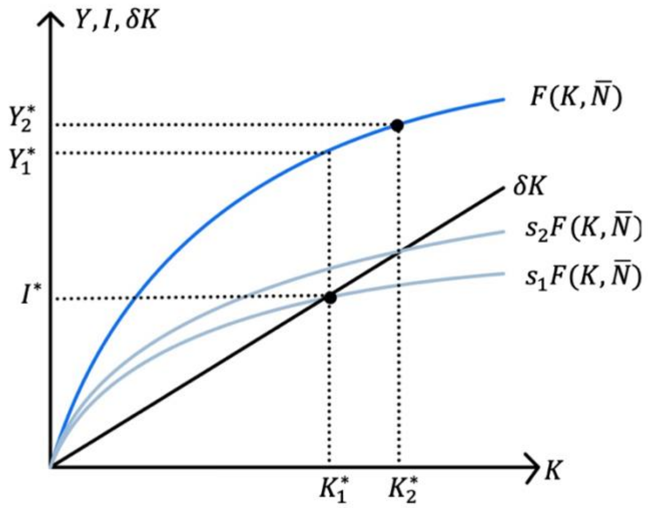

Figure 2.1.3 The effect of increased saving rate on income.

An increased saving rate from s_1 to s_2 will shift the investment curve upwards as illustrated in the figure 2.1.3. This will lead to a higher equilibrium level for capital and therefore higher income which is shown in figure 3 by the change in Y^* from Y_1^* to Y_2^*. An increased saving rate will lead to economic growth for a period but won't lead to lasting economic growth. The higher the saving and investment rates are, the higher the capital gets and hence GDP per capita in a steady state. Since a bigger capital holding involves increased investments to keep up the capital level, a too high saving rate will lead to lower consumption.

So, what is the optimal saving rate? There is a golden rule that will answer this question very easily. The optimal saving rate is the saving rate that gives an equilibrium on capital which again gives the highest consumption in steady state. This level of capital is the point on the production function where the slope is the same as on the depreciation curve.

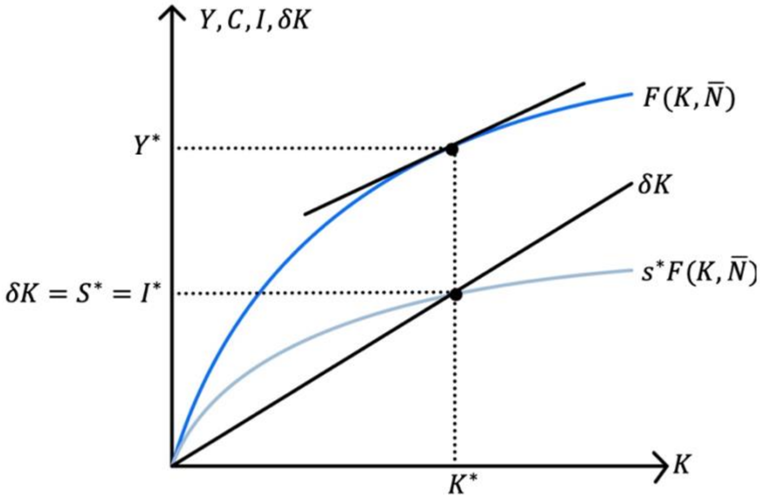

Figure 2.1.4 The optimal saving rate.

The function for the highest possible consumption can be written as follows:

$Max\ C = F(K, \bar{N}) - S = F(K, \bar{N}) - I$ (Where $F(K, \bar{N})$ equals Y), given that $I = \delta K$
$\rightarrow C = F(K, \bar{N}) - \delta K$

$$\frac{\partial C}{\partial K} = F'_K - \delta = 0 \rightarrow F'_K = \delta$$

2.2 The Solow Model with Population Growth

In this part we're extending the model to include population growth to see what effect this has on economic growth. We assume that the population grows with a constant rate h ($h > 0$) and that employment grows at the same rate. With population growth and increased employment, we're mostly interested in looking at production per worker since this is a good estimate on material prosperity in an economy.

Table 2.2.1 Overview of variables used in the Solow Model with population growth.

Variable name	Definition
i	Gross investment in capital per worker.

s	Savings rate.
$y = \frac{Y}{N}$	Production per worker.
$k = \frac{K}{N}$	Capital per worker.
n	Population growth.
δk	Depreciation rate for capital per worker.

Solving the Model

Here we have a production function $Y = F(K, N)$ with constant returns to scale:

$$(6) \frac{Y}{N} = F\left(\frac{K}{N}, \frac{N}{N}\right) = F\left(\frac{K}{N}, 1\right)$$

This gives us equation (7):

$$(7)\ y = f(k)$$

New investments must compensate for depreciation and population growth for capital per worker to be constant. This is the steady state, which I also talked about earlier in the thesis. This is the basis of equation (8).

$$(8)\ \Delta k = sf(k) - \delta k - nk = sf(k) - (\delta + n)k$$

Change in k is equal to actual capital per worker minus necessary capital per worker when capital is constant. This means that when there is no change in capital per worker, actual capital per worker is equal to necessary capital per worker.

Increased saving and investment rate

If the population increases, there will be a need of a higher investment rate to be able to keep up the capital per worker. In a steady state the investments must compensate for the depreciation, and at the same time, capital must increase accordingly to the population growth.

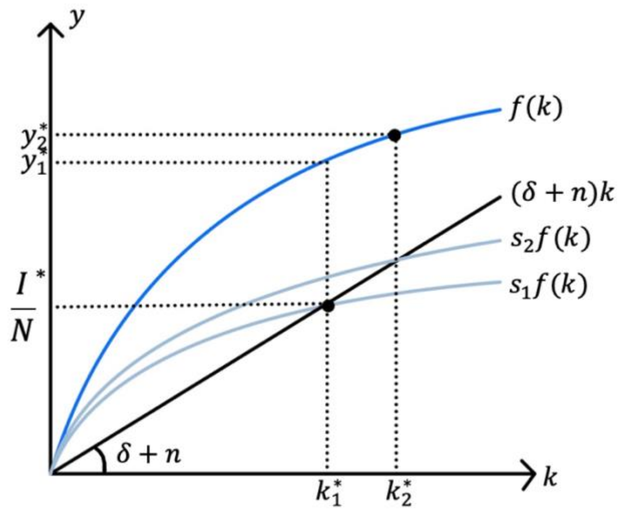

Figure 2.2.1 Increased saving (and investment) rate.

