Global development of densities:

A study in the urban development of countries using the stages of development model and density changes in cores, suburbs and rural areas on a global scale

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Abstract
As cities develop this has many influences on human health, productivity and the environment. The development of these cities is therefore important in understanding how what effects they will have in the future. Cities are believed to follow the theoretical stages of urban development model (Van den Berg et al., 1982). As cities have many interlinkages with each other and rural areas, this study investigated if this model could be extended to explain urban development of countries. It is however found is that countries are the aggregations of the urban development of individual cities of the countries. How these interact and a spatial pattern is not found. Furthermore have density changes, associated with the stages of urban development model been studied. Average densities were found to increase between 1975 – 2000 and slightly decrease between 2000 – 2015, possibly marking the start of the predicted decreasing densities. Density changes were, however, not found to follow this model, but mostly be effected by other variables. Density changes were found to influenced differently in cores, suburbs and rural areas, with a large influence of initial density and population growth in cores, suburbs and rural areas.

1. Introduction

Urban areas cover about 3% of total land worldwide and is expanding rapidly (Balk et al., 2005). Land use change to urban has a large impact on the ecosystems and their functioning (Metzger et al., 2006). As urban areas expand, natural areas will both directly and indirectly suffer (van Vliet, 2019) and lead to fragmentation of these natural areas (Batisani & Yarnal, 2009). Externalities as noise- and air-pollution and a complete transformation of the land have a lasting effect on ecosystems, and can cause large decreases in biodiversity (Braimoh & Onishi, 2007; Hasan et al., 2020). Urban expansion models agree in that urban area will increase globally in the future (Gao & O'Neill, 2020; M. Li et al., 2022). With the general consensus about the problems of climate change and the loss of biodiversity, expansion of urban land is and will continue to pose as a global problem. Increasing global population is a major driver of this process. Global population is expected to peak at about 11 billion around 2100 (3.3 billion more than today) and therefor will continue to drive the expansion of urban areas (Gu et al., 2021). Increasing population will increase the demand for housing and urban amenities like shops and hospitals. This in term increases demand for urban expansion (Eichholtz & Lindenthal, 2014). Gao & O'Neill (2020) find that urban area could increase by a factor of between 1.8 and 5.9 by the year 2100, depending on the future scenario. This would cause urban area to expand to cover between 5 and 18 percent of global area. This large increase cannot be explained by an increase in population alone. Per capita urban land use, better known as urban population density are changing too. Gao & O'Neill modelled changes in urban land per capita and found a possible increase of a factor of between 1.1 and 4.9 by the end of the century. Resulting in urban land per capita to increase from about 100m^2 per capita to between 110 and 490m^2 per capita. This increase can be explained by increasing demand for more spacious houses, lower household sizes, large gardens and more space to recreate (Williams, 2009). This is mostly seen to occur in areas outside of cities, where room is to expand (M. Li et al., 2022). At the same time do some countries show big clustering in cities, where densities will increase (Angel et al., 2021; M. Li et al., 2022; Tikoudis et al., 2022). How these trends behave on a global level will determine how population densities will change and together with changes in population how urban expansion will be effected. So have M. Li et al. (2022) found that in the last decennia, between 37.5 and 49.6 percent of urban expansion has been related to density decreases. Current models for urban expansion use both predictions in population change and local determinants for urban expansion, but mostly leave the effect of per capita urban land uncharted (Chaudhuri & Clarke, 2013; Li & Gong, 2016; Zhou et al., 2019). However, as shown by Gao & O'Neill (2020) and M. Li et al. (2022) is density change a major contributor to urban growth and should therefore not be excluded in modelling of urban expansion (L. Li et al., 2003; Seto et al., 2012).

Much theoretical research occurred (Alberti & Waddell, 2000; Paddison, 2001; Van den Berg et al., 1982; Yigitcanlar, 2015). These studies focus on theoretical models that explain changes in population and population densities in different urban hierarchies. Most commonly, urban areas are divided in the urban hierarchies of cores and suburbs, as these are very different and follow different paths of development. However has the distinction become increasingly blurred with time and development (T. Champion, 2001).

One commonly used model is the hypothetical model of 'Stages of urban Development' , by Van den Berg et al. (1982). This model shows overall population changes and population density changes in the urban hierarchies of cores and suburbs over time. Next to time is income believed to be a driving force of this model that causes shifts in the stages (L. Li et al., 2003). In this model, 4 stages are described which cities are believed to undergo in their development.

In all stages of the model, cores and suburbs interact with rural areas, but this urban hierarchy is not included. The reason for this is that all cities in a country interact with the same rural area and can therefore not be prescribed to one city. However, on a country level, the influence on rural areas could also be included in the model. Not only should a country level approach of the model make changes in rural areas visible, also interlinkages with other cities in the same country should become visible. This could provide a larger frame of the stages of urban development model. Current research on the development of cities is thorough and has proven to mostly follow the theoretical stages of urban development model (A. G. Champion, 1986; Clarke, 2017; Gnatiuk, 2017; Kabisch & Haase, 2011; Paddison, 2001). These studies however only focus on single or a limited amount of cities. The model however shows many interactions between rural areas and other cities and is therefore appliable to larger areas. The urban development of larger areas as countries in connection with the Stages of urban development model however is not studied.

Furthermore has quantitative research occurred. Changes in urban population density have been thoroughly studied and have resulted in many determinants that are believed to influence these density changes (Braby, 1989; Krause & Seidel, 2020; Martori et al., 2016; G. Xu et al., 2019). Likewise to the stages of urban development model, only individual cities or small regions have been studied. Spatial differences over the globe are however expected. Countries have different cultures and thereby different preferences, norms and values. For instance is living with the whole family very normal in some cultures or do some countries primarily build houses with a single floor (Holdsworth et al., 2013). These could present different determinants or alter the strength of certain determinants. Furthermore have determinants only been studied for population density changes in general without differentiating in urban hierarchy. As the stages of urban development model suggests, do these urban hierarchies follow different development patterns. This could indicate that densities changes therefor behave differently in the hierarchies and have different determinants driving these population density changes. However, no global studies or studies that divide hierarchies have occurred that focus on the determinants of population density changes as of yet. This could however prove useful for a better understanding of the subject. This study will therefore attempt to fill these gaps in the current research. This results in the following research questions:

1) How do density trends change in the last few decennia in cores, suburbs and rural areas and how do these influence global average density changes?

2) Can the stages of development model be applied to the urban development of a country?

3) Are densities found to follow density changes suggested by stages of urban development model?”

4) What variables influence population density changes in cores, suburbs and rural areas around the world?

These will be studied by expanding on the stages of urban development model and observing the changes of population in cores, suburbs and rural areas for most countries worldwide. Hereby observing both the changes in total population and the accompanied fluctuations in population density that are described by the model. This is furthermore aided by a quantitative study on the determinants of density changes in these different urban hierarchies worldwide.

2. Broader context

Prior to the analysis of this research, a broader literary foundation needs to be provided. This chapter will go deeper in on the Stages of urban development model and factors that are believed to influence population density changes. The stages of urban development model and reason density changes will be discussed in further detail.

2.1 Stages of urban development model

Figure 1 shows these stages of urban development model. The theory behind the model is that, initially, cities grow in population fast, both in the core and the suburbs. This was first observed to occur in the 18th century when all over the world people moved to cities as it less people were needed for agriculture (Berry, 2008). This is stage 1, urbanization and is driven by rural-urban migration. People move to cities as there is work and other urban amenities to be found.
Stage 2, sub-urbanization is the migration of population from city cores to the suburbs. Suburbanization was most strongly observed with the arrival of motorised vehicles, especially with the introduction of cars. These vehicles reduced travel time and thereby travel costs. This made living in the suburbs much more affordable and preferable, which caused a shift from the cores to the suburbs (Glaeser & Kahn, 2004). Stage 3, counter-urbanization is the urban-rural movement where people move from both the cores and suburbs towards rural areas or smaller cities. It is believed to occur as a reply on deprivation of cores (Berry, 1980). It was already predicted by some researchers in the early 20th century (Wells, 1902), but only observed in the early 1970’s in the United States which was followed by many more cities in the developed world (Mitchell, 2004). More recently counter urbanization has also occurred due to political decisions (Baiping et al., 2004). This stage is however often skipped (Jain et al., 2013) and causes development to continue with stage 4, re-urbanization.
In this stage people go back to the cities again as

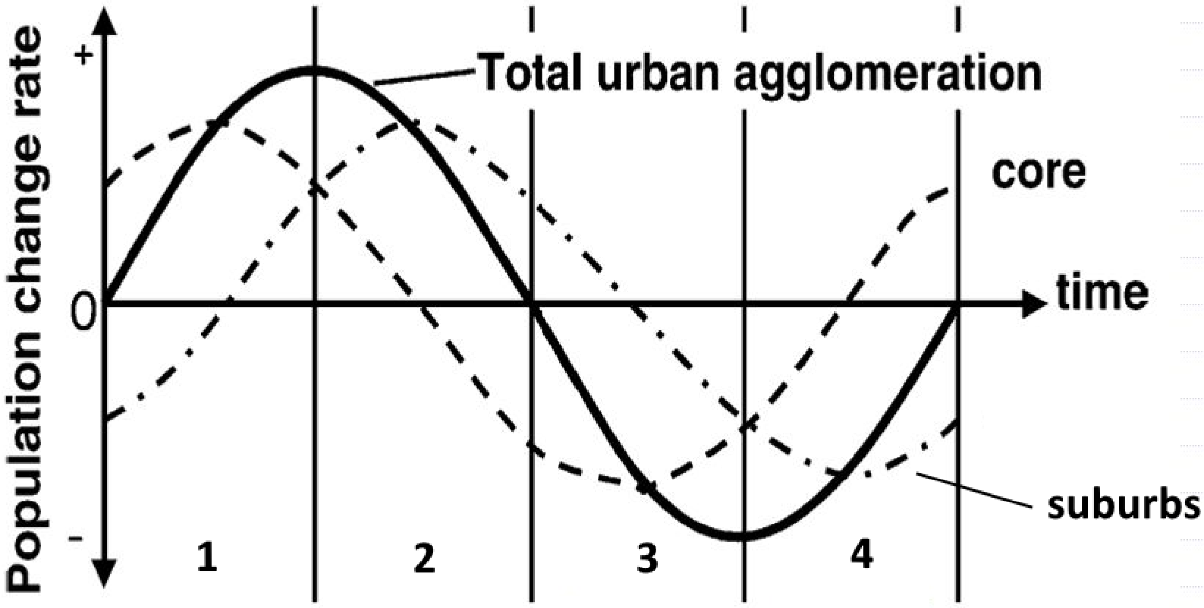

***Figure 1** Graph of the stages of urban development of cities, with population change rate on the vertical axis and time on the horizontal axis. Stage 1 is urbanization, stage 2 is sub-urbanization, stage 3 is counter-urbanization and stage 4 is re-urbanization (Van den Berg et al., 1982; Paddison, 2001)*

