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Border regions across the globe: Analyzing border typologies, economic and political disparities, and development dynamics

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ABSTRACT

The cosmopolitan dream of a borderless world has little to do with reality. Today's borders bear witness to regulatory intervention in the circulation of goods, information, capital and people. These interventions, naturally, have an impact at border regions. For analyzing these impacts, we map, quantify and relate border typologies, development dynamics near borders, and economic and political indicators of neighboring nation-states. We do so on global scale for all current 315 land borders. We rely on data from a mix of border dossiers, in-depth literature review, censuses and multi-temporal mapping products from satellite imagery. Our analysis strategy is two-fold: First, in a descriptive analysis, we map the various border typologies. And, we also compute development dynamics over a 15-year period from 2000 to 2015. Since there are few consistent, appropriately spatially resolved, and globally available datasets, we measure development by the proxies 'settlements' and 'population' instead of the usual economic characteristics. We use an ensemble of metrics that show not only the developments in the border region but also the dynamics in the border region relative to the respective nation-state. By means of a global ranking, we show the variability of development dynamics at borders across the globe. Second, we relate these dynamics to the different border typologies, and to economic and political differences of neighboring nation-states. We find the following trends: higher political or economic differences of neighboring nation-states relate to stronger border fortification, greater economic or political disparities relate to stronger population or settlement accumulation at the poorer or less free side of the border, and stronger fortification hinders settlement and population development to a certain degree. These empirically measured trends, however, are only partially statistically significant and not as strong or unambiguous as assumed. In a critical discussion, we reflect on the capabilities and limitations of such an empirical global approach.

1. Introduction

From space, astronauts see our beautiful blue planet in its entirety. They observe the distribution of land as a borderless picture. In contrast, the most common cartographic representation of our world divides land into distinct territories of nation-states. These borders demarcate jurisdictional territorial units, but they also testify to political, economic, social, cultural, religious differences in space (Popescu, 2012). This striking juxtaposition naturally leads to the questions of how and to what extent developments are influenced by these borders and, vice versa, how border typologies are defined by these developments, and if so, what the effects are near these borders.

In this paper, we approach these questions in a global approach and embed them in the sense of an existing dialectic related to borders between nation-states: On the one hand, the 21st century hallmarks of globalization (Beck, 1997), cosmopolitanism and networked individualism (Wellman, 2001), networked people, communities and cities (Sassen, 2002), mobilities (Urry, 1999) and flows (Castells, 2000) reveal an increasingly interconnected, and perhaps in this sense increasingly uninterrupted, borderless world beyond territorial units of seemingly less importance. Some have predicted that we are moving into the direction of a "borderless world" (Ohmae, 1990) and that borders have effectively lost their function, not at least due to the fact that the global flow of capital, finance, goods, services, people, ideas, and cultures was

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a common argument for economic growth (e.g. Friedmann, 2006; Moore, 2003). With the internationally celebrated fall of the Berlin Wall and the Schengen Agreement abolishing stationary border controls at the EU's internal borders, all of this seemed to herald an era of open borders, i.e. the abolition, dissolution and crossing of borders (Kamwela & van Bergeijk, 2020). On the other hand, exactly this expectation of falling borders or even a borderless world has not materialized. A larger strand of border research has argued that though globalization indeed impacted on cross-border flows, it did neither abandon borders nor make all cross-border transactions possible. Moreover, most scholars agree that borders are still powerful institutions of demarcation and separation, in some sense, borders have even gained importance through heightened cross-borders flows and the interest of states in exercising control (e.g. Mau, 2021; Newman, 2006; Paasi, 2019). States have reacted to increased human mobility, economic interdependence and perceived external challenges by heavily investing in border infrastructure and border technology (e.g. Dijstelbloem, 2021; Simmons, 2019). A world without borders, as Haselsberger (2014) argues, is a utopia: Territory cannot be managed if it is not clearly delimited. It is claimed that a "border orientation" has become a salient feature in international politics and that states heavily invest in infrastructure to "secure" their borders and to control movement across borders, even into fences and walls (Simmons & Kenwick, 2021; Vallet, 2016). And, according to Stiglitz, J., 2017, the positive effects of econometric expectations in globalization have also been overestimated: Trickle-down economics assumed to ensure that everyone benefits when GDP increases were overestimated, and the costs, including negative distributional effects, were underestimated. It resulted in the opposite of 'borderless': more than 50 new walls between nation-states have been built in the last 30 years (Bissonnette and Vallet, 2020; Vernon & Zimmermann, 2019). These borders are there to separate the 'inside' from the 'outside', between 'us' and 'them' (Brown, 2010). That means in addition to the dissolution of borders, a simultaneous trend towards closure, border selection and control in various border typologies exists (Mau, 2021).

In this paper, we investigate what this dialectic indirectly implies: Borders have in their differences, different implications – on many levels such as political, economic, demographic, jurisdictional, to name just a few. Since we conduct our investigation on a global level, we obviously cannot consider all levels. Here, we focus the empirical investigation to the following: we assume that border typologies, economic and political situations between neighboring nation-states, and the development of settlements and population in borders regions relate with measurable effect to each other.

Such dependencies and relations have been at the focus in manifold research studies in domains such as border rules (e.g. Simmons, 2019), border security and control (e.g. Simmons & Kenwick, 2021), customs and trade (e.g. Carter & Poast, 2020) or migration and immigration (e.g. Mau et al., 2015). Kamwela and van Bergeijk (2020), e.g., investigated economic effects of physical border walls. For nation-states separated by a wall, on average 46 to 73 percent less trade has been measured than it would ceteris paribus be the case if the border wall did not exist. Other studies, e.g. on migration, measure, contrary to expectations, that fortified borders even lead to an increase of immigration flows (Pécoud & de Guchteneire, 2006; Schon & Leblang, 2021), but it is also apparent that "hard" borders increase cross-border selectivity (Mau, 2021; Korte, 2021). Beyond this, there are studies investigating environmental effects of borders. For example, Trouwborst et al. (2016) or Linnell et al. (2016) document how borders cut up connected natural environments and affect habitats negatively. The cited studies investigated the impact of heavily fortified borders. A gradation of border types across this dichotomy between heavily fortified and open border, however, has not yet been considered.

The cited studies are focused on selected individual or few border regions. We are not aware of any studies on a global scale on effects related explicitly to the vicinities of borders. This is primarily due to inconsistent or missing comprehensive data sets on economics, migration or other relevant topics at the spatial scale of border regions across the world. The capability to spatially investigate the developments in the vicinity of borders regardless of administrative or other large reference units is challenging. Earth observation (EO) from space is currently the only data source allowing for a consistent, global analysis at these spatial scales. But still, a global analysis in this field of research is unknown. However, since economic (e.g. Chen & Norhaus, 2019) or demographic (Sapena et al., 2022) information can only be derived indirectly from EO-data, the focus in existing studies is on proxies. For example, Bennett and Faxon (2021) used nighttime light emissions as proxy for development along the fortified border of Myanmar revealing significantly lower light emissions than in the nation-state as a whole or in the border regions of neighboring nation-states. Kolosov et al. (2018) used remotely sensed information on road networks, land use and density of settlements as geographical attributes to visualize that the difference in urban development is greater at Russian borders that were also part of the Soviet Union than at post-Soviet borders. Röder et al. (2015) documented urban development on the Namibian-Angolan border based on multi-temporal land cover classifications. By and large, these studies remain limited to the specific situation at transitions between two nation-states at regional level. At a continental level, Taubenböck et al. (2017) mapped the interconnected settlement areas of Europe across open borders using EO-data. They showed how the proxy 'settlement density' reflects economically interconnected spaces, such as the so called 'Blue Banana' crossing many European borders. Stephenne et al. (2009) developed a border permeability model for the EU-25 and Central African land borders based on accessibility, hiding opportunities and probability of arrest by border police using a variation of EO-data, statistical databases and surveys.

However, to the best of our knowledge, assessing developments at border regions based on EO-data and derivatives such as settlements or population in combination with other data sets such as a differentiated categorization of border typologies as well as economic of political data sets has not been systematically investigated at global scale.

The remainder of the work is structured as follows: Section 2 briefly presents the conceptualization of this study. Section 3 introduces the empirical set-up, i.e. the data, the spatial concepts and methods. In section 4 the results on border typologies, rankings of settlement and population dynamics at border regions across the world are presented. Furthermore, relationships of various border typologies, economic and political differences of neighboring nation-states to settlement and population dynamics are illustrated. This is followed by a discussion in section 5, where we try to evaluate which influence determinants have on border developments and we discuss the limitations of our data, conceptual assumptions, and the related main results. Section 6 concludes with a perspective.

2. Conceptualization of this study

In this study, we investigate border regions at global scale. Unlike existing studies, our analysis is performed on all 315 current international land borders of nation-states and takes account of the two-sidedness of borders. i.e. their dyadic nature.

As basis for the investigation, we, on the one hand, record and map border typologies for all land borders. On the other hand, we compile a set of economic, political, physical and demographic indicators that are globally available and which describe the nation-states or the particular border regions: the gross development product (GDP) per capita and types of political regimes for the year 2017; the settlements and the population development dynamics for a time period of 15 years.

