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The Effect of Population Growth on the Environment: Evidence from European Regions

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Abstract There is a long-standing dispute on the extent to which population growth causes environmental degradation. Most studies on this link have so far analyzed cross-country data, finding contradictory results. However, these country-level analyses suffer from the high level of dissimilarity between world regions and strong collinearity of population growth, income, and other factors. We argue that regional-level analyses can provide more robust evidence, isolating the population effect from national particularities such as policies or culture. We compile a dataset of 1062 regions within 22 European countries and analyze the effect from population growth on carbon dioxide (CO_2) emissions and urban land use change between 1990 and 2006. Data are analyzed using panel regressions, spatial econometric models, and propensity score matching where regions with high population growth are matched to otherwise highly similar regions exhibiting significantly less growth. We find a considerable effect from regional population growth on carbon dioxide (CO_2) emissions and urban land use increase in Western Europe. By contrast, in the new member states in the East, other factors appear more important.

Keywords Population growth · CO_2 emissions · Land use · NUTS-3 regions

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1 Introduction

Somewhere around 1990, the mood in Europe turned against limiting population growth. By the turn of the millennium, the dominant narrative had shifted from worries over "too many people" to worries over "too few people," highlighting the global divergence between negative European population trends and those of less developed states still experiencing significant growth. In 1983, a majority of 52% of Italians considered the recent dramatic drop in the total fertility rate to 1.4 children per women in their country to be "a good thing" (Palomba et al. 1998). Only 15% thought the Italian population should increase, while a large majority preferred either a decreasing (29%) or a stationary population (52%) (see ibid.). By 1995, this picture had changed considerably. According to Eurobarometer survey data, 40% of Italians now wanted their nation to grow, with less than 20% supporting a population decline (European Commission 1995). In the year 2000, according to the second wave of the "Population Policy Acceptance Study," only 8% of the respondents in 12 European countries preferred their respective populations to decrease, compared to 49% who favored an increase (Höhn et al. 2008). Rapid and intense population aging—and in many cases, shrinking—is partly responsible for this shift in European viewpoints on optimal population trends. Viewed in the context of Europe's environmental plans, however, desires for population increase might contradict those states' ambitious climate goals.

Primarily because of concerns over economic strains, the EU is scrambling to institute policies that soften the economic effects of population aging and decline on the size of the workforce (European Commission 2015). Yet, by 2020 the EU aims to reduce CO_2 emissions by 20% and achieve no new net urban land by 2050 (European Commission 2011). Can these population and environmental goals exist side by side? Has fear of "overpopulation" damaging the environment rightly been dismissed in Europe? To answer these questions we estimate the effect of population growth on two dimensions of environmental degradation in Europe, greenhouse gas (CO_2) emissions and urban land use, for 1062 European NUTS-3 regions.[1] We analyze CO_2 emissions and urban growth as outcomes in this paper since these factors are recognized as drivers of adverse climate change by both environmental research and EU policies. CO_2 emissions directly affect world climate, while urban growth can have (among other consequences) an additional effect on air pollution and carbon stock in soil and vegetation by soil sealing and increased vehicular traffic (see, e.g., De Ridder et al. 2008; Schulp et al. 2008).

Our results demonstrate that net population growth in Europe will undermine ambitious climate goals. While some cities and regions have been able to experience high or medium population growth and still reduce emissions, particularly in Western Europe, many regions have not. Reducing emissions of a growing population requires significant planning and investment. Contemporary population

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[1] The EU classifies its territory into four layers according to the *Nomenclature des Unités Territoriales Statistiques* (NUTS). The lowest level consists of NUTS-3 regions, designed to usually host between 150,000 and 800,000 people. France, for instance, consists of 100 NUTS-3 regions (départements), 20 NUTS-2 regions (régions), 8 NUTS-1 regions (groups of régions), and one NUTS-0 region (metropolitan France).

policies within EU member states are usually concerned with stimulating growth. Possible benefits for the environment accompanying low or negative population growth are rarely discussed in official documents (see, e.g., European Commission 2014).

In the European Union, fertility rates have been at or below replacement level for two or more decades in most countries and projections by the United Nations and others routinely expect Europe to shrink—the UN (2015) estimates Europe to lose 32,000 people by 2050. By contrast, Bijak et al. (2007) project the EU-27's population to remain constant by 2052 in their "base" scenario, while higher immigration rates could lead to an increase to 563 million people by mid-century, up from 504 million in 2015 and 482 million in 2000. Migration is incredibly difficult to predict, but we do know that migrants will conform to the general consumption behavior of where they move to, rather than retaining consumption patterns from where they came. And if we consider density instead of just total population, "depopulation" is not imminent for the EU. After all, with around 116 people per km^2, the EU's population density is more than twice the world's average and by far greater than the USA's (35/km^2), Africa's (36/km^2) and also Asia's (87/km^2). Despite a lower per capita consumption of natural resources than the USA, Canada, or Australia, densely populated European countries such as the Netherlands, Belgium, the UK, or Germany have a high ecological footprint, i.e., they consume a multitude of renewable resources compared to what their lands produce (Wackernagel and Rees 1996).

2 Theoretical Accounts on the Population–Environment Link

The relation between population and environmental degradation is often considered straightforward: More people should have a greater impact on the environment, if all other factors (such as per capita consumption) remain unchanged. As Laurie Mazur (2012, p. 2) writes, "if we increase by 30% by 2050, we must swiftly reduce our collective impact by a third just to maintain the disastrous status quo." The formal expression of this idea is the famous IPAT decomposition (Holdren and Ehrlich 1974), where humans' environmental impact (I) is conceived to be a product of population size (P), per capita affluence (A), and technology (T) per unit of affluence. IPAT is still frequently referred to in the scientific debate, in particular by critics of population–environment (P–E) studies (e.g., Angus and Butler 2011). However, researchers in this field have long acknowledged the limits of IPAT for empirical research. In many applications, T is simply a ratio of I and A, and thus, the relative impact of population growth cannot be empirically assessed (see, e.g., York et al. 2003). In addition, in its simplest form, IPAT neglects possible interactions between the right-hand side variables.

Problems with IPAT are less acute in its stochastic version known as STIRPAT (Dietz and Rosa 1997) which allows for over- or underproportional weights of the factors in the equation determined by empirical data. Unobserved variables or interactions lead to a large error term which informs the researcher that the model only partly captures what is going on in the real world. There are many mechanisms of environmental degradation that do not involve population size or growth (see, e.g., de Sherbinin et al. 2007 for an overview). In the following, we review theoretical arguments on the link between population and the two outcomes of interest in this paper: urban land use change and CO_2 emissions.

With regard to urban growth, Lambin et al. (2003, p. 224) list five “high-level causes” of land use change, only one of which specifically involves population growth. The other causal pathways focus on, among other factors, changing economic opportunities, policy interventions, and cultural change. In recent decades, cities such as Liverpool (the UK) or Leipzig (Germany) have experienced urban sprawl during periods of population decline (Couch et al. 2005). Many mechanisms driving urbanization of previously undeveloped land exist in the absence of population growth: Investors seek to build out-of-center retail facilities on cheaper building sites, and many families prefer detached houses in the “green” periphery (ibid.). This is particularly the case if income levels rise and households can afford larger homes (Patacchini et al. 2009). Commuting costs and public transport infrastructure in and around cities are also obvious determinants of how and where urban growth occurs (ibid.). Historical trajectories, local policies, and cultural preferences affect how compact or dispersed residential areas are built. For instance, European cities such as Barcelona are often contrasted against North American cities with a comparable population size, but a much larger urban area (e.g., Catalán et al. 2008). As an example of a more complex mechanism, urban growth into formerly suburban or rural areas can depend on whether socially deprived areas with high crime rates are more prominent in city centers (as is typical for North America) or in suburbs (as in many European cities, see Patacchini et al. 2009). Nevertheless, urban growth should ceteris paribus be stronger in the case of rapid population growth as compared with a stagnant population scenario. More people lead to a greater demand for accommodations and traffic—the question is whether this direct effect is empirically suppressed by other mechanisms as outlined above. Research mostly finds that population growth fosters urban land cover change, but there are geographical differences. In their meta-analysis, Seto et al. (2011) find that urban land expansion in India and Africa is mainly driven by population growth, while in China, North America, and Europe the main factor is GDP growth.