The model gives a period of economic growth in GDP per capita, and a new long-term equilibrium where GDP per capita is constant, but at a higher level.

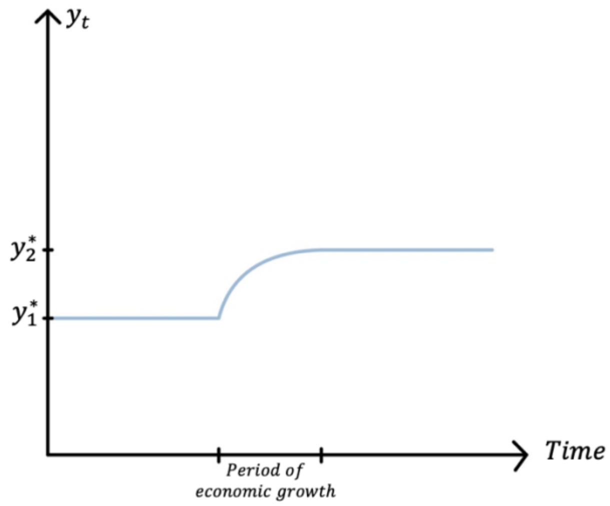

Figure 2.2.2 Period with economic growth.

Here as well, we can ask whether k_1^* and k_2^* are stable equilibriums, and the short answer is yes. If $k < k^*$, actual saving per worker is greater than necessary investment per worker to keep capital constant and capital per worker increases. If $k > k^*$, we have an opposite effect. Capital per worker is reduced until $k = k^*$. We can conclude that k_1^* and k_2^* are stable equilibriums. But what happens with higher population growth?

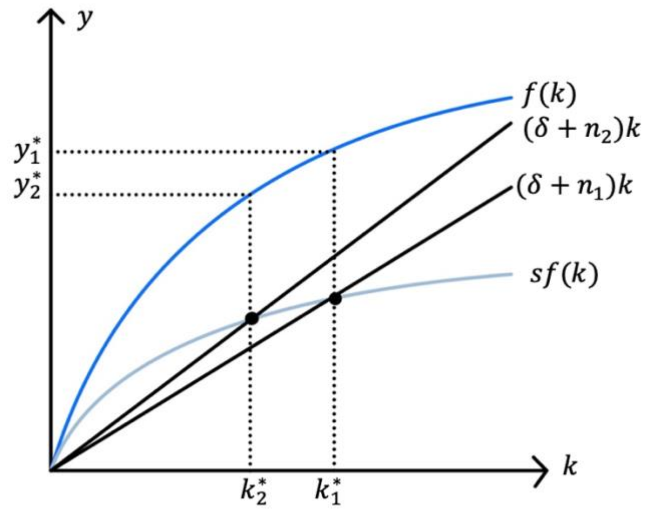

Figure 2.2.3 Higher population growth.

Population growth is shown in the figure 2.2.3 by the shift from n_1 to n_2. Higher population growth leads to lower k^* and lower GDP per capita. There will be a period with lower economic growth.

Based on a Cobb-Douglas product function we can explain differences in income between countries (or regions).

$$Y = AK^{\frac{1}{3}}(hN)^{\frac{2}{3}} \rightarrow \frac{Y}{N} = A(\frac{K}{N})^{\frac{1}{3}}h^{2/3}$$

It's essentially production per worker that explains these differences. Production per worker depends on three different factors being productivity (A), capital per worker ($\frac{K}{N}$) and human capital (h).

2.3 The Nelson-Phelps Model – Technological Catch-Up

There are two main sources to productivity growth. These are innovation and technological catch-up. For less developed countries technologic catch-up is especially important, but for more developed countries both are important. Since we want to look at whether poorer countries have a higher growth rate than richer countries, I want to present a model including technological catch-up. The model I'm using to explain this is the Nelson-Phelps Model. In the Solow Model we assumed no productivity growth. This is not the case here. The Nelson-Phelps Model assumes that the potential for productivity growth in less developed countries is higher than in more developed countries.

Table 2.3.1 Overview of variables used in the Nelson-Phelps Model.

Variable name	Definition
$g(h)$	A measure of technological innovation, as a function of h.
h	Human capital per worker.
$g'(h) > 0$	Better access of human capital leads to more or better technological innovation.
$c(h)$	Technological adaption, as a function of h.
$c'(h) > 0$	Better access of human capital leads to better adaption.
$A(t)$	Domestic productivity level in year t.
$T(t)$	The productivity level of the international technology front in year t.
$\hat{A}$	Domestic productivity growth.
$\hat{T}$	Productivity growth in the international technology front.
$\frac{A}{T}$	Relative productivity.

Solving the Model

The function for productivity growth is given by equation (9):

$$(9)\ \hat{A} = g(h) + c(h)\left(\frac{A(t)}{T(t)} - 1\right)$$

The first part of the function is technological innovation and the second part is technological catch-up. What the function tells us is that a country's productivity growth is positively related to innovation and technological catch-up, and that technological catch-up will affect the productivity less the higher their productivity is relative to the productivity of the front. This will give us a negative slope that is convex as shown in figure 2.3.1. In the following part we will leave out the t.

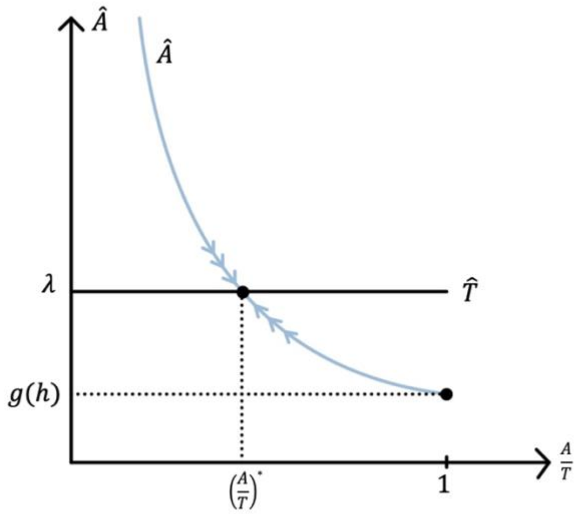

Figure 2.3.1 Graphical representation of the productivity growth function.