In the analysis, we approach border regions first through a descriptive study of border typologies and development dynamics (1), and second, we investigate relationships between the economic and political indicators, border typologies, and the settlement and demographic dynamics (2).

(1) We basically document, map and quantify the *variability of border typologies* for the current time step (cross-sectionally), as well as *settlement and population development dynamics* over 15 years in a descriptive analysis.

Conceptually, we equate higher growth rates over time with stronger development. Development is typically measured by economic indicators (e.g. Shashoua et al., 2015) or in border regions often by quantities of border crossings (e.g. Hodges, 2007) or movement of goods (e.g. Carter & Poast, 2020). However, economic analyses are on the one hand mostly based on data at administrative spatial units, i.e. data are aggregated to heterogeneous spatial reference units and therefore they are not always appropriate for comparison due to differences in size and form (e.g. Openshaw, 1984). And on the other hand, these data are often only inconsistently or not available everywhere for a global study. As studies have shown that there are positive declining correlations between settlement area growth/urbanization and GDP per capita (e.g. World development indicators, 2005), we understand in this paper the variables *settlements* and *population* as proxies for development. We do so, as these data sets have been derived in comparatively high spatial resolution from remotely sensed and census data at global level. That means, these two variables allow us to spatially define the vicinity to border areas independently from any administrative unit and thus it is possible to create a uniform, consistent and thus comparable spatial reference unit near borders.

(2) For the investigation of relationships between the selected indicators, we follow two guiding hypotheses:

a) Borders separating the territories of nation-states from each other come with different typologies. We hypothesize that the way in which borders between nation-states are physically built and crossings managed – among other historical and geopolitical factors – are a direct result of political or economic disparities between neighboring nation-states. We formulate as guiding hypotheses: The higher the political or economic differences between neighboring nation-states, the stronger the border fortification, while not excluding that fortifications in place may strengthen existing differences. To put this homology assumption differently: The smaller the disparities are in economic and political terms, the less likely walled borders and strong fences should be in place.

b) Developments in settlement and population vary in the vicinity of borders and we assume the greater the economic and political disparities between neighboring states, the greater are differences in growth rates. And, we specifically assume that in the case of neighboring nation-states separated by heavily fortified borders and with extreme differences in political and economic systems, a strong pull effect leads to accumulation effects on the poorer or more unfree side of the border. This relates to the fact, that fortified borders are in most cases built only by one state and are associated with gaps in wealth and political disparities so that the function is to deter unwanted cross-border transactions and movements. Accumulation on the poorer and more unfree side would indicate a retention or magnet effect of strong border barriers.

3. Empirical set-up

3.1. Data basis

3.1.1. Typologies of borders

Borders feature a wider variety of forms than the often-used dichotomic classification of 'open' and 'closed'. They may be partially physically non-existent, unguarded and crossed completely without control, but they may also be fortified and allow passage only under certain conditions for certain groups. In this study, we rely on a categorical classification of five different border types.

In general, we understand border types according to their physical-material design and the associated possibility of crossing the border. We apply a typology which is based on various data: 1) on *border dossiers*, which were compiled for all nation-states and their borders between April 2018 and October 2019. The border dossiers contain information on the physical-material layout of borders collected through an in-depth literature review, i.e. digital repositories (e.g., Scopus) and online searches; 2) *satellite imagery* of georeferenced border crossings were queried for a visual check; 3) *existing studies* have been reviewed to compare our coding (cf. Avdan, 2019; Carter & Poast, 2017; Gülzau & Mau, 2021; Hassner & Wittenberg, 2015; Jellissen & Gottheil, 2013; Jones, 2012; Simmons & Kenwick, 2021).

The typology is conceptualized in five different types of borders.

1) *Frontier borders*: borders with no infrastructure or only rudimentary infrastructure. These no-man's-land borders are often located at border crossings that are difficult for state officials to reach because they run in remote regions (e.g., jungles or deserts). The border is left to its own, but this does not preclude the development of lively informal economies.
2) *Landmark borders*: borders characterized by little state control architecture. This includes borders that have been dismantled through bilateral or multilateral treaties, for example, to facilitate the movement of goods and people (Nita, 2017).
3) *Checkpoint borders*: these are characterized by border posts installed at specific border crossings. In satellite imagery, we often find roads that become multi-lane, eventually ending in a control point where documents are checked and customs are collected.
4) *Barrier borders:* these are installed by states that want to ensure that such controls are not undermined. Barriers are used to direct border traffic toward regular border crossings. However, physical barriers such as fences and ditches that characterize such barrier borders do not extend along the entire border route, but are rather located at neuralgic border crossings.
5) *Fortified borders:* these are borders where states have erected fences or walls along the entire borderline to further discourage uncontrolled border crossings. In contrast to barrier borders, which are characterized by the installation of obstacles at neuralgic points, states with fortified borders attempt to reinforce the border line as complete as possible.

Fig. 1 illustrates these five different border types.

3.1.2. Settlements and population

We rely on global data sets derived from remote sensing and census data. We apply the product suite of the Global Human Settlement Layer (GHSL) for measurement of two parameters: the settlements and the population. We measure changes over the time period 2000 until 2014 for settlements and until 2015 for population. We rely on the GHS_BUILT_LDSMT_GLOBE_R2018A (Corbane et al., 2018) and the GHS_POP_MT_GLOBE_R2019A (Schiavina et al., 2019) datasets, both covering the whole world with a spatial resolution of 250 m (in the following the time period 2000 until 2015 generally stands for the time period of both development proxies). The former provides the percentage of settlement area per pixel. It is derived by fully-automated symbolic machine learning from Landsat satellite data (Corbane et al., 2019). The settlement layer is used to disaggregate population census data to a population grid showing the absolute amount of people per pixel (Freire et al., 2016). Fig. 2 illustrates the used data sets by the example of the western part of the Mexican-US-American border.

3.1.3. Economic and polity data

As stated in our hypothesis, it is assumed that economic and political differences between neighboring nation-states affect which border typologies are implemented and how dynamically development occurs. In

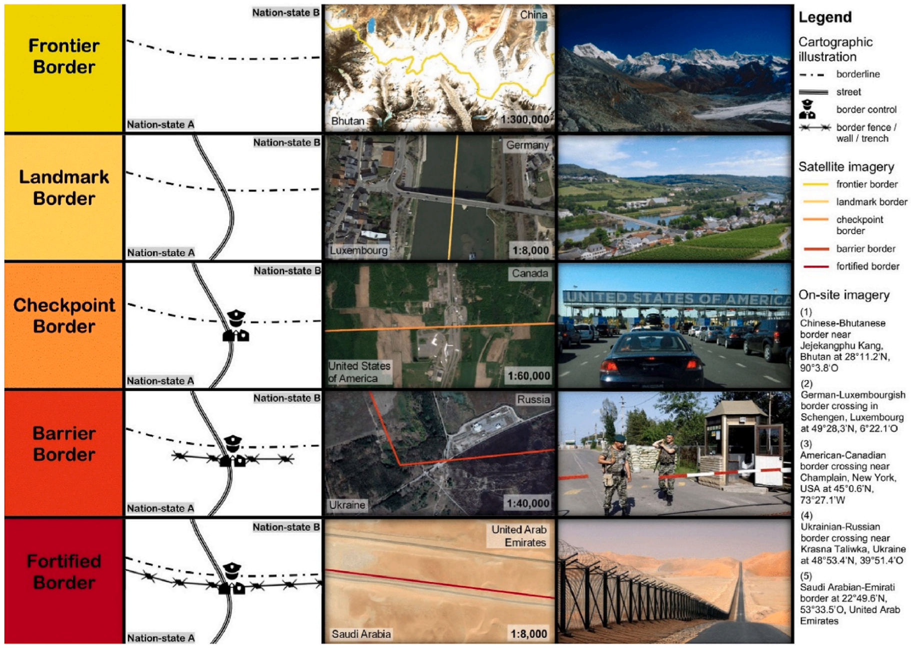

Fig. 1. Border typologies and cartographic as well as photographic illustrations: (1) Frontier border: © Steve Razzetti, http://www.razzetti.com/; (2) Landmark border: © LFT_OliverRaatz; (3) Checkpoint border: © Bobby Hidy; (4) Barrier border: © Kyiv Post; (5) Fortified border: © John A. Kelley, Soil Scientist, Environment Agency-Abu Dhabi, UAE.

our study, we understand the parameters *GDP* per capita and the *classification of political regimes* as our proxy variables in this regard.

We rely on the *GDP* per capita calculated in current US-Dollars for the year 2017 (The World Bank, 2021). With this variable, we approximate the degree of economic disparity between neighboring states. And, we rely on a *classification of political regimes* for the nation-states using the situations in the year 2017. Here, we apply the political conditions to a scale from −10 to +10: The values −10 to −6 are a gradation for autocratic regimes from maximum unfree and restrictive; −5 to 5 is a gradation for anocratic regimes and +6 to +10 is a gradation to a maximum free democracy. The classification relies on Marshall and Elzinga-Marschall (2017) and is referred to below as polity indicator. These data are not available in grid resolution. Here, we refer for both variables to the reference unit of the respective nation-state.

