

INSTITUTIONAL SETTINGS AND URBAN SPRAWL: EVIDENCE FROM EUROPE*

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Abstract

This article explores the role of institutional settings in determining spatial variation in urban sprawl across Europe. We first synthesize the emerging literature that links land use policies and local fiscal incentives to urban sprawl. Next, we compile a panel dataset on various measures of urban sprawl for European countries using high-resolution satellite images. We document substantial variation in urban sprawl across countries. This variation remains roughly stable over the period of our analysis (1990-2012). Urban sprawl is particularly pronounced in emerging Central and Eastern Europe but is comparatively low in Northern European countries. Urban sprawl – especially outside functional urban areas – is strongly negatively associated with real house price growth, suggesting a trade-off between urban containment and housing affordability. Our main novel empirical findings are that decentralization and local political fragmentation are significantly positively associated with urban sprawl. Decentralized countries have a 25 to 30 percent higher sprawl index than centralized ones. This finding is consistent with the proposition that in decentralized countries fiscal incentives at local level may provide strong incentives to permit residential development at the outskirts of existing developments.

JEL classification: R3, R4, R5, H2, H3, H4, H7.

Keywords: Decentralization, housing supply, supply constraints,
land use regulation, urban sprawl, Europe.

1. Introduction

Urban sprawl – the spatial dispersion of settlements – is a major policy concern in many European countries. Yet little is known about how urban sprawl varies across countries and how it has evolved over time. Even less is known about the determinants of the spatial variation in urban sprawl across Europe and, in particular, about the potential role of country-specific institutional settings in determining sprawl outcomes. The aim of this article is to start to fill these gaps in our knowledge and to identify areas for fertile future research.

Sprawl is an emotionally loaded, vague and contested concept that means different things to different people. It typically has a negative connotation among policy makers and the wider public. However, from a welfare economics point of view, it is not obvious whether the observed level of land use dispersion deviates from the optimum. Sprawl may be the consequence of market failure or policy failure, in which case reducing sprawl could be welfare improving. However, it may also simply be a reflection of the income elasticity of demand for space being satisfied rather than frustrated. In this paper, we refrain from a normative analysis of sprawl. Instead, our focus is on quantifying sprawl and identifying its determinants.

Point of departure is the fact that we can only analyze sprawl if we are prepared to define it in a way that actually allows us to measure it. In this article, we use land cover data derived from high-resolution satellite imagery to compute an index of the spatial dispersion of residential settlements. We provide details on how we compute this index in Section 3.2.

Europe is an excellent laboratory to study the phenomenon of urban sprawl for at least two reasons. First, high-resolution satellite imagery is available consistently for all European countries and for several time periods spread over more than two decades (1990, 2000, 2006 and 2012). We compile this data for 36 European countries to derive various measures of settlement dispersion and provide some stylized facts on the spatial distribution of sprawl and its evolution over time.

Second, European countries differ enormously not only in their economic conditions but also, crucially, in their institutional settings. This provides useful spatial variation that we can exploit in our empirical analysis, allowing us to shed some light on the impact of institutional settings that may influence land use and tax policies and, ultimately, sprawl outcomes.

The contribution of this article is fourfold. First, we provide a synthesis of the emerging literature that links land use policies and local fiscal incentives to urban sprawl. A main lesson of this literature, we would suggest, is that these factors, themselves ultimately determined by a country's institutional settings, may be crucial factors explaining urban sprawl.

Second, we provide several stylized facts on urban sprawl in Europe. We document significant spatial variation in its extent across countries. It is particularly pronounced in emerging Central and Eastern Europe. It is comparably low in Northern European countries and in the United Kingdom. Despite the remarkable differences in urban sprawl between countries, interestingly, within each country it has remained roughly stable over time, hinting

at the importance of – effectively time-invariant – differences in country-specific institutional settings.

Third, we provide stylized facts on the potential trade-off between urban containment and housing affordability. Our country specific measures of sprawl are strongly negatively associated with country-specific real house price growth and the ratio of house prices to incomes. Countries that allow residential development outside functional urban areas have particularly low house price growth. Countries with strict containment policies – most notably the United Kingdom, which introduced very extensive green belts surrounding larger cities during the early 1950s – are today confronted with serious housing affordability crises.¹

Fourth, we explore the determinants of urban sprawl across European countries and document that conditional on country-specific economic factors (as measured through GDP per capita and a dummy for formerly communist Central and Eastern European ‘catch up’ economies), institutional settings (degree of decentralization and local political fragmentation) are crucial drivers of urban sprawl. While our sample size is rather small, and our findings thus need to be interpreted with some caution, simple regression analysis implies that decentralized countries have a 25 to 30 percent higher sprawl index than centralized ones. Moreover, greater political fragmentation is associated with increased urban sprawl. To our knowledge, our study provides the first evidence persuasively linking country-specific institutional settings – in particular the degree of decentralization – to urban sprawl. Our findings are consistent with the proposition that centralized systems often lack sufficient fiscal incentives for local governments to allow residential development thereby making housing supply price inelastic and, ultimately, causing housing shortages and price increases.

Our article is structured as follows. Section 2 provides a synthesis of the emerging literature on the regulatory and fiscal determinants of urban sprawl with a focus on the potential role of decentralization. In Section 3, we describe and document the data and our approach to measuring urban sprawl. Section 4 presents stylized facts on its spatial and intertemporal variation across European countries, stylized facts on the link between urban sprawl and housing affordability, and our main result that various measures capturing the institutional setting of a country affect urban sprawl. The final section concludes with an interpretation of our main findings and an agenda for future research to establish more firmly the causal links between national institutional settings, land use and tax policies, and urban sprawl.

2. Background and Relevant Literature

2.1. Land use planning in decentralized settings

The literature points out two main reasons why urban sprawl is likely to be more pronounced in decentralized settings. First, as argued by Glaeser and Kahn (2004), a system of local governments in which each government takes autonomous decisions with regard to land supply and land use may increase sprawl. Land developers and households can easily avoid

¹ Land use policies other than urban containment may also contribute to housing affordability problems. For example, height restrictions, preservation policies or lack of fiscal incentives to permit development capitalize demand shocks into higher prices.

growth restrictions in a given jurisdiction by simply moving to another one, creating a pattern defined as ‘leapfrogging’. Although sound from a theoretical point of view, empirical evidence on this mechanism is ambiguous. Glaeser and Kahn (2004) find that suburbanization only weakly correlates with the number of jurisdictions in a given area, thus arguing that jurisdictional sorting is likely not the main force driving sprawl.

Second, while local residents might have first-hand knowledge of local market failures – such as incorrect pricing of incompatible land uses and the social value of open land preservation – and local authorities might implement land use policies to correct them, recent empirical research (Cheshire and Sheppard, 2002; Glaeser *et al.*, 2005; Cheshire and Hilber, 2008; Hilber and Robert-Nicoud, 2013; Turner *et al.*, 2014; and Gyourko and Molloy, 2015, for an overview) strongly rejects this idea in favor of the hypothesis that self-interest guides land use policy. The literature identifies fiscal zoning as one of the main instruments to pursue this self-interest. Fiscal zoning describes the process by which local residents (and homeowners in particular) get land use policies enacted in an attempt to create exclusive clubs in which only individuals with similar incomes and social backgrounds will live. The use of ‘minimum lot size controls, discussed below, as an instrument to reduce the proportion of poor in a jurisdiction itself is a significant cause of lower density urban development. How does fiscal zoning relate to development patterns? Empirical evidence suggests that more extensive regulation hinders new development and decreases the responsiveness – or supply price elasticity – of local housing markets (see Mayer and Somerville, 2000; Quigley and Raphael, 2005; Glaeser and Ward, 2009; Dempsey and Plantinga, 2013; Hilber and Vermeulen, 2016).

As mentioned above, in decentralized settings, developers can easily circumvent the policies of a local government by moving into a nearby, less restricted jurisdiction. In more centralized settings, in which land use policies are coordinated or even applied homogeneously throughout the country or a metropolitan area, such behavior is much less likely. In this line, Cunningham (2007) finds that by imposing an urban growth boundary around the greater Seattle area, development in rural areas declined, whereas in urban areas it increased. This is not surprising, as implementing land use regulation at the regional rather than local level leaves households with no other choice but to comply or move away from the region altogether. Interestingly, Brueckner and Sridhar (2012) illustrate what happens when land use regulation is implemented locally. In particular, they show that by imposing height restrictions – by setting maximum Floor to Area Ratios (FARs) – on Indian cities, their spatial size has increased to accommodate the increasing population. Additionally, building heights in non-restricted areas are higher than they would have been in the absence of any restriction. In a similar vein, Geshkov and De Salvo (2012) analyze the impact of different land use regulation policies on US urbanized areas and find, among other things, that minimum lot size requirements and maximum FARs increase their spatial extent.

Fiscal zoning relates to the literature sparked by Tiebout’s (1956) seminal contribution on “voting with the feet”. Over the past century, individuals have become both wealthier and more mobile. They have started to bid in land markets located at the outskirts of major urbanized areas, arguably choosing to live in places offering the preferred combination of land consumption and fiscal packages. In this respect, fiscal zoning is much more likely to happen in more decentralized settings, where local governments enjoy some fiscal autonomy

and have the power to shape land use regulations. As such, the literature analyzing the role of fiscal decentralization for inter-jurisdictional competition (e.g. Besley and Case, 1995) can also be applied to decentralization of land use policy and its interaction with the local tax system.

Another strand of the literature argues that stricter land use regulation in the form of minimum lot size restrictions and open land preservation may spur sprawl even within the local area where they are implemented (see Fischel, 2000). Moss (1977) and Pasha (1996) provide two alternative theoretical frameworks that help understand the conditions under which this may occur. Irwin and Bockstael (2004) argue that land use regulations produce not only a direct effect via increasing development costs of undeveloped land, but also create a land use externality on adjacent parcels. In particular, they suggest that land use regulations that preserve open space create a positive amenity effect on nearby developable land. Looking at development patterns in Calvert County, Maryland, they find that parcels surrounded by preserved land have higher development rates, whereas parcels near industrial development showed lower development rates. They conclude that land use controls that preserve open land may have the effect of i) draining development from central high-density areas, and ii) attracting new development towards areas that have protected open space. As a consequence, such policies may contribute to leapfrogging and sprawling development. McConnell *et al.* (2006) also consider land use patterns in Calvert County, and find that those surrounding an individual parcel affect its development intensity and that zoning regulation in the form of minimum lot size restrictions encourage low-density sprawling residential development.

