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Can Internet Infrastructure Help Reduce Regional Disparities? Evidence from Turkey*

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Abstract

This study presents novel evidence regarding the role of regional internet infrastructure in reducing regional per capita income disparities. We base our study on the assumptions that (1) the diffusion of information homogenizes regional economies through reducing the dissimilarities in institutions and culture, and (2) the telecommunication capacity, represented as the internet infrastructure of a region, facilitates this flow of information. Using the data from the twenty-six statistical regions of Turkey, we find evidence that internet infrastructure has contributed to regional convergence during the period 1999-2011. We also observe that the Turkish economic geography is defined by a strong core-periphery pattern and significant spatial clustering.

Key words: Convergence, Internet, Telecommunication, Infrastructure, Regions.
JEL Classifications: R12, L96, E20, H41, O18, O47.

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1 Introduction

According to the Solow (1956) neo-classical model of long-run growth, economies should eventually converge to a steady-state growth rate of per capita income. In other words, economies with relatively less income per capita should grow faster than richer ones until all economies converge to a steady-state per capita income growth rate of zero. On the other hand, in the presence of equally shared exogenous labour-augmenting technological progress, this process would imply convergence to a positive growth rate. If, in addition, the aggregate production functions of all economies are assumed to be identical, convergence should also occur in terms of per capita income level (Islam, 2003).

The assumptions of equal access to common technology, and identical production functions are not unreasonable in cases where the units of analysis are sub-national regions. Barro and Sala-i-Martin (2003) point out that even though technological and structural differences may exist between regions, these differences can be expected to be less than those between countries, and convergence to similar steady-states would be more likely. In this study on Turkish regions, while we do observe sufficient homogeneity that allows for regional convergence, we also see that the speed of this process is only considerable when region-specific conditions are accounted for.

The conditions that influence the process of convergence can be considered in two categories: those that influence convergence through their impact on regional economic growth, and those that play a similar role through enhancing the connections between economies. In this regard, the role of public and human capital have been highly emphasized in the growth literature among a large number of other variables (Leon-Gonzalez and Montolio, 2004). Stemming from growth models, convergence equations have been often augmented by these two types of capital. Examples of such convergence equations are found in Button (1998); Lall and Yilmaz (2001); Leon-Gonzalez and Montolio (2004); Ding et al. (2008); Del Bo et al. (2010), and Onder et al. (2010) among others, where the role of especially public capital is examined.

In this study, we focus on a specific class of public capital which is internet infrastructure, as an enhancing factor regarding regional telecommunications capacity. It can be seen that many studies, communication infrastructure is often grouped within the same infrastructure category with transportation public capital. However, within the encompassing definition of public capital, the role of communication infrastructure can be considered to be different from other infrastructure types (Robins and Gillespie, 1992; Carey, 2008). The distinction between communication and transportation increasingly needs to be taken into account as these two categories are becoming more and more distinct from each other with technological progress: while transportation capabilities reduce travel time and effective distance, communication is often argued to transcend space and time, at least to some extent, by allowing information to travel instantly. Carey (2008) suggests that it was

as early as the invention of the telegraph when communication and transportation first started to be clearly distinguished from each other, and observes a significant spatial economic consequence of this communication technology: the telegraph had lessened the gap in the market prices in different locations, reduced the "information gap" between stock markets, giving rise to "everywhere markets and everytime markets" Carey (2008, p. 169). In this regard, Dokmeci and Berkoz (1996) observe that telecommunications has a strong impact on financial services which stimulate capital flows, which in turn influence the economic geography. In more general terms, within the context of European regions, Tranos (2012) identifies information and communication technology (ICT) infrastructure as a necessary condition for economic development.

In order to further explore this proposed relationship between telecommunications and spatial differences, we focus on the σ-convergence and β-convergence[1] of Turkish regions in relation to regional internet infrastructure. While it is common to use phone subscription data as an indicator of telecommunication infrastructure,[2] we focus on a more modern medium of communication measured by the density of of asymmetric digital subscriber lines (ADSL's). Previous evidence regarding the telecommunications-convergence relationship, especially from a modern technology perspective, is almost non-existent.[3] In this regard, our study presents novel evidence on how improved internet capabilities of regions may help reduce regional disparities.[4]

We examine absolute and conditional β-convergence for the years 1999 through 2011 by taking two other connectivity-enhancing infrastructure categories into account along with internet infrastructure: air and land transportation infrastructure. On the other hand, σ-convergence is examined for a longer time period of 1990-2011.[5]

This study proceeds as follows: Section 2 elaborates on the mechanism of how modern telecommunications is expected to affect convergence, and reviews the theoretical foundations of the concepts of σ-convergence and β-convergence together with a discussion of spatial interactions. The regional patterns of the distribution of per capita income in Turkey, and the clustering of similar regions are discussed in Section 3. Section 4 discusses the empirical strategy. The explanation of the data used is presented in Section 5, and Section 6 elaborates on the estimation results. Finally, Section 7 makes the concluding discussion and policy recommendations.