3.1.4. *Border lines and related land areas*

For the spatial definition of all borderlines worldwide, we base our analysis on the *Large-Scale International Boundaries 10.0* (Office of the Geographer and Global Issues at the U.S. Department of State, 2021) data set. This data set features all international borders and special lines on land with an estimated positional accuracy of 100 m. They are the respective starting point for defined border regions (cf. section 3.2.).

We consider the total number of land borders worldwide, which amounts to 315, or 630 in total, respectively (based on the Direct Contiguity Dataset (Version 3.2) of the Correlates of War Project). Each borderline occurs twice in the dataset, as border infrastructures need not continue across the border. The crossing from one nation-state to another might have a fortified form with complete checks. The return way might only be a checkpoint border with punctual controls (e.g. Mexican-American border). Accordingly, our border lines dataset has a dyadic format.

For the definition of the land areas, we use the OpenStreetMap dataset to spatially define the extent of the nation-states (OSM, 2021).

3.2. *Spatial reference units*

Our input data on border typologies, settlement and population dynamics, and economic and political situations have different spatial references: Border typologies refer to a border line, settlement and population dynamics have a grid resolution and can therefore be related to freely configurable reference units such as border regions or entire nation-states, and the economic and political data refer to the respective nation-states. While the reference units of border lines and entire nation-states are self-explanatory, the reference unit related to the spatial

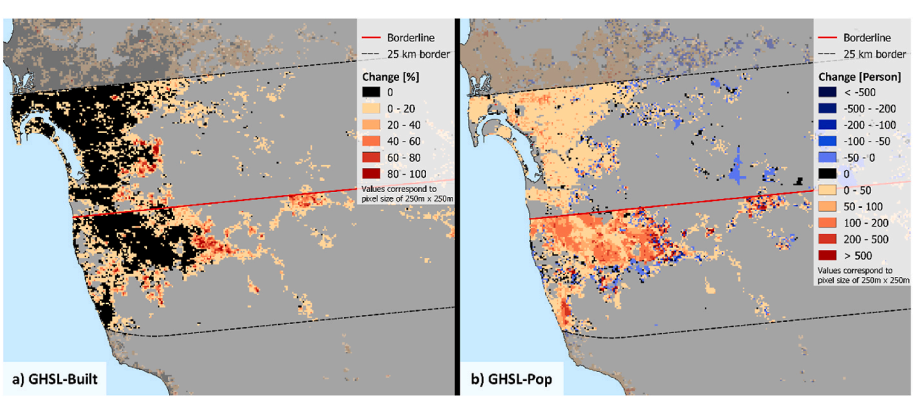

Fig. 2. Development for a 15-year period from 2000 to 2015 at the border vicinity (25 km) using proxies: a) the settlements, and b) the population. Data are based on the GHSL-product suite. The example illustrates parts of the Mexican-US-American border with San Diego (USA) and Tijuana (Mexico) along the coastline. In this example it is remarkable how pronounced the area growth and especially the population increase on the Mexican side in the south is in comparison to the USA in the north.

vicinity of borders needs to be defined.

In general, we have the border line in its territorial course. This line, however, has no spatial extension. As it is nowadays the case that the border as a linear control post has been replaced by an ensemble of control sites, technologies, and infrastructures that can enable, channel, or prevent mobility or exchange, the border of the 21st century moves away from the border line and spatially reaches far into the adjacent space or even beyond to distant areas where mobility is controlled (e.g. Shachar, 2020; Mau, 2021). This makes control monitoring spatially porous and spatially elusive. It is very difficult to grasp this spatially, especially since mobility control often takes place in distant regions. Against this background, we limit our spatial reference unit to the vicinity of border regions and thus we follow the basic idea that a border has an impact on the geographical area directly surrounding it. We do so, because for our global approach, precise spatial coverage of control points away from the border line is not data feasible.

By these considerations, we analyze the developments in the *spatial vicinity of the respective border lines*. Of course, it is a priori not clear which distance is meaningful to possibly measure border effects. Rather, it can be assumed that there can be no uniform distance value for this. In order to create global uniformity and thus consistency in the methodological approach, we have defined a border region of 25 km, which is considered to spatially approximate the catchment area of the borders. As there are two border typologies for each border line (see chapter 3.1.4.), the border region of a nation state is assigned the typology of the border that defines immigration. However, the analysis exclusively on the border region of 25 km does not go far enough, since dynamics are very different across the globe. The extent to which the border inhibits or strengthens developments must therefore also be assessed relative to the development dynamics in the specific national context. Against this background, we rely on an additional spatial unit where we relate the development in the *spatial vicinity of the border lines* to the development of the *respective entire nation-states*.

3.3. Concept for analyses

Our concept of analyses is two-fold: first, we apply a *descriptive analysis* on border typologies as well as on settlement and population dynamics across the globe. And second, we test the *relations* of our variables to each other along our guiding hypotheses, as stated in chapter 2, to reveal global trends.

3.3.1. Descriptive analysis: the distribution of border typologies and ranking of border dynamics

We map and quantify, on the one hand, the border typologies based on the introduced classification scheme across the globe. We relate the typologies to the quantitative occurrence at global and continental level and present this in cartographic representations as well as in pie charts. On the other hand, we quantify which nations across the world have the highest dynamics in border regions. To do this, we develop a ranking of the highest dynamics by the variables 'settlement' and 'population'.

However, a single metric seems to be unsuitable for this purpose. For example, relative settlement or population growth in the vicinity of the border with virtually no existing settlement area in the year 2000 could be classified with very high dynamics, although the actual absolute growth is very little. And, at the same time, absolute growth naturally includes a bias due to the unequal lengths of borders.

To address these challenges, we develop an index to compute the dynamics based on an ensemble of relative metrics. We calculate the relative growth of settlements and population for our period of analysis for two different spatial units:

Firstly, the relative growth is calculated at the *spatial vicinity of the respective border lines*, i.e. at the border regions of 25 km distance to the border line (cf. equations (1) and (2)).

$$\textit{Settlement growth}_{\textit{border region}} = \frac{\textit{settlement area border region}_{2014}}{\textit{settlement area border region}_{2000}} \quad (1)$$

$$\textit{Population growth}_{\textit{border region}} = \frac{\textit{population border region}_{2015}}{\textit{population border region}_{2000}} \quad (2)$$

In general, the results can be assigned to three classes: A growth rate lower than 1 means decrease of settlement areas or population within the border region over the monitoring period, a growth rate equal or close to 1 stands for no development, and a growth rate higher than 1 signifies increase of a development proxy.

Secondly, we apply two further metrics which put the growth rates in the vicinity of the border (border region of 25 km distance to the border line) in relation to the growth rates of the respective *entire nation-state* (cf. equations (3) and (4)). Growth rates are highly variable around the world and this is also true in areas close to borders. By calculating these in relation to the entire particular nation-states, we try to assess the dynamics in the national or supra-regional context. With this, we quantify whether we see different development tendencies near the border than for the entire respective nation-state:

$$\textit{Settlement growth ratio}_{\textit{border region vs. nation-state}} = \frac{\textit{Settlements growth}_{\textit{border region}}}{\frac{\textit{settlement area nation state}_{2014}}{\textit{settlement area nation state}_{2000}}} \quad (3)$$

$$\textit{Population growth ratio}_{\textit{border region vs. nation-state}} = \frac{\textit{Population growth}_{\textit{border region}}}{\frac{\textit{population nation state}_{2015}}{\textit{population nation state}_{2000}}} \quad (4)$$

Again, the results can be assigned to three classes: A growth rate lower than 1 means lower settlement or population growth rates within the border region than in the entire nation-state, a growth rate of 1 stands for equal development dynamics, and a growth rate higher than 1 signifies higher development rates.

For the four formulas, we interpret a growth rate in the range from $\frac{1}{1.05}$ to 1.05 as no development or equal development dynamics in the border region as in the entire nation-state, respectively.

For the calculations of all these metrics, we apply two exceptions: Firstly, we remove border regions from the analysis that have a growth rate of 0 or infinity (4 border strips for the proxy settlement and 3 border strips for the proxy population are removed). And secondly, we specify border regions where less than 0.1% of the area in 2000 (2015, respectively) is settlement. If the settlement area shares are below 0.1% of the total area and growth is so low that the uncertainty of the input data exceeds the measured growth, we set development to 1. We do so as existing errors in the GHSL would distort growth rates with such low area shares (95 border strips for the proxy settlement and 45 border strips for the proxy population are set to a growth rate of 1).

From these four metrics, we generate two rankings, each based on a different composition to estimate the highest dynamics near the border. The first ranking is composed of the mean of the two metrics related to the vicinity of the border (eqs. (1) and (2)), the second one is composed of the mean of the two metrics for the ratio of the developments in the vicinity of the border to the entire nation-state (eqs. (3) and (4)).

3.3.2. Testing relations between variables

The dynamics in the vicinity of borders – as diverse as they are on our planet – are related to a multitude of factors which are often even very locally specific such as border typologies, demographic, economic, social, political, environmental or topographic situations, among many others. In this second methodological part, we relate the presented global data (cf. sec. 3.1.) of border typologies, political and economic status quo of the nation-states, and settlement and population dynamics to each other following the guiding hypothesis formulated in section 2. It is therefore clear that our data sets do not cover all the various influencing factors in a comprehensive manner and that locally specific circumstances cannot be depicted. Rather, we search for these specific relationships at a more aggregated, general level.