the cores become more popular, for instance by being gentrified. In the late 1970's this stage first was being observed in developed countries (MATTHIESSEN, 1980; Vining Jr & Kontuly, 1978). This was about 20 years after the first hypothetical models about the development of cities arose (Gibbs, 1963). This model included stages of urbanization, sub-urbanization and de-concentration, which coincides with counter-urbanization. Re-urbanization was not yet included in this model. Over the years the model was elaborated on and when the presence of a fourth stage was found in the late 1970s (MATTHIESSEN, 1980; Vining Jr & Kontuly, 1978) and Van den Berg et al. (1982) created his model of stages of urban development. This theoretical model was thoroughly tested and found to be observable in the development of cities (A. G. Champion, 1986; Clarke, 2017; Gnatiuk, 2017; Kabisch & Haase, 2011; Paddison, 2001).

The stages in the model are unidirectional and move continuously from stage 1 to 4, with no possibility to move back. In practice however, have some cities shown to be going back and forth between stages (Nefedova & Treivish, 2019).
The model furthermore describes the changes in density that follow these stages. The trends in population density in cores and suburbs would follow the same pattern as shown in figure 1. This is because cores and suburbs are assumed to be uniform and not expanding. For this reason, the trends of population density changes in the cores should, in practice, be least influenced by this as cores show the least urban expansion. Suburbs however, can have very large urban expansion and are therefore expected to be less accurately following the density changes in the stages of development model.

2.2 Population densities.

Population densities are believed to differ with distance to the so called central business district (CBD) (Carlino & Mills, 1987; Frenkel, 2002; Krause & Seidel, 2020). Cities are believed to follow the Alonso-Muth-Mills model (Alonso, 2013; Mills, 1967; Muth, 1969). Residence maximize their utility in this model by allocating their income by allocating income to housing and the consumption of a composite good. People in the model commute to the CBD with a certain transport cost. This model explains how, among others, population densities, housing prices and building heights decrease with distance to the CBD.

The level of population density, however also has to do with many other factors. People make trade-offs when deciding where to live. This is, as Carozzi & Roth (2020) describe it, the important trade-off of urban density between health benefits and environmental and productivity benefits. High urban densities are associated with many problems to human health (Gordon & Richardson, 1997). Larger numbers of people living close to each other are presumed to decrease air and water qualities, mostly by concentrated use of transportation (Carozzi & Roth, 2020). The urban heat island (UHI) effect is another problem of densification of urban areas (Li et al., 2020; Liu et al., 2020). This is the trapping of heat in urban areas, which causes increased urban temperatures. This results in (heat) stress and decreases air quality even further (Borck & Schrauth, 2021). Moreover are higher crime numbers associated with higher population densities (Jargowsky & Park, 2009). On the other side do, along with a lower demand for urban expansion, increased urban densities also have many positive externalities (Kahn, 2000; Habibi & Asadi, 2011). High population densities are associated with efficient energy and vehicle use, as efficient public transport and shareable cars are available and work is often close by (Jones & Kammen, 2014; Stone Jr et al., 2007). Furthermore are higher spill over effects (Knudsen et al., 2007), more innovations (Carlino et al., 2007), lower share of material stock that is absorbed in infrastructure (Schiller, 2007) and optimalization of (Glaeser & Kahn, 2004) considered products of high population densities. In areas with lower densities, negative externalities are less profound and mostly positive externalities are felt. When densities become higher, the negative effects start to outweigh the positive externalities (Lehmann, 2016). Initial densities are therefore believed to decrease densities in dense cities while they would increase densities in scarcely populated rural areas (G. Xu et al., 2019).

Many policies that effect population densities and its externalities are in place over the world. These policies can both be targeted to increase or decrease these densities, based on the desired results. Well-designed policies can cause the desired results, while less well-designed policies can have a negligible or even opposite effect (McConnell, 2010). Mustafa et al. (2018), hereby found that a badly designed urban planning policy, increased urban sprawl instead of reducing it. Claassens et al. (2020) contrarily found that a lack of policies caused densification. Policies can therefore have both a negative or positive effect on population density depending on the level of design and the intended result of the policy.

The trade-off is furthermore influenced by house prices. Housing prices are found to increase with population density (Alonso, 2013; Holmes et al., 2019; Kholodilin & Ulbricht, 2015). Higher densities are associated with limited land endowment, causing a restrained on higher supply of houses, thereby increasing the price. Using hedonic pricing method, urban amenities, which are more profound in higher densities were also found to add to the house price (Diamond & Tolley, 2013; Powe et al., 1995). These house prices cause many people to migrate to areas with lower house prices, causing an urban – rural movement (Antolin & Bover, 1997; Rabe & Taylor, 2012).

Whether to choose for an expensive house in cores or a cheaper house in rural areas is also influenced by travel time. As work is more abundant in cores, travel time to work is, in general lower in cores than in rural areas. Places with roads close by and in more abundance are therefore found to be popular and have higher densities (Mustafa et al., 2018; Tan et al., 2014; Zhang et al., 2013).

moreover is income believed to play a role in the trade-off. More income, is associated with more wellness, as larger gardens and more spacious houses and at the same time with living in dense urban cores as that of Amsterdam (Teye et al., 2017). That is why income is both seen to cause decreased densities and to decrease densities (Braby, 1989; Carlino & Mills, 1987; Krause & Seidel, 2020).

All these trade-off are based on preferences. Preference are different for everybody and can change over time (Birch, 1999; Hansson & Grüne-Yanoff, 2008; Meier & Sprenger, 2010). People have for instance been taking children at a later age and more people do not take children at all (Group, 2001). Retirement in rural areas is hereby postponed, which increases population in cities. Also has a shift to preferring more green in inner cities been observed, causing more demand for lower population densities (Kuo et al., 1998). How these preferences change over time will change what influence the previous factors will have on population densities.

Population density is however not only effected by variables that are dependent on preferences. Population growth is also a widely used determinant of population density changes. An increased population would need to stay somewhere, which is commonly in already urban areas. This effect is also seen in studies, where an increasing population is seen to increase population density (Carlino & Mills, 1987; Sridhar, 2007).

Furthermore is inequality observed to be related to population density. (Milanovic, 2018; H. Xu et al., 2015). Dense areas are found to have little inequality, while areas with low densities are found to have more inequality. These are local inequalities. When looking at inequalities in a country however the opposite is observed. Areas with high densities of poor people, as slums and favelas, are seen in countries with high levels of inequality (Lindsey, 2012; Milanovic, 2016).

Finally do expansion limitations also influence density changes. Countries with less room to expand have more incentive to expand inwards and increase population density. Available land would decrease with more national parks, mountains, water bodies and urban areas. Broitman & Koomen (2020) used available land for urban expansion in their research and found this relation, where population density decreases with available land to expand.

3. Methodology

This section will focus on the methodology that is used in the analysis of this study. It will be divided in three parts that will attempt to answer the four research questions. The first part will focus on the research question "How do density trends change in the last few decennia in cores, suburbs and rural areas and how do these influence global average density changes?". Average population densities in each urban hierarchy for each country will be calculated and compared to other research. The second part will focus on the research question "Can the stages of development model be applied to the urban development of countries?". Following theory of the stages of urban development model by Van der Berg et al. (1982), countries will be divided in stages. Spatial distribution and development of the stages will thereafter be studied. The third part of this research will focus on the research questions "Are densities found to follow density changes suggested by stages of urban development model?" and "What variables influence population density changes in cores, suburbs and rural areas around the world?". This is done with a regression analysis on the determinants of population density changes that differentiates between density changes in the cores, suburbs and rural areas on a global level.

This study will look at 189 countries and 4 study years; 1975, 1990, 2000 and 2015. Countries in this study have at least one core, suburb and rural area and are shown in appendix B.

3.1 Changes in density

The first part of this study will look at the trends in population density changes in the four study years. The results are split in urban hierarchies of cores, suburbs and rural areas in order to observe where changes occur and how these can be explained. Hypothesised is that time same trend as by Li et al. (2022) will be observed, where densities are believed to increase in cores and suburbs, but decrease in rural areas, leading to an overall decrease in density.

3.1.1 data manipulation

In order to be able to do this analysis, data needs to be manipulated. This chapter will dive deeper in on what data is used and what changes are made to make them useable in this study.

Foremost are the countries split on a basis of a country map that is used in the 2UP model of PBL (van Huijstee et al., 2018), which was provided by Jip Claassens. All countries globally are identified with their borders. Lakes and other large water bodies are however not included. To exclude water from the analysis, the GHS-SMOD is used (Pesaresi et al., 2019). This map classifies urban hierarchies on a basis of population density and separates waterbodies. As in this dataset urban hierarchies are already a function of population density, it cannot be used in this study's analysis. The separation on urban hierarchies is performed with the GHS-UCDB and GHS-FUA maps (Florczyk et al., 2019; Schiavina et al., 2019). These are datasets from the Global human settlement layer (GHSL) by the European commission and the joint research centre. As this study used many datasets of the GHSL, both these layers are chosen to be consistent with the data and reduce errors between datasets. GHS-UCDB (urban centre database), provides the spatial distribution of urban centres on a global scale and the GHS-FUA (functional urban area), provides the spatial distribution of functional urban areas globally. Functional urban areas are defined as "areas in which at least 15% of the population is commuting to the main urban centre of the area". These FUA include the urban centres from the GHS-UCDB, which were therefor excluded from the FUA to form the suburbs. Excluding the GHS-FUA from the country map, provides the rural areas.