[1] These concepts are summarized in Section 2.

[2] For example Ding et al. (2008); Del Bo et al. (2010) who examine income convergence as a response to telecommunications infrastructure among other factors.

[3] Forman et al. (2012).

[4] We further elaborate on the previous research results in Section 2.3.

[5] The reason for the time period used in the former case being shorter is the unavailability of data for all covariates except GVA per capita for the years before 1999, while for GVA per capita, data is available starting from 1990.

2 Theoretical background

2.1 The theory and analysis of convergence

When looking at the relationship between internet and convergence, we focus on the two well established concepts in the literature: σ-convergence and β-convergence where the latter can exist as *absolute* or *conditional* convergence. In the context of regional economies, *Absolute convergence* is observed if the output per capita of poorer regions grow faster than the richer ones without being conditional on other regional structural characteristics (Barro and Sala-i-Martin, 2003). Therefore, regions are treated as structurally homogeneous. Following Barro and Sala-i Martin,[6] an absolute β-convergence equation can be stated as follows:

$$(1/T)ln\left(\frac{y_{i,t_0+T}}{y_{i,t_0}}\right) = \alpha - \left(\frac{1-e^{-bT}}{T}\right) ln(y_{i,t_0}) + \varepsilon_i \tag{1}$$

where y is income per capita and the term on the left-hand-side is the average per capita income growth rate of economy i. The subscripts t_0 and $t_0 + T$ index the initial and final years in the data respectively, and T is the number of years minus one. α is a constant and ε_i is the error term. β-convergence is observed if a negative relationship, represented by the convergence factor $\beta = -\left(\frac{1-e^{-bT}}{T}\right)$, exists between the growth rate of per capita income and the initial income level (Sala-i Martin, 1996b). Therefore, a significant and negative β estimate would imply that regions with lower initial output levels generally have higher average growth rates, and provide evidence for absolute convergence.

In addition to testing the convergence hypothesis, two additional issues are of interest: (a) the *speed of convergence* which is defined as the rate an economy approaches its steady-state (Barro et al., 1991), represented by the term b in equation (1), and (b) the *half-life* of convergence which is defined as "the time span which is necessary for current disparities to be halved" Monfort (2008, p.4), and computed as $\frac{ln(2)}{b}$ (Arestis et al., 2007). Thus, for all estimation results that we present in this study, we report the associated convergence speeds and half-lifes and discuss their implications. Expressing equation (1) in levels leads to

$$ln(y_{i,t_0+T}) = \theta + (1+\beta)ln(y_{i,t_0}) + \nu_i \tag{2}$$

where $1 + \beta = e^{-bT}$. The constant θ is αT and the error term ν_i equals ε_i/T. Equation (2) is the base absolute convergence equation we estimate in the empirical analysis.

The existence of a steady-state conditional on economies sharing similar technologies and other structural parameters is referred to as *conditional convergence* (Mankiw et al., 1992). This type of convergence is observed if the relationship between y_{i,t_0} and the rate of per capita income growth

[6] Barro et al. (1991); Barro and Sala-i Martin (1992) and Sala-i Martin (1996b).

varies across regions such that convergence exists only if they share similar structural characteristics. In other words, regions have different steady-state rates of growth towards which they converge (Barro et al., 1991). However, when estimating equation (1), structural differences between regions cannot be accounted for. Islam (1995) suggests the use of panel data methods in convergence models to control for unobserved individual effects and to avoid the omitted variable bias that may exist in cross-section regressions. Following this view, the expression of equation (2) in discrete form for all time periods in the data, together with the addition of time-varying covariates, leads to the conditional convergence model:

$$ln(y_{i,t}) = \theta + \ (1+\beta)ln(y_{i,t-1}) + \sum_{k=1}^{m} \gamma_k x_{k,it} + \mu_i + \eta_t + \xi_{it} \tag{3}$$

where t indexes the discrete time periods in the data, ξ_{it} is the error term, and convergence is conditioned on $x_{k,it}$, a set of m regional structural characteristics k for region i at time t, and μ_i and η_t which are the region-specific and year fixed effects respectively.[7] The absolute convergence counterpart of equation (3) omits the region-specific conditions represented in the explanatory variables and the region fixed effects:

$$ln(y_{i,t}) = \theta + \ (1+\beta)ln(y_{i,t-1}) + \eta_t + \xi_{it} \tag{4}$$

2.2 σ-convergence and its relation to β-convergence

Regarding the distinction between the two concepts of convergence Sala-i Martin (1996b, p. 1328) states that

> "...the two concepts examine interesting phenomena which are *conceptionally different*: σ-convergence studies how the distribution of income evolves over time and β-convergence studies the mobility of income within the same distribution."