For the analyses, we present the variables in boxplots via the respective reference variable. We evaluate the extent to which the medians in our boxplots show truly significant differences by means of p-values to the rank-sums based Kruskal-Wallis H tests. We apply this test as we do not have normal distributions in the samples. Where applicable, we evaluate pair-wise significance in variance differences through post-hoc Tukey-Kramer-Nemenyi all-pairs test with Tukey-Dist approximation.

When linking the data sets, it must be considered that the different variables are available at different spatial reference units (section 3.2.) and that the variables are accordingly spatially linked to each other: For the relation of border typologies and economic and political differences among nation-states, naturally, the spatial reference units are the entire nation-states. For the relation of economic and political differences and settlement and population dynamics, two metrics referring to different spatial reference units are applied: Relative to the border region and relative to the ratio of border region to the entire nation. In this specific case, we calculate the relationships as follows: The relative settlement (or population) growth in the border region (or the relative growth in the border region vs. the entire nation) to the relative growth in the border region of the neighboring nation-state (or the relative growth in the border region vs. the entire nation for the neighboring nation-state). For the relation of economic and political differences and settlement and population dynamics, we also apply these two metrics referring to the two spatial reference units. For the analyses, we present the variables in boxplots via the respective reference variable.

4. Results

4.1. Descriptive results: distribution of the border typologies and the dynamics in border regions across the world

Border typologies vary across the globe – from frontier to fortified. From the cartographic representation (Fig. 3) and the quantitative shares of border typologies at global and continental levels, we explicitly point out the following aspects: On *global scale*, checkpoint borders (59.4%) are the dominating border typology, while the other four border types more or less share about 10% among all borders. Every fifth border on our planet, thus, belongs to the most fortified border categories (barrier, fortified) (20.6%). On *continental level* there are spatial differentiations: Landmark borders only exist in Europe and were created by the entry into force of the Schengen Agreement in Europe (Felbermayr et al., 2017). In contrast, frontier borders do not exist in Europe and North America at all. The most fortified border categories (barrier, fortified) occur predominantly in Asia (71 out of 130); however, they exist on any continent.

Near these borders, just over 610 million people lived in 2015. This means that 8.2% of the world's population lived within 25 km or less of a border.

In general, we measure border regions not as dynamic in terms of settlements compared to the global development. Settlement areas in border regions increased by 16.1% between 2000 and 2015, while globally they increased by 20.3%. It is interesting to note, however, that for population it is vice versa. The population has grown by 24.5% near the border, while globally it has increased only by 20.0%. Thus, at global

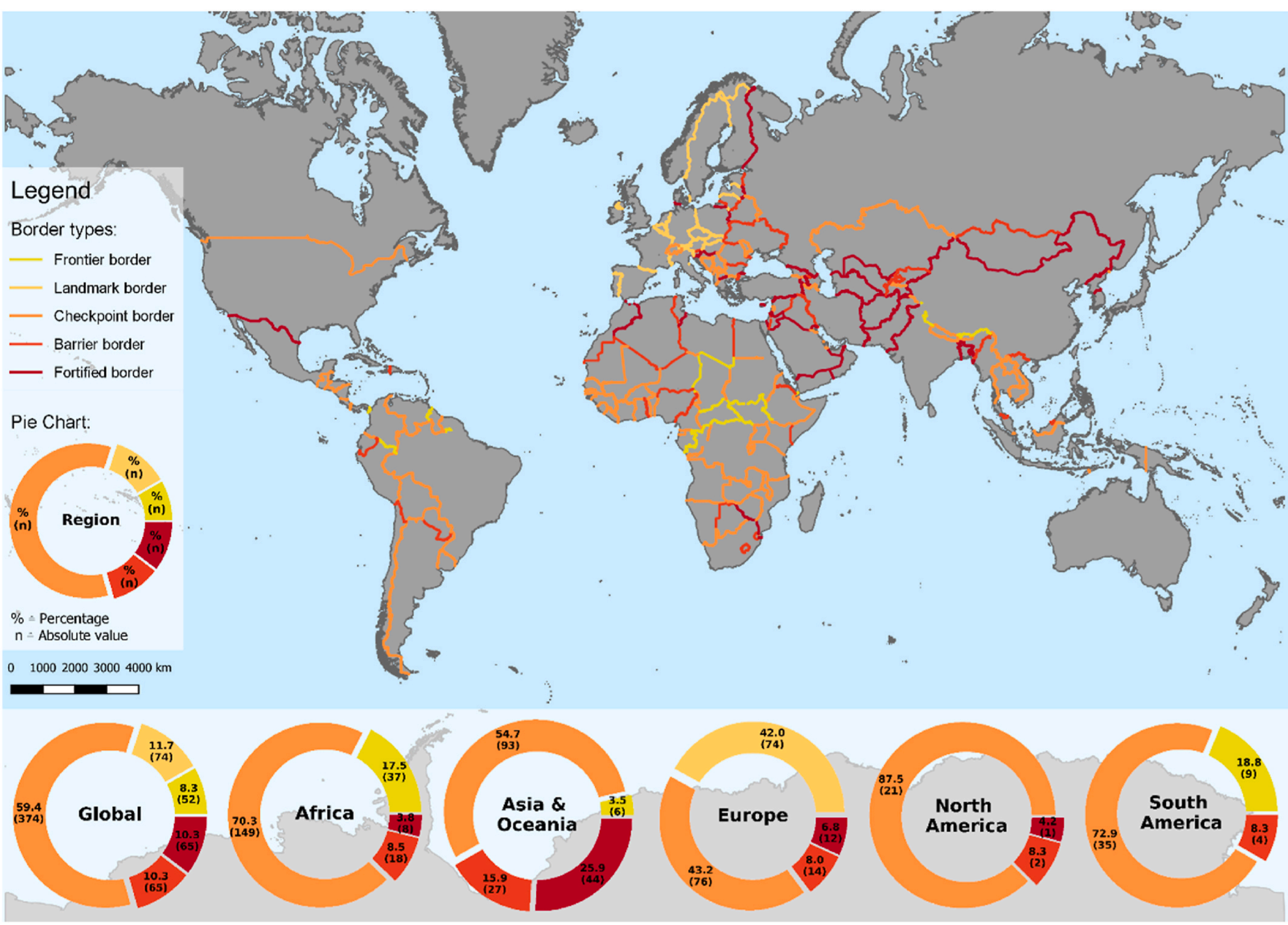

Fig. 3. Border typologies and their distribution across the globe in the year 2017 (the map shows the color of border type of higher fortification per border line).

scale, we measure a balanced growth in settlement and population. In border regions, however, we observe that population growth is higher than settlement area development. A trend that points to population accumulation effects.

Settlement and population densities and trends over time in the vicinity of borders, however, are highly variable in relation to border typologies or to regions or continents (Fig. 4). Although, many people live close to borders, globally, border regions are of comparatively low-density, at just over 0.5% settlement density. Here, the landmark borders have by far the highest settlement density at 3.24% (in 2015), while checkpoint, barrier and fortified borders have much lower settlement shares at about 0.5%. The same is true for population density. Landmark borders have 104 people per km^2 in 2015, almost twice as many as the global average. The other three types of borders have 58, 40 and 84 inhabitants per km^2, respectively. It is interesting to see that frontier borders are in fact no man's land. In the border regions, we see a settlement density of only 0.01% for this type and only 7 people per km^2 in 2015.

With respect to continents, it is interesting to see how Europe and North America feature higher settlement densities than the global average in the border vicinities. Due to a large amount of frontier borders in Africa, Asia and South America, the average densities are below the global averages. For population, we see similar trends with Europe above the global average. Over the 15 years of monitoring, Asia features high growth rates reaching population densities above the global average.

As shown, border typologies and development dynamics for the 15-year study period are not equally distributed around the world. We now illustrate these differences per border line of two neighboring states. For this purpose, we use rankings according to the growth dynamics of *settlements* and *population* in the *vicinity of the borders* and as *ratio in the vicinity of borders to the growth rates of the respective entire nation-states*.

In the *vicinity of the borders* (Fig. 5a), we measure highest *settlement growth rates* for the borders of Bhutan-China (settlement growth rate in the border region of first named nation-state: 15.35-fold), Bhutan-India (5.02) and Norway-Finland (4.35). 59 borders (i.e. 9.5%) of the 624 border regions across the world are measured with higher settlement growth rates than 1.50-fold. Of these borders of highest dynamics, 89.8% are located either in Africa (29) or in Asia (24). The remotely sensed input data on settlement development results in virtually no single border with a setback. This may reveal a correct trend that built-up landscapes are inert and mostly even remain so, even with population loss. But it also shows that the algorithms and data probably cannot detect these low levels of deconstruction activity, if they exist. The border of Surinam to Brazil is an example of no development at all.