2.2. The interaction between fiscal and land use instruments

In more decentralized settings local governments finance public services mainly by levying local taxes, allowing them to set fiscal incentives to attract new residents and expand the tax base. Because local jurisdictions can autonomously decide which fiscal instruments to use and to what extent – and households react to these incentives – land use varies across jurisdictions. Such heterogeneity in land use patterns is less likely in more centralized settings, since taxes are levied centrally and redistributed to local governments in the form of transfers. In this case, unless fiscal redistribution favors specific places that allocate more land for development, the fiscal system does not add variation to land use patterns, as there are no positive fiscal incentives at the local level.²

A wide range of the empirical literature shows that households and firms react to local fiscal incentives. Households choose to locate in jurisdictions that they deem offer the largest net fiscal benefit, i.e. the best tax-public services relation. Considering multistate metropolitan areas, Coomes and Hoyt (2008) document that location decisions of households are indeed influenced by tax rate differentials and differences in public spending. Similarly, Rohlin *et al.* (2014) find that firms sort across state boundaries to avoid adverse tax effects.

Fiscal instruments may also affect the composition, mostly residential versus commercial, of new development. Solid evidence is limited to a handful of studies. Quigley and Raphael

² Of course, variation in land use patterns is still possible in more centralized settings, as local jurisdictions differ e.g. in their amenities or their proximity to major urban centers.

(2005) point out how California's tax policies create fiscal disincentives to build new, mid-priced housing in favor of expensive housing and retail buildings. In fact, jurisdictions in California can benefit from sales tax revenues, whereas property taxes are limited to 1% of the last transaction price. Cheshire and Hilber (2008) investigate the effects of the Uniform Business Rate adopted in the United Kingdom in 1990, documenting that fiscal centralization implied a significant disincentive for local authorities to allow new commercial development, making the supply of office space more inelastic and capitalizing demand for such space into higher market prices. Although Cheshire and Hilber did not explore this, a corollary of their main finding is that by making development of commercial real estate comparably less attractive, local authorities might have been comparably more willing to allocate scarce local sites for residential purposes. Burnes *et al.* (2012) document that those jurisdictions in Florida that have higher sales tax rates prefer to attract large shopping malls over manufacturing firms. Jacob and McMillen (2015) find that higher sales tax rates give jurisdictions an incentive to attract commercial and industrial firms. Finally, focusing on German municipalities, Buettner (2016) provides a theoretical approach investigating the trade-off between increasing the land available for commercial use – the main source of revenue of German municipalities is a business tax – and quality of life in the jurisdiction. He argues that making too much land available for commercial development may actually hurt mobile households.

If local governments have fiscal incentives to attract new residents and businesses, they are likely to compete with each other to attract them. The strategic behavior of jurisdictions is likely multidimensional and not limited to fiscal instruments, as often assumed. Theoretical models show that the uncooperative equilibrium may not only be characterized by inefficiently low taxes on mobile factors but also by an overprovision of public inputs that benefit the mobile factor (Bucovetsky, 2005; Fenge *et al.*, 2009). Hauptmeier *et al.* (2012) suggest that local governments do in fact use both tax rates and public inputs to compete for mobile tax bases. Given this evidence, it seems reasonable to assume that land use regulation as well may be implemented strategically. Brueckner (1995) and Helsley and Strange (1995) are among the first to analyze such interactions. They point out how local land use regulations – in the form of growth control policies – may be strongly intertwined: the adoption of a growth control policy restricting the supply of new land for development in a given jurisdiction creates spillovers that influence land use policies of nearby jurisdictions. Brueckner (1998) provides empirical evidence by investigating strategic interactions of growth-control restrictions implemented by Californian cities. In line with the results obtained for property tax competition, local jurisdictions seem to mimic the growth control policies of nearby jurisdictions. Put differently, a given jurisdiction is likely to adopt stringent growth control restrictions when nearby jurisdictions implement tight growth controls as well. Brueckner's (1998) theoretical framework suggests that this interdependency arises because growth control policies in a given municipality depend on the regional housing market supply-responsiveness, which results from growth control policies in other jurisdictions.

Thus, competitive behavior of local governments in taxes and land use regulation is likely to have important consequences for land use patterns. Competition between local governments is likely to be most intense in highly decentralized countries, where local governments have

considerable control over both land use and tax policies and benefit from attracting specific groups of residents and businesses. In all cases, the ways in which local governments compete depends on the incentives that they face and the instruments that they control.

Heyndels and Vuchelen (1998) investigate the potential strategic interactions among Belgian municipalities in setting property taxes. They find that local jurisdictions do indeed mimic tax rates of neighboring municipalities, but this interdependency decreases with geographical distance. Brueckner and Saavedra (2001) do a similar analysis for 70 cities of the Boston metropolitan area. Consistent with Heyndels and Vuchelen (1998), they also find an upward-sloping reaction function.

Because the competition between local governments is likely multidimensional, local governments might affect land use patterns by interacting land use and fiscal policies (taxation and provision of public goods). From a theoretical perspective, the joint effect on land use patterns of strategically using the two instruments simultaneously is not obvious. Moss (1977) conceptualizes an interaction between minimum lot size restrictions and property taxes. In his model, minimum lot size requirements may increase the conversion rate of rural into urban land, thus increasing the size of an urban area. However, this conversion is slowed down when property taxes on developed land increase faster than those on agricultural property. Voith and Gyourko (2002) adopt a theoretical framework in which a public policy that subsidizes homeownership according to income, thereby favoring higher income households, may lead to greater income segregation when lot size restrictions are binding. Even in a setting where poor and rich households have the same preferences for city versus suburban living, there is residential sorting by income. This implies that the observed migration of richer households towards suburban areas – and the subsequent low-density development – could have occurred, in part, due to a combination of land use policies and fiscal incentives. A study by Basten *et al.* (2017) supports this conclusion as it documents that high-income households systematically sort into low-tax jurisdictions that tend to be low density places, where the provision of local public goods and services is more expensive.

2.3 Capitalization mechanisms and land use patterns

Recent research shows that binding housing supply constraints – such as tight land use regulation – and tax differentials may be responsible for misallocating households across space. In a widely quoted study, Hsieh and Moretti (2015) argue that housing supply constraints are responsible for misallocation of the labor force across the United States: as mobile workers were increasingly unable to live in more productive cities due to regulatory supply constraints, wage dispersion across 220 US metropolitan areas doubled from 1964 to 2009, lowering the output and welfare of the whole country. Similarly, Fajgelbaum *et al.* (2015) argue that US state taxes may be responsible for the spatial misallocation of individuals and firms, thus reducing workers' welfare. Capitalization effects may prevent mobile workers to move to larger, more productive agglomerations.

The empirical literature provides strong evidence in support of the hypothesis that local land use constraints are capitalized into house prices (for recent rigorous evidence see e.g. Saiz, 2010, for the US or Hilber and Vermeulen, 2016, for the United Kingdom). Fischel (1990)

and Quigley and Rosenthal (2005) provide a literature review linking growth control with land and house prices. The main message is that tighter land use constraints tend to benefit owners of developed land and hurt owners of undeveloped land (see the early work of Engle *et al.*, 1992, or more recently Hilber and Robert-Nicoud, 2013). Zoning restrictions reduce the amount of land available for development and thus increase its price. The price of developed land may also be higher because zoning restrictions create a positive amenity effect, thus increasing the willingness to pay of would-be residents. Finally, prices may increase if zoning restrictions attract wealthy households, thereby expanding the local tax base. In contrast, the price of undeveloped land falls, as new development becomes more difficult and expensive, thus decreasing demand from land developers.

Similarly, capitalization of local taxes into house prices largely depends on the willingness to pay of households for the public services obtained in return. If the local government underprovides a given public service, raising tax rates will increase the willingness to pay to live in the jurisdiction. This is because households benefit from higher public spending (assuming that local jurisdictions are not leviathans and do not waste money). In this case, capitalization of the tax increase into higher house prices can be expected. However, if the additional tax is used to fund a public service that is overprovided, households are not willing to pay more to live in the jurisdiction the local tax increase should be negatively capitalized into house prices.³

3. Data

3.1. Data description

To analyze the relationship between governmental decentralization and land use patterns, we gather data from several European agencies. Below we provide the main data sources as well as a brief description of the data. Summary statistics are provided in Table 1. The reader may want to refer to Appendix Table A1 for supplementary information on the data sources and to Table W1 in the Web Appendix for the full data set used in our core analysis. We provide maps of the spatial variation of key explanatory variables in the Web Appendix as well.

Land cover – The Corine Land Cover (CLC) inventory provides high-resolution satellite imagery data classifying land cover into 44 categories. The inventory includes four waves – 1990, 2000, 2006, and 2012 – for a panel of European countries. There are data on 20 Western European countries – Austria, Belgium, Germany, Denmark, Finland, France, Greece, Ireland, Iceland, Italy, Liechtenstein, Luxemburg, Malta, Norway, Netherlands, Portugal, Spain, Sweden, Switzerland, and United Kingdom – and on 16 Central and Eastern European countries – Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Macedonia, Montenegro, Poland, Romania, Slovakia, Slovenia, and Serbia. In Section 3.2, we illustrate how we use the CLC inventory to measure sprawl.

³ See Hilber (2017) for an in depth discussion of the capitalization of local public goods and taxes into house prices, and the economic implications of such capitalization effects.

Decentralization – Several decentralization measures have been suggested in the literature. Various measures based on a country’s constitution are obtained from Treisman (2008). Our first measure is a variable that captures whether a country’s constitution provides autonomy to subnational legislatures in certain specified areas or assigns residual powers to subnational governments, i.e. allows them to legislate on areas not explicitly assigned to other levels. We denote this dummy variable *subnational autonomy* in the tables. Second, we consider whether a country’s constitution can be classified as federal according to Elazar (1995). This dummy variable is referred to as *federal constitution*.⁴ Third, still relying on data derived from Treisman (2008), we measure how many levels of government there are in a country. We refer to this variable as *no. tiers*.⁵ Lastly, we use the Regional Autonomy Index (RAI), proposed by Hooghe *et al.* (2016). This variable summarizes different dimensions of governmental decentralization into one single index. We refer to it as *regional autonomy index*. Specifically, the country-level RAI aggregates decentralization measures computed for sub-national tiers. There are 10 categorical measures entering the RAI index, with low values corresponding to heavily centralized institutional settings and high values to heavily decentralized ones.⁶ The RAI index is available for 81 countries from 1950 to 2010. According to the literature surveyed above, we expect that more decentralized countries are generally characterized by more dispersed residential development.