If the relative productivity is 1 then the productivity growth is equal to technological innovation; there is no technological catch-up. If relative productivity moves towards zero, then we'll have a case of productivity growth moving towards being infinite. This is called the advantage of backwardness

We assume that the productivity growth in the international technology front is constant and equal to λ ($\hat{T} = \lambda$), and that $\lambda > g(h)$. So, what happens if $\hat{A}$ is different from $\hat{T}$? If $\hat{A} > \hat{T} = \lambda$, being that the productivity growth is higher than the international level, then the relative productivity increases and the difference in domestic and international productivity decreases due to technological catch-up. When it's opposite, being $\hat{A} < \hat{T} = \lambda$, we'll have an opposite effect on the gap between domestic and international productivity. If $\hat{A} = \hat{T} = \lambda$, then the relative productivity is constant. This gives long term stable equilibrium that can be written as $\left(\frac{A}{T}\right)^*$.

To find this equilibrium we solve for $\frac{A}{T}$ when $\hat{A} = \lambda$:

$$\left(\frac{A}{T}\right)^* = \frac{c(h)}{c(h) - g(h) + \lambda}$$

This is the steady state level on relative productivity and gives a period where $\frac{\hat{A}}{\hat{T}}$ is higher than 1 so that the relative productivity increases and the gap up to the front reduces. This is called technological catch-up.

Increased human capital

The effect of increased human capital is shown in figure 2.3.2 by the shift from h_1 to h_2.

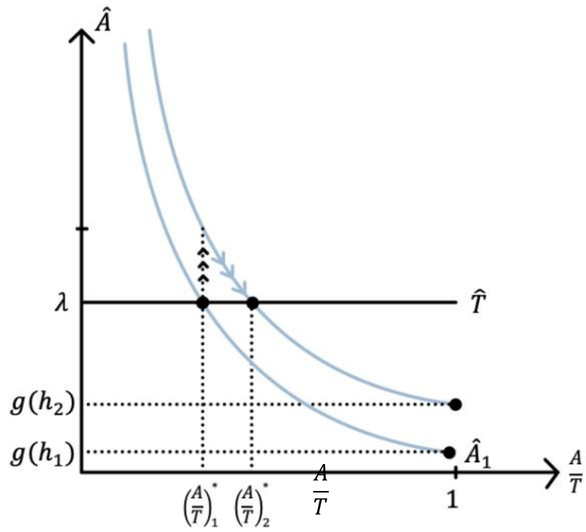

Figure 2.3.2 The effect of increased human capital.

We start off with the equilibrium showed in the model by $\left(\frac{A}{T}\right)_1^*$. When human capital increases productivity growth curve shifts upwards and becomes steeper since technological catch up also increases. We get a new equilibrium showed in the model by $\left(\frac{A}{T}\right)_2^*$.

Implications of the Model

We get three main results when looking at the Nelson-Phelps Model for technological catch up:

1. We get a period where the domestic productivity growth is higher than the international level which will result in a reduced gap to the front.
2. Provided that $\hat{A} = \hat{T} = \lambda$, we'll get a non-permanent effect on the productivity growth.
3. When human capital increases, there will be a permanent effect on the relative productivity shown as the shift from $\left(\frac{A}{T}\right)_1^*$ to $\left(\frac{A}{T}\right)_2^*$ where $\left(\frac{A}{T}\right)_2^* > \left(\frac{A}{T}\right)_1^*$ in figure 2.3.2; increased human capital leads to increased relative productivity. This is due to both increased innovation and increased technological catch-up.

3 Presentation of Data

In this chapter I will present the data that will be used in the empirical analysis. To be able to do such an analysis I will mainly need regional data on growth rate and gross domestic product per capita. I will also introduce two control variables, education and average population growth rate. The data is collected from Eurostat. I will start by explaining why I'm choosing to look at regional data instead of national data and how the regions are divided before going into the dataset.

3.1 Regional Data and the NUTS classification

Often, the EU member states are compared with each other, when in reality, it's difficult to compare states because of differences in population. For example, comparing Malta, which is the smallest country in the European Union, to Germany, as the biggest state, wouldn't give a valid picture. Therefore, it can be useful to look at regions instead. Data on regional levels are more detailed and will give a better and more meaningful picture of reality, showing similarities or differences across EU regions.

Table 3.1.1 Minimum and maximum average population for the NUTS classification.

Level	Minimum	Maximum
NUTS 1	3 million	7 million
NUTS 2	800 000	3 million
NUTS 3	150 000	800 000

Eurostat has defined three levels which regions are divided into by the size of their population. How they are divided is shown in table 3.1.1. Above level 1, is the national level of the EU member states. Each region is given a unique code that tells us which level it belongs to. For example, we have Spain with the code *ES* meaning that it's at national level. Then we have the code *ES5*. This code tells us that we're looking at a region on NUTS 1 level since there is only one number. The region with this code is the eastern region of Spain. This region can be divided into smaller regions which will be at NUTS 2 level and NUTS 3 level.

Belonging to the east part of Spain we have for example the Balearic Islands with the code *ES53*. This region can again be divided into even smaller regions. *ES53*2 is the code belonging to the region of the Spanish island Mallorca. We see that there is a pattern in the way the codes are formed; the letters tell us the country, the first number tells us which NUTS 1 region, the second number tells us which NUTS 2 region and the third number tells us which NUTS 3 region we're looking at.

Empirical analysis can be done on all NUTS levels. Which one is most suited depends on what you're looking for, and on what level. From the explanation given above, we know that a lower level includes more region. Therefore data on lower level regions will give a more accurate analysis. For my analysis, I have chosen to look at data for regions on NUTS 2 level.

3.2 Presentation of the Dataset

To be able to answer the research question, I need data on both growth rate and GDP per capita for the regions on NUTS 2 level. The data I will be using is collected from Eurostat, the statistical office of the European Union. They produce statistics in partnership with National Statistical Institutes and other national authorities in the EU-member states. They also provide statistics on the European Economic Area (EEA) countries and Switzerland (Eurostat, n.d.). I originally planned on using data on the period 2000-2020, but due to covid affecting the economy drastically, I will exclude 2020 and use 2019 instead. The time horizon I will be looking at is therefore 2000-2019.