Further, it is interesting to see that high settlement growth rates do not necessarily mean high population growth rates, as the top 3 in this ranking are other border regions: For *population*, we measure highest growths rates for the borders of Angola – Republic of Congo (population growth rate in the border region of first named nation-state: 6.55-fold), Venezuela-Brazil (5.26) and Chad–Niger (3.91). Expanding the list, the Oman-Yemen (3.71), Chad-Libya (3.53), Libya-Chad (3.53), Libya-Niger (3.53) or Kenya-Somalia (3.46) borders follow – all regions with generally high population growth and particularly high numbers of refugees. For population, 114 borders (i.e. 18.27%) are measured with higher growth rates than 1.50-fold. Dominating shares among them are with 57% in Africa, 28.1% in Asia, and 10.5% in South America. In contrast to the settlement development, where in principle there is no decline measured, we are measuring a decline in terms of population for 129 border regions, i.e. for 20.7% of all of them. Among them, 70.5% are located in Europe. The strongest population declines were recorded in the Iran-Turkey border region with 0.45 followed by Surinam - Brazil (0.65) and Albania – Kosovo (0.69).

In the joint ranking of both variables in the *vicinity of the borders*, we measure for 578, i.e. for 92.63% of all border regions increases. The Bhutan-China border region (settlement growth rate in the border region of first named nation-state: 15.35-fold; population growth rate: 1.41-fold) is at rank 1, and the lowest rank has the Suriname-Brazil border region (1.00; 0.65). It is again striking that 28 of the 30 border regions with the highest growth rates in this respect (top 5%) are solely located in Africa (17) and Asia (11), while 20 of the 30 border regions with the lowest growth rates in this respect (lowest 5%) are located in Europe. The measured growth rates in the vicinity of the borders basically reflect uneven growth rates on our planet.

As a second statistic on border development, we look at *growth rates in the vicinity of borders and consider them in relation to the growth rates for*

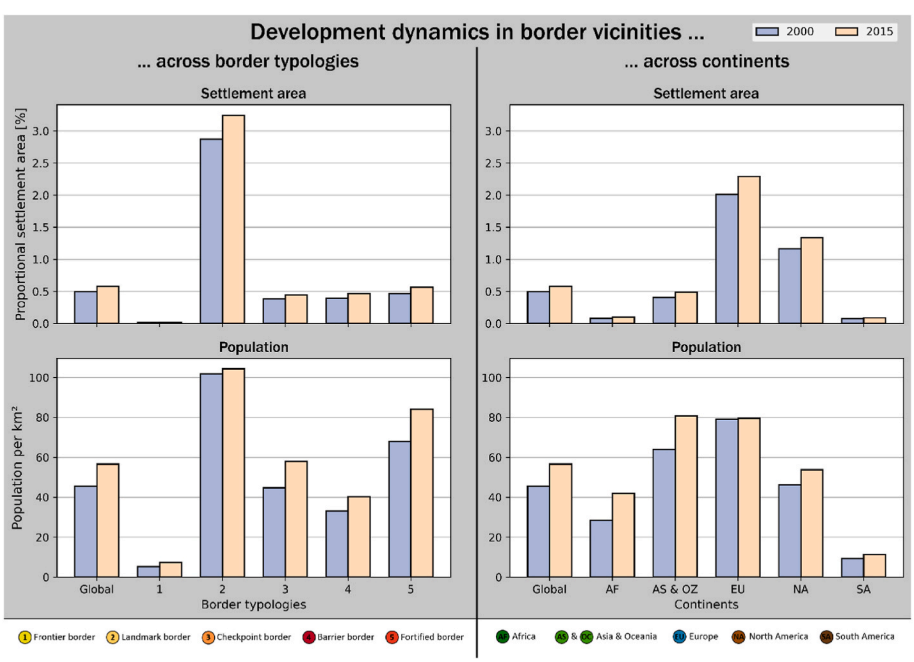

Fig. 4. Development dynamics for settlements and population from 2000 to 2015 in the border vicinities with respect to border typologies and continents and in global comparison.

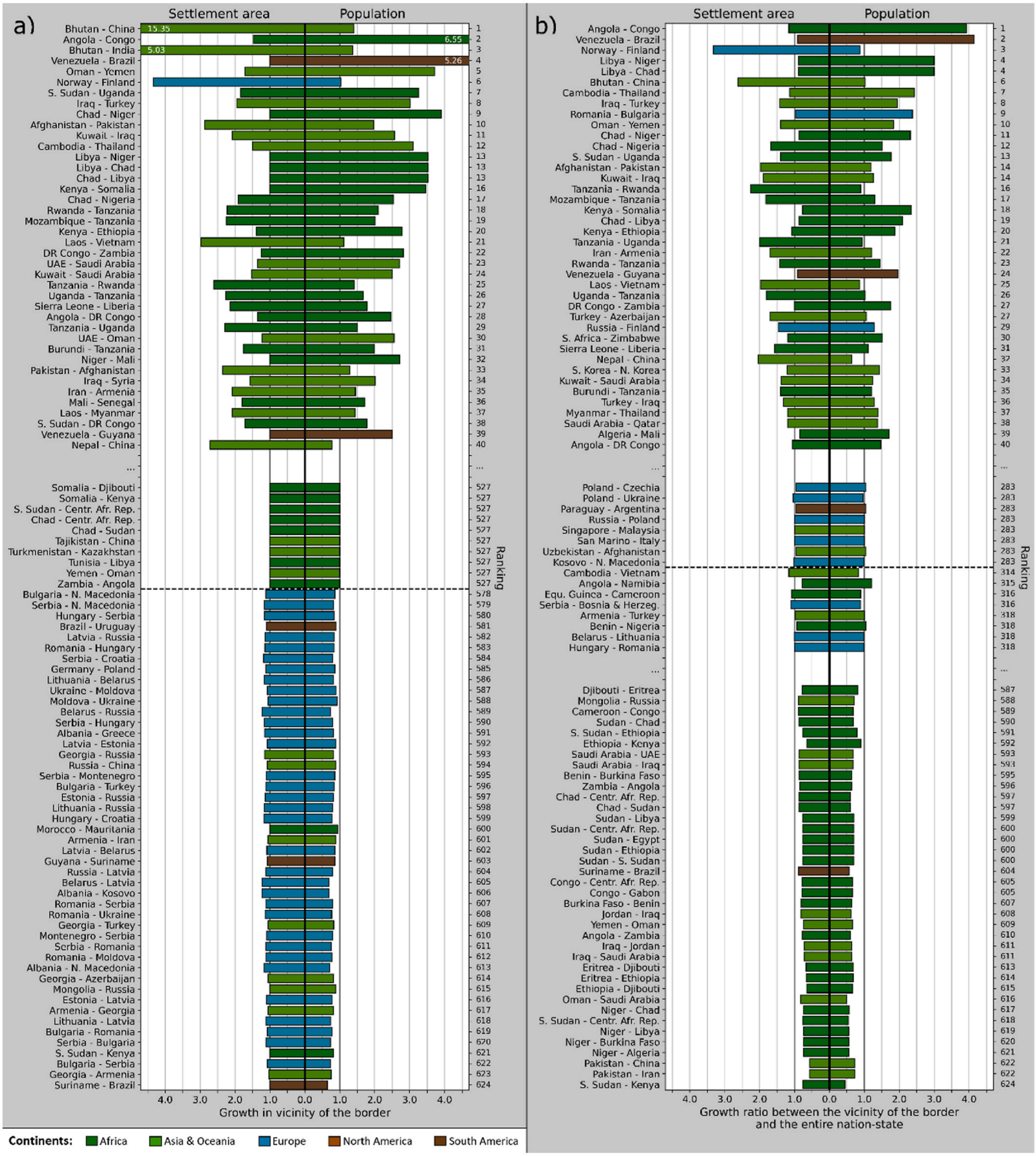

Fig. 5. Ranking based on development dynamics: a) relative growth rates of settlements and population in the border regions; b) relative growth rates of settlements and population in the border regions in relation to the relative growth rates of the entire nation-state. Above the dashed line we measure a positive joint growth of population and settlements, below a negative rate.

the respective entire nation-states (Fig. 5b). Here, the *growth rates of settlements* on the border Norway to Finland are the highest (3.33-fold), followed by Bhutan - China (2.62), and Tanzania - Rwanda (2.26). The lowest settlement growth rates relative to the nation-state are measured at 0.56-fold for the border from Pakistan to Iran, Pakistan to China (0.57), and Ethiopia to South Sudan (0.65). In total, there are 301 border regions (i.e. in 48.2% of all border regions) where growth is higher near the border than in the nation-state (30.9% of these are in Africa, 28.2% in Asia and 26.6% in Europe). This result at the global level is a first indication that our measures of settlement development do not reflect a general difference between growth rates in border regions and nation-states. Nor does their distribution across continents suggest any obvious trend for border regions of different political, economic, or cultural circumstances to be an explanatory factor here.

In terms of *population* trends, we see that 359 border regions (i.e. 57.5% of all borders) are experiencing lower population growth rates in border vicinity than in the entire nation-state between 2000 and 2015. Even if a somewhat stronger trend toward lower population development near the border can be identified here, it is still not very pronounced. The Iran-Turkey border is the frontrunner in this respect: population development is only 38% as strong in border vicinity as in the entire nation-state. It is followed by South Sudan - Kenya (0.45) and Oman - Saudia Arabia (0.5). For 11.7% of the sample, growth near the border is at least one-fifth lower than in the nation-state as a whole. 54.8% among them are in Africa.