Institutional fragmentation – The degree of dispersion of residential development should also depend on the intensity of competition between subnational units. Conditional on the population size, the competition intensity can be expected to depend on the number of competitors. Eurostat publishes detailed information on low-tier (municipality-level) administrative boundaries for the whole of Europe. We use 2013 municipality boundaries to compute the number of municipalities in a country and label this variable in the tables as *no. municipalities*. Holding constant the country’s population, we can interpret this variable as capturing the municipality density per country inhabitant. This density, which varies widely across countries⁷, proxies the degree of country-specific institutional fragmentation. Conditional on the degree of decentralization, we expect more fragmented countries to display more scattered land use patterns.

Functional urban areas – The OECD provides a harmonized definition of European functional urban areas based on commuting patterns. We use these functional urban areas to compute sprawl at a more disaggregated level. More precisely, for each country we compute

⁴ See Web Appendix Figure W1 for a map with the federal status by country.

⁵ Web Appendix Figure W2 illustrates the wide variation in this measure by country.

⁶ These measures include the degree of autonomy of a regional government, the authority of a regional government to implement specific policies (such as economic, welfare, education, security, and immigration policies), the degree of a sub region’s fiscal autonomy, borrowing autonomy, the extent to which a sub region can autonomously legislate and execute laws, the degree to which regional representatives can influence national legislation, the extent to which sub-regional governments impact national policies, the extent to which the national tax revenue distribution is affected by regional representatives, the degree to which a regional government influences subnational and national borrowing constraints, and the extent to which sub-national representatives affect constitutional changes. See the Web Appendix Figure W3 for a map illustrating the spatial variation in the RAI.

⁷ See the Web Appendix Figures W4 and W5 for an illustration of country-specific discontinuities in municipality size and for a map of resulting municipality densities by country.

sprawl for country areas outside major functional urban areas, and within functional urban areas but outside city centers. This allows us to investigate whether development patterns significantly differ across countries depending on urban areas and commuting patterns.

House prices and other controls – We consider real house price indices published by Girouard *et al.* (2006). These indices are computed by adjusting nominal price indices based in 2010 with the private consumption deflator published by national statistical offices. This allows us to relate long-term price dynamics to development patterns. Additionally, we control for GDP per capita in the year 2000 (adjusted for PPP) to account for the disparity of economic activity across countries. Per-capita GDP and population data stem from the World Development Indicators.

3.2. Measuring Urban Sprawl

Sprawl is an elusive concept and a variety of measures has been used in the literature to try to capture it, depending on both theoretical and practical considerations. Wassmer (2000), Galster *et al.* (2001), and Song and Knaap (2004) offer an overview of alternative measures.⁸ Theoretical work tends to identify sprawl with population density gradients (Glaeser and Kahn, 2004; Song and Zenou, 2006) and the urban spatial extent (Brueckner and Sridhar, 2012). In line with theoretical work, early empirical analyses measured sprawl with population density and urban extent (Brueckner and Fansler, 1983). There is, however, a recent trend to rely on Geographical Information System (GIS) data to measure sprawl patterns more systematically. A major contribution was that of Burchfield *et al.* (2006), who rely on satellite images mapping the US surface in cells of 30x30 meters. Burchfield *et al.* (2006) define a sprawl index for US metropolitan areas by computing for each individual developed cell the share of undeveloped land surrounding that cell within a square kilometer, and then averaging across all developed cells in the urban area. The index corresponds to the share of open land surrounding an average developed cell within a square kilometer, thus providing insights on the spatial dispersion of development that may not be captured by a simple density measure.

In the present paper, we follow Burchfield *et al.*'s (2006) approach and employ 100 x 100 meter resolution raster data provided by the CLC. We group the 44 land cover categories into four main classes: *residential developed*, *non-residential developed*, *developable*, and *undevelopable*. The *non-residential developed* category includes, in particular, industrial and transportation surfaces. The *developable* class contains plots of land that are not developed but are potentially developable. Agricultural, woodland, and pasture areas belong – among others – to this class. The *undevelopable* class comprises parcels that are physically undevelopable or extremely costly to develop, such as lakes or glaciers.⁹

Using these four land cover classes, we compute a sprawl index Spr_{ct} for each European country c in a given year t according to the following formula:

⁸ A more complete discussion of alternative measures of sprawl and urban form is provided in Clifton *et al.* (2008).

⁹ See Appendix Table A2 for a precise definition of these classes according to the CLC land cover categories.

$$Spr_{ct} = \frac{1}{\sum_{i \in c} 1(l_t(i) = res)} \sum_{i \in c} 1(l_t(i) = res) \frac{\sum_j 1(d_{ij} \leq 500 \cap l_t(j) = free)}{\sum_j 1(d_{ij} \leq 500 \cap (l_t(j) = free \mid l_t(j) = res))}, \quad (1)$$

where d_{ij} denotes the “crow flight” distance between pixels i and j , the function $l_t(\cdot)$ maps pixels to one of the four class values at time t , and $1(\cdot)$ is an indicator function. The intuition behind formula (1) is the following: for each individual pixel, we compute the share of developable (free) land within a radius of 500 meters. This share is obtained by dividing the number of free pixels by the total number of free and residential pixels within the considered area. Next, we average the computed shares over all pixels classified as residential in a given country.

Two characteristics of our sprawl measure are worth noting. First, as in Burchfield *et al.* (2006), we average exclusively over residential pixels. This allows us to estimate the percentage of developable land surrounding an *average* residential plot of land. Second, developed and undevelopable land do not enter the share of ‘free land’ in Equation (1). We would justify this exclusion with the argument that scattered residential development should be considered as sprawling only in those areas where development is not (physically) constrained. For example, according to our definition a residential pixel of a coastal urban area will not be counted as ‘sprawling’ if it is located close to a body of water. This exclusion leads to sprawl values that are more conservative than those suggested in the literature, and in particular by Burchfield *et al.* (2006). Heterogeneous geography should be accounted for as it may potentially affect cross-country comparisons of urban sprawl.¹⁰

4. Empirical Analysis

4.1. Urban Sprawl across Europe and over Time

Figures 1 and 2 illustrate the cross-sectional variation in aggregate urban sprawl and sprawl outside functional urban areas. The countries with the highest levels of urban sprawl are the Czech Republic, Slovenia, Albania, Poland, and Slovakia while the United Kingdom, Iceland, the Netherlands, Norway and Denmark display the lowest degree of sprawl. Cross-country differences range from a sprawl level of 0.52 in the Czech Republic to less than half of this in the United Kingdom. Overall, sprawl turns out to be most pronounced in Eastern and Central Europe and least pronounced in Northern Europe. The cross-sectional variation is similar for sprawl outside functional urban areas, with one notable exception. Portugal is overall only the 12th most sprawling country in Europe but it has the second highest sprawl level outside functional urban areas. Figure 3 (for Western European countries) and Figure 4 (for Central and Eastern European countries) depict the development of sprawl over time for the countries in our sample. It is evident that the levels of sprawl are rather stable over time.¹¹

¹⁰ An alternative approach would be not to exclude developed and undevelopable land and add (i) the share of undevelopable land and (ii) a proxy for topography as control variables in our regressions. This would allow us to identify and disentangle the effects of land cover types and topography on our measure of urban sprawl. We leave this for future work.

¹¹ This and the fact that we do not have detailed information on changes for the key explanatory variables prevent us from estimating first difference models. However, we note that a very simple analysis regressing the first difference of sprawl on a dummy variable for Central and Eastern Europe, conditional on log income, is mildly supportive of the hypothesis that sprawl has increased more in Central and Eastern Europe than in the rest

4.2. Urban Sprawl vs. Housing Affordability

Many Central and Eastern European countries but also countries such as Portugal, Austria or Switzerland are characterized by residential development taking place on the outskirts rather than in central, high-density areas. Yet, not all European countries are sprawling. Urban development in countries such as the United Kingdom, Sweden, Norway or Iceland is largely ‘contained’. The case of the United Kingdom is particularly interesting in that containment is the result of a highly restrictive planning system that for six decades has imposed, amongst other measures, very extensive ‘green belts’ surrounding larger cities. While green belts – in conjunction with a lack of fiscal incentives to permit development, height restrictions, view corridors and widespread preservation policies – largely¹² successfully contain urban development, they create a different kind of problem. By limiting the long-run supply of housing, these policies contribute to a severe housing affordability crisis (Hilber and Vermeulen 2016). Sweden and Norway similarly observed strong increases in real house prices over the last two decades.

To investigate whether there is a common trade-off between containment and housing affordability, we collected data on real house price indices from the OECD and Knoll *et al.* (2017). Figure 5 shows the growth of real house prices – smoothed over a 12-year moving average (6 years on either side of the central year) to partial out the impact of cyclical dynamics – between 2000 and 2015¹³ against the average sprawl between 1990 and 2012. It is evident that urban sprawl is significantly negatively correlated with the growth of real house prices. The data suggests a correlation coefficient of -0.42. Countries with a high average degree of urban sprawl such as Portugal, Spain or Austria experienced comparably low increases in real house prices, whereas the ‘contained’ United Kingdom, Sweden and Norway observed strong real house price increases during the same period.

In Figure 6, we excluded functional urban areas from the computation of the sprawl index in order to compare only areas with comparatively low density across countries.¹⁴ The negative association between sprawl and the average quarterly change in real house prices is even more pronounced, with a correlation coefficient of -0.61.

While the real house price growth numbers in Figures 5 and 6 account for inflation differences across countries, the picture might be blurred by a more pronounced increase in real incomes in countries with low sprawl. Thus, to establish more confidence in our proposition that there is indeed a trade-off between containment and housing affordability, we further consider the change in the ratio between house prices and incomes. As illustrated in

of Europe. We find that the change in sprawl was about 0.01 units higher in Central and Eastern Europe with this effect being statistically significant at the 10 percent level.