With regard to CO_2 emissions, there are also conflicting expectations in the literature. In general, few seem to doubt that a causal effect from human activity on the level of CO_2 emissions exists, mostly as a result of fossil energy combustion for purposes such as residential heating or transportation (e.g., de Sherbinin et al. 2007). Even though there are considerable differences in per capita consumption of energy, more humans ceteris paribus emit more CO_2. As O’Neill et al. (2012, p. 159) emphasize, if all other determinants of emissions and all relevant causal pathways are accounted for in a statistical model, “population can only act as a scale factor and its elasticity should therefore be 1.” However, the indirect effect of population growth via interactions and feedbacks with other variables remains often unclear. For instance, Simon (1993, 1994) famously assumed that while population growth might create shortages of resources, rising prices for goods made with those resources will motivate technological innovations (which are more likely to occur in large populations) and therefore, in the long run, “more people equals (…) a healthier environment” (Simon 1994, p. 22). Similar to the view put forward by Boserup (1965), technology is seen as endogenous to population growth (and positively affected by it). On the other hand, recent research suggests that more efficient technologies are paradoxically accompanied by an increase in energy consumption and thus emissions rise despite technological progress (York and McGee 2016). Empirically, most research finds that population growth is positively associated with CO_2 emissions increase (Bongaarts 1992; MacKellar et al. 1995; Dietz and Rosa 1997; Shi 2003; York et al. 2003; O’Neill et al. 2012; Liddle 2013). Against this body of research, critics point out that the bivariate correlation between population growth and emissions growth on the level of countries is zero or even negative (Satterthwaite 2009): Many countries marked by rapid population growth have low levels and low growth rates in emissions, and vice versa. This perspective suggests that differences in consumption levels caused by economic inequality, rather than population size or growth, are responsible for CO_2 emissions increase.

The biggest theoretical challenges to P–E research arguably lie in the insufficient knowledge about interactions and feedbacks between population, environment, and other factors. Most notably, population growth can interact with affluence. It is well established that fertility rates vary with factors such as socioeconomic modernity (e.g., Lutz and Qiang 2002), especially education (Schultz 1993), and human capital (Becker et al. 1990). According to the theory of demographic transition (Caldwell 1976; Dyson 2010), lower infant and child mortality rates (offset by higher affluence levels) are the primary cause of fertility decline (because humans have fewer children if they can expect more of them to survive). Due to a delay between the onsets of mortality and fertility decline, a population grows rapidly for a certain period and then stabilizes at a higher level. After fertility levels have dropped, a country can enjoy the “demographic dividend” (Bloom et al. 2003), as many young adults enter the workforce, but have fewer children to take care of. This change in age structure can also be accompanied by changing aspirations and preferences for accommodation (e.g., larger living space) and consumption, as has happened, for instance, in China in recent decades (Zhu and Peng 2012). Thus, in terms of IPAT, a decrease in P (or delta P) can cause an increase in A (and vice versa) and therefore halting population growth could possibly result in more environmental degradation rather than less.

In sum, most scholars agree that population size and growth have a *direct* effect on urban land cover and CO_2 emissions if all other factors are held constant. However, some authors argue that indirect effects—e.g., interactions and feedback processes with income or technology—typically compensate or even reverse the direct effect from population over time. We cannot solve this controversy in this paper. Instead, our research objective is to assess the total effect (i.e., direct and indirect effects) from population growth on the environment in Europe. The goal is to come to reasonable assumptions about what would happen if Europe’s population grew more or less rapidly. As described above, we use two operationalizations for environmental degradation: urban land use growth and CO_2 emissions.

2.1 Methodological Issues and Research Design

Contemporary P–E studies typically follow one of three types of approaches. The first approach focuses on an in-depth understanding of the causal pathway from P to E, including interactions and feedback with other factors. This approach often involves qualitative research, e.g., in the form of case studies of a particular country or region (e.g., Lutz et al. 2002; Gorrenflo et al. 2011). These studies can provide valuable insight for quantitative research with regard to how to model these direct and indirect effects. Yet, it is often difficult to generalize these qualitative findings on how population, policies, culture, and the economy interact in a specific setting to other countries or regions. The second approach quantitatively analyzes large (mostly cross-country) datasets with various statistical methods (for recent reviews see Hummel et al. 2013; Liddle 2014). These include linear regressions (Shi 2003; York et al. 2003) or more advanced econometric techniques for the analysis of panel data (Liddle 2013). They seek to attain generalizable knowledge of how P and E are usually correlated. Yet, different model specifications (with regard to how to deal with endogeneity or interaction effects) have produced different results in the past. Finally, a third approach uses simulations to arrive at different scenarios and predictions for future trends under varying assumptions. Simulations can either be done with macro-level models (e.g., Bongaarts 1992; O'Neill et al. 2010) or with bottom-up agent-based simulations, where household decisions, policy reactions, and feedback processes are modeled to study the emergent macro-level outcome (e.g., An et al. 2005). The validity of these predictions depends on how well the set of assumptions calibrating the simulations reflects reality, and they are commonly critiqued for excluding relevant variables and oversimplifying with regard to indirect effects and interactions. For instance, O'Neill et al. (2010) do not explicitly model any feedback effects from affluence or environment on population growth, which is why Angus and Butler (2011) refer to their models as "Malthus in, Malthus out."

One of the biggest methodological problems in global cross-country research is the high level of collinearity usually found for many socioeconomic, political, and other variables (Schrodt 2014). Many comparative studies in P–E research suffer from the dissimilarity of the observed cases with regard to nearly anything that might affect population, environment, or both. For instance, emission levels have increased considerably in developed countries such as France over the past century, whereas this increase has been only modest in developing countries such as Ethiopia. The opposite is true for population growth. Thus, the observed correlation between population growth and emissions change is negative, as pointed out by Satterthwaite (2009) and others. However, this can hardly lead to the conclusion that France's low population growth was causally responsible for the increase in emissions and a much higher population growth rate would have benefitted the environment. This is because France and Ethiopia also differ with regard to previous levels of population density and state of the environment as well as many other economic, technological, and other factors. A better approach could be to match France to a similar country that has experienced notably higher (or lower) rates of population growth and compare emission levels between the two countries. This could certainly provide a better foundation for a counterfactual scenario to determine what would happen if France's population grew more or less rapidly. There might just not be many countries that meet the requirements for such a design to provide us with a sample sufficiently large to conduct quantitative analyses.

We argue that a good way to find appropriate cases is to examine the sub-national level (as in, e.g., Cramer 2002). Regions within one country are affected by the same national policies and are usually highly similar with regard to many potentially relevant factors such as climate, culture, or technological standards. For instance, Siedentop and Fina (2012) find that country-specific drivers of urban land use are important beyond demographic and economic variables; this distinction cannot be made in global country-level analyses. We avoid a large number of potential fallacies if we compare population growth and environmental trends in two French regions as opposed to comparing France to Ethiopia.

It might seem counterintuitive to select contemporary Europe as the location to examine the effects of population growth. As is well known, Europe is the world region with by far the lowest growth rate. Empirical studies usually find a much stronger detrimental population effect on the environment on other continents (e.g., Seto et al. 2011; Liddle 2013). However, net population growth—whether through natural increase or migration—in higher-income European areas potentially has greater detrimental effects on the environment than does growth in a lower-income area because the average European inhabitant has such high consumption. Additionally, from a methodological perspective, European regions provide a good sample to study the effect of population change on greenhouse gas emissions and urban land use because population is growing in some European regions, while in others is stationary or declining. Europe also includes considerable variation with regard to changes in emissions and land use. At the same time, the broader demographic, socioeconomic, and political context is held constant to some extent—our sample includes only upper-middle-income countries so we can move beyond emphasis on consumption patterns that dominate discussions of population and environment at the global level, and can isolate population growth to see if it is still a relevant issue for environmental discussions in developed states. By contrast, previous studies have often compared countries at various stages of the demographic transition that are embedded in different socioeconomic and political contexts. This wide sample poses some serious methodological issues as well as a risk of misinterpreting the data. By analyzing sub-national regions, we can also achieve greater statistical power through a larger sample size.

All European countries have already completed the demographic transition, and fertility rates are at or below replacement level. Variation in population growth is therefore not rooted in different levels of human development or broad cultural values, factors that could also affect the environment. Even differences in fertility rates between urban and rural regions, which were prominent until the mid-twentieth century, have almost disappeared. For instance, in 1960, the total fertility rate (TFR) in Switzerland was below 2 in urban areas such as Geneva compared with 3.5 or more children per woman in several rural cantons; today in all cantons the TFR falls somewhere between 1.2 and 1.7 (Basten et al. 2012). Population growth in Europe today mainly depends on internal and external migration. Net migration into a region partly varies with economic factors, such as employment opportunities, as in, say, south–north movements within Italy. On the other hand, international migration, especially, is path dependent and networks often lead to spatial variation in inflows long after the original cause of the first migration wave is gone (see, e.g., Mayda 2010). Consider, for instance, that many immigrants in Europe came as workers in the 1960s and 1970s and clustered into industrial areas. Later, new immigrants continued to prefer these cities over other destinations because family members or other co-ethnics already live there, despite the decline in the heavy industry in cities such as Lille (France), Duisburg (Germany), or Malmö (Sweden), where employment or income levels are similar or even worse compared with other regions hosting fewer immigrants. It also seems reasonable to assume that migrants do not target specific cities or regions primarily due to their environmental quality. Thus, we can argue that population growth in European regions is at least partly exogenous to the other variables in the equation and therefore issues of endogeneity or unobserved interactions should be much smaller compared with global cross-country analyses.