The classification made in the GHS-UCDB and the GHS-FUA however, still exclude many areas that are cities, but are not classified as such. As there is no better alternative database and it is not feasible to define all cities manually, these areas will therefore be included in the rural areas in this study and may cause increased densities to be found in rural areas. Furthermore are the classifications based on urban centres and FUA from 2019, which differ from the urban hierarchies in the other study years. To compensate for this, only urban area of the corresponding year, as classified by GHS-BUILT (Corbane et al., 2018), that is inside the urban hierarchy will be used, which is the same method that the OECD has used to show expansion of urban hierarchies (Haščič & Mackie, 2018).

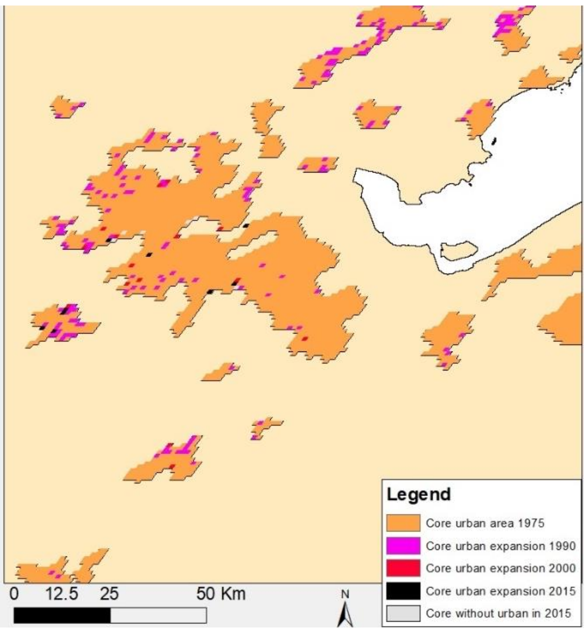

Figure 3.a *Example of changes in cores between 1975 and 2015 (western China)*

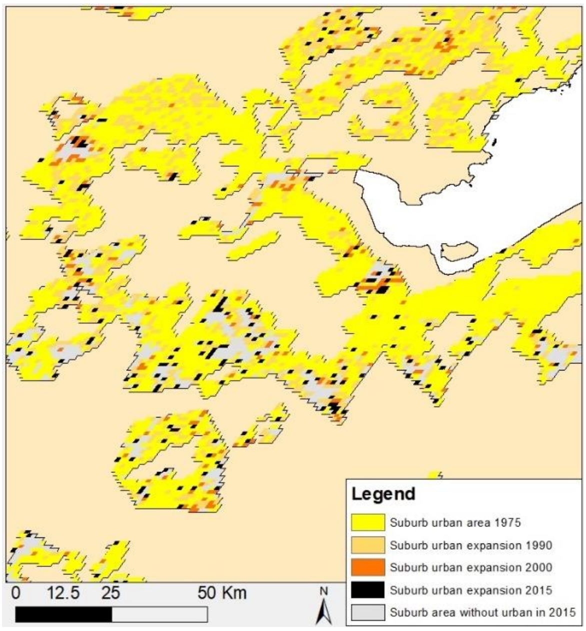

Figure 2.b *Example of changes in suburbs between 1975 and 2015 (western China)*

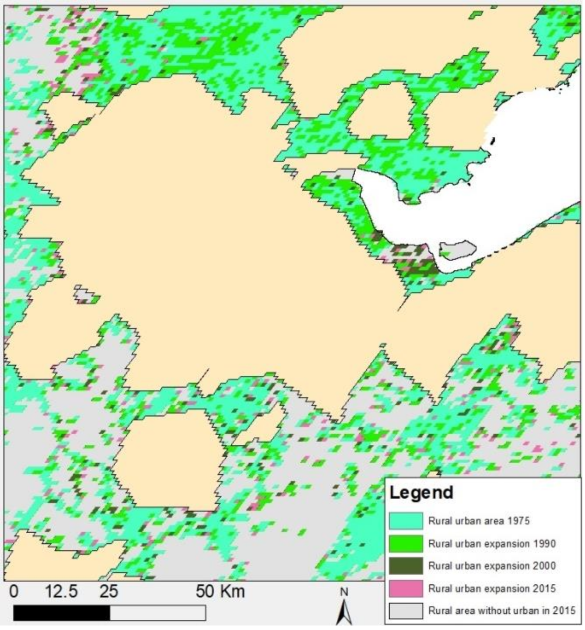

Figure 4.c *Example of changes in rural areas between 1975 and 2015 (western China)*

Although this will give a better indication of growth of cores than leaving them stationary, over time. What used to be considered suburbs, can be considered a core some time later (Ottensmann, 2022).

This results in a division of urban hierarchies over the study years as shown in figures 2.a, 2.b and 2.c for cores, suburbs and rural areas respectively.

Population density per km^2 from GHS-POP (European commission, 2015) are then split over all three urban hierarchies in the different study years, for all countries. These densities were then aggregated to obtain total population per urban hierarchy in each country and divided by the sum of pixels overall and per hierarchy to obtain average population density and average population density in cores, suburbs and rural areas.

3.1.2 Data evaluation

GHS-BUILT is considered to predict urban area decently well, compared to other global maps that predict the presence of urban area (Blei et al., 2018; Tripathy & Balakrishnan, 2021). However as of yet, still many inaccuracies persist, although the accuracy of the GHS-BUILT is observed to increase over time (Corbane et al., 2019). Inaccuracies mostly occur in rural areas, where in China low density areas were mostly underestimated (Liu et al., 2020) and in the USA both overestimations and underestimations were observed (Leyk et al., 2018). Denser areas, show more accurate result, but can still over- or underestimate by some margins from direct measurements (Leyk et al., 2018; Liu et al., 2020). Error in rural areas are commonly due to difficulties in observing urban areas with spatial data like heavy tree cover or buildings that use the same stones as the rocks they are built on.

GHS-POP likewise, seems to perform as one of the best estimates of population densities although it many inaccuracies persist (Archila Bustos et al., 2020; Calka & Bielecka, 2020). Unpopulated areas are accurately-, however occasionally, over-predicted (Archila Bustos et al., 2020) and on a local level, large differences occur between predictions and observations, which become significantly smaller when studying at national level (Calka & Bielecka, 2020). Just like the GHS-BUILT do some clear inaccuracies occur, where large parts of deserts or icecaps are identified as inhabited.

3.2 Stages of urban development

The second part of this study focusses on the stages of urban development as defined by Van den Berg et al. (1982). Preliminary research with the data showed that population changes had a very large impact on the results. Between 78 and 90 percent of all countries were found to be in stage 1 and only between 0 and 6 percent in stage 3. None of the countries were observed to be in stage 4. This results from large increases in population that cause population in most countries to increase in all three urban hierarchies. To account for this increase in population, changes in shares of population in each urban hierarchy are calculated for all study years. Total population of cores, suburbs and rural areas are divided by total population in each country to get these shares.

Table 1 shows how countries are separated in the Stages of urban development by changes in shares of population in the urban hierarchies. As rural areas are not included in the model, density changes in rural areas are left open in stages 2 and 4, rural densities can either increase or

***Table 1** Division in stages by changes of shares in cores, suburbs and rural areas.*

Stage	Share cores	Share suburbs	Share rural areas
1	+	+	-
2	-	+	
3	-	-	+
4	+	-	

decrease in these stages. Hereby development of the stages over time and space can be observed. Next, the development of individual countries can be observed by plotting the changes in shares of cores, suburbs and rural areas. This will show how shares of each urban hierarchy behave and will provide insights in the development of countries. Hypothesised is that the urban development of a country can be split in stages of the model, but that a country will be effected by the behaviour of individual cities. The development of many cities at the same time are influencing the urban development of a country, therefore can many different stages of development coexist in a country. Country development will show the dominant trend of these cities, which can shift as individual cities shift through stages. The behaviour of these individual cities however cannot be studied in this research as many of the cores of the GHS-UCDB, do not have a suburb ascribed to them yet by the GHS-FUA, which makes it impossible to show the urban development of individual cities in a country.

3.3 Regression

The third part of this study focusses on the determinants of population density changes on a global scale in cores, suburbs and rural areas. This will be done with a regression analysis. This is the most commonly used analysis in studies that want to test hypothesis and find correlations. The effect of a set of independent variables on the dependent variable is here tested. This effect can be shown by providing each variable with a T-value that results from the T-test. This provides the level of significance and determines whether variables present significant correlations. Values closer to 0 indicate higher p-values that will provide a higher probability that the null hypothesis is true and that the correlation occurred by chance. When a significance level of 95% ($p<0.05$) is reached, variables will be seen as significant and be included in the regression. The regression will also provide the coefficient of each variable. This shows how much the dependent variable changes with an increase in the dependent variable and the sign of this change. Finally will the adjusted R^2 be given, which indicates how much of the dependent variable can be explained with the set of independent variables. Ordinary least squares (OLS) is used to find the coefficient of the independent variables. OLS does this by minimization of the sum of squares of the differences between the dependent variable and the predicted coefficients of the independent variables. Stata will be used in performing these regressions. However before performing the regressions, there are multiple OLS assumptions that need to be tested prior to the analysis.

1. Linearity. Linearity should be tested as a non-linear relation would violate the equation used for regression analysis. This will be tested in Stata with the -Lowess- function to see if squared variables should be added to account for the non-linearity.
2. No Autocorrelation. Autocorrelation occurs when the error terms in the model are correlated. As data is taken from all countries, there is no reason to expect autocorrelation.
3. Normality. Normality assumes that the error term is normally distributed with a constant variance that does not depend on any of the independent variables. By doing a skewness and kurtosis normality test, normality is tested. As this test is dependent on sample size, the histogram with kernel density is observed to see the fit. When this assumption is violated

either the natural log of the variable will be taken.