For GDP per capita, I'm using the table called *Gross domestic product (GDP) at current market prices by NUTS 2 regions.* The data is measured in euro per inhabitant. I will be using GDP per capita measured as a natural logarithm to make it as "normal" as possible for the data to be more valid. This data is collected from the year 2000 as this is the start of the period I'm looking at.

For the dependent variable I planned on using Eurostat's data on real growth rate of regional gross value added. Unfortunately, their dataset was quite deficient. To get a more accurate picture, it's best to include as many regions as possible. I'm therefore using data on GDP per capita for year 2000 and year 2019 to calculate average growth rate:

$$\left(\frac{GDPpc\_19 - GDPpc\_00}{GDPpc\_00} * 100\%\right)/19$$

The data is measured in percentage change on previous period.

Since I'm missing data on some regions I will have to drop them from the analysis. As I mentioned earlier, Stata also collects data on the EFTA countries which are also divided into NUTS regions. It's mainly these countries who don't have data available for GDP per capita on regions. This also goes for candidate regions for NUTS 2. See appendix A.2 for the full list of which regions are excluded. The number of regions and observations in the dataset will be presented in the next part.

Including Control Variables

GDP measures the value of total final output of goods and services produced by an economy within a certain period. GDP takes account for goods and services which have markets or could have markets. It also includes products produced by general governments and nonprofit institutions. GDP is a measure of economic activity and is used for measuring a country or regions material living standards. The issue with this measure is that it doesn't consider for example unpaid household work or negative effects of economic activity, such as environmental degradation. Therefore, it's only I limited measure of economic welfare (Eurostat, 2022). Because of this, it could be interesting to look at some other factors that could contribute to economic development in addition to GDP.

As stated in chapter 2, human resources are central when looking at economic growth. One form of human resources that is likely to contribute to economic growth is higher educational level. I will be doing a second regression analysis including higher education as a control variable. The data I have collected is from Eurostat's dataset *Population by educational attainment level, sex and NUTS 2 regions* and consists of both women and men in the age group 25-64 that has attained tertiary education (levels 5-8). The data is measured in percentage of the population with higher education.

Another control variable I would like to look at, is average yearly population growth. Many analysists suggests that rich countries are expected to slow down the economic growth due to predicted decreasing in the population growth (Baker, et al., 2005). Others argue that increased population growth will slow down economic growth. They say that when more people will use more of the finite resources we have, which is inevitable, potential long-term growth will be reduced (Linden, 2017). If the population grows, there will be a need of a higher investment rate to be able to keep up the capital per worker, as suggested in chapter 2.3.

Here as well, the dataset on Eurostat is deficient. For example, Denmark hasn't reported any data on higher education for their population and will therefore be dropped from the analysis. The same goes for Ireland. There are also a few regions missing data on population for 2000. See appendix A.2 for the full list of regions that has been dropped from the analysis due to missing data.

Table 3.2.1 Overview of variables in the dataset.

Variable name	Variable description
GEO code	Region code after the NUTS classification.
GEO label	Region name.
GDPpc_00	GDP per capita in year 2000 measured in euro per inhabitant.
GDPpc_19	GDP per capita in year 2019 measured in euro per inhabitant.
lnGDPpc_00	Natural logarithm of GDP per capita in year 2000.
GDPGrowth_0119	Average yearly growth in GDP per capita in the period 2000-2019.
Educ_00	Percentage of the population that has attained tertiary education.
Pop_00	Population in the year 2000.
Pop_19	Population in the year 2019.

PopGrowth_0119	Average yearly population growth in the period 2000-2019

3.3 Summary and Descriptive Statistics

As I've had to leave out quite a few regions du to missing data, the dataset consists of 197 regions in year 2000 and 2019. Even though the dataset is deficient, it should still be valid in answering whether there has been income convergence between EU regions as we still have data on most of the regions over a decent period. There are 1576 observations in this dataset, whereas 788 of them will be relevant for the analysis performed in Stata.

Table 3.3.1 Overview of descriptive statistics.

Variable	Mean	Standard deviation	Min	Max
GDPGrowth_0119	.0525693	.0584596	.0052258	.2993421
GDPpc_00	18400	10065.43	1300	52600
lnGDPpc_00	9.597511	.7761906	7.17012	10.87047
Educ_00	.1756193	.077075	.036	.391
PopGrowth_0119	.0027301	.0058062	-.0104397	.0238849

Descriptive statistics provide summarizing information about the data that will be used later in the analysis. We can see that there is a huge difference in GDP per capita in the start of the period. RO21 Nord-Est had 1300 in GDP per capita against LU00 Luxemburg with 52 600 in GDP per capita, a difference of as much as 51 300. When it comes to economic growth in the period, we see that there is a difference of 29.4% in average yearly growth rate with RO11 Nord-Vest with the highest of 29.9% and EL64 Sterea Ellada with the lowest of 0.5%. The average growth in GDP per capita is 5.26% with a standard deviation of 5.8%. We can see that the mean growth rate is closer to the minimum value, than the maximum value. What this tells us is that most regions have had a relative low growth rate, and that there might be a few regions with very high growth rate which led to big differences in the extreme values. In the period I'm looking at, no region has had negative growth in GDP. The rest of the table can be read the same way. For complete list of regions included in the analysis, see appendix A.1. With this in mind, it will be interesting to see whether these differences equalize over time. To answer my research question, I will perform a regression analysis using the data presented. This will be done in the next chapter.

4 Regression Analysis

In this chapter, I will specify the econometric method I will be using to answer the research question, being the OLS method. I will then be using the software STATA to perform a regression analysis based the ordinary least squares method. I will start by performing an analysis with only one independent variable before introducing two new independent variables. What I want to explore is whether less developed regions have had a higher growth rate than more developed regions. In chapter 5, I will discuss the results gathered from the analysis.