For the combination of both variables (settlement and population) for the *ratio in the vicinity of borders to the growth rates of the respective entire nation-states*, we measure for 314, i.e. for 50.3% of all border regions increases. Highest growth rates are measured in the Angola - Republic of the Congo border region (settlement growth rate in the border region of the first named nation-state: 1.16-fold; population growth rate: 3.93-fold), and the lowest in the South Sudan - Kenya border region (0.76; 0.45). In this ranking, it can be emphasized that 25 of the 30 border regions with the highest growth rates in this respect (top 5%) are again solely located in Africa (16) and Asia (9). However, 29 of the 30 lowest growth rates in this respect (lowest 5%) are also exclusively located in Africa (22) and Asia (7). This indicates that predominantly African (and by extension also Asian) nation-states developed compared to each other quite differently between 2000 and 2015.

Overall, this ranking shows that the variability of settlement and population development at border vicinities is highly variable across the globe and even highly variable on regional levels. While we identify certain region-specific tendencies (e.g. lowest growth rates and partly even population decline in border vicinities in Europe, or highest growth rates predominantly in Asia and Africa), regional specifics (economy, demography, topography, conflicts, etc.) are too diverse and do not reveal obvious, simple geographical relations. On this basis, no clear-cut pattern can be discerned, though one should not jump to conclusions and infer that border infrastructures do not matter for settlement and population issues. A straight forward relationship might be thwarted by a larger number of context variables.

4.2. Relations of border typologies, economic and polity indicators, settlement and population dynamics for neighboring nation-states

4.2.1. Relation of border typologies with GDP per capita and polity indicators

With regard to our first guiding hypothesis (a), i.e. that we assume the higher political or economic differences between neighboring nation-states are, the stronger the border fortification is, we see this thesis basically confirmed in the global empirical analysis (Fig. 6).

For both variables, relations are found: For *political difference* among neighboring nation-states, we find the greater the differences in the political systems of the respective two bordering nation-states, the more fortified the border. While the measured variance per border typology is, except for the landmark borders, high, we still see a clear trend with rising medians. The medians increase from 0 for the landmark borders to 2 for the checkpoint borders ($p < 0.001$) to 5 ($p < 0.001$) and 6 ($p < 0.001$) for barrier and fortified borders and these are based on the Krukals-Wallis test statistically significant. The frontier borders, however, seem to represent a special case: Although the borders are not physically fortified or strongly controlled, their inaccessible terrain then takes over this control function of nation-states featuring on median (6) great political differences. (Appendix, Tab. 1). For *economic ratio* among neighboring nation-states, we find the smaller the GDP per capita of the nation-state facing the border in relation to the GDP at the neighboring nation-state is, the more fortified a border is. These results indicate a trend that richer nation-states shut themselves off from poorer neighboring nation-states. Again, the variances among our sample across the world per border typology are high and capture the influence of various factors not considered in the study. This means that the relationship is neither unambiguous nor linear. However, a recognizable trend of lower medians with greater negative disparity in GDP per capita is given; however, the p-values of the Kruskal-Wallis H test show only significance for pair-wise comparison to fortified borders (see Appendix, Tab. 2). The medians decrease from 1.17 for the frontier borders, to 1.04 for

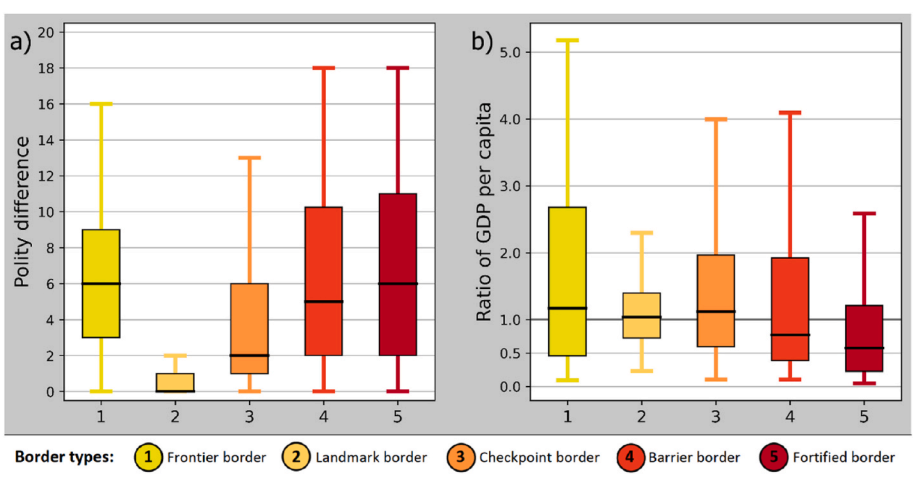

Fig. 6. a) Relation between polity difference and border typologies of neighboring nation-states, Krukals-Wallis test p-values <0.001 ***; b) Relation of the ratio of GDP per capita between neighboring nation-states and border typologies, Krukals-Wallis test p-values <0.001 ***.

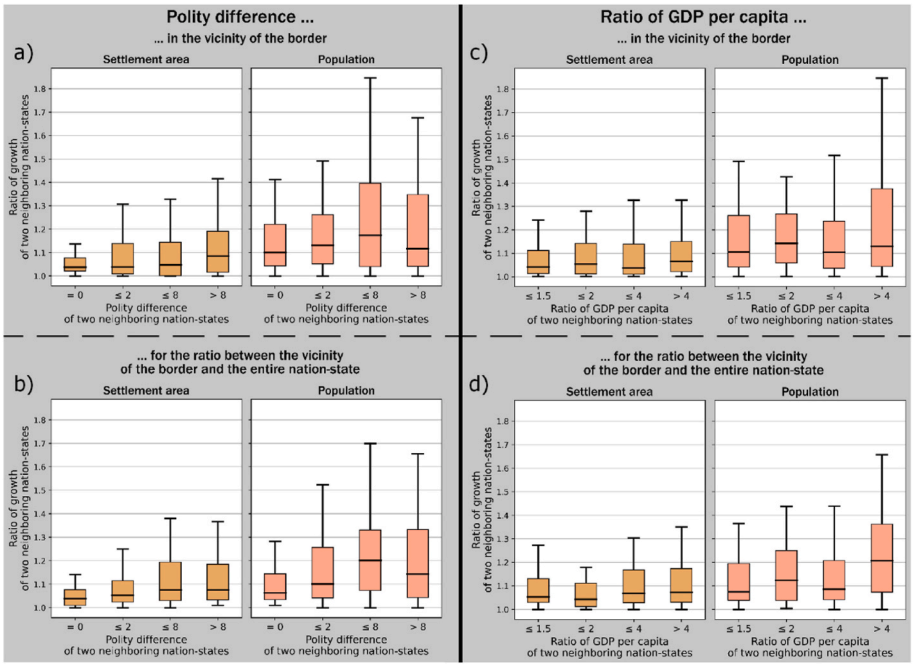

Fig. 7. Ratio of settlement and population dynamics of two neighboring nation-states: a) in the vicinity of the border in relation to the polity difference of two neighboring nation-states, Krukals-Wallis test p-values: left 0.356, right 0.415; b) for the ratio between the vicinity of the border and the entire nation-state in relation to the polity difference of two neighboring nation-states, Krukals-Wallis test p-values: left 0.002 **, right 0.001 **; c) in the vicinity of the border in relation to the ratio of GDP per capita of two neighboring nation-states, Krukals-Wallis test p-values: left 0.719, right 0.217; d) for the ratio between the vicinity of the border and the entire nation-state in relation to the ratio of GDP per capita of two neighboring nation-states, Krukals-Wallis test p-values: left 0.162, right 0.004 **.

landmark and 1.12 for the checkpoint borders, respectively to 0.77 and 0.57 for barrier and fortified borders.

4.2.2. *Relation of settlement and population dynamics with GDP per capita and polity indicators and with border typologies for neighboring nation-states*

For the first part of our second guiding hypothesis (b), we assume that the greater the political or economic disparities of neighboring nation-states, the greater are differences in settlement and population growth rates in border regions. We see this thesis also basically confirmed in the global empirical analysis (Fig. 7).

With regard to *polity differences*, we observe the higher political differences between neighboring nation-states, the higher on medians the growth rate disparities of settlements and population. While this confirms the hypothesis, the statistical relationship is not significant (Appendix, Tab. 3 & Tab. 4) for the spatial unit of the vicinity of the border (Fig. 7a). In relation to the whole nation-state, this trend is also observed. Here, the Krukals-Wallis test even shows statistical significance (Fig. 7b; Appendix, Tab. 5 and 6). P-values for pair-wise comparison of settlement and population growth rates between 'states without political disparities' to 'neighboring states with political disparities' in the range between 2 and 8 ($p = 0.009$, settlement growth ratio; $p = 0.001$, population growth ratio) and by more than 8 ($p = 0.004$) return statistical significance. With regard to the *ratio of GDP* per capita, we generally observe that with higher disparities among neighboring nation-states, we have predominantly higher growth rate disparities on medians among neighboring border regions. This confirms the hypothesis, but the relationships are not significant for the ratios of growth rates in the vicinity of the border (Fig. 7c; Appendix: Tab. 7 and 8). In relation to the whole nation-state, this trend is also observed and partly even statistically significant. For example, we see the highest medians when GDP disparities are larger than 4-fold. The Kruskal-Wallis H p-values for pair-wise comparison between states with low economic disparities (≤1,5) to neighboring states versus states with high economic disparities (>4) ($p = 0.003$; population growth ratio) reveal significance (Fig. 7d; Appendix: Tab. 9 and 10).