¹² Green belts are not entirely successful in containing urban sprawl because in the most prosperous cities (London, Cambridge, Oxford), one can observe that urban development ‘jumps’ over green belts. In a similar vein, Cheshire *et al.* (2017) document that tight local land use restrictions cause an increase in the commuting distance.

¹³ We choose the window of the moving average based on the average duration of country-specific housing cycles as found in Bracke (2013).

¹⁴ For instance, in the Netherlands 18 percent of the total land is assigned to functional urban areas whereas functional urban areas make up only 1.2 percent of all land in Latvia.

Figure 7 for aggregate urban sprawl and in Figure 8 for sprawl outside urban areas, a negative correlation is evident even for the change in the house price-to-income ratio plotted against the sprawl measures. These correlations are somewhat lower than the simple real house price growth ones and there may still be various confounding factors so we cannot read too much into these correlations. Yet, a trade-off between containment and housing affordability is consistent with theory as well as with the stylized facts presented in this paper.

In a next step, we empirically investigate underlying factors that determine urban sprawl and, in this context, we highlight the role of decentralization and political fragmentation.

4.3. *Determinants of Urban Sprawl in Europe*

Urban sprawl is likely affected by a country's state of economic and demographic development as well as by its institutional setup, which in turn determines both planning policies and fiscal incentives to permit development at the local level. In the following, we focus on the institutional setup while controlling for the state of economic and demographic development. In Table 2, we present the effects of four alternative measures of decentralization on urban sprawl. Our regression sample consists of 31 countries because we lack information on the decentralization measures for Lichtenstein, Montenegro and Serbia and information on the number of municipalities is missing for Albania, Bosnia-Herzegovina and again Montenegro. In each of the specifications, we control for the state of economic development by including the logarithm of per-capita GDP in the year 2000 (adjusted for purchasing power parity). We also include a dummy variable for Central and Eastern European (CEE) countries. This variable captures unobserved characteristics associated with these countries, possibly the unique institutional setting related to their common history as communist countries. The negative correlation between log per capita GDP and the CEE dummy variable is very strong at -0.76, indicating that the CEE dummy may at least partially capture 'very low income' levels as well.

We run simple OLS regressions and keep the empirical model parsimonious due to the low number of observations. Three results stand out. First, CEE countries display a higher degree of urban sprawl. This may be due to urbanization being still less pronounced in these catching-up countries and thus policies aiming at urban containment receive less attention. Controlling for decentralization urban sprawl is between 12 and 18 percentage points higher in CEE countries compared to non-CEE countries. Controlling for the CEE status, log GDP per capita is positively associated with urban sprawl in four out of five specifications, but the effect is never statistically significant at conventional levels.

Second, decentralization is significantly positively correlated with urban sprawl, independent of the measure of decentralization we use. Countries where subnational legislatures have 'autonomy in certain areas or residual powers' have a level of sprawl that is 0.095 to 0.116 units higher. The average level of sprawl in countries without autonomous subnational jurisdictions is 0.39 such that countries characterized by subnational autonomy display a 25 to 30 percent higher level of sprawl. This is consistent with the literature – discussed in Section 2 – which suggests that regional competition and a lack of inter-regional coordination in decentralized settings spur urban sprawl. These results are robust to using alternative

measures of decentralization. Countries classified as federal according to Elazar (1995) exhibit a level of urban sprawl that is about 7 percentage points higher. Urban sprawl is also strongly positively associated with the number of tiers of government, as a proxy for decentralization, as well as with the continuous index of regional autonomy introduced by Hooghe *et al.* (2016).

Third, we directly exploit variation in the degree of inter-regional competition across countries. In column 5 of Table 2, we account for the degree of institutional fragmentation in addition to the indicator about whether subnational units have some degree of autonomy. In particular, we estimate the effect of the number of municipalities that are potentially competing for new residents or a mobile tax base. As the absolute number of municipalities is strongly dependent on country size, we further control for country population. We find that the degree of sprawl increases significantly with the number of municipalities. This is consistent with the literature on jurisdictional competition in federations and adds further confidence in the hypothesis that the degree of decentralization is an important determinant of urban sprawl. Remarkably, our simple regressions explain up to 51 percent of cross-country variation in urban sprawl.

Table 3 follows the same structure as Table 2 but exploits variation in residential sprawl outside functional urban areas. Consistent with the results reported in Table 2, we find that decentralization matters. The effects of the individual proxies for decentralization remain qualitatively and quantitatively similar to the ones for aggregate sprawl. The only exception relates to the proxy for the degree of competition as measured by the municipality density, which ceases to be significant. However, the magnitude of the effect remains similar.¹⁵

Another potential explanatory variable of interest is the subnational competence and authority in spatial planning. Silva and Acheampong (2015) provide up-to-date information on land-use planning systems and policy instruments for all OECD countries, including the 24 European OECD countries in our sample (we lose data points for seven European countries that do not belong to the OECD). Estimating a regression with only 24 observations and a rather coarse measure of ‘planning autonomy’ is problematic. Leaving this caveat aside, we report results in Appendix Table A3. The effect of the planning autonomy variable on residential sprawl is positive across most specifications (as expected) but never close to statistically significant at conventional levels. Importantly, however, including the variable does not greatly affect the coefficient estimates of our measures for the degree of decentralization. These remain qualitatively and quantitatively remarkably similar compared to those reported in Table 2.

5. Conclusions and Outlook

This article explores patterns of urban sprawl and their determinants across Europe and aims to provide a road map for fertile future research. We show that urban sprawl is particularly prevalent in Central and Eastern Europe but also, to a lesser extent, in the Alpine and some of the Southern European countries. Interestingly, although urban sprawl patterns differ vastly across countries, at country level, they do not change substantially over a 20-year period, and

¹⁵ Note also that an alternative specification, which includes the municipal density, instead of the number of municipalities and the population size separately, shows a significantly positive effect of municipal density.

there is no clear European-wide time trend. This is suggestive that institutional settings – that vary substantially across countries but little within countries over time – may drive urban sprawl.

Our main empirical results indicate that institutional factors are important in determining urban sprawl, most likely via determining the restrictiveness of land use policies and fiscal incentives to develop at the local level. Holding economic conditions – as measured by per capita GDP – constant, decentralized European countries have a 25 to 30 percent higher level of sprawl compared to centralized ones. Moreover, countries with greater political fragmentation at local level – and presumably a greater degree of interjurisdictional competition and poorer coordination – also are more sprawling, other things held equal. To the best of our knowledge, this study is the first to provide direct evidence of a link between variables capturing the institutional setting and urban sprawl.

Of course, our analysis is limited in scope by its very nature. Our cross-sectional regression sample is confined to 31 countries. Future work may be able to conduct a more disaggregated analysis at the regional, sub-regional or even local level and perhaps exploit variation within country over time, controlling for area and time fixed effects. Additionally, our variables capturing the ‘institutional setting’ are coarse. Future work ought to try to understand better the underlying channels that create such a strong discrepancy in sprawl between decentralized and centralized countries. Such research may also explore the interaction effects of planning and tax policies and the various underlying instruments.

Measures of political and fiscal decentralization available to us are too coarse and the variation not sufficient to disentangle the two drivers separately. Moreover, few measures are available for all – or even most – countries in our sample. Careful future data collection efforts could help shed more light on the underlying channels that drive urban sprawl in Europe and elsewhere.

Our findings can only be suggestive of causation. Whilst it seems highly plausible to argue that the degree of decentralization and political fragmentation themselves are not driven by sprawl (reverse causation), spurious correlation is a potential problem. That is, factors that happen to be correlated with measures of decentralization or political fragmentation might be driving urban sprawl. We are not aware of omitted variables that (i) are correlated with the degree of decentralization or political fragmentation but are not driven by these institutional variables, and, (ii) have their own independent effect on urban sprawl. However, we are wary of the possibility.

Lastly, our analysis suggests that containment policies – such as those implemented in the United Kingdom – are not a ‘free lunch’. All countries in our sample – that are at the bottom end of the sprawl distribution with the notable exceptions of the Netherlands and to a lesser extent Denmark – have observed strong growth in real house prices and a deterioration of housing affordability as measured by an increase in the house price-to-income ratio between 2000 and 2015. These findings point to a trade-off between containment and housing affordability. However, we stress that we do not believe reducing sprawl necessarily implies housing affordability crises. Land use regulations serve an important purpose – to correct market failures (such as externalities or the provision of local public goods). In theory, it is

possible to devise policies or ‘solutions’ that correct market failures without leading to excessive sprawl or driving up housing costs massively (see e.g. Cheshire and Sheppard 2005; Cheshire 2009, 2013). However, in practice, political economy forces make achieving welfare-maximizing solutions hard (Fischel 2000; Hilber and Robert-Nicoud 2013). Future research could focus on these political-economy forces. Better understanding these, might allow well-intended policy makers to design institutional settings (at constitutional level) that optimize social welfare via minimizing the powers of vested interests.

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TABLES

Table 1
Summary Statistics

	Mean	Std. Dev	Min	Max
Urban sprawl	0.399	0.081	0.222	0.517
Urban sprawl outside FUA	0.419	0.120	0.215	0.671
Urban sprawl inside FUA	0.408	0.090	0.222	0.555
Central and Eastern Europe	0.417	-	0	1
Ln(GDP per capita)	9.683	0.704	8.305	10.930
Subnational autonomy	0.242	-	0	1
Federal constitution	0.182	-	0	1
No. tiers	3.328	0.617	2	4.5
Regional autonomy index	10.116	10.543	0	35.642
No. municipalities	3.752	6.660	0.011	36.703
Population	14.217	20.231	0.031	80.600

Notes: Population is measured in millions, number of municipalities in thousands, per-capita GDP is adjusted by purchasing power parity and measured in the year 2000. In total we have 36 country with non-missing information about urban sprawl. Information on the decentralization measures is missing for LIE, MNE, and SRB; information about the number of municipalities is missing for ALB, BIH, MNE such that we have in total 31 countries entering our benchmark regression specification.