4.1 Econometric Specification

I will be using simple linear regression (SLR) to estimate the parameters in question using the ordinary least squares method. This is done under the assumption that the model is linear in parameters. The purpose of using simple linear regression is to study how y changes when x changes. That is, studying how the explained, or dependent, variable changes when the explanatory, or independent, variable changes. In this thesis, the dependent variable will be average yearly growth rate for the given period, being 2000-2019, and the most important independent variable will income level in the start of the period, being GDP per capita in the year 2000. I will later add two additional independent variables that I expect to affect economic development. The relationship between the dependent and independent variable can be formulated as follows:

$$(10)\ y = \beta_0 + \beta_1 x + u$$

This equation is what defines the simple linear regression model, where β_0 is the intercept parameter (the constant) and β_1 is the slope parameter. The slope parameter indicates the expected change in y with one unit change in x. The last variable, u, is called the error term and represents other factors than x that will affect y.

The ordinary least squares method is used to estimate the parameters in the model. This is done by minimizing the sum of squared residuals (SSR). The residuals are the difference between an observed value of the independent variable and the value of the predicted regression line. The predicted regression line is written as follows:

$$(11)\ \hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_i$$

For the OLS to be unbiased, there are a set of assumptions that must be satisfied. These assumptions are called the Gauss-Markov assumptions and can be summed up as follows:

1. SLR.1 – Linear in Parameters, $\boldsymbol{y = \beta_0 + \beta_1 x + u}$
   We assume that the model is linear in parameters. This is explained through the equation (Equation 10).
2. SLR.2 – Random Sampling, $\{(\boldsymbol{x_i}, \boldsymbol{y_i}): \mathbf{1}, \mathbf{2}, \dots, \boldsymbol{n}\}$
   We have a random sample n, drawn from the population model in equation 10.
3. SLR.3 – Sample Variation in the Explanatory Variable, $\{\boldsymbol{x_i}, \boldsymbol{i} = \mathbf{1}, \dots, \boldsymbol{n}\}$
   We have sample variation in the explanatory variable, meaning that the outcomes on x, are not all the same value.
4. SLR.4 – Zero Conditional Mean, $\boldsymbol{E(u|x) = 0}$
   Assumption 4 is an essential assumption for the analysis to be useful. This assumption states that the error, noted by u in the model, has an expected value of zero no matter the value of the explanatory variable.

Under these four assumptions, the OLS estimator is unbiased ($E(\hat{\beta}_0) = \beta_0$ and $E(\hat{\beta}_1) = \beta_1$). However, we'll introduce a fifth assumption to give the most precise estimator.

5. SLR.5 – Homoskedasticity, $\boldsymbol{Var(u|x) = \sigma^2}$
   This last assumption assumes that the error, u, has the same variance no matter the value of the explanatory variable.

It's the estimated coefficient for the independent variable that tells us whether there has been income convergence between the regions. If the estimated coefficient is negative, we have income convergence. Those with the highest income level at the start of the period, have the lowest average growth rate in the years 2000-2019. If the estimated coefficient is positive, it will be opposite. Those with the highest income level in 2000, also have the highest average growth rate over the next 19 years and we have income divergence; the differences increase over time.

Since I want to extend the model to a multiple regression model, I also want to briefly mention the assumptions for such a model. For multiple regression we have 6 assumptions, being linearity, random sampling, variation and no perfect collinearity, zero conditional mean and homoscedasticity and normality. For both sets of assumptions, it's the zero conditional mean that would be most critical. I will come back to this later.

4.2 Regression Analysis of Income Convergence Between EU-regions

In this part I will perform simple linear regressions based on the OLS method and theory presented to answer my research question.

Will poorer countries have a higher growth rate than wealthier countries leading to income convergence over time?

For the first model we're only including one independent variable. The dependent variable will be average yearly growth rate for 2000-2019, and the independent variable will be income level at the start of the period, being GDP per capita in the year 2000 measured as a natural logarithm. The model takes the form:

$$GDPpcGrowth\_0119 = \beta_0 + \beta_1 lnGDPpc\_00 + u$$

The purpose of the model is to estimate the impact of GDP per capita in the start of the period on economic growth over the next 19 years. The variables in the model were defined in chapter 3.2. The estimated model takes the form:

$$GDPpc\widehat{Growth}\_0119 = .06407406 - .06128837 \times lnGDPpc\_00$$

When all else equal, the estimated model can be interpreted as when the natural logarithm of GDP per capita in year 2000 is zero, growth is expected to increase by 6.4%. This wouldn't happen as we know that the lowest value of GDP per capita when measured as a natural logarithm was 7.17. The coefficient for the variable *lnGDPpc_00* is negative with a value of approximately -0.0619. That is, with a 1% increase in the independent variable, measured in euro per inhabitant, income growth is expected to decrease by 0.06% in the period we're looking at. This coefficient is the derived of the growth rate with respect to initial income level. The R-squared is defined by Woolridge (2009) as how much of the total variation in the dependent variable that is explained by the independent variable. The R-squared related to the model is 0.6621, meaning that 66% of the variation in the model is explained.

As mentioned in chapter 4.1, we have income convergence when the estimated coefficient is negative. When only including GDP per capita as our independent variable, we get evidence of income convergence between EU-regions. To confirm that this is correct, I want to run a hypothesis-test at a 5% significance level. My null and alternative hypothesis are defined as:

$$H_0: \beta_1 = 0$$
$$H_1: \beta_1 \neq 0$$

From the alternative hypothesis I know that we're looking at a two-tailed test. The test takes the form:

$$T = \frac{\hat{\beta}_1 - \beta_1}{se(\hat{\beta}_1)} = \frac{\hat{\beta}_1 - 0}{se(\hat{\beta}_1)} = \frac{-.06128837 - 0}{.0031352} = -19{,}55$$

Under the null hypothesis and simple linear regression assumptions, *TS* $\sim t_{n-k-1}$, where $n - k - 1 = 197 - 1 - 1$, we have 195 degrees of freedom. As I mentioned, we're looking at a two tailed test. The critical region, also called the rejection region, for a two-tailed test is when $|T| > c$. This means that we reject the null hypothesis if the test statistic is lower than the negative value of the critical value or higher than the positive value of the critical value. This should only happen about 5% of the time. For T_{195} and a significance of 5% we have a critical value of approximately 1.645. Under the rejection rule above, this means that the null hypothesis is rejected if the test statistic is lower than -1.645 or higher than 1.645. From the test in Stata, we get a test statistic of approximately -19.55. This value is well below the critical value, and we can reject the null hypothesis. The rejection is also confirmed by the p-value of zero obtained in Stata. This means that the probability of observing such an extreme T-statistic when the null hypothesis is true is approximately 0%. Thus, we have evidence of income convergence between EU regions.