It can be concluded that large disparities between nation-states in economics or political regimes also implicate higher growth rate disparities than in nation-states that are more similar in these domains. However, it should also be noted that the global variability is again high, trends are given but only in parts with statistical significance and thus, one-to-one conclusions cannot be drawn due to the wide variety of local, regional or national specifics.

For the second part of our second guiding hypothesis (b), we specifically assume that in the case of neighboring nation-states separated by barrier or fortified borders and with extreme differences in political and economic systems, a strong pull effect leads to accumulation effects on the poorer or more unfree side of the border. The assumption here is, that hard borders structure space and population primarily on the economically weaker and less democratic side.

Therefore, we specifically analyze all border regions across the globe where democratic (polity indicator >5) and undemocratic (polity indicator <5) states are separated by barrier or fortified borders (in total 20 border regions). The results show that the magnet effect of democratic states is very pronounced. The median growth rates in the border regions on the autocratic side are throughout all variables well above those on the democratic side (Fig. 8), although not statistically significant ($0.381 < p < 0.849$).

The same is measured when we analyze border regions where the ratio of the GDP per capita between the two neighboring nation-states is larger than 5.59. This value accounts for the sum of the mean of all ratios of the GDP per capita between two neighboring nation states that are greater than 1.0 and its standard deviation. This scenario applies for 23 border regions in total. Here, we see for all variables on medians a higher accumulation of settlements and population on the poorer side of the border between 2000 and 2015 (Fig. 8), although again not significant ($0.232 < p < 0.752$). Thus, the observed trend goes in the direction of the hypothesis: when there are strong political or economic differences among neighboring states separated by barrier or fortified borders, an accumulation effect occurs on the poorer or less free side of the border. However, the results are statistically not significant and therefore we cannot fully confirm the hypothesis.

5. Discussion

From a *geographical* point of view, we were interested in the relation between border infrastructures and population and settlement development dynamics. Given that borders separate territories as well as

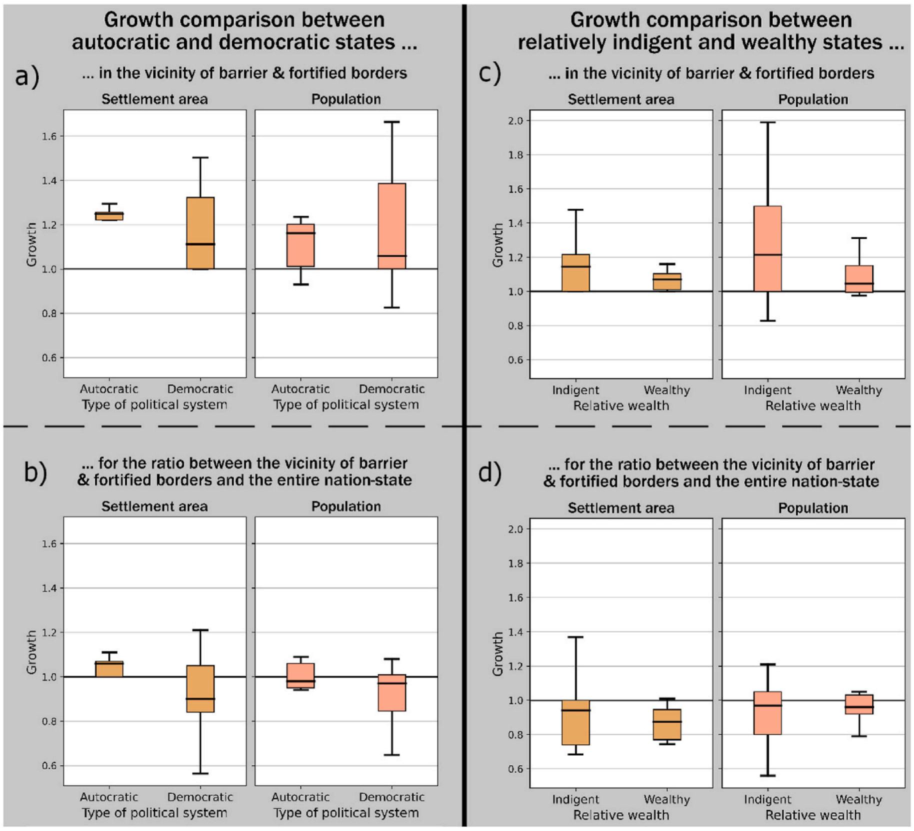

Fig. 8. Comparison of settlement and population development; a) in the vicinity of barrier and fortified borders between autocratic and democratic nation-states, Krukals-Wallis test p-values: left 0.616, right 0.849; b) for the ratio between the vicinity of barrier and fortified borders and the entire nation-state between autocratic and democratic nation-states, Krukals-Wallis test p-values: left 0.446, right 0.381; c) in the vicinity of barrier and fortified borders between indigent and wealthy nation-states, Krukals-Wallis test p-values: left 0.348, right 0.232; d) for the ratio between the vicinity of the border and the entire nation-state between indigent and wealthy nation-states, Krukals-Wallis test p-values: left 0.752, right 0.752.

populations and manage and modulate mobility, we departed from the assumption that they should matter. In this study, we documented the variability of border typologies across the globe and, we measured that in border regions settlement development is lower and population growth, however, is stronger than in a global comparison. However, we have generally not found a uniform pattern with regard to development paths of settlements and population in border regions, i.e. we have quantified very different development dynamics across the world.

Settlement areas have grown by 16.1% and the population by as much as 24.5% in the vicinity of the borders. Basically, we measured an increase in settlements in the border regions almost everywhere. When relating settlement growth rates in border regions to the entire nation-states, we found higher growth rates for about half of our sample and lower growth rates for the other half. Thus, initially and on this general level, no positive or negative influence on development can be assigned to border regions. For population, we registered a decline in 20% of all cases in the border regions, and we measured lower growth rates for 57.5% of all border regions than in the respective nation-state. An indication that borders hinder population development in their vicinity. However, these results reveal that simple conclusions about the causes of less and more development fall short.

When relating our variables to each other, we observed statistically significant trends that the greater political or economic disparities between neighboring nation-states are, the stronger the border fortification is. We also saw that the greater the economic or political disparities of neighboring nation-states are, the stronger population or settlement accumulation disparities in border regions are on medians, but mostly not with statistically significant relations. And, it becomes apparent that strong fortification in neighboring states of high discrepancies in polity or economy trigger settlement and population accumulation on the more unfree and poorer side of the border implying that the effect is much stronger on the side “against which” border walls and fences have been erected. This could be interpreted as a “magnet effect”.

However, we need to be aware that all of this is overlaid by so many factors that we can only show relationships and not causalities. The large variances in the boxplots capture the influence of various factors not considered in the study. Although certain trends can be interpreted from the figures, we must also state that settlement and population developments near the borders cannot simply be attributed to the border typologies or political and economic variables. The interpreted trends were only in parts statistically significant, not recognizable in correlation diagrams and there was little correlation measured. In other words, this trend in medians does not allow for an easy conclusion because there the high variances within the respective groups feature countless examples where these indicated trends are vice versa.

And yet there seems to be a statement here about the relations of the used variables. The fact that the results not ambiguously support assumptions shows that global studies remain in their aggregated format limited in their conclusions. This is because too many macro and micro indicators in the political (e.g. visa policies), demographic (e.g. migration), economic (e.g. trade), social (e.g. family ties), environmental (e.g. climate change, topography) or other spheres influence development lines, which can only be statistically represented here as variances. The incompleteness in our data set, the limited number of borders and the large number of covariates to be considered hinder the production of causalities. However, these mentioned data sets will be difficult to achieve at the global level with sufficient quality and spatial resolution. But, we believe, in spite of these shortcomings, it is necessary to first generate the empirical basis and descriptive statistics in order to be able to basically assess or even model the developments at the macro level.

Of course, the question arises whether the selected variables are really suitable as proxies for development. For a global study with this spatial resolution, we currently have, however, no alternative as the applied database is unique on a global scale.