4. Homoscedasticity. Homoscedasticity occurs when the distribution of the dependent variable is not constant as this could lead to less accurate results. This can visually be inspected to control if the distribution is constant.
5. No Multicollinearity. Multicollinearity occurs when 2 or more variables show a large correlation, this weakens results and makes unclear which variable has which effect. Primarily a Pearson correlation is applied to check this. When two variables have a significant relation and a Pearson coefficient above 0.5, the variables are will be regressed separately. Secondly, multicollinearity is controlled by variance inflation factors (vif), where values above 10 require more investigation in the variable.
6. No Endogeneity. Endogeneity can occur when an independent variable affects a dependent variable, while the dependent variable also affects the independent variable, creating a feedback loop between these two variables. Hereby is the independent variables correlated with the error term. an omitted variable that is correlated with the independent variable.
7. No large outliers. Large outliers are observations whose values deviate significantly from values of other observations. These large outliers can have a large effect on the results and should therefore be excluded. This is also controlled for visually by plotting the data.

3.3.1 Variables

In this study, 9 regressions will be conducted, for period between 1975 – 1990, 1990 – 2000 and 2000 – 2015, from here on period (1), (2) and (3) respectively in cores, suburbs and rural areas. Table 2 shows the variables that are used in this study, the dataset, the units and type of data. These are chosen as data is freely available on a country level or on a level that can be aggregated to a country level. Furthermore have correlations been found for most of these variables in earlier research, indicating that correlations are probable.

Table 2 *The variables studied, the dataset from which the data is used, the type of data and the units of the data.*

	Variables	Dataset	Type	Units
Dependent	Change in population density	GHS-POP	Raster (1km²)	Average yearly change in population/km²
Independent	Lagged population density	GHS-POP	Raster (1km²)	Average population / km²
	Population growth	GHS-POP	Number data	Yearly change in Population
	Lagged available land	GHS-BUILT	Raster (1km²)	km²
	Road density	GRIP4	Raster (1km²)	Average meters road / km²
	Lagged GDP per capita	Worldbank	Number data	Current USD
	Change in GDP per capita	Worldbank	Number data	Yearly change in current USD
	Gini-index	Worldbank	Number data	Gini-value
	Government effectiveness	Worldbank WGI	Number data	Rank

3.3.2 Dependent variable

Absolute change in population density

Absolute change in population density is the variable that will be tested in the regressions. Data from GHS-POP is used here that have been modified as is explained in 3.1.1. It is classified as the absolute change in average population density between study year *t* and study year *t-1*. The difference between the years will be divided by the amount of years difference in order to obtain these yearly changes. This results in the yearly absolute change in population density for cores, suburbs or rural areas per country.

3.3.3 Independent variables

Lagged/initial density

Lagged or initial density shows the population density per km^2 in study year t-1 and is also taken from the GHS-POP dataset. Following the stages of urban development model, initial population density should not be correlated with population density changes. As can be seen in figure 1, can any value of initial density cause both an increase or a decrease of population density change. Stages 1 and 2, and 3 and 4 can have the same densities, but have a complete opposite change. This will cause a random relation between initial density and density change and have no significant correlation. This variable will therefore test if population densities follow the population density trend that are described in the stages of urban development model.

If however, the initial density does not follow the Stages of urban development model, initial densities in cores are hypothesised to have a negative impact on population density change. As discussed in chapter 2, will negative externalities become more profound in higher density. As cores have the highest densities, this can cause a reduced demand for even higher densities. In both the suburbs and rural areas, densities will not be that high and are therefor hypothesised to increase densities changes as benefits will be more profound

Population growth

Population growth is given as the absolute change in population between study year *t* and study year *t-1* and is obtained from the GHS-POP database. Total population of the urban hierarchies is summed for each country to obtain the total population per country. The difference between the years will be divided by the amount of years difference in order to obtain these yearly changes. An increasing population is found, as described in chapter 2, to increase pressure on both inward and outward growth. It is therefore hypothesised that increasing population causes an increase in density changes.

Lagged available land

Lagged available land of a country is taken as *1 – u*, where *u* is the percentage of urban area over total area of a country, where lakes and other water bodies are excluded. These are obtained from the GHS-BUILT database. Protected areas and areas that are uninhabitable for other reasons are not included. As described in chapter 2 are countries with less space to expand believed to have more incentive to grow inwards and increase population density. Accordingly is lagged available land hypothesised to increase population densities in cores, suburbs and rural areas.

Road density

Road densities are obtained from the GRIP4 database (Meijer et al., 2018) and provides the average meters of road per km^2 per urban hierarchy. This database shows a high accuracy as 500 meters is the maximum error in positional accuracy. In this database the roads are differentiated in 5 types of roads that form a total of 21 million kilometres of roads. In this study, road density of all types of roads will be used and no distinction between them will be made. GRIP is widely used in studies, among which in studies for the 2UP model of PBL that estimates global city growth and changes in urban extent (van Huijstee et al., 2018). Although GRIP is the largest global road database with great accuracy, on a local scale, still many roads are missing (Poley et al., 2022). Despite that this missing data will have some effect on the results, does GRIP presents

the best current database on global roads. Road density is only available for the year 2018 however and therefor does not show changes in road density. This could have implications on the results on density changes that arise in earlier periods. These are not likely to be influenced by road densities in periods later.
However, as described in chapter 2, will more road accessibility make living more preferable. Thus, in suburbs and rural areas, road density is hypothesised to increase population density change. Contrarily, cores are places that people gather for work or for other utilities and more roads can only result in less living space. Consequently are roads in cores not expected to be correlated to population density in cores.

Lagged GDP per capita

Lagged GDP per capita shows the GDP per capita in study year *t-1* in current USD and is obtained from the World bank (World bank, 2022). This variable will test if population densities follow the population density trend that are described in the stages of urban development model. When following the assumption that GDP per capita, alongside time drives the stages of urban development, no a linear relation, but a polynomial relation with density change is expected. This relation would follow figure 1 which can be accomplished with using GDP, GDP^2 and GDP^3. In urban cores and suburbs, GDP is expected to have a positive sign, GDP^2 a negative and GDP^3 again a positive sign to follow the stages trend shown in figure 1. As Rural areas are not included in the model, no quadratic relations are hypothesised. Before these quadratics are used, OLS assumption for linearity will be inspected.
If GDP per capita would not follow the stages of urban development model, no clear hypothesis can be made as GDP is in some cases seen to increase densities, while in others to decrease densities as was discussed in chapter 2.

Change in GDP per capita

The change in GDP per capita in absolute values of USD will also be studied and is obtained from Worldbank data (World bank, 2022). Change in GDP per capita is given as the absolute change in GDP per capita between study year *t* and study year *t-1*. The difference between the years will be divided by the amount of years difference in order to obtain these yearly changes. Just as initial population density should a change in GDP per capita not result in a significant relation if GDP per capita indeed drives the stages of urban development. The transition between stages would cause errors in the results to arise. A large increase in change of GDP per capita could cause no density change while at the same time, when on a different place in the model, could cause a large increase or decrease.

Gini-index

Another way of economically differentiating of countries can be done with the Gini-index. The Gini-index shows the income distribution of a country with a Gini-coefficient between 0 and 100 and is obtained from World bank data (World bank, 2022). As discussed in chapter 2, indicate higher coefficients more inequality, which is are found to cause lower densities (Milanovic, 2018; H. Xu et al., 2015). Contrarily are densities hypothesised to increase with higher Gini-values. As discussed in chapter 2 are poor people in countries with much inequality are believed to live closer together. As these are much more poor people, overall densities are believed to increase. Because these changes are more visible in cities, this variable is hypothesised to have little influence in rural areas. In urban cores and suburbs, these differences are believed to be more profound and thereby expected to be shown.

Government effectiveness

Government effectiveness will provide a proxy for government policies and is provided by Worldbank WGI dataset (Worldbank, 2022) as a rank between 1 and 100. A higher rank is associated with a higher effectiveness of a government and better designed policies. Lower levels of government effectiveness therefor also represent less effective policies, as was discussed in chapter 2. Higher government effectiveness can still cause urban expansion, decreasing densities and cause more housing restrictions and increasing densities. It is therefore not clear whether government effectiveness will be have a significant relation with population density changes. Consequently can government effectiveness show a positive or a negative effect or no effect at all. As rural areas can expand even with restrictions and is not often subject to forced expansion, government effectiveness is not believed to influence density changes in rural areas. In suburbs and urban cores however, can policy decisions have an influence and is hypothesised that government effectiveness may have an influence.

4. Results

The methodology from the previous chapter was performed, which yielded the following results.

4.1 Changes in density

Population and urban extent were calculated for all countries. These results can be obtained by requesting the author. Population size for all countries differs from population estimates of the World bank (World bank, 2022). These differences can range from 20 percent positive to 20 percent negative.

Table 3 shows the average density per urban hierarchy in each study year.

***Table 3** Average population density in population per km² of all countries studied over all four study years and a split between cores, suburbs and rural areas*

Average global density per functionality				
	1975	1990	2000	2015
Cores	2950	3921	4554	5502
Suburbs	367	382	395	452
Rural	381	388	415	370
Global	619	660	687	674

Primarily can be observed that densities are highest and increase the most in cores. From 1975 till 2015 do densities here increase with an overall by almost 100%. Likewise do suburbs show increasing densities over the whole period, this increase however is a lot smaller than that in the cores. Densities in rural areas increases from 1975 till 2000, yet between 2000 and 2015 decreases again to a lower level than in 1975. Average rural densities are higher from 1975 – 2000 than those in the suburbs. Only in 2015 is the average density lower in rural areas than in the suburbs. Overall densities show the same trend as rural areas, where densities increase until 2000 and between 2000 and 2015 decrease again. This is however still an overall increase of 55 people per km^2 compared to 1975.