As I said, I want to include two control variables in the model. The reason for this is that there are many factors other than just GDP per capita that affects economic growth. A model with more than one independent variable is more likely to give an accurate answer and will give us more information on the dependent variable, whether the new variables add a significant value to the model or not. The two factors I want to look at is the share of population with higher education and population growth for the NUTS 2 regions. When extending the model with two additional independent variables, we get the following model:

$$GDPpcGrowth\_0119 = \beta_0 + \beta_1 lnGDPpc\_00 + \beta_2 Educ\_00 + \beta_3 PopGrowth\_0119 + u$$

The new variables were also defined in chapter 3.2. The new estimated model when adding two control variable takes the form:

$$GDPpc\widehat{Growth}\_0119 = .6953073 - .0703529 \times lnGDPpc\_00 + .1858136 - .0577131$$

With all else equal, the constant is now approximately 0.7. This tells us that when GDP per capita (measured as a natural logarithm), education and population growth is zero, GDP is expected to increase by 69%. From the descriptive statistics presented in the previous chapter, we know that this has not been the case. Here as well, we have a negative coefficient for *lnGDPpc_00* with a value of approximately -0.07. A 1% increase in natural logarithm of GDP per capita in year 2000, is expected to decrease income growth by 0.07% in the period 2000-2019. A one unit change in the other two independent variables, education (measured in percentage of the population) and population growth (measured in percentage change on the previous year), is expected to, respectively, increase income growth by 18.58%

and decrease income growth by 5.77% in the same period. The negative coefficient for population growth is consistent with that theory that population growth will decrease economic growth. The R-squared has now increased to 0.7021; 70% of the variation in the model is explained and the new model is an improvement.

For the natural logarithm of GDP per capita for year 2000, there is not much of a difference from the previous model just looking at them. We can see that there is a slight negative change in the coefficient. From the first model we have a 95% confidence interval of [-0.0674671; -0.0551004]. When including the two extra independent variables we get a 95% confidence interval of [-0.0777941; -0.0629118], and if we're using a 99% confidence interval we get [-0.0801679; -0.0605379]. All interval levels include the value of estimated coefficient from the first model, -0.061. In short, this means that adding additional variables such as education and population growth does not affect the result. They might be helpful in looking at economic growth but aren't strongly related to GDP per capita.

In Stata I find that the correlation between education and GDP per capita, and population growth and GDP per capita in the start of the period, is respectively 0.5037 and 0.5217. This indicates a moderate positive correlation between the two control variables and the main explanatory variable. The correlation between education and population growth is 0.3339 which is a weak positive correlation. If we omit the control variables, leaving them in *u,* they will not impose any bias in $\hat{\beta}_1$

Next, I want to test whether the two additional variables, education and population growth, are jointly significant. What that means is whether they should be included in the model. To do this I'm using an appropriate command in Stata. We have the following null and alternative hypothesis for the test:

$$H_0: \beta_3 = 0, \beta_3 = 0$$
$$H_1: not\ H_0$$

To test if they are jointly significant, I'm using a F-test which takes the form:

$$F = \frac{(SSR_r - SSR_{ur})/q}{SSR_{ur}/(n-k-1)} = 14.68$$

SSR stands for sum of squared residuals, which I talked briefly about in the previous part, where I specified the econometric method that I would use. The test-statistic is 14.68 and under the null hypothesis, the F-test is distributed as $F_{2,193}$. The p-value reported in Stata is zero. What the p-value tells us is the strength of the evidence in support of the null hypothesis we have. If the p-value is less than the significance level, we reject the null hypothesis. A p-value of zero, which it is in our case, is below any level of significance and we should reject the null hypothesis. We can conclude that two variables education and population growth are jointly statistically relevant, meaning that both variables are relevant for the model.

4.3 Results

First, I ran a simple linear regression where we are observing a negative relationship between economic growth and GDP in the start of the period. A negative coefficient for independent variable tells us that regions with the highest income level in the year 2000, have a lower growth rate over the next 19 years than less developed countries: we have evidence of income convergence. To confirm this, I ran a hypothesis test using a 5% significance level. The null hypothesis was rejected on basis of the p-value. This further confirmed my intuitive conclusion about the estimated beta coefficient. Given the data I've collected and methods I've used, I concluded that there has been income convergence between EU-regions.

I then extended the model to a multiple linear regression model, including two more independent variables. The estimated coefficient wasn't much different when eyeballing it, or even statistically when looking at the coefficient intervals. The most important independent variable was within all intervals, meaning that the results does not change when including education and population growth in the model. None of the independent variables were strongly correlated. To test whether these two new variables were jointly significant, I did a hypothesis test where I stated a null hypothesis where the two variables were equal to zero against an alternative hypothesis being not the null hypothesis. To test this, I used a F-test. From the test I concluded that both variables belong in the model. Both education and population growth have affected economic growth in the period 2000-2019.

5 Discussion and Conclusion

5.1 Discussion

The results were in accordance with my expectations. As mentioned, there are different opinions on how population growth will affect economic growth. Some suggest that decreasing population growth will lead to decreasing economic growth, while others argue that population growth will slow down economic growth due to more labor per finite resource. The last statement is in accordance with the Solow Model. The Solow Model says that a higher population will lead to a lower steady state of capital and lower GDP per capital, which will lead to a period with lower economic growth. We have evidence of this in the model with the given data and period.

Education as well, has an expected effect on economic growth. The Nelson-Phelps Model states that when human capital increases there will be a permanent effect on the relative productivity. The relative productivity will be in a higher steady state than before, meaning that when human capital increase, due to for example a higher level of education, the relative productivity increases as well. This is due to both increased innovation and increased technological catch-up.