The evolution of the distribution of income in a group of economies is represented by the trend in the cross-sectional variance of $ln(y_{it})$, denoted by σ, and σ-convergence is observed if this variance is decreasing between a given time t and any future period $t+T$ over time, such that $\sigma_t^2 > \sigma_{t+T}^2$ (Sala-i Martin, 1996a). In this regard, since β-convergence asks whether poorer economies grow faster than the richer ones, its focus is on the behavior of the "relative locations within the income distribution" (Durlauf et al., 2005). On the other hand, as stated by Durlauf et al. (2005), the focus of the σ-convergence approach is on the shape of the distribution as a whole rather than the relative locations within it.

[7] Random effects instead of fixed effects can be of interest in cases where units of observations are randomly drawn from a larger population. In this study, we only consider fixed effects as our data covers all Turkish regions.

Despite these conceptual differences, the following strong links exist between the two convergence approaches. Absolute β-convergence is a necessary condition for σ-convergence to occur: it must be due to poor economies growing faster if the income differences among regions lessen through time (Sala-i Martin, 1996a). This can be seen by taking the sample variance of equation (4) which yields the relation $\sigma_{t+1}^2 = (1+\beta)^2\sigma_t^2 + \sigma_\xi^2$ between σ_t and σ_{t+1} (Sala-i Martin, 1996b).[8] Sigma convergence can hold only if $-1 < \beta < 0$ since $\beta \geq 0$ implies divergence, and $\beta < -1$ implies a negative association between $ln(y_{it})$ and $ln(y_{i,t+1})$ which would result with a series that could oscillate between negative and positive values, making little economic sense (Young et al., 2008), a situation also known as "leapfrogging" or "overshooting" (Sala-i Martin, 1996b). Finally, if $\beta = -1$, then σ_t^2 is equal to the constant σ_ξ^2 at all time periods and σ-convergence does not occur.

It is important to note that β-convergence is not a sufficient condition for σ-convergence. Given β-convergence, the variance in the distribution of income among economies can either increase or decrease depending on an initial level of variance with respect to the variance in the steady-state (Sala-i Martin, 1996b; Islam, 2003), and β-convergence itself can lead to an increase in income dispersion if economies have different structural characteristics such that the convergence of economies to their own separate steady-states can lead to σ-divergence (Young et al., 2008). Therefore, as an increase in disparities between economies can still persist even if β-convergence exists, this type of convergence "cannot guarantee falling variance" (Islam, 2003).

2.3 Communications, geography, and convergence

The effects of the regional communication on inter-regional equity (or inequality) has been discussed in several studies. In a recent paper, Breuer et al. (2014) observe an absolute convergence of US states in the period 1929-2011 which they argue that can be explained by the explosion of the internet and the migration to cities, resulting in the homogenization of institutions and culture, and the elimination of regional distinctions. The authors refer to this phenomenon as the "globalization hypothesis." This view is partly supported by Ding et al. (2008) who show evidence that a more traditional type of communication infrastructure measured by fixed and mobile telephone lines, has positively contributed to the conditional convergence of 29 Chinese regions from 1986 through 2002, and Del Bo et al. (2010) who observe a positive sign on their telecommunication infrastructure variable (mobile phone lines) in their conditional convergence equation for European regions during the period 1995-2006 where spatial dependence is considered. On the other hand, it can be argued that in many economies regions are satiated in terms of such traditional forms of communication infrastructure. The only study we are aware of which examines the relationship between telecommunications and convergence by focusing on a modern telecommunication technology is the county-level research on US firms by Forman et al. (2012), who observe that investments by firms

[8] Our expression of the sample variance of the convergence equation is slightly different from the original formulation of Sala-i Martin (1996b) in which the coefficient on σ_t^2 is $(1-\beta)^2$.

on advanced internet capabilities has led to regional wage *divergence* in the period 1995-2000. It is clear that further evidence is needed regarding the internet-regional disparities relationship.

Within the context of Krugman's New Economic Geography (NEG) model (Krugman, 1991), Tranos (2012) and Maignan et al. (2003) argue that ICT enhancement reduce the costs of communications, which in turn could change the NEG equilibrium defined by the *centripetal and centrifugal forces*.[9] More specifically, the generally proposed mechanism of how telecommunication affects economic geography is through the increase in the speed, and the decrease in the cost of diffusion of information between markets. Goddard (1992) identifies information as a "key strategic resource on which the effective delivery of goods and services in all sectors of the world economy is dependent" and argues that "economic transformation is being underpinned by a technical transformation in the way in which information can be processed and distributed." On the other hand, Ding et al. (2008) suggest that telecommunications infrastructure, as an input to the process of production, may positively contribute to the productivity of other inputs while "liberating economic activities from geographical restraints" (Ding et al., 2008, p.846). The authors also point out that telecommunication infrastructure can lead to resources from other regions to be attracted, contributing to economic growth. In this regard, Celbis et al. (2013) observe that telecommunications infrastructure has a significant and positive impact on the imports of an economy, which can be seen as a result of enhanced possibilities of accessing information regarding goods and resources from other economies.