4.2 Stages of urban development on country level

Changes in shares of average population density per urban hierarchy were calculated and countries were divided in stages of development. Table 4 shows the amount of countries per stage of development.

It can be observed that during 1975 – 1990, most countries were showing an overall trend of either stage 1 or stage 2. During the period of 1990 – 2000, the overall trend of most countries changed to either stage 2 or 3. Moreover can be observed that in this period only very few countries showed an overall trend of stage 4. Finally, in the period between 2000 and 2015, almost no countries showed an overall trend of stage 3, but almost all countries were showing a trend of stage 1.

***Table 4** Amount of countries in each stage of development per study period*

Stage:	Count 1975 - 1990	Percentage	Count 1990 - 2000	Percentage	Count 2000 - 2015	Percentage
1	72	38.30%	38	20.21%	131	69.68%
2	63	33.51%	67	35.64%	38	20.21%
3	24	12.77%	77	40.96%	5	2.66%
4	29	15.43%	6	3.19%	14	7.45%

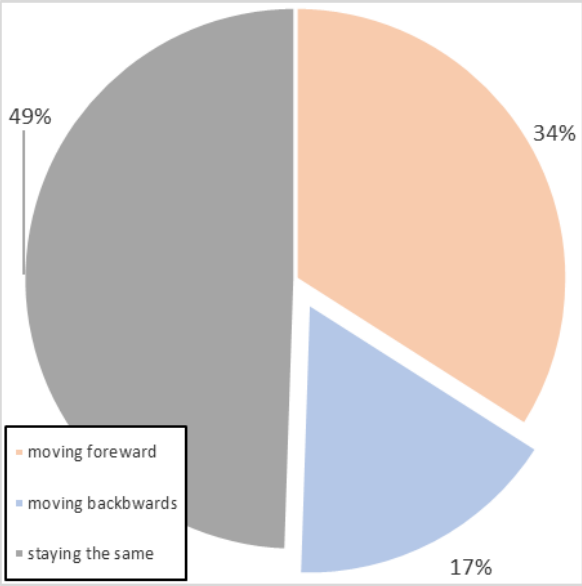

__Figure 5.a__ Shift in stages of urban development between period (1), 1975 - 1990 and period (2), 1990 - 2000

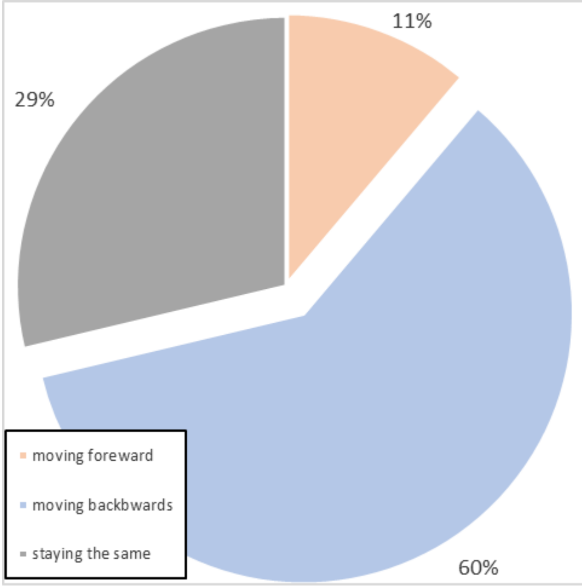

__Figure 3.b__ Shift in stages of urban development between period (2), 1990 - 2000 and period (3), 2000 - 2015

Figure 3.a, shows the changes in stages of urban development between period (1) and (2). and shows that almost half of the countries do not move between stage of development, while 34% of the countries show a forwards movement and 17% a backwards movement between stages.

Figure 3.b shows the changes in Stages of urban development between period (2) and (3). Many more countries move back in stage of development, than forewords or staying in the stage of urban development.

Figures 4.a, 4.b and 4.c show the distribution of Stages of urban development of countries over the world in each period. Every period shows a different distribution, with no clear patterns.

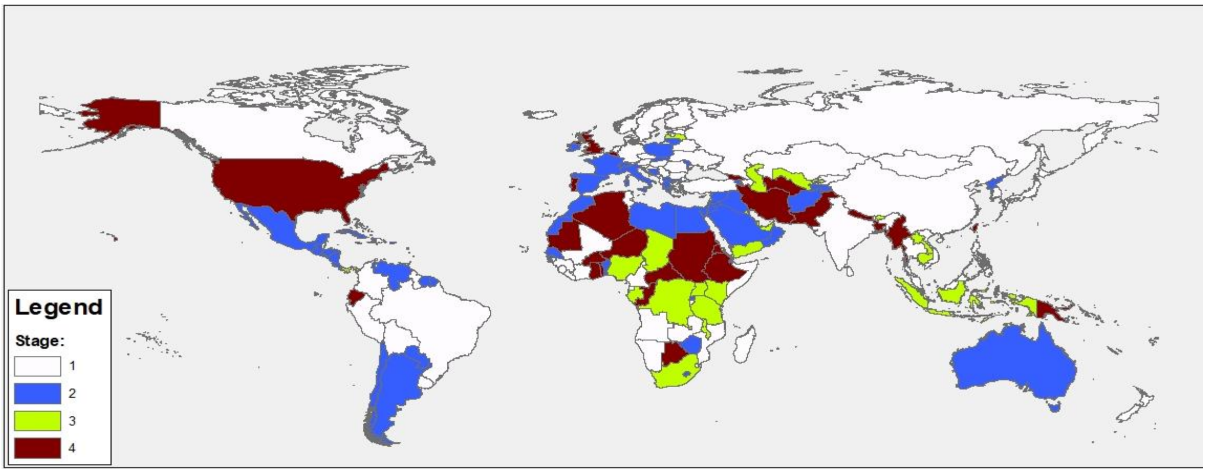

__Figure 4.a__ Spatial distribution of the stages of urban development in period (1), 1975 - 1990

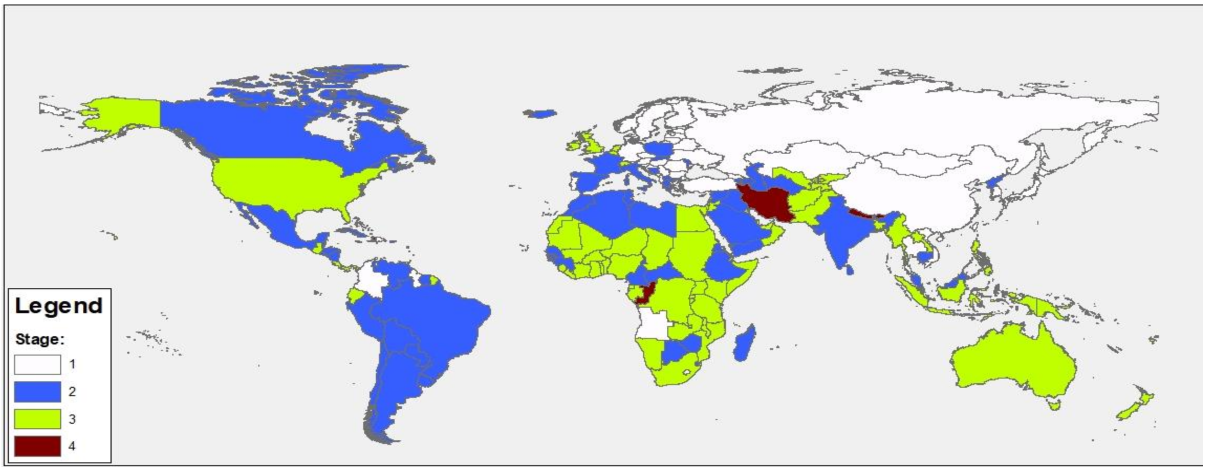

__Figure 4.b__ Spatial distribution of the stages of urban development in period (2), 1990 - 2000

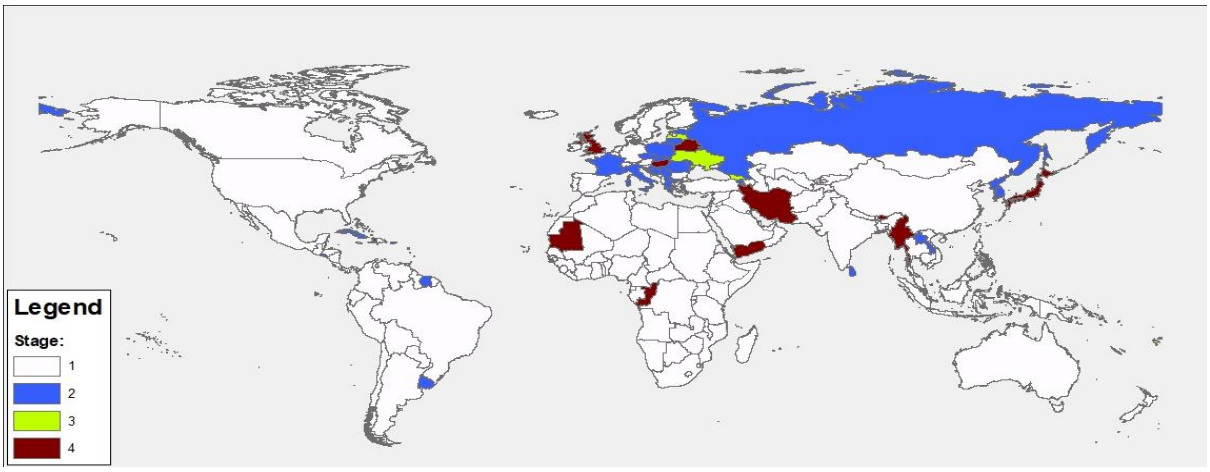

__Figure 4.c__ Spatial distribution of the stages of urban development in period (3), 2000 - 2015

Zooming in on country level, changes in shares of population in the urban hierarchies can show stages of urban development that countries are in, as shown in figures 5.a, 5.b, 5.c and 5.d.