Table 2
Determinants of Sprawl

	Dependent Variable: Residential Sprawl				
	(1)	(2)	(3)	(4)	(5)
Subnational autonomy	0.095*** (0.025)				0.116*** (0.025)
Federal constitution		0.074*** (0.026)			
No. tiers			0.049** (0.021)		
Regional autonomy index				0.002* (0.001)	
No. municipalities					0.005*** (0.001)
Population					-0.0014* (0.001)
Central and Eastern Europe	0.131** (0.056)	0.140** (0.058)	0.179*** (0.051)	0.143** (0.061)	0.120** (0.058)
Log GDP per capita (2000)	0.006 (0.039)	0.030 (0.046)	0.065 (0.046)	0.030 (0.049)	-0.007 (0.042)
Constant	0.259 (0.408)	0.034 (0.475)	-0.472 (0.495)	0.018 (0.504)	0.394 (0.437)
Observations	31	31	31	31	31
Adjusted R-squared	0.44	0.34	0.36	0.30	0.51

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Population is measured in millions, number of municipalities in thousands, per-capita GDP is adjusted by purchasing power parity.

Table 3
Determinants of Sprawl outside Functional Urban Areas

	Dependent Variable: Sprawl outside Functional Urban Areas				
	(1)	(2)	(3)	(4)	(5)
Subnational autonomy	0.092*** (0.029)				0.097** (0.036)
Federal constitution		0.073** (0.031)			
No. tiers			0.067*** (0.023)		
Regional autonomy index				0.003* (0.001)	
No. municipalities					0.003 (0.002)
Population					-0.0003 (0.001)
Central and Eastern Europe	0.082 (0.075)	0.092 (0.076)	0.152** (0.059)	0.101 (0.082)	0.086 (0.083)
Log GDP per capita (2000)	-0.036 (0.052)	-0.014 (0.052)	0.034 (0.047)	-0.013 (0.056)	-0.037 (0.059)
Constant	0.710 (0.543)	0.491 (0.550)	-0.205 (0.493)	0.464 (0.592)	0.709 (0.618)
Observations	31	31	31	31	31
Adjusted R-squared	0.29	0.22	0.33	0.22	0.28

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Population is measured in millions, number of municipalities in thousands, per-capita GDP is adjusted by purchasing power parity.