Beyond the geographical aspects of this study, we are aware that results might be influenced by *uncertainties in the input data sets*. In general, our data sets contain slight temporal offsets. The borders relate to the reference year 2018, GDP and data on the political regime are from 2017, settlement growth rates relate to the time period of 2000–2015. Beyond this, our input data sets naturally contain errors: The accuracy of the GHSL, assessed by over 40 million building footprints spread over different continents and settlement density characteristics, is reported with a balanced accuracy of 0.86 with slight regional differences (Corbane et al., 2019). However, large variations in accuracy due to location, surrounding land-cover, structural compositions, among others have been revealed (Klotz et al., 2016; Mück et al., 2017). For the population data, the quality assessment also has limits, due to the lack of worldwide independent but compatible reference data. However, a correlation analysis with 18 European nation-states using official GEOSTAT 2011 resident population data yielded a correlation coefficient of 0.83 (Freire et al., 2016). And, of course, for the economic and political data sets as well as for the border typologies errors or misclassifications may exist which cannot be quantified. What does this mean now? We believe that the database is solid especially for a global approach, but we cannot quantify and evaluate the impact of misclassifications. As example, we expect most misclassifications for settlements in peripheral areas with low densities, i.e. also in areas where some of our border strips are located. And still, as we measure to a certain extent that our assumptions are quite empirical in the data, we assume the general trends identified are plausible.

From a *methodological* point of view, this study can be considered as an entry point with expansion and development potential in many respects. The conceptual and methodological approaches applied in this study derive from the available data or are based on logical reasoning. However, these approaches can, of course, be adapted or extended to confirm or refute the identified trends: 1) The *variables*: other satellite data such as night light emissions have already shown the capability to also proxy economic development (e.g. Chen & Norhaus, 2019; Bachtrögler-Unger et al., 2021). Or data sets of higher spatial resolution such as from Landsat or Sentinel would allow to improve accuracies and spatial precision (e.g. Taubenböck et al., 2012). Thus, these data sets could extend thematic dimensions and spatial precision. Beyond, as we have seen, the resulting large variances in the boxplots capture the influence of various factors not considered in the study. This means, for example, extending the feature sets by data such as on the particular country's policy of purposefully supporting or impeding population migration would allow to model local effects needed to better fathom the complex nesting of this wide variety of factors. However, the demand for global availability of these data sets in consistent manner is a prerequisite, not always easy to meet. 2) the *spatial metrics*: the four metrics used to measure development can be expanded almost arbitrarily and other statistical approaches could be tested for comparison; 3) the *spatial concept* can be systematized, since it is a priori unclear how far the influence of borders on the surrounding area goes (e.g. Brackmann et al., 2012), i.e. tests of different spatial units near the border would allow to systematize the derived trends beyond the here used border regions of 25 km distance to the border line. Beyond this aspect, nowadays borders consist more and more of an ensemble of control sites, technologies, and infrastructures that sometimes replace the linear control post. The border line thus virtually reaches far into the adjacent space or even beyond to distant areas where mobility is controlled and thus calls for other spatial concepts and data types. In addition, the influence of adjacency, sub-adjacency and other spatial positional relationships among countries can be considered in future studies; 4) the *time period* of analysis can be extended, i.e. due to the availability of data, we referred in this study only to the type of border fortification in 2017. However, this ignores the fact that the degree of permeability or closure of borders change over time (Brackman et al., 2012; Sohn & Licheron, 2018). Thus, a multi-temporal classification of border typologies is in demand. Or, satellite data such as from night-time lights or Landsat would allow longer time periods of monitoring development processes. These data, conceptual, and methodological ideas are one sampling of ways among many more possibilities to put global studies on a broader empirical footing in the future.

Global studies can certainly capture trends, as this study has proven. But, as this study also shows, the revealed trends are only partly of the expected signs, partly their signal is weak due to discussed data-related, conceptual or methodological issues. This calls for further research: This study should therefore be understood as a first empirical approach to flank local studies on border regions with general global trends. And, together with the ideas just discussed to expand this study, we want to lay the scientific foundation to analyze impacts more systematically.

6. Conclusion and outlook

This study attempted to describe and quantify border typologies, to document and quantify development with the proxies 'settlement' and 'population' for a 15-year period from 2000 to 2015 in the vicinity of borders and, to relate all of these variables to economic and political indicators. The analysis was carried out for all 315 land borders across the globe. All of this was based on a completely new empirical data set where heterogenous data from literature surveys, censuses and remote sensing are synergistically analyzed. Such a global study does not replace in-depths and case-study research, but allows discerning general patterns and associations. Our umbrella question was: How do border infrastructures relate to settlement and population growth? Do they matter?

In general, we found highly different development dynamics in border regions across the globe. From it, we state that the border effects related to our variables do show trends: higher political or economic differences relate to stronger border fortification, greater economic or political disparities of neighboring nation-states relate to stronger population or settlement accumulation disparities in border regions, and strong fortification separating nation-states of high economic or polity differences trigger settlement and population accumulation on the poorer or more unfree side of the border. However, these general trends are measured on medians, they only are partially statistically significant, and thus these trends are not as strong or unambiguous as assumed. Variations across the globe are large and one-to-one conclusion cannot be drawn. And still, these trends are an empirical statement towards the effects of economic and political situations, border typologies and settlement and population development in border vicinities.

Of course, this study is not an all-encompassing test of the assumptions as the influencing factors are manifold and local specifics occur. Rather, we see this study as a first approach to globally systematize these relations and developments. This study and many further studies are needed not least to rationalize simplistic arguments with empirical information in a highly emotional political and societal debate.

Author statement

Hannes Taubenböck: Conceptualization, Data curation, Formal analysis, Methodology, Writing - Original Draft, Supervision. Christoph Otto: Conceptualization, Data curation, Formal analysis, Methodology, Writing - Review & Editing, Visualization. Fabian Gülzau: Conceptualization, Data curation, Investigation, Writing - Review & Editing. Steffen Mau: Conceptualization, Data curation, Investigation, Writing-Reviewing and Editing, Supervision.

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Appendix

Table 1
Kruskal-Wallis H p-values for pair-wise comparison between border type and polity difference in Fig. 6 (left)

Border type	1 *Frontier*	2 *Landmark*	3 *Checkpoint*	4 *Barrier*
2 *Landmark*	<0.001 ***	−/−	−/−	−/−
3 *Checkpoint*	0.001 **	<0.001 ***	−/−	−/−
4 *Barrier*	0.985	<0.001 ***	0.004 **	−/−
5 *Fortified*	0.999	<0.001 ***	<0.001 ***	0.953

Table 2
Kruskal-Wallis H p-values for pair-wise comparison between border type and ratio of GDP per capita in Fig. 6 (right)

Bordertype	1 *Frontier*	2 *Landmark*	3 *Checkpoint*	4 *Barrier*
2 *Landmark*	0.971	−/−	−/−	−/−
3 *Checkpoint*	0.999	0.971	−/−	−/−
4 *Barrier*	0.596	0.851	0.349	−/−
5 *Fortified*	0.011 *	0.015 *	<0.001 ***	0.245

Table 3
Kruskal-Wallis H p-values for pair-wise comparison between polity difference and settlement area growth ratios near the border in Fig. 7 a) (left)

Polity difference	= 0	≤2	≤8
≤2	1.00	−/−	−/−
≤8	0.98	0.98	−/−
>8	0.46	0.35	0.61

Table 4
Kruskal-Wallis H p-values for pair-wise comparison between polity difference and population growth ratios near the border in Fig. 7 a) (right)

Polity difference	= 0	≤2	≤8
≤2	0.82	−/−	−/−
≤8	0.35	0.77	−/−
>8	0.91	1.00	0.75

Table 5
Kruskal-Wallis H p-values for pair-wise comparison between polity difference and settlement area growth ratios for the ratio between the vicinity of the border and the entire nation-state in Fig. 7 b) (left)

Polity difference	= 0	≤2	≤8
≤2	0.24502	−/−	−/−
≤8	0.009 **	0.357	−/−
>8	0.004 **	0.193	0.968

Table 6
Kruskal-Wallis H p-values for pair-wise comparison between polity difference and population growth ratios for the ratio between the vicinity of the border and the entire nation-state in Fig. 7 b) (right)

Polity difference	= 0	≤2	≤8
≤2	0.375	−/−	−/−
≤8	0.001 **	0.042 *	−/−
>8	0.134	0.841	0.422

Table 7
Kruskal-Wallis H p-values for pair-wise comparison between GDP difference and settlement area growth ratios near to the border in Fig. 7 c) (left)

GDP difference	≤1.5	≤2	≤4
≤2	0.78	−/−	−/−
≤4	0.93	0.98	−/−
>4	0.77	1.00	0.97

Table 8
Kruskal-Wallis H p-values for pair-wise comparison between GDP difference and population growth ratios near to the border in Fig. 7 c) (right)

GDP difference	≤1.5	≤2	≤4
≤2	0.54	−/−	−/−
≤4	0.97	0.35	−/−
>4	0.58	1.00	0.37

Table 9
Kruskal-Wallis H p-values for pair-wise comparison between GDP difference and settlement area growth ratios for the ratio between the vicinity of the border and the entire nation-state in Fig. 7 d) (left)

GDP difference	≤1.5	≤2	≤4
≤2	0.85	−/−	−/−
≤4	0.63	0.27	−/−
>4	0.53	0.23	0.99

Table 10
Kruskal-Wallis H p-values for pair-wise comparison between GDP difference and population growth ratios for the ratio between the vicinity of the border and the entire nation-state in Fig. 7 d) (right)

GDP difference	≤1.5	≤2	≤4
≤2	0.606	−/−	−/−
≤4	0.986	0.805	−/−
>4	0.003 **	0.195	0.012 **

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