In these figures, clear and continuous stages can be observed. Figure 5.a shows the development of China and shows it to be in stage 1 from 1975 till 2015. Shares in rural area decrease here, while shares in cores and suburbs increase. Figure 5.b illistrates the development from Malta in stage 2. Shares of cores decrease here, while shares of

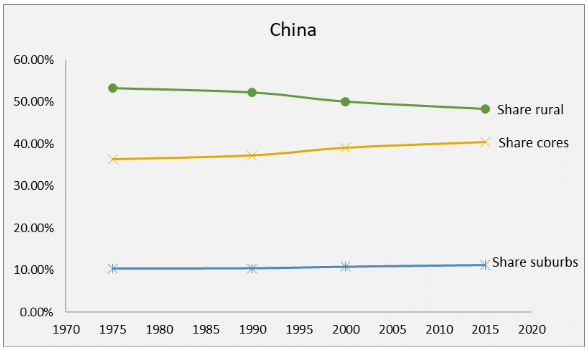

__Figure 5.a__ The development of China, which shows a dominant trend of stage 1 over all periods.

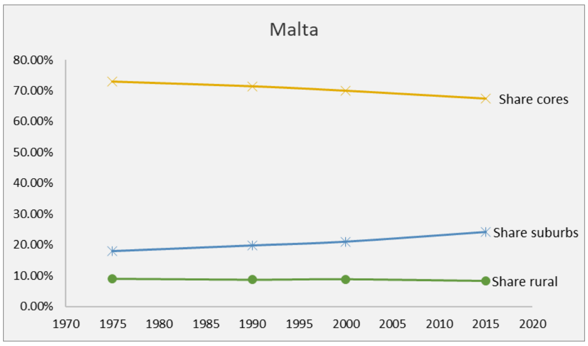

__Figure 5.b__ The development of Malta, which shows a dominant trend of stage 2 over all periods.

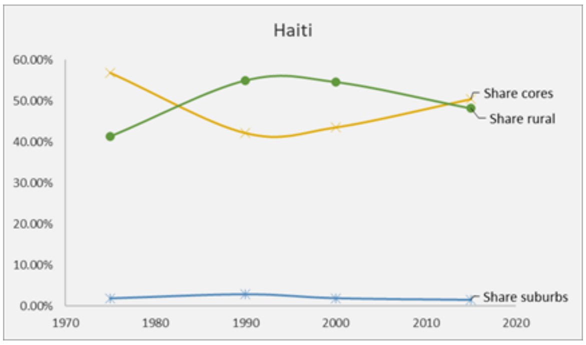

Figure 5.c *The development of Haiti, which shows the transition from a dominant trend of stage 3 to a dominant trend of stage 4.*

the suburbs increase. Figure 5.c, shows the transition from stage 3 to stage 4 in Haiti. Primarily do shares of cores decrease, while shares in rural areas increase, followed by a decrease of shares in rural areas and suburbs and an increase in cores. Figure 5.d finally shows Jersey in stage 4. Share of population in cores increases here, while suburbs and rural area decrease in shares.

Only a small amount of countries show these clear stages, these are mostly smaller countries with only one core and one suburb. Development of the major city of the country is therefore presented. Most of the countries instead present either no clear observable stages or many switches in dominant stage of urban development between the study periods.

4.3 Regression analysis

This chapter will provide the results from the regression analysis. Variables included are significant in at least one of the periods. Variables that are not included are therefore not significant in any of the periods.

Before the regression was run, OLS assumptions were inspected. This resulted in some alterations in the variables. Table 5 shows these alterations. Firstly, was linearity tested which found exponential relation between initial population density and change in population density in, cores and rural areas. Secondly, was a skewness and kurtosis normality test applied. This resulted in most of the variables to be altered to natural logarithms. Thirdly, did the Pearson correlation find a few variables that showed too much correlation to be included at the same time. The

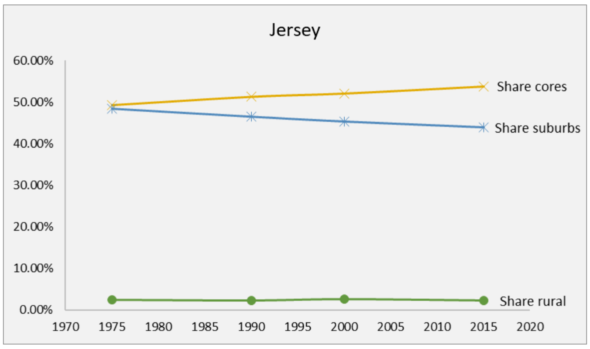

Figure 5.d *The development of Jersey, which shows a dominant trend of stage 4 over all periods.*

entire Pearson correlation can be found in appendix A. In order to make sure that initial population density variables are not correlated with their exponents, both variables have been transformed in an orthogonal polynomials. This alters the values of the set, but not their correlation, which will therefore only have effect on interpretation of the results. All regressions were examined by a ViF test, which showed no abnormalities. Finally, have a few large outliers been discarded. These are either war torn countries or very small countries. The countries that have been discarded can be found in appendix B.

Table 5 *The alterations to the variables to avoid violation of the OLS assumptions.*
**Lagged population density in suburbs will not be an orthogonal, as no quadratic relation is observed.*

Variable	ln	orthogonal
Change in ppulation density		
GDP per capita	●	
Lagged population density	●	●*
Gini-index		
Change in GDP per capita	●	
Road density	●	
Available land	●	
Government effectiveness		
Population growth		

With the no violations in OLS assumptions, the regression analysis could be run. Table 6 and 7 show, respectively, the results from the regression analysis for population density changes in the cores and the statistics of the variables of the regression.

Table 6 Results of the regression analysis for population density change in cores

	(1) 1975 - 1990	(2) 1990 - 2000	(3) 2000 - 2015
Initial density	37.51^{***} (0.000)	46.15^{***} (0.000)	55.27^{***} (0.000)
Initial density^2	8.260^{***} (0.000)	13.19^{***} (0.000)	24.48^{***} (0.000)
Population growth	9.981^{***} (0.000)	12.152^{***} (0.000)	30.959^{***} (0.000)
Government effectiveness	-0.107 (0.365)	0.102 (0.536)	-0.573^{***} (0.000)
constant	39.11^{***} (0.000)	20.87 (0.052)	66.01^{***} (0.000)
N	177	177	176
adj. R^2	0.679	0.716	0.846

p-values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7 Statistics of the variables from the regression analysis on population density changes in cores

Cores							
		Period (1) 1975 - 1990		Period (2) 1990 - 2000		Period (3) 2000 - 2015	
	Count	Min	Max	Min	Max	Min	Max
Initial density	187	-2.54187	3.2913	-2.564	3.3217	-2.5013	3.096565
Population growth	188	-0.18288	16.4939	-2.5736	11.7689	-0.5737	15.31281
Government effectiveness	178	0.480084	99.2266	0.48008	99.2266	0.48008	99.22659

From the statistics can the range of values of the variables be seen to have a better understanding of the coefficients of the regression analysis. Initial density is given as an orthogonal and is therefore ranged with an average of 0. From table 6 can be observed that initial density and population growth provide a significant correlation in all three periods. Government effectiveness only has a significant correlation in the period (3). Initial density shows an exponential correlation with a positive coefficient in all three years that increases over the periods. Population growth also has a significant correlation with a positive coefficient in an increasing amount over the periods. Government effectiveness however, is only significant in the period of (3) and does not show the same trend over all periods. In period (1) and (3) higher government effectiveness shows lower density changes, while in period (2) a positive effect is found. The periods show adjusted R^2 values of 0.679, 0.716 and 0.846 for periods (1), (2), (3) respectively.

Table 8 and 9 show, respectively, the results from the regression analysis for population density changes in the suburbs and the statistics of the variables of the regression.

Table 8 *The results from the regression analysis for population density change in suburbs*

	(1) 1975 - 1990	(2) 1990 - 2000	(3) 2000 - 2015
Initial density	4.649^{***}	3.931^{***}	6.446^{***}
	(0.000)	(0.001)	(0.000)
Population growth	0.973^{***}	0.581^{***}	5.247^{***}
	(0.000)	(0.001)	(0.000)
Gini-index	0.0458	0.127^{**}	0.0626
	(0.143)	(0.006)	(0.366)
Constant	-26.97^{***}	-25.38^{***}	-40.13^{***}
	(0.000)	(0.000)	(0.000)
N	82	80	84
adj. R^2	0.582	0.380	0.592

p-values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 9 *Statistics of the variables from the regression analysis on population density changes in suburbs*

Suburbs							
		Period (1) 1975 - 1990		Period (2) 1990 - 2000		Period (3) 2000 - 2015	
	Count	Min	Max	Min	Max	Min	Max
Initial density	184	4.411379	7.70925	4.69164	7.06887	5.15334	7.201495
Population growth	188	-0.18288	16.4939	-2.5736	11.7689	-0.5737	15.31281
Gini-index	84	22.9	61.3	23.8	62.75	25.5	63

From the statistics can the range of values of the variables be seen to have a better understanding of the coefficients of the regression analysis. Initial density is here not given as an orthogonal and therefor has a different range than in cores and rural areas.

For density changes in suburbs, initial density and population growth show a significant correlation with a positive coefficient for all periods. The Gini-index shows, for all periods a correlation with a positive coefficient, however only in period (2) a significant one. Both Initial density and population growth increase in period (3) compared to period (1), but period (2) shows lower values for both. In this period, the Gini-index however shows a higher coefficient. Overall values are lower than in the regression for cores. The periods show an adjusted R^2 values of 0.582, 0.380 and 0.592 for periods (1), (2), and (3) respectively. The adjusted R^2 values are lower than for the regression of population density in the cores.

Finally, do table 10 and 11 show, respectively, the results from the regression analysis for population density changes in the rural areas and the statistics of the variables of the regression.

From the statistics can the range of values of the variables be seen to have a better understanding of the coefficients of the regression analysis. Initial density is given as an orthogonal and is therefore ranged with an average of 0.