2.2 Data and Statistical Models

Our dataset encompasses 1062 NUTS-3 regions within 22 countries where data were available for our main variables of interest.[2] All countries are EU member states. We analyze changes between two time points with regard to urban growth and CO_2 emissions. Data for urban growth come from the CORINE Land Cover (CLC) project, a satellite-based classification of land surface by the European Environmental Agency (2007), distributed by the European Spatial Planning Observation Network (ESPON 2012). We use the first and the third releases of CLC with reference years 1990 and 2006, respectively, and calculate the change in the proportion of land in a NUTS-3 region that is classified as “artificial surfaces” (CLC-1), i.e., urban fabric, industrial areas, transport, etc., between these years. For greenhouse gas emissions we use data from the Emission Database for Global Atmospheric Research (EDGAR), aggregated for European NUTS regions as part of the “Greener Economy” project by ESPON (2014). The dataset contains estimates for total CO_2 emissions from fossil fuel combustion (excluding emissions from organic carbon, large-scale biomass burning, aviation, and shipping, as these cannot be directly attributed to human activity within the region) for the years 2000 and 2008. Average annual population growth within the same time period is calculated using data from Eurostat (2015a).[3] We include regional data for per capita GDP and GDP growth (from Eurostat 2015b) in our models. A list of all variables with descriptive statistics is given in “Appendix.”

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[2] These countries are Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Hungary, Italy, Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, and Spain. For CO_2 emissions, no data were available for Croatia. As a result of a reform of regional boundaries in the German state of Saxony, most regions in Saxony are missing from the analysis (note the white area on the maps).

[3] For the models explaining urban growth which is measured between 1990 and 2006, population growth is averaged for this period. However, population data are not available for all regions since 1990 in the source dataset; for these regions the values refer to average population growth between the earliest available year since 1990 and 2008. Figure 1 displays average annual population growth rates between 2000 and 2008 for all regions.

How are trends in population growth, emissions, and urban land use connected to one another? In a first step, we use the total sample of regions. We specify a dynamic model where changes in environmental impact Δy_i (representing either urban land use or CO_2 emissions) in region $i = 1, \ldots, N$ are regressed on their level at the time of the previous observation ($y_{i,t-1}$).[4] Using changes rather than levels in the dependent variable reduces the problem of non-stationarity that likely exists when analyzing time-series data of autoregressive phenomena such as land use cover. This is relevant because non-stationary processes imply the risk of finding spurious correlations (Granger and Newbold 1974). In addition, the lagged dependent variable (LDV) $y_{i,t-1}$ captures the unobserved time-constant causes that led to differences between regions in the first place and also controls for a "Matthew effect." (Urban land cover change occurs more often in areas that are already highly urbanized.) Note that observations are not yearly, but refer to first and last years of the observed period (thus $T = 2$) due to data availability. For both population (p) and per capita GDP (a), we include lagged level as well as change over the observed time period. Total population and per capita GDP are log-transformed to account for skewed distributions. A squared term of GDP to test for an environmental Kuznets curve (see, e.g., Carson 2010) was tested, but dropped from the final models since there was no evidence for such a pattern in Europe. As an additional control, we include a dummy for coastal location (c) of a region. The regression parameters are denoted by β_0 to β_6, while ε_i is the regional-level error term. Model 1 reports an ordinary least squares (OLS) estimation based on the following equation:

$$\Delta y_i y_i = \beta_0 + \beta_1 y_{i(t-1)} + \beta_2 \Delta y_i p_i + \beta_3 p_{i(t-1)} + \beta_4 \Delta y_i a_i + \beta_5 a_{i(t-1)} + \beta_6 c_i + \varepsilon_i. \quad (1)$$

In a second model, we consider spatial autocorrelation: Regions are likely influenced by neighboring areas because of, e.g., commuter networks between regions, leading to a correlation in error terms among nearby regions. For instance, we can expect a rural region close to a city to develop differently in terms of urban land change and CO_2 emissions compared to an otherwise similar but remote rural region. These expectations are in line with previous research showing that, e.g., urban expansion is affected by surrounding land use (Huang et al. 2009). In our data, a test for spatial autocorrelation reveals significant amounts of spatial interdependence: Moran's I is .31 for urban land use change and .46 for CO_2 emissions change in our sample. Neighboring regions are defined by contiguity here, and a binary weight matrix is applied, where the value is 1 if regions are contiguous and 0 otherwise. We estimate a spatial lag model (see Ward and Gleditsch 2008; LeSage and Pace 2009), where a spatially lagged dependent variable is added to the model. In Eq. (2), the term Wy denotes the spatially lagged dependent variable together with weight matrix W.

$$\begin{aligned} \Delta y_i y_i = \beta_0 + \beta_1 Wy + \beta_2 y_{i(t-1)} + \beta_3 \Delta y_i p_i + \beta_4 p_{i(t-1)} + \beta_5 \Delta y_i a_i \\ + \beta_6 a_{i(t-1)} + \beta_7 c_i + \varepsilon_i. \end{aligned} \quad (2)$$

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[4] Since urban land use is measured as a percentage of total land use and therefore 0–1 bounded, we use the logit transformation on this variable.

As a robustness test, we also use a distance-based concept of neighborhood since this might better capture some drivers of spatial dependence in our dependent variables (such as commuting flows). In addition to the spatial lag model, we also estimate a spatial error model and a spatial lag model where the independent variables are lagged as well. These models can be found in "Appendix."

Next, we add a country-specific error term α_j which is allowed to correlate with the other predictors (equivalent to a set of M-1 dummy variables for country $j = 1, \ldots, M$).[5] These country fixed effects control for unobserved country-specific influences such as national environmental policies. The equation for Model 3 can accordingly be written as:

$$\begin{aligned}\Delta y_i = {} & \beta_1 W y_i + \beta_2 y_{i(t-1)} + \beta_3 \Delta y_i p_i + \beta_4 p_{i(t-1)} + \beta_5 \Delta y_i a_i \\ & + \beta_6 a_{i(t-1)} + \beta_7 c_i + \alpha_j + \varepsilon_i.\end{aligned} \tag{3}$$

Since regions in formerly communist Central-Eastern European countries may be more similar to each other than to Western European regions, we run the same analysis as in Model 3 separately in subsamples of only Western (Model 4) and only Eastern (Model 5) regions. We used base R for OLS regressions (R Core Team 2013) and the spdep package (Bivand and Piras 2015) for spatial models.

Finally, we preprocess the data using different matching algorithms (see, e.g., Ho et al. 2007). The idea is that for every region with high population growth, we find a region with a considerably lower growth rate, but otherwise highly similar characteristics. This type of "most similar case" design results in a more balanced sample and arguably gets us as close to identifying the population growth effect as it can get with this quasi-experimental study design. Around 10% of all regions ($N = 96$) in the sample have experienced population growth rates of 1% or more per year on average during the study period. These regions represent the "treatment" group. As reported below, this "treatment" is only weakly correlated with other predictor variables in the data and therefore issues of endogeneity appear to be of low salience. The control group consists of regions with less than 0.5% growth per year ($N = 815$). This cutoff value is chosen arbitrarily, though the results do not change significantly if we use a somewhat different threshold. We perform one-to-one nearest neighbor matching with a propensity score matching algorithm (Ho et al. 2007).[6]

The result leaves us with a sample of 96 high-growth and 96 most similar low-growth regions. We then compare the distributions of urban growth and change in CO_2 emissions between "treatment" and control cases. To deal with missing values we used multiple imputation, creating ten multiply imputed datasets with Amelia II software (Honaker et al. 2011). Matching and model estimation are performed in each of the datasets, and the results are averaged with Rubin's (1987) rules. (Note that 1029 out of 1062 cases have complete information, so missingness is not a major issue in our data.) An acceptable balance between the distributions of the variables in the two

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[5] A random effects model was initially considered (providing similar results to the fixed effects model), but a Hausman test suggested superiority of the fixed effects estimator. Since we are not interested in estimating country-level predictors, we went without random effects (or multilevel) models.