The most critical weakness of these models is in the assumptions they are based up-on. As I mentioned, it's the assumption of the zero conditional mean that is most critical. The requirement for SLR.4 (and MLR.4) is $E(u|X) = 0$. In general, this assumption is hard to satisfy. The issue could be that there are other factors in *u* related with GDP and economic growth that we aren't capturing. Some of these factors, such as natural resources, can be hard to account for and therefore be difficult to include in such an analysis.

5.2 Conclusion

I have in this thesis explored whether there has been income convergence between EU regions and how higher education and population growth affects economic growth. Since I wanted to look at regions, I've used data on NUTS 2 regions in the period 2000-2019. I've performed a simple regression analysis to explore my research question, before extending my model to include two more variables that helps explain economic growth. Since Eurostat didn’t have data on all regions, I left out some to make a more precise analysis. When leaving out the regions without data, I was left with 197 regions.

In accordance with my findings, income differences equalized over the period in the EU regions. The most important explanatory variable for economic growth, is GDP in the start of the period. The coefficient for this variable were negative in both of my estimated models. Thus, I could conclude that there has been income convergence. This was also further confirmed by the hypothesis test, were I tested the relationship between the dependent and the independent variable.

We also have evidence that a multiple linear regression model is better fit when studying economic growth, which were as expected. As mentioned earlier, GDP is only a limited measure of economic welfare as it for example doesn’t take account of negative effects of economic activity. It’s therefore useful to look at other explanatory variables as well. For my analysis, I looked at education and population growth for an explanation in economic growth. The conclusion on income convergence still stands when including these variables. I also found that both variables have an explanatory power on the dependent variable, meaning that they are both relevant for the model.

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Appendix

A.1 Regions included in the analysis

Country	GEO code and label
Belgium (BE)	BE10 Région de Bruxelles-Capitale/Brussels Hoofdstedelijk Gewest, BE21Prov. Antwerpen, BE22 Prov. Limburg (BE), BE23 Prov. Oost, Vlaanderen, BE24 Prov. Vlaams-Brabant, BE25 Prov. West-Vlaanderen, BE31 Prov. Brabant wallon, BE32 Prov. Hainaut, BE33Prov. Liège, BE34 Prov. Luxembourg (BE), BE35 Prov. Namur
Bulgaria (BG)	BG41 Yugozapaden
Czech Republic (CZ)	CZ01Praha, CZ02Strední Cechy CZ03Jihozápad, CZ04Severozápad, CZ05Severovýchod, CZ06Jihovýchod, CZ07Strední Morava, CZ08Moravskoslezsko
Germany (DE)	DE11 Stuttgart, DE12 Karlsruhe, DE13 Freiburg, DE14 Tübingen, DE21 Oberbayern, DE22 Niederbayern, DE23 Oberpfalz, DE24 Oberfranken, DE25 Mittelfranken, DE26 Unterfranken, DE27 Schwaben, DE30 Berlin, DE40 Brandenburg, DE50 Bremen, DE60 Hamburg, DE71 Darmstadt, DE72 Gießen, DE73 Kassel, DE80 Mecklenburg-Vorpommern, DE91 Braunschweig, DE92 Hannover, DE93 Lüneburg, DE94 Weser-Ems, DEA1 Düsseldorf, DEA2 Köln DEA3 Münster, DEA4 Detmold, DEA5 Arnsberg, DEC0 Saarland, DED2 Dresden, DEE0 Sachsen-Anhalt, DEF0 Schleswig-Holstein, DEG0 Thüringen
Estonia (EE)	EE00 Eesti
Greece (EL)	EL30 Attiki, EL41 Voreio Aigaio, EL42 Notio Aigaio, EL43 Kriti, EL51 Anatoliki Makedonia, Thraki, EL52 Kentriki Makedonia, EL53 Dytiki Makedonia, EL54 Ipeiros, EL61 Thessalia, EL62 Ionia Nisia, EL63 Dytiki Ellada, EL64 Sterea Ellada, EL65 Peloponnisos
Spain (ES)	ES11 Galicia, ES12 Principado de Asturias, ES13 Cantabria, ES21 País Vasco, ES22 Comunidad Foral de Navarra, ES23 La Rioja, ES24 Aragón, ES30 Comunidad de Madrid, ES41 Castilla y León, ES42 Castilla-la Mancha, ES43 Extremadura, ES51 Cataluña, ES52 Comunitat Valenciana, ES53 Illes Balears, ES61 Andalucía, ES62 Región de Murcia ES63 Ciudad de Ceuta, ES64 Ciudad de Melilla, ES70 Canarias
France (FR)	FR10 Île de France, FRB0 Centre - Val de Loire, FRC1 Bourgogne, FRC2 Franche-Comté, FRD1 Basse-Normandie, FRD2 Haute-Normandie, FRE1 Nord-Pas-de-Calais, FRE2 Picardie, FRF1 Alsace, FRF2 Champagne-Ardenne, FRF3 Lorraine, FRG0 Pays-de-la-Loire, FRH0 Bretagne, FRI1 Aquitaine, FRI2 Limousin, FRI3 Poitou-Charentes FRJ1 Languedoc-Roussillon, FRJ2 Midi-Pyrénées, FRK1 Auvergne, FRK2 Rhône-Alpes, FRL0 Provence-Alpes-Côte d'Azur, FRM0 Corse
Italy (IT)	ITC1 Piemonte, ITC2 Valle d'Aosta/Vallée d'Aoste, ITC3 Liguria, ITC4 Lombardia, ITH1 Provincia Autonoma di Bolzano/Bozen, ITH2 Provincia Autonoma di Trento, ITH3 Veneto, ITH4 Friuli-Venezia Giulia, ITI1 Toscana,