Population growth shows a significant correlation in period (1) and (2) with a positive coefficient,

Table 10 The results from the regression analysis for population density change in suburbs

	(1) 1975 - 1990	(2) 1990 - 2000	(3) 2000 - 2015
Population growth	1.549***	3.053***	-6.590
	(0.000)	(0.000)	(0.127)
Initial density	9.691***	16.53***	63.32***
	(0.000)	(0.000)	(0.000)
Initial density^2	3.205***	8.217***	25.43***
	(0.000)	(0.000)	(0.000)
GDP per capita	3.336***	7.036***	12.69**
	(0.000)	(0.000)	(0.009)
Constant	-26.78***	-59.24***	-137.6***
	(0.000)	(0.000)	(0.001)
N	171	174	174
adj. R^2	0.546	0.492	0.286

p-values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 11 Statistics of the variables from the regression analysis on population density changes in suburbs

Rural areas							
		Period (1) 1975 - 1990		Period (2) 1990 - 2000		Period (3) 2000 - 2015	
	Count	Min	Max	Min	Max	Min	Max
Initial density	188	-3.70864	3.25722	-2.1192	3.34073	-3.2185	3.067237
Population growth	188	-0.18288	16.4939	-2.5736	11.7689	-0.5737	15.31281
GDP per capita	175	3.555378	10.3177	3.82168	11.2816	4.79068	11.38709

but a non-significant correlation with a negative coefficient in period (3). Initial density shows a significant exponential correlation with a positive coefficient in all three periods. This coefficient increases in value over the periods. GDP per capita shows a significant correlation with a positive coefficient in all periods with an increasing coefficient over the periods. Adjusted R^2 values are 0.551, 0.388 and 0.335 for period (1), (2) and (3) respectively.

5. Discussion

The following chapter will elaborate on the results of the previous chapter and will put these results in to wider perspective. Furthermore will these results be compared to other researches and will the results be explained as far as possible.

Before this will we done however, it should be noted that these results are very dependent on the many assumptions and limitations in the data. As mentioned in chapter 3, are both the GHS-BUILT and GHS-POP associated with many inaccuracies that could have an effect on the results. Inaccuracies are seen in scarcely populated areas. Population densities were here occasionally overestimated even in areas with no inhabitants (Archila Bustos et al., 2020; Leyk et al., 2018). Denser areas are believed to be more accurately estimated, however occasionally also over- or underestimated (Leyk et al., 2018). These inaccuracies could have an effect on the results, by over or underestimating changes in densities. Furthermore have populations found to differ from those observed by the Worldbank (Nations, 2019), concurring that both over and underestimations in the data exist.

Results are moreover very dependent on the division of these urban hierarchies. Some cities can be classified as rural while some rural areas can be classified as suburbs. However, as Champion (2001) stated, has the boarder between urban and suburban become increasingly blurred. As table 3 showed, are densities in rural areas from 1975 till 2000 found to be lower than those in suburbs which is not was is found practice (Pozzi & Small, 2002). This could be because many urban areas are not classified as such and therefor included in rural areas. Further research should therefore been done in the division in urban hierarchies.

5.1 Changes in density

Hypothesised was that the same trends as Gao & O'Neill (2020) and Li et al. (2022) of a decreasing average density would be observed. Where as described by Li et al. (2022) densities would continue to increase in cities, but decrease in rural areas. The results of this paper, however show this trend to only occur from 2000 onwards. Cores continue to increase where average density almost doubled between 1975 and 2015. Densities in the suburbs also increases in all periods during the study years. Only rural densities show a decrease in densities between 2000 and 2015. This decrease caused average densities also to decrease slightly in this period. This is the same trend as was described by Li et al. (2022) and could be the start of the continuous decrease average densities that Gao & O'Neill (2020) predict. This trend could also be explained by countries transitioning to stages 1 or 4, where people move away from rural areas, while simultaneously spreading out in the rural areas. Countries, as shown in figure 4.c, indeed primarily show to be following stage 1, urbanization, where population moves to the cities. Why people would spread out could then be explained by an increased preference for more spacious housing and smaller household sizes as was observed by Williams (2009).

5.2 Stages of urban development on country level

In a theoretical view, stages are believed to move unidirectional. Kabisch & Haase (2011) already observed that more stages of urban development can exist at the same time, which disobeys this principle. Figures 3.a and 3.b show that many countries move back and forth in dominant stages of urban development. Countries can have a clear dominant strategy in one period and have a different one in the following period. Nefedova & Treivish (2019) and Baiping et al. (2004) also observed this in Russia and China where stages of urban development switched or were influenced by government decisions to move back and forth. Figures 5.a 5.b 5.c and 5.d show that some countries follow the stages of development, but that almost all of these are very small countries with only one core and one suburb. The rest of the countries showed no clear stages or switching stages throughout the periods. This shows that in larger countries with more cities and suburbs, cities can be in contradicting stages of urban development. Urban development on a country scale involves urban development of all cities in this country. Many cities in the same country can hereby be in different stages of urban development and thereby show little changes on a country level. Showing that countries do not per se develop as a whole and are only an aggregate of the development of individual cities. The stages of urban development model on a country level therefore also are not unidirectional, but multidirectional. Dependency on income changes is therefore also questionable as a switch back in dominant Stages of urban development occurs very commonly in figure 3.b, while income does not increase that commonly. Furthermore do figures 4.a 4.b and 4.c show no clear spatial relation between the stages of urban development. If income would drive the stages as was suggested by L. Li et al. (2003), differences between continents and between the global north and south was expected. This however does not show, stages do not follow a clear pattern especially throughout the years.

5.3 Determinants of urban population density

The results of the regression analysis concur with income not driving population density changes in the Stages of urban development. Hypothesised was, that GDP per would follow figure 1 in the cores and suburbs. However is GDP not found to have a significant relation with population density changes in both these urban hierarchies. This could be because both trends of increasing density and decreasing density that were found, are occurring (Braby, 1989; Carlino & Mills, 1987; Krause & Seidel, 2020), thereby causing no correlation. Another reason can be that GDP per capita has a negligible influence in cores and suburbs, but that it mostly causes density changes in rural areas, as is observed here. GDP per capita is here seen to cause an increase in density in all three periods. As GDP continues to increase, this would cause the opposite effect than that is observed in trends of density changes. This could however be explained by looking at countries with higher GDP per capita versus countries with lower GDP per capita. Countries with lower GDP per capita are overall more dependent on agriculture (World bank, 2020). People in rural areas of poorer countries therefore mostly live very far away from each other close to their agricultural land here. On the other hand will rural population in richer countries live more in rural villages that are more densely populated. This can explain why GDP per capita increases cause increases in population density changes. The coefficient of GDP per capita also increases each period, which indicates that GDP per capita drives density changes more each year.

Government effectiveness is found to have a negative relation in cores for periods (1) and (3), but a positive relation in period (2). In all these years, the coefficient is very low, which indicates that government effectiveness does not influence population density changes much. Only period (3) however has a significant correlation. This would indicates that more effective governance results in lower densities in cores between 2000 and 2015. This can be explained as highest densities occur in cores, policies here will most likely try to reduce negative effects of densities. Thereby having a negative effect on population density changes. Why the other two periods do not have a significant correlation could be because of poor data or because policies from 2000 onwards focussed on reducing densities in cores as negative effects of higher densities came more into political focus (Fu & Somerville, 2001). In suburbs and rural areas is government effectiveness not found to have an influence on population density changes. This follows the hypothesis on rural areas, but shows that policies are not resulting in one effect, policies can here be contradicting, with some increasing and others decreasing densities or the effects of policies can be negligible here.

Population density changes in suburbs are however found to be influenced by the Gini-index, although only for period (2). Higher Gini-coefficients are here found to increase population densities in suburbs in all periods. This indicates that more unequal income distribution in a country causes increases in densities changes in the suburbs. This was does not coincide with the results found by Xu et al. (2015) and Milanovic (2018), but was hypothesised. Countries with much inequality are commonly countries where slums or favelas are common in the suburbs (Conant, 1961). These are commonly places where people live in high densities. However, the Gini-index is not found to be significant in As the Gini-index of countries in not common, only an N of 77 or 76 is obtained, which could not be enough to find significant correlations in the other two periods. Likewise to government effectiveness could poor data effect the results. Cores and rural areas show no significant relation with the Gini-index. For rural areas, this follows the hypothesis, but shows that inequalities also have a negligible effect in cores.

Initial population density was hypothesised to have no effect on population density changes if it would follow the stages of urban development model. In all periods and in all urban hierarchies a significant correlation however was found. This provides evidence that population densities do not follow the stages of urban development model, indicates that density changes function entirely outside of the model. In cores, initial density has an exponential effect on population density changes. This indicates that countries with higher densities will have exponentially higher changes in population density. This was not hypothesised as more densely populated cores were expected to suffer from many of the negative externalities and drive people away from the cores, as is observed in densely populated cities (Guastella et al. 2019). The opposite however was found. This could be elucidated by the data. Average density over all cores in a country are taken, therefore have countries with very densely populated cores more cities that drive the average density down. When people move away from the most densely populated cities to cities with lower densities, together with the growth of these cities themselves will causing an amplified growth of cores in these regions. An exponential correlation with initial density is also seen in rural areas. This effect was hypothesised as primarily benefits from increased densities are obtained in rural areas. In both cores and rural areas, coefficients increase over the, indicating an amplified effect which would cause very large changes in population densities in coming periods. In suburbs, no exponential, but a linear correlation is found in all periods. Initial densities here also cause increased population densities. This was also hypothesised as mostly benefits are obtained from higher densities.

Population density is also found to be significantly correlated with population density changes in all urban hierarchies in all periods, except for period (3) in rural areas. All coefficients show, as was hypothesised a positive correlation, that increases over the periods, with a slight decrease in suburbs in period 2. Increasing population hereby shows an increase population density change which increases over time. Only period (3) for rural population density change is non-significant and negative. There is no real indicator why this could be the case. This could be the result of the massive dominant urbanization trend in this period, which decreased share population in the rural areas although population in the country as a whole increased. When we believe the trend of decreasing population densities in rural areas will continue, population growth might become significant with a negative coefficient in coming periods.