[6] Optimal matching and genetic matching were used as alternative algorithms. Since the results do not differ substantially, we only report the findings from propensity score matching here.

groups can be achieved with the algorithm. In the matched dataset for urban growth, both the high and the low population growth groups consist of predominantly Western European regions (93 vs. 91%), around half of them with a coastline (compared with 22% in the total sample). Per capita GDP averages at 27,500 Euros in the treatment group and 27,300 Euros in the control group (compared with 23,000 Euros in the total sample). Mean GDP growth rates are 4.0% over the observed period of time in both groups; only in terms of initial population size (652,000 vs. 548,000) the average values differ somewhat. For CO_2 emissions, balance is equally acceptable. Initial level of emissions (4400 tons vs. 4200 tons), per capita GDP (27,500 Euros vs. 27,600 Euros), GDP growth (4.0 vs. 4.1%), coastal location (49 vs. 52%), and location in Western Europe (93 vs. 91%) are very similar among the high and the low population growth groups. Again, initial population size (652,000 vs. 571,000) slightly differs. Some examples from the match tables: Madrid, Spain (high population growth), was matched with Rome, Italy (low population growth). The Irish South-East (high growth) was paired with South Jylland, Denmark (low growth). Dutch city of Utrecht (high growth) was matched with Salzburg, Austria (low growth), while the fast-growing Algarve in southern Portugal was paired with French department of Yvelines, where population growth was low.

3 Results

Figures 1, 2, and 3 show the regional variation in population growth, CO_2 emissions, and urban land use between the regions in our dataset. Population growth was highest in Spain and Ireland in the 2000s, as these two countries witnessed the largest increase in their immigrant populations (in percentage points), followed by Italy (see Fig. 1). For Germany and France, the 2000s was a decade of low net immigration, but France's major urban agglomerations still increased. Many Central-Eastern European countries had a net population loss, although not all regions; several populations in metro areas around cities such as Budapest, Prague, or Poznan increased. Urban growth, as Fig. 2 shows, is clearly related to the level of urbanization that was already present in a region. Artificial land use increased strongest in the already highly densely populated regions in the Netherlands and West Germany, along the Spanish, Portuguese, and French coastlines and in their respective capital regions, around the Irish and Danish capitals, in the tourist hotspots of Tyrol and in the industrial centers of northern Italy and Polish Silesia and capital region. The amount of soil sealing (destruction of soil due to urbanization construction, such as buildings) of farmland, pasture, or forests was rather low in many rural regions, in the Baltics and Balkans, or in inland France and Spain, apart from their capitals. There are observable differences in CO_2 emissions between countries and regions, too (see Fig. 3). Emissions grew strongly in the Baltic countries and in many parts of Ireland, Spain, and Bulgaria. By contrast, Denmark, Germany, and the Czech Republic largely reduced the emission of CO_2.

Tables 1 and 2 show the regression results using the full dataset with urban land change (Table 1) and CO_2 emissions change (Table 2) as the respective dependent variables. Table 1 confirms that population growth is positively correlated with urban

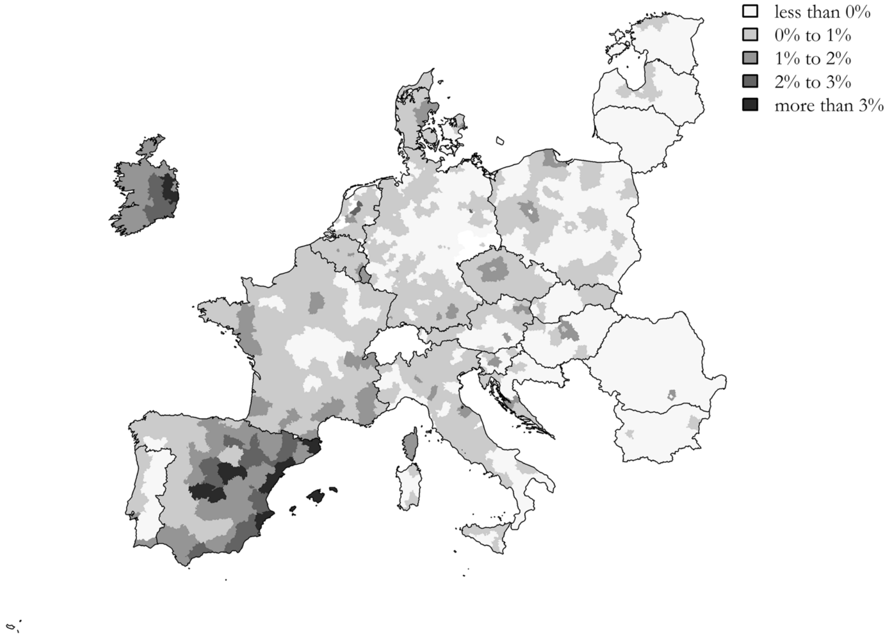

Fig. 1 Population growth in 20 European countries, 2000–2008, average annual rate

growth. This effect holds when spatial autocorrelation (Model 2) and country-level fixed effects (Model 3) are taken into account, while the effect of GDP vanishes. When East and West are differentiated, a fairly strong positive effect for population growth is shown to exist in the West, while this effect is insignificant in the East. By contrast, urban growth is strongly determined by regional per capita GDP in the formerly communist countries, while affluence has no impact in the West.

The pattern is similar for CO_2 emissions (see Table 2). One additional percentage point of annual population growth is associated with 2.5 additional kilotons CO_2 emitted between 2000 and 2008 in Western Europe. In the East, however, there is no significant correlation between population and emissions change. Rather, the interesting finding here is that the lagged value of CO_2 emissions is negatively related to its increase. This finding means emissions grow stronger in Eastern regions where the level has previously been low, indicating that these regions seem to “catch up” in terms of CO_2 emissions. These emissions are not related to economic activity, however, since the coefficient for GDP growth is negative in all models where country-specific differences are controlled for.

Our data lend some support for the argument that population growth in European regions is partly exogenous to other variables in question, where on the level of Western European regions, population growth between 2000 and 2008 is only weakly correlated with per capita GDP in 2000 ($r = .10$) and even negatively with GDP growth ($r = -.19$) for the observed period. Note, however, that in Eastern Europe, the correlation between regional per capita GDP in 2000 and population growth between 2000 and 2008 is considerably stronger ($r = .41$) than in the West