FIGURES

Figure 1
Cross-Sectional Variation in Aggregate Urban Sprawl

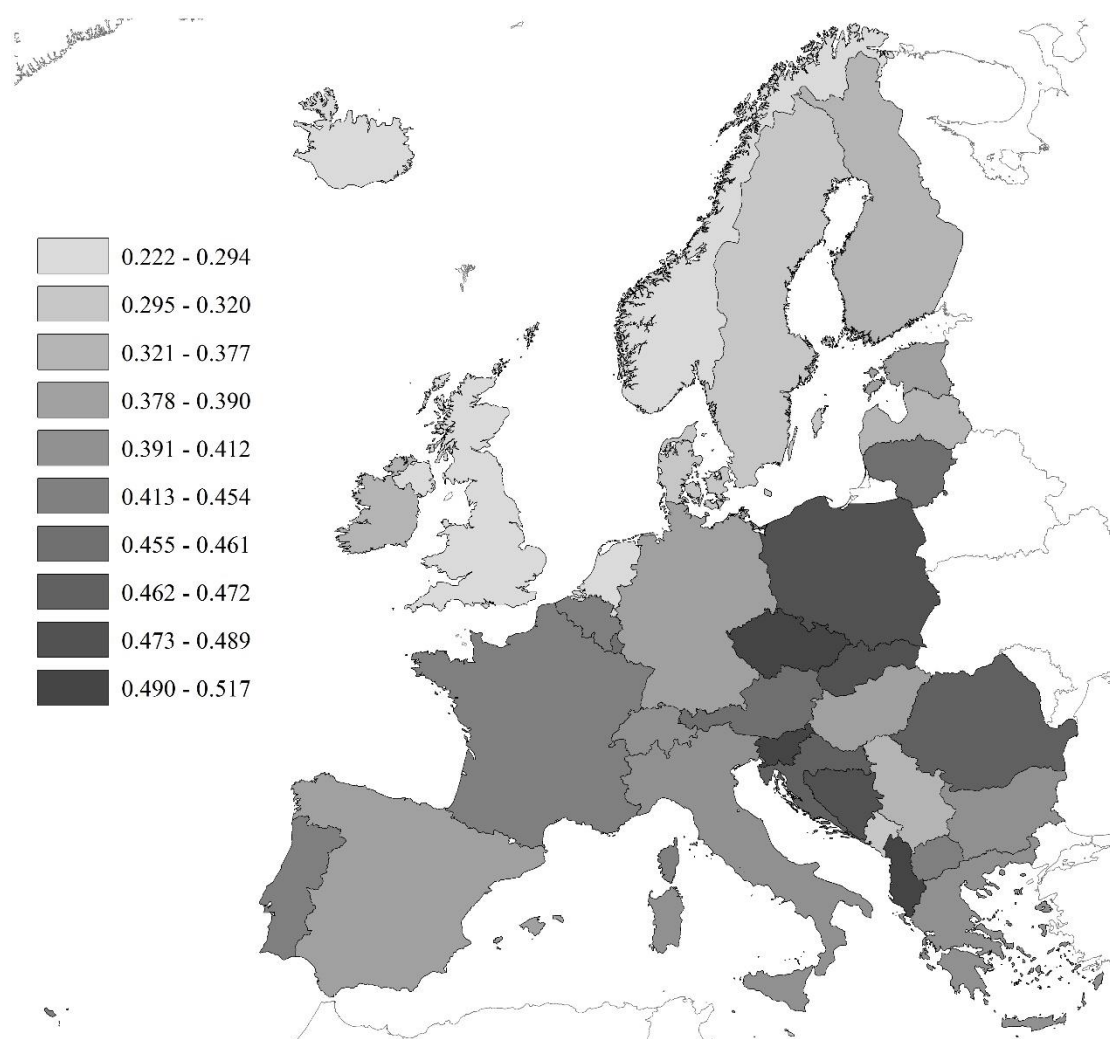


Figure 2
Urban Sprawl outside Functional Urban Areas

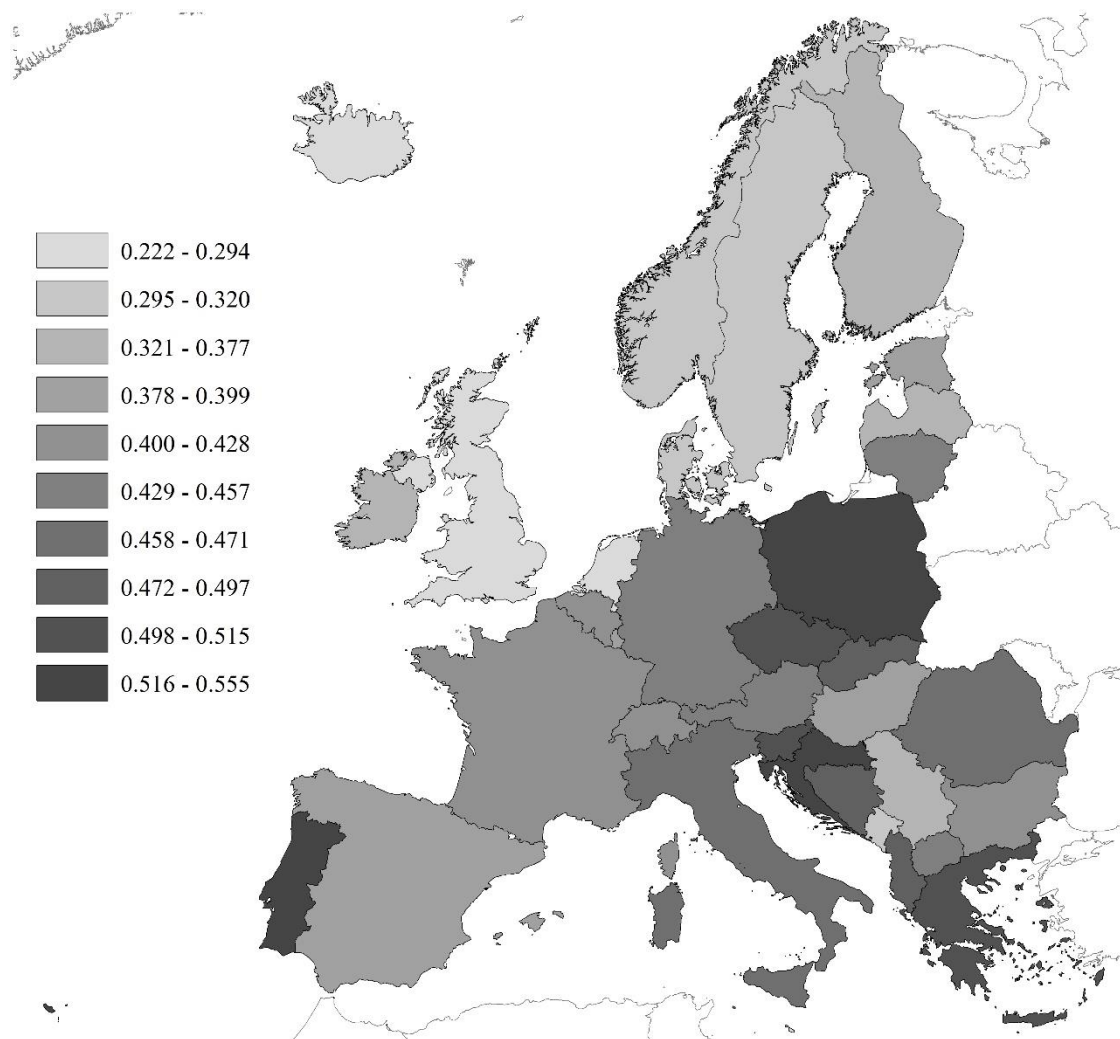


Figure 3
Urban Sprawl 1990-2012: Western European Countries

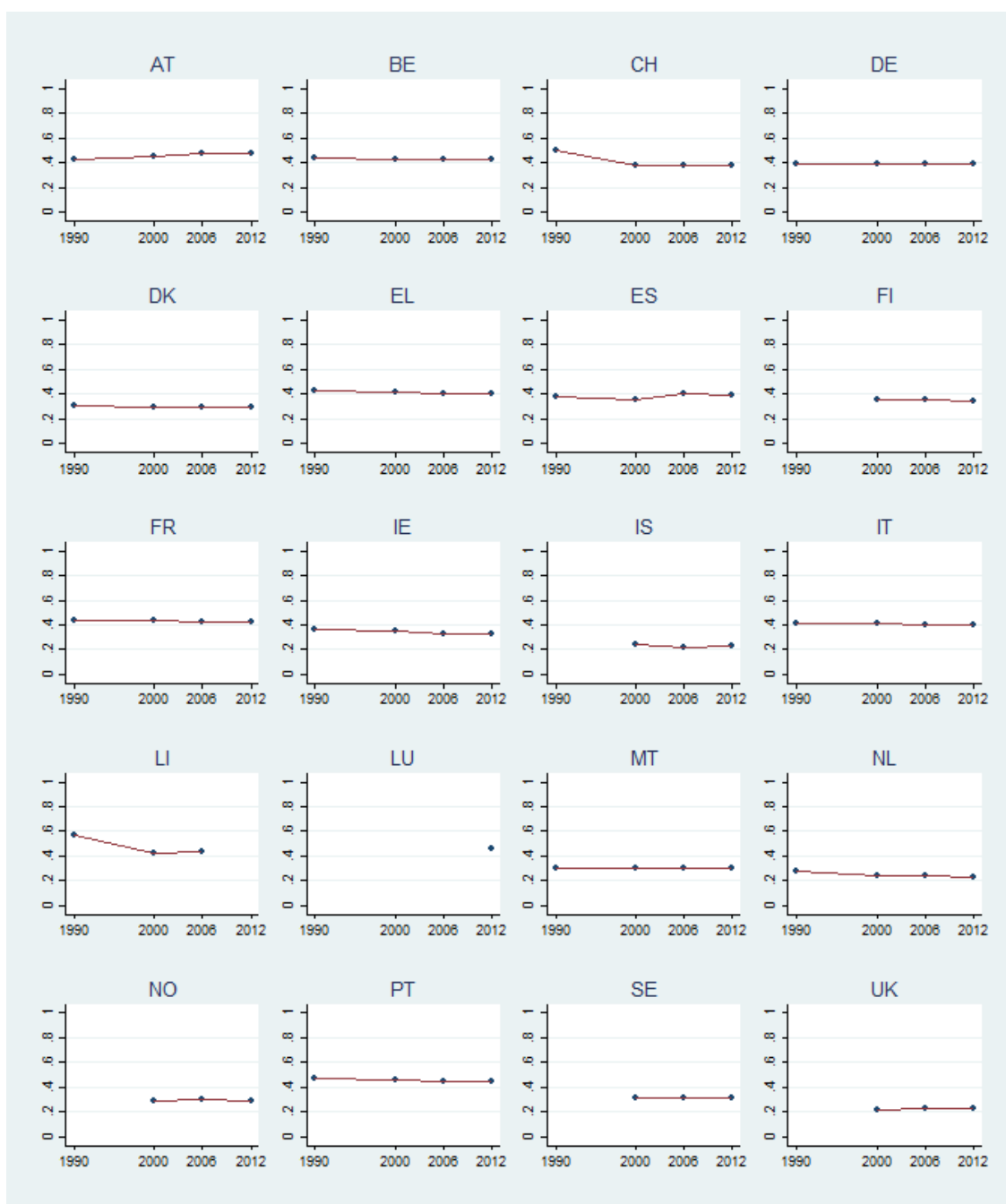


Figure 4
Urban Sprawl 1990-2012: Central and Eastern European Countries

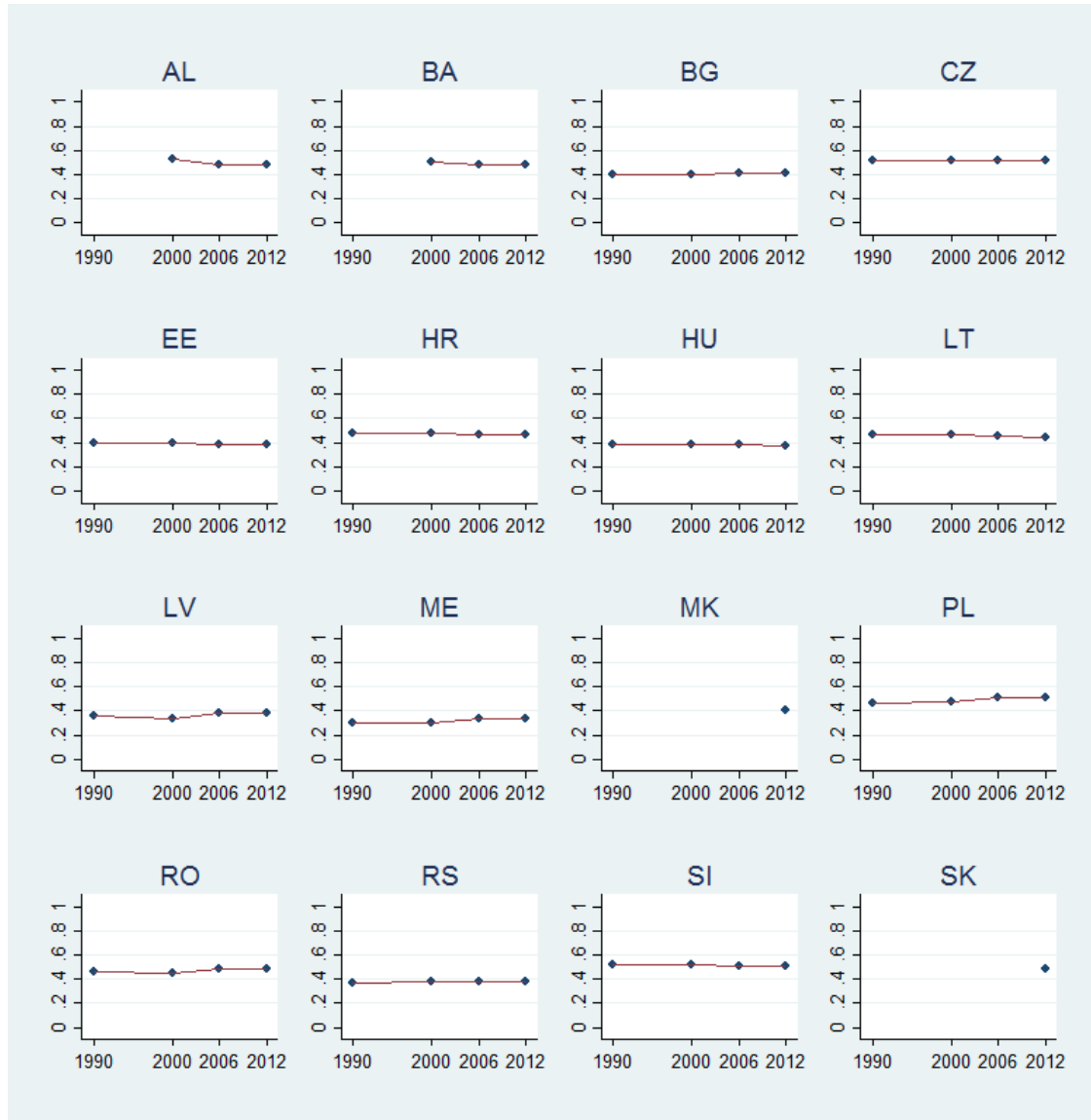


Figure 5
Change in Real House Prices (in %) vs. Urban Sprawl

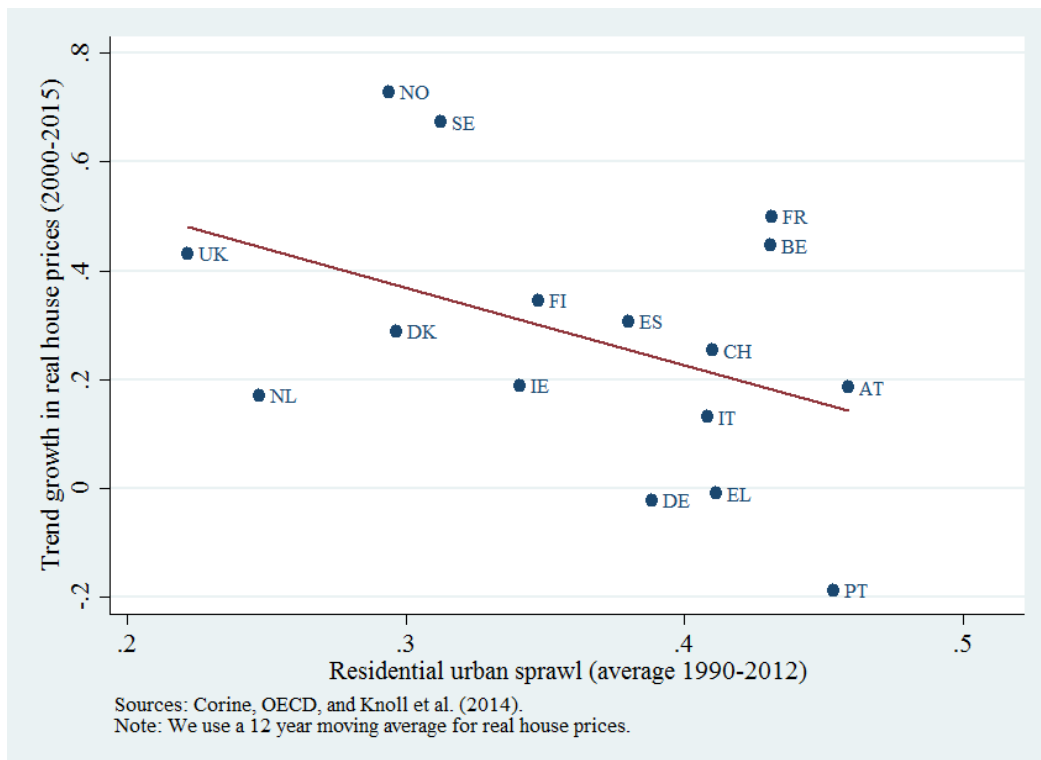


Figure 6
Change in Real House Prices (in %) vs. Sprawl outside Functional Urban Regions