Available land, road density and change in GDP per capita both did not have a significant correlation in any of the urban hierarchies and any of the periods. Available land might not be significant as many more factors than only urban area and waterbodies are influencing this. Protected areas, areas with large slopes and mountainous areas have an influence too and might cause available land to not represent the true available land of a country. Road density is a non-changing factor, which is probably the reason no correlation was found. When new roads are added, this was found to have an effect on density by, among others, Lavinson (2008) and Meng & Han (2018), yet this is not observable in the variable as is used now. Yearly changes in road density however, are not available however at a global level. Change in GDP also does not show a significant correlation in any of the regressions. This indicates that GDP is not driven by changes in GDP and that the correlation with GDP that is found in rural areas purely a split between poorer and richer countries.

6. Conclusion

Changes in densities have many effects on human health, productivity and nature. Understanding what influences these changes and how they develop over time is of detrimental importance in predicting changes in densities in the future and its implications. Densities are believed to decrease in the coming years and cause increased pressure on urban expansion (Gao & O'Neill, 2020; Williams, 2009). Between 1975 and 2000, densities were observed to increase in cores, suburbs and rural areas, leading to an increased global average density. Between 2000 and 2015 population densities in cores and suburbs continued to increase, but rural areas were decreasing in density. This decreased also caused average global density to decrease compared to the period before. This could mark the start of decreasing average densities over the coming decades. It could also be explained by a global urbanization trend where shares of people in cities increases, while at the same time people decide to live more spacious.

Furthermore is the stages of urban development model tested on a the urban development of a country. Urban development is shown to be the sum of individual cities in a country that can be at different stages of urban development and therefore does not follow the stages of urban development model. Urban development of a country is not unidirectional and can switch from dominant strategy each period with no clear pattern. How cities interact with each other in urban development could shed a light on the urban development of a country.

Densities changes described in the stages of urban development model do not show the structural form that is described in the model. Densities in all cores, suburbs and rural areas are found to be driven by initial density and population growth, in increasing amounts over the periods. Moreover are in rural areas density changes found to be influenced by GDP per capita. Higher GDP per capita is here associated with higher increases in densities. Density changes in cores are furthermore showed a correlation with government effectiveness. This relation however is only found in one period and the sign of the coefficient changes over the years. Before firm conclusions can be made, more research is needed. The same is true for the correlation found in the suburbs with the Gini-index that is only significant in one period, but shows an increase in densities with more income inequality.

Finally are changes in GDP per capita, road density and available land not found to be influencing density changes.

This is an exploratory study into the urban development of countries and the global determinants of population density changes split with a division in cores, suburbs and rural areas. Much more research on these topics could be done in order to get a better understanding of global trends and development of countries.

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8. Appendix

A. Pearson correlation

A.1 period (1) 1975 - 1990

	Government	GDP per capita	Rural road density	Core road density	Suburbs road density	Available land
Government	1					
GDP per capita	0.728***	1				
Rural road density	0.457***	0.279***	1			
Core road density	0.380***	0.325***	0.470***	1		
Suburbs road density	0.281***	0.207**	0.618***	0.820***	1	
Available land	-0.437***	-0.292***	-0.607***	-0.267***	-0.313***	1
Change in GDP per capita	0.436***	0.0961	0.318***	0.305***	0.282***	-0.301***
Population growth	-0.335***	-0.233**	-0.362***	-0.172*	-0.219**	0.287***
Initial density cores	-0.389***	-0.422***	-0.0728	-0.0217	-0.0294	0.0943
Initial density rural	-0.626***	-0.714***	-0.192*	-0.238**	-0.177*	0.332***
Initial density suburbs	-0.193*	-0.253**	0.0781	-0.0526	-0.00617	0.0188

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

	Change in GDP per capita	Population growth	Initial density cores	Initial density rural	Initial density suburbs
Change in GDP per capita	1				
Population growth	-0.192*	1			
Initial density cores	-0.0679	-0.137	1		
Initial density rural	-0.175*	0.325***	0.476***	1	
Initial density suburbs	-0.0212	-0.0673	0.342***	0.346***	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A.2 period (2) 1990 - 2000

	Government	GDP per capita	Rural road density	Core road density	Suburbs road density	Available land
Government	1					
GDP per capita	0.825***	1				
Rural road density	0.442***	0.367***	1			
Core road density	0.371***	0.392***	0.471***	1		
Suburbs road density	0.288***	0.283***	0.625***	0.833***	1	
Available land	-0.431***	-0.379***	-0.604***	-0.265**	-0.312***	1
Change in GDP per capita	0.646***	0.666***	0.383***	0.298***	0.238**	-0.394***
Population growth	-0.458***	-0.415***	-0.394***	-0.192*	-0.216**	0.274***

Initial density cores	-0.492***	-0.510***	-0.162	-0.0723	-0.0810	0.160
Initial density rural	-0.654***	-0.714***	-0.230**	-0.269**	-0.205*	0.286***
Initial density suburbs	-0.269**	-0.352***	0.0718	-0.137	-0.123	0.0454

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

	Change in GDP per capita	Population growth	Initial density cores	Initial density rural	Initial density suburbs
Change in GDP per capita	1				
Population growth	-0.192*	1			
Initial density cores	-0.360***	0.213*	1		
Initial density rural	-0.459***	0.623***	0.578***	1	
Initial density suburbs	-0.324***	-0.0222	0.267**	0.446***	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A.3 period (3) 2000 - 2015

	Government	GDP per capita	Rural road density	Core road density	Suburbs road density	Available land
Government	1					

GDP per capita	0.859^{***}	1				
Rural road density	0.457^{***}	0.426^{***}	1			
Core road density	0.380^{***}	0.444^{***}	0.470^{***}	1		
Suburbs road density	0.281^{***}	0.329^{***}	0.618^{***}	0.820^{***}	1	
Available land	-0.442^{***}	-0.414^{***}	-0.614^{***}	-0.279^{***}	-0.323^{***}	1
Change in GDP per capita	0.715^{***}	0.752^{***}	0.316^{***}	0.341^{***}	0.251^{**}	-0.337^{***}
Population growth	-0.165^{*}	-0.0837	-0.250^{**}	-0.0568	-0.0866	0.124
Initial density cores	-0.602^{***}	-0.610^{***}	-0.315^{***}	-0.148	-0.130	0.253^{**}
Initial density rural	-0.0658	-0.0674	-0.100	-0.148	-0.189^{*}	0.00181
Initial density suburbs	-0.510^{***}	-0.522^{***}	-0.160^{*}	-0.323^{***}	-0.222^{**}	0.189^{*}

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

	Change in GDP per capita	Population growth	Initial density cores	Initial density rural	Initial density suburbs
Change in GDP per capita	1				

Population growth	0.0715	1			
Initial density cores	-0.464***	0.357***	1		
Initial density rural	-0.0107	0.0707	0.0227	1	
Initial density suburbs	-0.543***	0.239**	0.451***	0.135	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

B. Countries

Afghanistan
Angola
Algeria
Albanië
Argentina
Armenia
Australia
Austria
Azerbaijan
Bahamas
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Belize
Benin – excluded from suburbs in period (2)
Bhutan – excluded in period (3) for cores and all periods in suburbs
Bolivia
Bosnia and Herzegovina
Botswana
Brazil
Brunei
Bulgaria
Burkina Faso – excluded from rural areas in period (1)
Burundi
Cambodia
Cameroon
Canada
Cape Verde
Caspian Sea
Central African Republic
Chad
Chile
China
Colombia
Comoros
Costa Rica

Côte d'Ivoire
Croatia
Cuba
Curaçao
Cyprus
Czech Republic
Democratic Republic of the Congo
Denmark
Djibouti
Dominican Republic
East Timor
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea – excluded from suburbs and rural areas in period (1)
Estonia
Ethiopia – excluded from suburbs and rural areas in period (1)
Fiji
Finland
France
French Guiana
French Polynesia – excluded from suburbs in all periods
Gabon
Gambia
Georgia
Germany
Ghana
Gibraltar – excluded in cores and suburbs in all periods and rural areas in periods (1) and (2)
Greece
Guadeloupe
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
Hong Kong
Hungary
Iceland
India
Indonesia
Iran – excluded from suburbs in periods (1) and (2)
Iraq
Ireland
Israel – excluded from suburbs in period (2)
Italy
Jamaica – excluded from suburbs in period (2)
Japan
Jersey
Jordan
Kazakhstan
Kenya
Kuwait

Kyrgyzstan
Laos
Latvia – excluded from suburbs in period (2)
Lebanon
Lesotho
Liberia
Libya
Lithuania – excluded from suburbs in period (2)
Luxembourg
Macao
Macedonia
Madagascar
Malawi
Malaysia
Mali
Malta
Martinique
Mauritania
Mauritius
Mayotte
Mexico
Moldova
Monaco – excluded from suburbs in all periods and rural areas in period (2)
Mongolia
Montenegro
Morocco
Mozambique
Myanmar – excluded from suburbs in periods (1) and (2)
Namibia
Nepal
Netherlands
New Caledonia
New Zealand
Nicaragua
Niger
Nigeria
North Korea
Norway
Oman
Pakistan
Palestina
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Puerto Rico
Qatar
Republic of Congo – excluded in all periods in suburbs
Reunion
Romania
Russia

Rwanda
Sao Tome and Principe – excluded in cores in all periods and suburbs in period (2)
Saudi Arabia
Senegal
Serbia
Sierra Leone
Singapore
Slovakia
Slovenia
Solomon Islands
Somalia
South Africa
South Korea
Spain
Sri Lanka
Sudan
Suriname
Swaziland
Sweden
Switzerland
Syria
Taiwan
Tajikistan
Tanzania – excluded from suburbs in period (2)
Thailand
Togo
Trinidad and Tobago
Tunisia
Turkey
Turkmenistan
Uganda
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Uzbekistan
Venezuela
Vietnam
Western Sahara
Yemen
Zambia
Zimbabwe