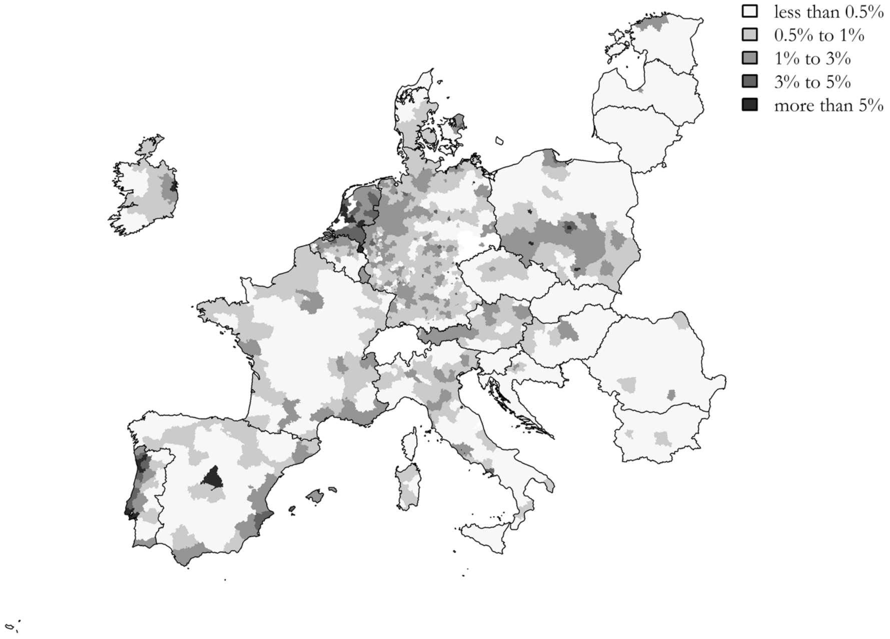

Fig. 2 Urban land use change in 20 European countries, 1990–2006

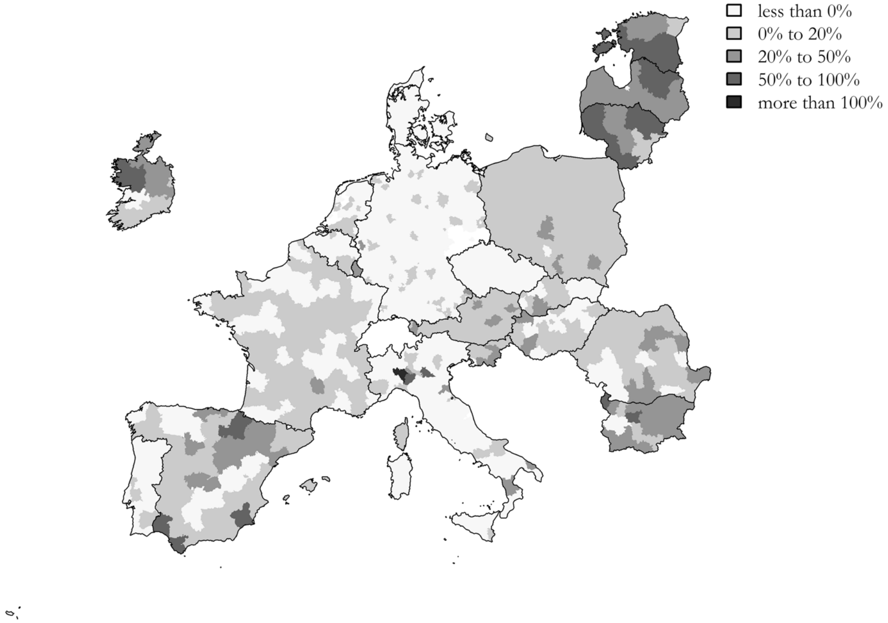

Fig. 3 CO2 emissions change in 19 European countries, 2000–2008

(while for GDP growth, the coefficient is also weak and negative (− .18)). This might indicate that in Eastern Europe, population growth is endogenous to wealth to some extent, probably as a result of intra-national (e.g., rural–urban) migration, as international migration only played a minor role in most Eastern countries during the period under study.

It is also instructive to compare the effect of per capita GDP between models with (Model 3) and without (Models 1 and 2) country-specific errors in Table 2. Judging from Model 1, we would assume a strong negative relationship between GDP and CO_2 emissions in Europe. This could be interpreted as showing that European regions are beyond the turning point on an environmental Kuznets curve, and the higher the affluence, the cleaner the regions with regard to emissions. These differences can entirely be attributed to the country level, however, and disappear once the country level is included. Thus, it seems as if the more affluent countries have made greater efforts to reduce emissions, but *within* countries there is no such relationship. These differences point to a possible interaction between

Table 1 Predictors of urban growth as a percentage of total land use (logit-transformed) in 1062 European NUTS-3 regions between 1990 and 2006, all regions and by location in Eastern or Western Europe

	Method/sample				
	OLS	Spatial lag	Spatial lag with country fixed effects		
	All regions (1)	All regions (2)	All regions (3)	Only Western Europe (4)	Only Eastern Europe (5)
Constant	− .051 (.124)	.217* (.104)	.176 (.137)	.233 (.155)	− .274 (.222)
Urban land use in 1990	− .080***(.004)	− .044*** (.004)	− .049*** (.005)	− .056*** (.005)	− .028** (.009)
Log (population size in 2000)	− .006 (.005)	− .019*** (.005)	− .011* (.005)	− .009 (.005)	− .007 (.014)
Annual population growth rate	.057*** (.006)	.052*** (.005)	.039*** (.005)	.042*** (.006)	.014 (.012)
Log (GDP per capita)	.041*** (.009)	.015(.008)	.022 (.012)	.017 (.014)	.050* (.024)
GDP growth	.0002 (.002)	.002 (.001)	.004* (.002)	.003 (.003)	.003 (.002)
Coastline	.028* (.011)	.042*** (.009)	.011 (.009)	.008 (.010)	.021 (.018)
Country fixed effects	No	No	Yes	Yes	Yes
Observations	1062	1054	1054	822	232
Adjusted R^2	.365				
Spatial coefficient Rho		.096	.027	.012	.114
Akaike Inf. Crit.		− 1521.82	− 1945.38	− 1505.37	− 493.96

Cells show unstandardized coefficients with standard errors in parentheses. *$p < .05$ **$p < .01$ ***$p < .001$

Table 2 Predictors of change in CO_2 emissions (in kilotons) in 1033 European NUTS-3 regions between 2000 and 2008, all regions and by location in Eastern or Western Europe

	Method/sample				
	OLS	Spatial lag	Spatial lag with country fixed effects		
	All regions	All regions	All regions	Only Western Europe	Only Eastern Europe
	(1)	(2)	(3)	(4)	(5)
Constant	36.404* (14.323)	29.708* (13.306)	13.515 (14.374)	.621 (15.749)	85.952** (30.258)
CO_2 emissions in 2000	− 2.915***(.597)	− 2.232*** (.552)	− .908 (.503)	.339 (.560)	− 5.375*** (1.047)
Log (population size in 2000)	4.707*** (.930)	2.928***(.862)	1.162 (.879)	− .087 (.951)	.152 (2.480)
Annual population growth rate	3.581*** (.654)	2.962*** (.607)	1.920** (.648)	2.484*** (.704)	.474 (1.888)
log(GDP per capita)	− 7.584*** (.962)	− 5.097*** (.923)	− .337 (1.350)	1.399 (1.498)	− 2.136 (3.225)
GDP growth	.603*** (.169)	.350* (.157)	− 1.174*** (.232)	− .793* (.334)	− .820* (.342)
Coastline	− 1.341 (1.199)	− 1.771 (1.106)	− 3.725*** (1.070)	− 3.286** (1.129)	− 3.570 (3.039)
Country fixed effects	No	No	Yes	Yes	Yes
Observations	1033	1033	1033	822	211
Adjusted R^2	.185				
Spatial coefficient Rho		.079	.002	.001	.005
Akaike Inf. Crit.		8407.40	8070.84	6390.61	1650.31

Cells show unstandardized coefficients with standard errors in parentheses. *$p < .05$ **$p < .01$ ***$p < .001$

socioeconomic prosperity and country-level policies, while dismissing a direct negative effect from affluence on emissions. A research design restricted to cross-country comparison likely fails to differentiate the effects of this sort.

Finally, results from the preprocessed sample using propensity score matching are shown in Figs. 4 and 5. Figure 4 displays differences in urban land take between regions with high population growth compared with a control group of otherwise most similar regions but where population growth was small or zero. Again, high population growth regions show a significantly larger increase in urban fabric compared with regions of similar size, affluence, and income growth, but with lower population growth. Urban land use increased at a mean rate which was more than twice as high in the high population growth regions compared with the control group. With regard to CO_2 emissions, the differences are similarly large (see Fig. 5). While regions with low to medium population growth have on average kept their level between 2000 and 2008, similar regions with higher population growth increased emissions by more than 10%.

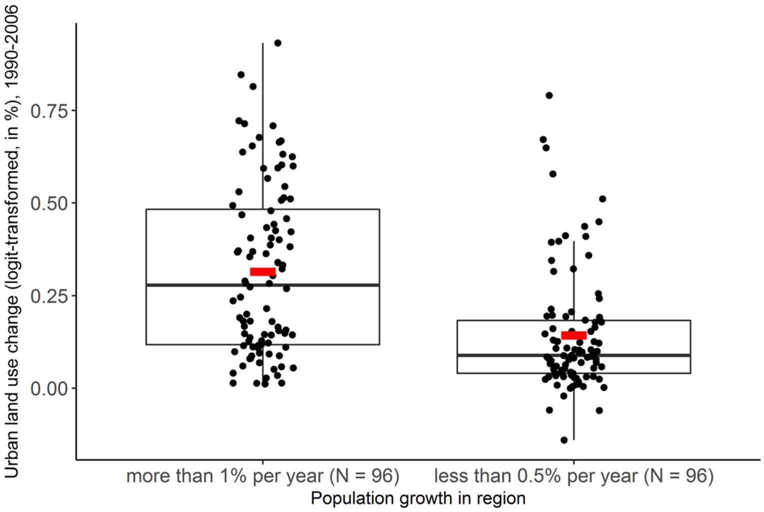

Fig. 4 Urban land use change in European regions with high population growth and matched control group with low growth (red mark = mean). *Note* Thick black lines denote the median, box limits are 25th and 75th percentile, respectively, red marks are mean values, and jitter points are regions (*N* = 96 in high population growth group and *N* = 96 in control group). (Color figure online)

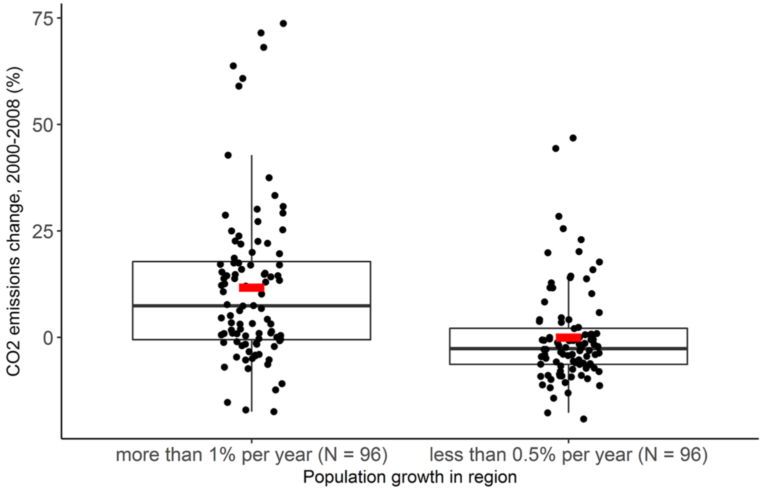

Fig. 5 CO2 emissions change in European regions with high population growth and matched control group with low growth (red mark = mean). *Note* Thick black lines denote the median, box limits are 25th and 75th percentile, respectively, red marks are mean values, and jitter points are regions (*N* = 96 in high population growth group and *N* = 96 in control group). (Color figure online)

The significant population effect remains if we run multivariate models on this reduced sample where the other covariates are taken into account.