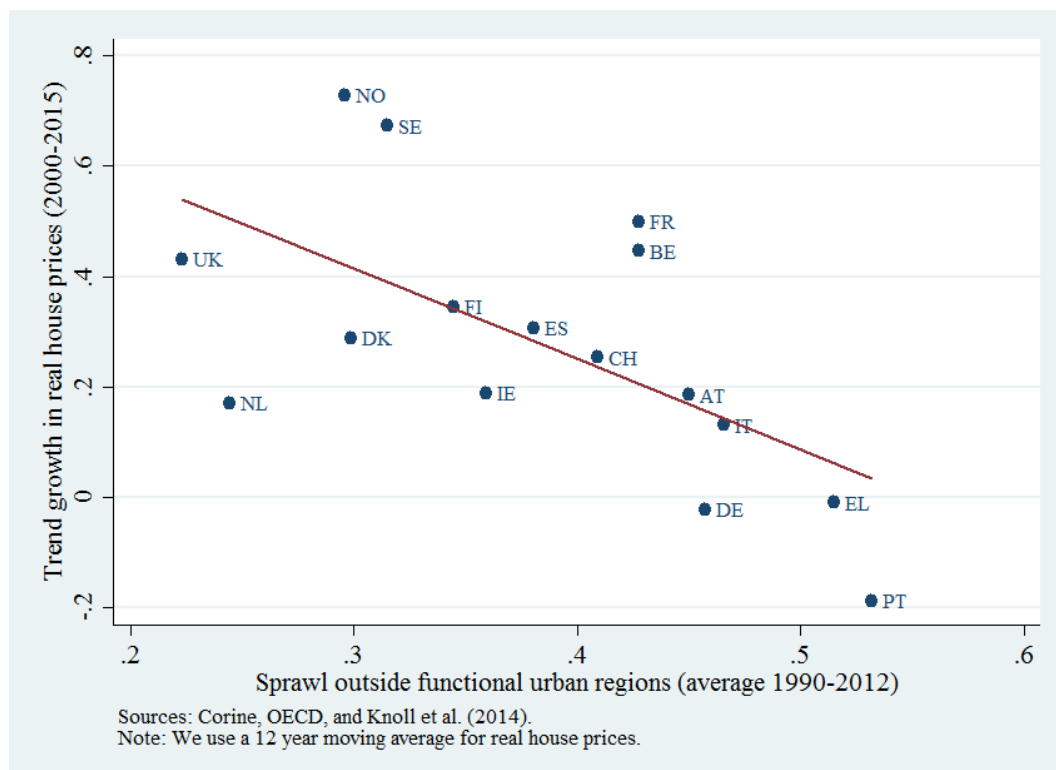


Figure 7
Change in House Price to Income-Ratio (in %) vs. Urban Sprawl

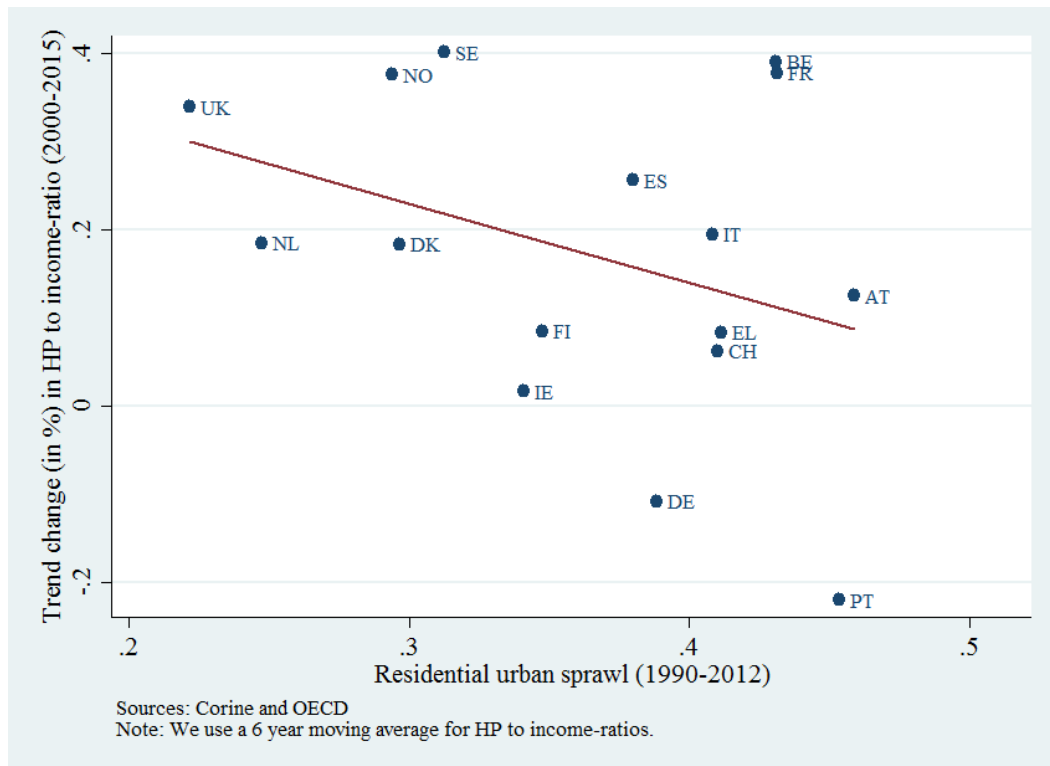
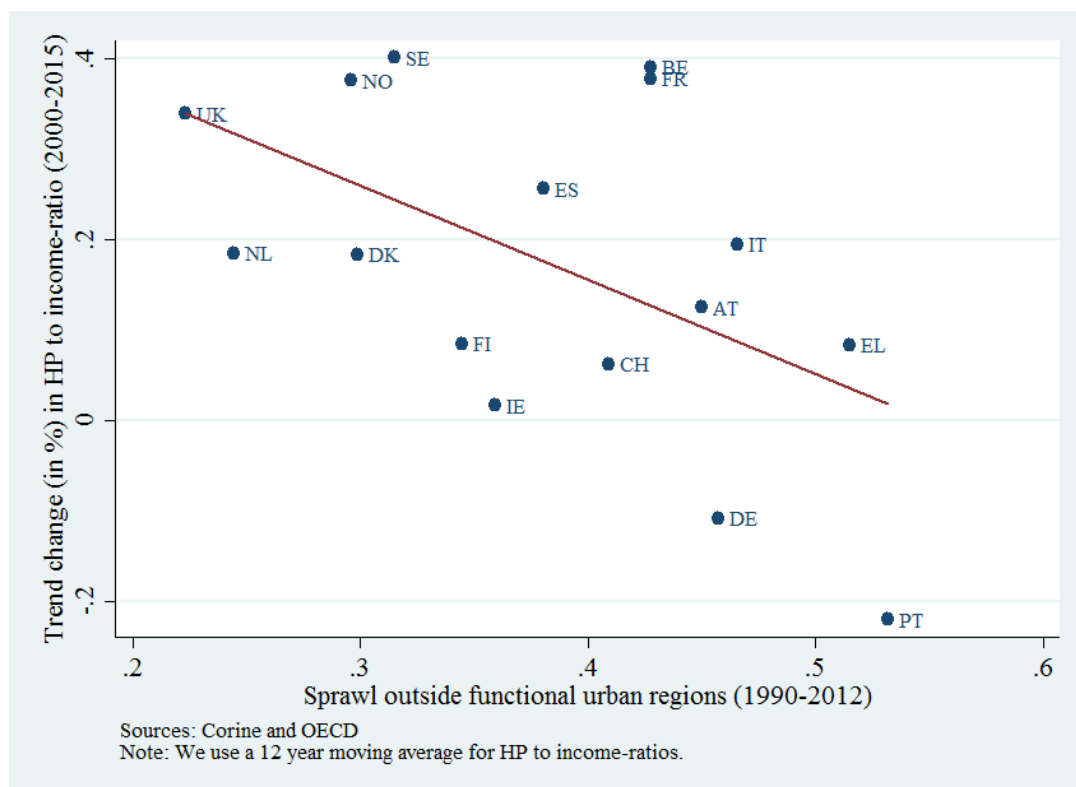


Figure 8
Change in House Price to Income-Ratio (in %) vs. Sprawl outside Functional Urban Regions



APPENDICES

Appendix A: Appendix Tables

Table A1
Data Sources and Complementary Information

Type of data	Source
Land cover	Corine Land Cover (CLC) inventory: http://land.copernicus.eu/pan-european/corine-land-cover
Decentralization	Hooghe <i>et al.</i> (2016) – Regional Autonomy Index (RAI) : https://www.arjanschakel.nl/regauth_dat.html Treisman (2008): http://www.sscnet.ucla.edu/polisci/faculty/treisman/Papers/Decentralization.xls
Institutional fragmentation	Eurostat municipality boundaries: http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/communes#communes13
Functional urban areas	Eurostat urban audit: http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/urban-audit Additional information: http://ec.europa.eu/eurostat/statistics-explained/index.php/Archive:European cities %E2%80%93 the EU-OECD functional urban area definition
House prices	OECD house price indices: https://stats.oecd.org/Index.aspx?DataSetCode=HOUSE_PRICES
Others	World Bank ‘world development indicators’ (GDP per capita, population): https://data.worldbank.org/data-catalog/world-development-indicators

Note: Hyperlinks last accessed on October 16, 2017.