	ITI2 Umbria, ITI4 Lazio, ITF1 Abruzzo, ITF2 Molise, ITF3 Campania, ITF4 Puglia, ITF5 Basilicata, ITF6 Calabria, ITG1 Sicilia, ITG2 Sardegna
Cyprus (CY)	CY00 Kypros
Latvia (LV)	LV00 Latvija
Luxemburg (LU)	LU00 Luxemburg
Hungary (HU)	HU21 Közép-Dunántúl, HU22 Nyugat-Dunántúl, HU23 Dél-Dunántúl, HU31 Észak-Magyarország, HU32 Észak-Alföld, HU33 Dél-Alföld
Malta (MT)	MT00 Malta
Netherlands (NL)	NL11 Groningen, NL12 Friesland (NL), NL13 Drenthe, NL21 Overijssel, NL22 Gelderland, NL23 Flevoland, NL31 Utrecht, NL32 Noord-Holland, NL33 Zuid-Holland, NL34 Zeeland, NL41 Noord-Brabant, NL42 Limburg (NL)
Austria (AT)	AT11 Burgenland (AT), AT12 Niederösterreich, AT13 Wien, AT21 Kärnten, AT22 Steiermark, AT31 Oberösterreich, AT32 Salzburg, AT33 Tirol, AT34 Vorarlberg
Poland (PL)	PL21 Malopolskie, PL22 Slaskie, PL41 Wielkopolskie, PL42 Zachodniopomorskie, PL43 Lubuskie, PL51 Dolnoslaskie, PL52 Opolskie, PL61 Kujawsko-Pomorskie, PL62 Warminsko-Mazurskie, PL63 Pomorskie
Portugal (PT)	PT11 Norte, PT15 Algarve, PT16 Centro (PT), PT17 Área Metropolitana de Lisboa, PT18 Alentejo, PT20 Região Autónoma dos Açores (PT), PT30 Região Autónoma da Madeira (PT)
Romania (RO)	RO11 Nord-Vest, RO12 Centru, RO21 Nord-Est, RO22 Sud-Est, RO31 Sud – Muntenia, RO32 Bucuresti – Ilfov, RO41 Sud-Vest Oltenia, RO42 Vest
Slovakia (SK)	SK01 Bratislavský kraj, SK02 Západné Slovensko, SK03 Stredné Slovensko, SK04 Východné Slovensko
Finland (FI)	FI19 Länsi-Suomi, FI20 Åland
Sweden (SE)	SE11 Stockholm, SE12 Östra Mellansverige, SE21 Småland med öarna, SE22 Sydsverige, SE23 Västsverige, SE31 Norra Mellansverige, SE32 Mellersta Norrland, SE33 Övre Norrland

A.2 Regions dropped from the analysis due to missing data

Country	GEO code and label
Bulgaria (BG)	BG31 Severozapaden, BG32 Severen tsentralen, BG33 Severoiztochen, BG34 Yugoiztochen, BG42 Yuzhen tsentralen
Denmark (DK)	DK01 Hovedstaden, DK02 Sjælland, DK03 Syddanmark, DK04 Midtjylland, DK05 Nordjylland
Germany (DE)	DEB1 Koblenz, DEB2 Trier, DEB3 Rheinhessen-Pfalz, DED4 Chemnitz, DED5 Leipzig
Ireland (IE)	IE04 Northern and Western, IE05 Southern, IE06 Eastern and Midland
France (FR)	FRY1 Guadeloupe, FRY2 Martinique, FRY3 Guyane, FRY4 La Réunion, FRY5 Mayotte

Croatia (HR)	HR02 Panonska Hrvatska, HR03 Jadranska Hrvatska HR05 Grad Zagreb, HR06 Sjeverna Hrvatska
Italy (IT)	ITH5 Emilia-Romagna, TI3 Marche
Lithuania (LT)	LT01 Sostines regionas, LT02 Vidurio ir vakaru Lietuvos regionas
Hungary (HU)	HU11 Budapest, HU12 Pest
Poland (PL)	PL71 Lódzkie, PL72 Swietokrzyskie, PL81 Lubelskie, PL82 Podkarpackie, PL84 Podlaskie, PL91 Warszawski stoleczny, PL92 Mazowiecki regionalny
Slovenia (SI)	SI03 Vzhodna Slovenija, SI04 Zahodna Slovenija
Finland (FI)	FI1B Helsinki-Uusimaa, FI1C Etelä-Suomi, FI1D Pohjois- ja Itä-Suomi
Norway (NO)**	NO02 Innlandet, NO06 Trøndelag, NO07 Nord-Norge, NO08 Oslo og Viken, NO09 Agder og Sør-Østlandet, NO0A Vestlandet, NO0B Jan Mayen and Svalbard
Switzerland (CH)**	CH01 Région lémanique, CH02 Espace Mittelland, CH03 Nordwestschweiz, CH04 Zürich, CH05 Ostschweiz, CH06 Zentralschweiz, CH07 Ticino
Montenegro (ME)*	ME00 Crna Gora
North Macedonia (MK)*	MK00 Severna Makedonija
Albania (AL)*	AL01 Veri, AL02 Qender, AL03 Jug
Serbia (RS)*	RS11 Beogradski region, RS12 Region Vojvodine, RS21 Region Sumadije i Zapadne Srbije, RS22 Region Juzne i Istocne Srbije
Turkey (TR)*	TR10 Istanbul, TR21 Tekirdag, Edirne, Kirklareli, TR22 Balikesir, Çanakkale, TR31 Izmir, TR32 Aydin, Denizli, Mugla, TR33 Manisa, Afyonkarahisar, Kütahya, Usak, TR41 Bursa, Eskisehir, Bilecik, TR42 Kocaeli, Sakarya, Düzce, Bolu, Yalova, TR51 Ankara TR52 Konya, Karaman, TR61 Antalya, Isparta, Burdur, TR62 Adana, Mersin, TR63 Hatay, Kahramanmaras, Osmaniye, TR71 Kirikkale, Aksaray, Nigde, Nevsehir, Kirsehir, TR72 Kayseri, Sivas, Yozgat, TR81 Zonguldak, Karabük, Bartin, TR82 Kastamonu, Çankiri, Sinop, TR83 Samsun, Tokat, Çorum, Amasya, TR90 Trabzon, Ordu, Giresun, Rize, Artvin, Gümüshane, TRA1 Erzurum, Erzincan, Bayburt, TRA2 Agri, Kars, Igdir, Ardahan TRB1 Malatya, Elazig, Bingöl, Tunceli, TRB2 Van, Mus, Bitlis, Hakkari, TRC1 Gaziantep, Adiyaman, Kilis, TRC2 Sanliurfa, Diyarbakir, TRC3 Mardin, Batman, Sirnak, Siirt

* Candidate countries

** EFTA countries

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