So how are some European regions with high population growth able to achieve low CO_2 emissions? The city of Brussels, which put ambitious climate policies in place in 2004, provides one such example. The city set a specific target to reduce CO_2 emissions by 40% per capita by 2025, partly through high energy and air quality standards. Although population is growing, the city aims to improve air quality by encouraging public transportation and reducing car traffic by 20% from 2001 to 2018 (European Union 2016).

East Jylland provides another example. East Jylland forms the eastern portion of the continental portion of Denmark, north of Germany. The largest city in East Jylland is Arhus, which is considered the economic, trading, and cultural hub of both Jylland and Denmark (outside of Copenhagen). In 2008 and 2009, Arhus was named one of the six "Eco Cities" by the Danish Ministry of Climate and Energy—a scheme "developed in order to acknowledge cutting-edge cities and to inspire other local authorities to make increased efforts in the field of climate and energy" (Rasmussen and Christensen 2010, p. 217). As a "cutting-edge" city in developing clean energy alternatives and fighting global warming, local officials in Arhus in 2007 committed the city to being CO_2 neutral by 2030 (ibid.). Arhus was also the first city to monitor and map its CO_2 emissions and to develop a "CO_2 calculator," which is now used across Europe. The city's current eco plan "consists of several generations of climate plans reaching towards 2030" (City of Aarhus 2016). The primary legs of these plans consist of: developing an extensive and efficient light rail, committing public funds to increasing the size of local forests and wetlands, improving biking accessibility and safety, improving the municipality's heating system (which is derived from the local incineration plant), planning and implementing flood prevention plans, increasing public knowledge of and funding for housing energy efficiency, and finally, increasing public knowledge and public–private partnerships. In direct public spending on these goals, local authorities have committed over 72 million Euros. However, the actual sum is much larger when you take into account government subsidies for energy efficiency improvements, investments in current energy infrastructure, and public–private partnerships. These investments are paying off. For example, improvements to the city's incinerator/zero-carbon energy producer have decreased CO_2 output by 60,000 tons per year, while investments into reforestation will begin absorbing nearly 14 tons of CO_2 annually (City of Aarhus 2016).

Hamburg, in northern Germany, is a case of low population growth and low emissions. With around 1.7 million inhabitants, Hamburg is one of the European Union's largest cities and its population grew at a modest 0.48% per annum during the study period. The city won the European Union's award for "Europe's Green Capital" in 2011. Rather than expanding outwards, Hamburg is focusing on redeveloping formerly industrial areas (brownfields), such as HafenCity, Hamburg, which sits on 388 acres and is slated to add 5500 homes, commercial areas, green space, offices, schools—including a university—and daycare, all following the city's green building standards. Hamburg's "urban densification" efforts, as opposed to urban sprawl, prevent the city's ecological footprint from spreading outward, potentially converting rural lands into suburban areas (Benfield 2011). Hamburg's city leaders have made raising awareness about air quality among its residents a priority and have "ambitious climate protection goals" that aim to reduce Hamburg's CO_2 emissions by 40% by 2020 and by 80% by 2050. Investments in energy-saving measures in public buildings are partly responsible for reducing the per capita emissions by 15% against 1990 (European Commission 2009).

Finally, Dublin, which has similar characteristics to Hamburg in terms of per capita income and other variables in our dataset, illustrates the environmental consequences possible with high population growth (1.51% during the period of study). With a growing population and growing emissions, Dublin, Ireland, does not represent the typical trend in European environmental standards. Between 1990 and 2006, Dublin's annual emissions increased by almost 15,000 kilotons (CO_2). The majority of that increase in emissions came from the rapidly increasing transport and residential sectors as a result of the transportation and housing demands of Dublin's burgeoning population. In fact, the transport sector has shown an increase of 165% from 1990 to 2006 (Environmental Protection Agency 2006). In addition, the Environmental Protection Agency projects Ireland will fail to meet its obligations under the EU emissions reduction agreement by 2020 (ibid). As a solution to Dublin's growing population and rising emissions, the Dublin City Council's 2016–2022 Development Plan proposes redeveloping "vacant, derelict, and under-used lands with a focus on areas close to public transport corridors as well as areas of under-utilized physical and social infrastructure." The city council also recognizes the importance of green infrastructure and has identified it as significantly contributing "in the areas of development management, climate change and environmental risk management" (Dublin City Council 2016).

4 Conclusion and Discussion

Bookchin (1996, p. 30) suggests that "[t]he 'population problem' has a Phoenix-like existence: it rises from the ashes at least every generation and sometimes every decade or so." But this is also true about the "depopulation problem," which has recurred periodically over the last centuries (see Teitelbaum and Winter 1985). Both Malthusian (abundance of population is bad) and "cornucopian" (abundance of population is good) ideas are found in writings throughout recorded history (see, e.g., Schumpeter 1954, pp. 250–251; Spengler 1998, pp .4–5). Today, worries about "too few" instead of "too many people" seem to dominate the European discourse (Coole 2013). Trends in public discourse may or may not reflect empirical evidence on the topic. The question of whether population growth is harmful for the environment cannot be solved by solely looking at the discourse. The fact alone that people (perhaps unfoundedly) warned of "overpopulation" at times when world population was 0.2 billion (Plato), 1.0 billion (Malthus) or 3.5 billion (Ehrlich 1968) does not prove that any further increases from today's 7 billion will necessarily come without further adverse consequences.

Population growth affects the environment in Europe: This is what our regional-level analysis of changes in urban land growth and CO_2 emissions indicates. However, we find significant differences between Western and Eastern Europe. In the West, regions with population growth are clearly experiencing both more urban growth as well as a greater increase in CO_2 emissions compared with stationary or shrinking regions. This suggests that population acts as a scale factor for environmental degradation in the West, as proponents of IPAT have argued. In the East, however, where population is mostly decreasing, there is no such correlation. Instead, urban growth in Eastern Europe seems to have more to do with affluence, and emissions have grown strongest in those regions where they have previously been low.

Many Western European regions are expected to experience population growth in the coming decades, mostly due to internal population shifts and international immigration. Immigration from non-European countries has clearly been one of the most salient political topics in recent years and will likely continue to be in the near future. However, it is also a strongly polarizing topic that has triggered schisms among many environmentalists (Huang 2012). Some have pointed out that, on a global level, migration is a zero-sum game and therefore world population growth matters, not changes in its spatial distribution (e.g., Mazur 2012). Others have shown that an individual's environmental footprint grows after moving to a developed country (e.g., Conca et al. 2002). This argument obviously only holds if the unequal distribution of wealth and pollutants is assumed to persist. In any case, there are no reasons to believe that for a specific ecosystem under pressure from human population growth, it matters whether the additional people were born within some specific borders or somewhere else. And global environmental problems can certainly not be solved by limiting immigration to Europe. However, the empirical evidence suggests that future population growth as a result of immigration will make it harder for the European Union to achieve its climate goals.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix

See Tables 3, 4, and 5.