Table A2
Land Cover Classification

CLC code	Label	Class (own definition)
111	Continuous urban fabric	Residential Developed
112	Discontinuous urban fabric	
121	Industrial or commercial units	Non-Residential Developed
122	Road and rail networks and associated land	
123	Port areas	
124	Airports	
131	Mineral extraction sites	
132	Dump sites	
133	Construction sites	
141	Green urban areas	
142	Sport and leisure facilities	
211	Non-irrigated arable land	Developable
212	Permanently irrigated land	
213	Rice fields	
221	Vineyards	
222	Fruit trees and berry plantations	
223	Olive groves	
231	Pastures	
241	Annual crops associated with permanent crops	
242	Complex cultivation patterns	
243	Land principally occupied by agriculture	
244	Agro-forestry areas	
311	Broad-leaved forest	
312	Coniferous forest	
313	Mixed forest	
321	Natural grasslands	
322	Moors and heathland	
323	Sclerophyllous vegetation	
324	Transitional woodland-shrub	
331	Beaches, dunes, sands	Undevelopable
332	Bare rocks	
333	Sparsely vegetated areas	
334	Burnt areas	
335	Glaciers and perpetual snow	
411	Inland marshes	
412	Peat bogs	
421	Salt marshes	
422	Salines	
423	Intertidal flats	
511	Water courses	
512	Water bodies	
521	Coastal lagoons	
522	Estuaries	
523	Sea and ocean	

Table A3
Subnational Planning Autonomy

	Dependent Variable: Residential Sprawl					
	(1)	(2)	(3)	(4)	(5)	(6)
Planning autonomy	0.004 (0.037)	-0.004 (0.029)	-0.010 (0.031)	0.014 (0.033)	0.003 (0.034)	0.002 (0.034)
Subnational autonomy		0.088*** (0.027)				0.112*** (0.030)
Federal constitution			0.084*** (0.029)			
No. tiers				0.080*** (0.025)		
Regional autonomy index					0.003** (0.001)	
No. municipalities						0.006*** (0.002)
Population						-0.002 (0.001)
Central and Eastern Europe	0.063 (0.085)	0.096 (0.095)	0.093 (0.091)	0.210* (0.101)	0.089 (0.105)	0.077 (0.089)
Log GDP per capita (2000)	-0.029 (0.085)	-0.026 (0.090)	-0.023 (0.088)	0.081 (0.100)	-0.041 (0.097)	-0.052 (0.086)
Constant	0.647 (0.858)	0.596 (0.922)	0.567 (0.894)	-0.759 (1.052)	0.723 (0.991)	0.854 (0.886)
Observations	24	24	24	24	24	24
Adjusted R-squared	0.13	0.30	0.26	0.34	0.23	0.41

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Population is measured in millions, number of municipalities in thousands, per-capita GDP is adjusted by purchasing power parity. Information on planning autonomy stems from Table 2 in Silva and Acheampong (2015).

Web Appendix: Additional Table and Figures

Table W1
Dataset – *Part 1*

Country	Sprawl	Sprawl outside	Sprawl inside	Central/Eastern	Ln(GDP/pop)	Autonomy
ALB	0.497	0.497	-	0	8.305	0
AUT	0.459	0.450	0.505	0	10.294	1
BEL	0.431	0.427	0.445	0	10.250	1
BGR	0.402	0.400	0.405	1	8.755	0
BIH	0.489	0.489	0.516	1	8.383	1
CHE	0.410	0.409	0.523	0	10.449	1
CZE	0.517	0.511	0.529	1	9.698	0
DEU	0.388	0.457	0.442	0	10.190	1
DNK	0.297	0.299	0.278	0	10.294	0
ESP	0.380	0.381	0.260	0	9.993	1
EST	0.390	0.399	0.347	1	9.181	0
FIN	0.348	0.345	0.375	0	10.184	0
FRA	0.431	0.428	0.452	0	10.165	0
GBR	0.222	0.223	0.220	0	10.270	0
GRC	0.412	0.515	0.215	0	9.867	0
HRV	0.472	0.519	0.510	1	9.311	0
HUN	0.382	0.387	0.344	1	9.401	0
IRL	0.341	0.359	0.284	0	10.296	0
ISL	0.228	0.222	0.631	0	10.296	0
ITA	0.408	0.465	0.412	0	10.190	1
LIE	0.468	0.468	-	0		-
LTU	0.455	0.452	0.500	1	9.071	0
LUX	0.461	0.394	0.504	0	10.930	1
LVA	0.364	0.356	0.492	1	9.008	0
MKD	0.442	0.442	-	1	8.739	0
MLT	0.305	0.294	0.325	0	9.939	0
MNE	0.320	0.320	-	1	8.797	-
NLD	0.248	0.244	0.273	0	10.359	0
NOR	0.294	0.296	0.277	0	10.513	0
POL	0.489	0.555	0.544	1	9.269	0
PRT	0.454	0.532	0.427	0	9.790	0
ROM	0.471	0.471	0.460	1	8.653	0
SRB	0.377	0.377	0.671	1	8.662	-
SVK	0.487	0.495	0.440	1	9.320	0
SVN	0.513	0.510	0.537	1	9.791	0
SWE	0.312	0.315	0.259	0	10.288	0

Table W1
Dataset – *Part 2*

Country	Federal	No. tiers	RAI index	No. municipalities	Population
ALB	0	3	1.158	-	3.044
AUT	1	4	22.677	2.354	7.901
BEL	1	4	32.271	0.589	10.179
BGR	0	4	1.100	4.617	8.344
BIH	1	4	28.450	-	4.066
CHE	1	3	24.855	2.453	6.986
CZE	0	3	5.333	6.253	10.309
DEU	1	4	35.642	11.426	80.600
DNK	0	3	11.568	2.178	5.266
ESP	1	4	30.874	8.200	40.509
EST	0	3	0.000	0.230	1.446
FIN	0	3	4.584	0.320	5.081
FRA	0	4	19.161	36.703	59.842
GBR	0	4	8.845	9.499	58.442
GRC	0	5	6.645	0.326	10.482
HRV	0	3	8.050	0.556	4.564
HUN	0	3	10.538	3.154	10.348
IRL	0	3	1.871	3.441	3.784
ISL	0	2	0.000	0.074	0.270
ITA	0	4	22.055	8.092	57.155
LIE	-	-	-	0.011	0.031
LTU	0	3	2.526	0.563	3.490
LUX	0	3	0.000	0.106	0.502
LVA	0	3	0.286	0.587	2.439
MKD	0	-	2.000	1.817	2.061
MLT	0	3	0.000	0.068	0.369
MNE	-	-	0.000	-	0.607
NLD	0	3	17.048	0.408	15.423
NOR	0	3	11.581	0.428	4.393
POL	0	3	5.857	2.479	37.874
PRT	0	4	3.706	4.260	10.171
ROM	0	3	8.750	3.186	22.207
SRB	-	-	5.400	0.205	7.517
SVK	0	4	8.000	2.927	5.389
SVN	0	2	0.571	6.031	1.983
SWE	0	3	12.645	0.290	8.743

Figure W1
Federal Constitution



A map of Europe showing the number of COVID-19 cases per 100,000 people by country. The map uses a grayscale color scale from 2 (lightest) to 4.5 (darkest). The legend indicates the following values:

- 2 (lightest gray)
- 3 (medium-light gray)
- 4 (medium-dark gray)
- 4.5 (darkest gray/black)

The map shows that countries like Iceland, Norway, and Sweden have the lowest number of cases per 100,000 people (lightest gray), while countries like the United Kingdom, France, and Germany have higher numbers (medium-dark gray). The Balkans and parts of Eastern Europe show the highest numbers (darkest gray/black).

Figure W3
RAI Decentralization Index

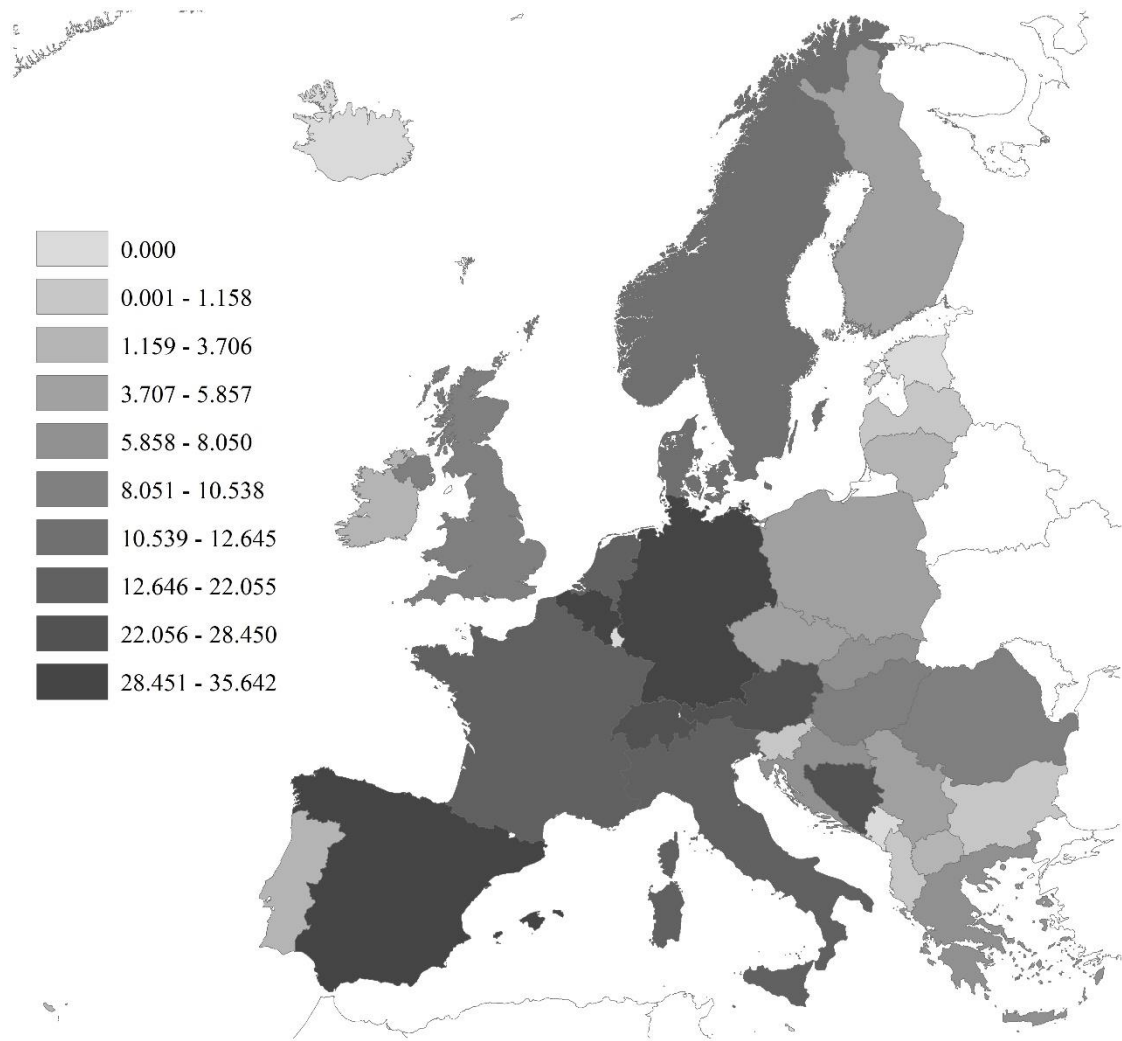


Figure W4
Map of Discontinuity in Municipality Size



Figure W5
Number of Municipalities per Population (in Million) in 2013