Table 3 Descriptive statistics

Variable	Definition	*N*	Mean	SD	Min	Max
Urban_1990	Urban fabric as percentage of total land use in 1990	1090	10.76	14.12	0.08	97.68
Urban_2006	Urban fabric as percentage of total land use in 2006	1090	11.77	14.70	0.17	97.68
CO_2_2000	CO_2 emissions from fossil fuel combustion in thousand tons in the year 2000	1047	2982.09	4513.23	0	42,54
CO_2_2008	CO_2 emissions from fossil fuel combustion in thousand tons in the year 2008	1047	3021.10	4563.45	0	41,71
Urban_change	Growth in urban fabric between 1990 and 2006 in percentage points	1089	1.02	1.47	− 4.99	12.66

Table 3 continued

Variable	Definition	*N*	Mean	SD	Min	Max
CO_2_change	Growth in CO_2 emissions between 2000 and 2008 in kilotons	1043	1.80	16.51	− 36.38	202.27
pop_2000	Population size in 2000	1062	376,602	437,562	9970	5953,550
pop_growth	Mean annual population growth in % between 2000 and 2008	1062	0.14	0.84	− 2.27	6.08
gdp_pc	Per capita gross domestic product in 2000	1068	22,979.78	12,099.12	2.40	84,40
gdp_growth	Total GDP growth between 2000 and 2008	1066	4.64	3.485	− 3.21	26.87
Coastline	Region has coastline (1) or is landlocked (0)	1090	0.21	0.41	0	1

Table 4 Determinants of urban land growth in European NUTS-3 regions (additional spatial model specifications)

	Method/weight matrix					
	Spatial lag model		Spatial error model		Spatial lag with lagged independent variables	
	Contiguity (1)	Distance (2)	Contiguity (3)	Distance (4)	Contiguity (5)	Distance (6)
Constant	.217* (.104)	− .050 (.117)	− .152 (.115)	.005 (.120)	− .154 (.120)	− .067 (.120)
Urban land use in 1990	− .044*** (.004)	− .086*** (.004)	− .074*** (.004)	− .081*** (.005)	− .076*** (.005)	− .090*** (.005)
Log (population size in 2000)	− .019*** (.005)	.005 (.005)	.00001 (.005)	− .009 (.006)	.003 (.005)	− .001 (.006)
Annual population growth rate	.052*** (.005)	.061*** (.006)	.058*** (.005)	.064*** (.006)	.059*** (.005)	.070*** (.006)
Log (GDP per capita)	.015 (.008)	.025** (.009)	.044***	.038*** (.009)	.043*** (.010)	.034*** (.009)
GDP growth	.002 (.001)	.0002 (.001)	.001 (.001)	.0004 (.001)	.001 (.002)	.001 (.001)
Coastline	.042*** (.009)	.030** (.010)	.018 (.010)	.017 (.011)	.016 (.010)	.006 (.012)
Observations	1054	1054	1054	1054	1054	1054
Spatial coefficient Rho	.096	.049			.131	.049
Akaike Inf. Crit.	− 1521.820	− 1297.133	− 1713.322	− 1303.096	− 1707.262	− 1336.125

Cells show unstandardized coefficients with standard errors in parentheses. $*p < .05$ $**p < .01$ $***p < .001$

Table 5 Determinants of CO_2 emission change in European NUTS-3 regions (additional spatial model specifications)

	Method/weight matrix					
	Spatial lag model		Spatial error model		Spatial lag with lagged independent variables	
	Contiguity (1)	Distance (2)	Contiguity (3)	Distance (4)	Contiguity (5)	Distance (6)
Constant	29.708* (13.306)	36.815** (13.982)	53.759*** (14.600)	38.682** (14.296)	53.201*** (15.915)	44.510** (14.273)
Log (CO_2 emissions in 2000)	− 2.232*** (.552)	− 2.817*** (.585)	− 2.149*** (.577)	− 2.996*** (.600)	− 1.906** (.586)	− 2.677*** (.599)
Log (population size in 2000)	2.928*** (.862)	4.057*** (.908)	2.678** (.930)	3.974*** (.953)	1.933* (.947)	2.638** (.981)
Annual population growth rate	2.962*** (.607)	3.264*** (.640)	3.481*** (.677)	3.234*** (.662)	3.302*** (.703)	2.557*** (.673)
Log (GDP per capita)	− 5.097*** (.923)	− 6.787*** (.943)	− 7.228*** (1.073)	− 6.715*** (.991)	− 6.361*** (1.294)	− 5.619*** (1.017)
GDP growth	.350* (.157)	.605*** (.165)	.576** (.187)	.629*** (.167)	.532* (.214)	.650*** (.169)
Coastline	− 1.771 (1.106)	− 1.570 (1.171)	− 3.304** (1.275)	− 1.550 (1.262)	− 4.520*** (1.369)	− 1.013 (1.355)
Observations	1033	1033	1033	1033	1033	1033
Spatial coefficient Rho	.079	.044			.077	.038
Akaike Inf. Crit.	8407.397	8499.164	8409.230	8498.734	8400.406	8480.008

Cells show unstandardized coefficients with standard errors in parentheses. *$p < .05$ **$p < .01$ ***$p < .001$

References

An, L., Lindermann, M., Qi, J., Shortdridge, A., & Liu, J. (2005). Exploring complexity in a human-environment system: An agent-based spatial model for multidisciplinary and multiscale integration. *Annals of the Association of American Geographers, 95*(1), 54–79.

Angus, I., & Butler, S. (2011). *Too many people? Population, immigration, and the environmental crisis*. Chicago, IL: Haymarket.

Basten, S., Huinink, J., & Klüsener, S. (2012). Spatial variation of sub-national fertility trends in Austria, Germany and Switzerland. *Comparative Population Studies, 36*(2–3), 615–660.

Becker, G. S., Murphy, K. M., & Tamura, R. (1990). Human capital, fertility, and economic growth. *Journal of Political Economy, 98*(5), S12–S37.

Benfield, K. (2011). How Hamburg became Europe's Greenest City. Citylab. Accessed 1 Apr 2016.

Bijak, J., Kupiszewska, D., Kupiszewski, M., Saczuk, K., & Kicinger, A. (2007). Population and labour force projections for 27 European countries, 2002–2052: Impact of international migration on population ageing. *European Journal of Population, 23,* 1–31.

Bivand, R., & Piras, G. (2015). Comparing implementations of estimation methods for spatial econometrics. *Journal of Statistical Software, 63*(18), 1–36.

Bloom, D. E., Canning, D., & Sevilla, J. (2003). *The demographic dividend. A New Perspective on the Economic Consequences of Population Change*. Santa Monica: RAND.

Bongaarts, J. (1992). Population growth and global warming. *Population and Development Review, 18*(2), 299–319.

Bookchin, M. (1996). *Which way for the ecology movement?*. San Francisco, CA: AK Press.

Boserup, E. (1965). *The condition of agricultural growth*. London: Allen & Unwin.

Caldwell, J. C. (1976). Toward a restatement of demographic transition theory. *Population and Development Review, 2*(3/4), 312–366.

Carson, R. T. (2010). The environmental Kuznets curve: Seeking empirical regularity and theoretical structure. *Review of Environmental Economics and Policy, 4*(1), 3–23.

Catalán, B., Saurí, D., & Serra, P. (2008). Urban sprawl in the Mediterranean? Patterns of growth and change in the Barcelona Metropolitan Region 1993–2000. *Landscape and Urban Planning, 85*(3), 174–184.

City of Aarhus (2016). Aarhus CO_2 neutral in 2030. https://stateofgreen.com/files/download/135. Cited 1 April 2016.

Conca, K., Princen, T., & Maniates, M. F. (2002). *Confronting consumption*. Cambridge, MA: The MIT Press.

Coole, D. (2013). Too many bodies? The return and disavowal of the population question. *Environmental Politics, 22*(2), 195–215.

Couch, C., Karecha, J., Nuissl, H., & Rink, D. (2005). Decline and sprawl: An evolving type of urban development–observed in Liverpool and Leipzig. *European Planning Studies, 13*(1), 117–136.

Cramer, J. (2002). Population growth and local air pollution: Methods, models, and results. *Population and Development Review, 28*(Supplement), 22–52.

De Ridder, K., Lefebre, F., Adriaensen, A., Arnold, U., Beckroege, W., Bronner, C., et al. (2008). Simulating the impact of urban sprawl on air quality and population exposure in the German Ruhr area. Part II: Development and evaluation of an urban growth scenario. *Atmospheric Environment, 42,* 7070–7077.

De Sherbinin, A., Carr, D., Cassels, S., & Jiang, L. (2007). Population and Environment. *The Annual Review of Environment and Resources, 32,* 5.

Dietz, T., & Rosa, E. A. (1997). Effects of population and affluence on CO_2 emissions. *Proceedings of the National Academy of Sciences of the USA, 94,* 175–179.

Dublin City Council. (2016). *Dublin City development plan 2016–2022 written statement* (Vol. 1). Dublin: Dublin City Council.

Dyson, T. (2010). *Population and development: The demographic Transition*. London/New York: Zed Books.

Ehrlich, P. R. (1968). *The population bomb*. New York: Sierra Club/Ballantine Books.

Environmental Protection Agency (2006). Ireland's Greenhouse Gas Emissions in 2006. Count Wexford: Environmental Protection Agency.

European Commission (1995). Eurobarometer 44.0. INRA, Brussels. GESIS Data Archive, Cologne. ZA2689 Data file Version 1.0.1. https://doi.org/10.4232/1.10916.

European Commission (2009). Environment: Stockholm and Hamburg win first European Green Capital awards. Brussels, European Commission 23 Feb.

European Commission. (2011). *Roadmap to a resource efficient Europe, Communication COM (2011) 571 of 20 September 2011*. Brussels: European Commission.

European Commission. (2015). *The 2015 ageing report: Economic and budgetary projections for the 28 EU Member States (2013–2060)*. Brussels: European Commission.

European Environmental Agency. (2007). *CLC2006 technical guidelines. EEA Technical report No 17/2007*. Luxembourg: Office for Official Publications of the European Communities.

European Spatial Planning Observation Network (2012). Corine land cover, third level of the nomenclature (CLC_AGG3). http://database.espon.eu/db2. Cited 9 March 2015.

European Spatial Planning Observation Network (2014). CO_2 emissions from ground transport. http://database.espon.eu/db2. Cited 11 March 2015.

European Union (2016). Brussels. http://ec.europa.eu/environment/europeangreencapital/winning-cities/previous-finalists/brussels/index.html. Cited 1 April 2016.

Eurostat (2015a). Population on 1 January by broad age group, sex and NUTS 3 region (demo_r_pjanaggr3). http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_r_pjanaggr3&lang=en. Cited 17 March 2015.

Eurostat (2015b). Gross domestic product (GDP) at current market prices by NUTS 3 regions (nama_r_e3gdp). http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_r_e3gdp&lang=en. Cited 13 March 2015.

Gorrenflo, L. J., Corson, C., Chomitz, K. M., Harper, G., Honzák, M., & Özler, B. (2011). Exploring the association between people and deforestation in Madagascar. In R. P. Cincotta & L. J. Gorenflo (Eds.), *Human population: Its influences on biological diversity*. Berlin/ Heidelberg: Springer.

Granger, C. W., & Newbold, P. (1974). Spurious regressions in econometrics. *Journal of Econometrics, 2*(2), 111–120.

Ho, D. E., Imai, K., King, G., & Stuart, E. A. (2007). Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference. *Political Analysis, 15*(3), 199–236.

Höhn, C., Avramov, D., & Kotowska, I. E. (Eds.). (2008). *People, Population Change and Policies. Lessons from the Population Policy Acceptance Study: Demographic knowledge—gender—ageing. Data CD-ROM* (Vol. 2). Berlin: Springer.

Holdren, J. P., & Ehrlich, P. R. (1974). Human population and the global environment: Population growth, rising per capita material consumption, and disruptive technologies have made civilization a global ecological force. *American Scientist, 62*(3), 282–292.

Honaker, J., King, G., & Blackwell, M. (2011). Amelia II: A program for missing data. *Journal of Statistical Software, 45*(7), 1–47.

Huang, P. (2012). Over-breeders and the population bomb. the reemergence of nativism and population control in anti-immigration policies. In L. Mazur (Ed.), *A pivotal moment. Population, justice, and the environmental challenge*. Washington, D.C./Covelo (CA): Island Press.

Huang, B., Zhang, L., & Wu, B. (2009). Spatiotemporal analysis of rural–urban land conversion. *International Journal of Geographical Information Science, 23*(3), 379–398.

Hummel, D., Adamo, S., de Sherbinin, A., Murphy, L., Aggarwal, R., Zulu, L., et al. (2013). Inter-and transdisciplinary approaches to population–environment research for sustainability aims: A review and appraisal. *Population and Environment, 34*(4), 481–509.

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources, 28*(1), 205–241.

LeSage, P., & Pace, R. (2009). *Introduction to spatial econometrics*. London/New York: CRC Press.

Liddle, B. (2013). Population, affluence, and environmental impact across development: evidence from panel cointegration modeling. *Environmental Modelling and Software, 40,* 255–266.

Liddle, B. (2014). Impact of population, age structure, and urbanization on carbon emissions/energy consumption: evidence from macro-level, cross-country analyses. *Population and Environment, 35*(3), 286–304.

Lutz, W., & Qiang, R. (2002). Determinants of human population growth. *Philosophical Transactions of the Royal Society of London B: Biological Sciences, 357*(1425), 1197–1210.

Lutz, W., Scherbov, S., Prskawetz, A., Dworak, M., & Feichtinger, G. (2002). Population, natural resources, and food security: Lessons from comparing full and reduced-form models. *Population and Development Review, 28,* 199–224.

MacKellar, F. L., Lutz, W., Prinz, C., & Goujon, A. (1995). Population, households, and CO_2 emissions. *Population and Development Review*, *21*(4), 849–865.

Mayda, A. M. (2010). International migration: A panel data analysis of the determinants of bilateral flows. *Journal of Population Economics, 23,* 1249–1274.

Mazur, L. (2012). Introduction. In L. Mazur (Ed.), *A pivotal moment. Population, justice, and the environmental challenge*. Washington, D.C./Covelo (CA): Island Press.

O'Neill, B. C., Dalton, M., Fuchs, R., Jiang, L., Pachauri, S., & Zigova, K. (2010). Global demographic trends and future carbon emissions. *Proceedings of the National Academy of Sciences, 107*(41), 17521–17526.

O'Neill, B. C., Liddle, B., Jiang, L., Smith, K. R., Pachauri, S., Dalton, M., et al. (2012). Demographic change and carbon dioxide emissions. *The Lancet, 380*(9837), 157–164.

Palomba, R., Menniti, A., & Mussino, A. (1998). Attitudes towards demographic trends and policy. *European Journal of Population, 4,* 297–313.

Patacchini, E., Zenou, Y., Henderson, J. V., & Epple, D. (2009). Urban sprawl in Europe. Brookings-Wharton Papers on Urban Affairs (pp. 125–149).

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org. Cited 30 September 2013.

Rasmussen, U.V. & Christensen, A.M.H. (2010). Danish EcoCities: Six cutting-edge climate and energy cities. In *2010 aceee summer study on energy efficiency in buildings*. http://aceee.org/files/proceedings/2010/data/papers/2264.pdf. Cited 1 April 2016.

Rubin, D. B. (1987). *Multiple Imputation for Nonresponse in Surveys*. Hoboken, NJ: Wiley.

Satterthwaite, D. (2009). The implications of population growth and urbanization for climate change. *Environment and Urbanization, 21*(2), 545–567.

Schrodt, P. A. (2014). Seven deadly sins of contemporary quantitative political analysis. *Journal of Peace Research, 51*(2), 287–300.

Schulp, C. J., Nabuurs, G. J., & Verburg, P. H. (2008). Future carbon sequestration in Europe—effects of land use change. *Agriculture, Ecosystems & Environment, 127*(3), 251–264.

Schultz, T. P. (1993). Returns to women's education. In E. M. King & M. A. Hill (Eds.), *Women's education in developing countries: Barriers, benefits, and policies*. Baltimore, MD: Johns Hopkins University Press. **(for the World Bank)**.

Schumpeter, J. A. (1994 [1954]). History of economic analysis. London/New York: Routledge.

Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PLoS ONE, 6*(8), e23777.

Shi, A. (2003). The impact of population pressure on global carbon dioxide emissions, 1975–1996: evidence from pooled cross-country data. *Ecological Economics*, *44*(1): 29–42.

Siedentop, S., & Fina, S. (2012). Who sprawls most? Exploring the patterns of urban growth across 26 European countries. *Environment and Planning A, 44*(11), 2765–2784.

Simon, J. L. (1993). Economic thought about population consequences: Some reflections. *Journal of Population Economics, 6*(2), 137–152.

Simon, J. L. (1994). More people, greater wealth, more resources, healthier environment. *Economic Affairs, 14*(3), 22–29.

Spengler, J. J. (1998). History of population theories. In: Simon, J. L. (Ed.) *The economics of population: Classic writings* (pp. 3–15). New Brunswick, NJ: Transaction Publishers.

Teitelbaum, M. S., & Winter, L. M. (1985). *The fear of population decline*. New York: Academic Press.

United Nations (2015). World Population Projections. The 2015 Revision. Volume I: Comprehensive Tables. New York: United Nations.

Wackernagel, M., & Rees, W. (1996). *Our ecological footprint: Reducing human impact on the earth*. Gabriola Island, BC: New Society Publishers.

Ward, M. D., & Gleditsch, K. S. (2008). *Spatial regression models*. Los Angeles: Sage.

York, R., & McGee, J. A. (2016). Understanding the Jevons Paradox. Environmental. *Sociology, 2*(1), 77–87.

York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics, 46*(3), 351–365.

Zhu, Q., & Peng, X. (2012). The impacts of population change on carbon emissions in China during 1978–2008. *Environmental Impact Assessment Review, 36,* 1–8.