On the other hand, even though it is a well accepted fact that modern modes of communication allow space to be transcended to some extent, "... space still exists and so does time" according to Castells et al. (2007, p. 178) who argue that "...wireless communication homogenizes space." In this regard, Robins and Gillespie (1992) point out that information and communication technologies are essential to the future of cities, regions and nations, but on the other hand they refer to the geographical dimension of these technologies by stating that

> "We need to acknowledge the spatial bias of new ICT's, their contribution to new patterns of homogenization and differentiation, their tendency to underpin new geographical divisions and hierarchies" (Robins and Gillespie, 1992, p. 149).

In relation to this spatial bias of ICT's, in their 1992 article, Robins and Gillespie (1992) argue that the restructuring of information and communication technologies is related to significant regional inequalities between regions. Supporting this argument, Goddard (1992) provides a real world example by arguing that the growth in information industries in the south-east UK in the eighties and early nineties has led to uneven regional development patterns. In this regard, Tranos and Gillespie (2009) draw attention to how information is distributed among settlements through "digital highways" and that being part of such networks creates locational advantages. Similarly, in their

[9] In the spatial context of the NEG model, centripetal forces pull economic activity together and the centrifugal forces push it apart, as put by Fujita and Krugman (2004).

assessment of wireless communications, Castells et al. (2007) point out that telecommunications infrastructure is dependent on access points in space, and that the ability to transcend time and space is determined by one's location.

Another mechanism through which the availability of information from other economies may play a role in shaping the economic geography can be through affecting regional demand for variety which is put forward as a contributing factor to technological progress in endogenous growth models: consumers who observe a greater variety of goods and services available in other regions will demand the same for their own locations, which could in turn make the region more attractive for firms that operate elsewhere. To summarize, it can be argued that telecommunications can affect the economic geography through:

1. the reduction of the information gap between markets (Carey, 2008),
2. stimulating capital flows (Dokmeci and Berkoz, 1996),
3. creating new patterns of homogenization (Robins and Gillespie, 1992) and homogenizing of institutions and culture (Breuer et al., 2014),
4. generating productivity spillovers to other inputs of production (Ding et al., 2008),
5. attracting resources to a regional economy from other economies (Ding et al., 2008),
6. creating locational advantages as a result of being in digital networks (Tranos and Gillespie, 2009),
7. changing the NEG equilibrium through decreasing the costs of communication (Tranos, 2012), and
8. increasing the demand for product variety and attracting firms to the region.

3 Regional patterns of income per capita in Turkey

Our interest lies in the mobility of regions in terms of their per capita income rather than the general trend in the disparities among them. Therefore, we put greater emphasis on the β-convergence process, its speed, and half-life. On the other hand, as a useful first look, the σ-convergence process in Turkey relative to the country-wide regional connectivity-enhancing public capacity, represented by the transportation and communication public investments (TPI), is visualized in Figure 1. We use the coefficient of variation (CV) in GVA per capita, a common indicator for looking at σ-convergence. Certain sharp kinks in the two curves in Figure 1 are prominent: we can see the response of the investments to the 2001 crisis in the form of a sharp drop,[10] followed by

[10] This was arguably the heaviest financial crisis in Turkish history.

an increase with a change of government from coalition to a single-party structure. Moreover, we see a clear correspondence of rising TPI to falling regional disparities, especially after the government change.[11] Therefore, a clear process of σ-convergence is apparent for Turkey for the period in question, possibly as a response to public investments targeted to enhance regional connections.

The spatial implications of this convergence process is of interest. As a preliminary exploration, we look at the Global Moran's I statistic (Moran, 1950), and its local decomposition, the Local Moran's I (Anselin, 1995), which are commonly used indicators for examining how regional interdependencies exist over space.[12,13] The Global Moran's I represents the degree of linear association between a variable and the weighted average of the same variable observed in neighboring regions (also referred to as its *spatial lag*) (Anselin, 1996) and can be seen as "... the simplest and most commonly used test statistics in the spatial econometric literature" (Arbia, 2006). Significant and positive global Moran's I results would imply that regions that are closer to each other have more similar per capita GVA levels than to those that are further away from them (Elhorst, 2012).

For the per capita income of Turkish regions, the Global Moran's I statistics for the years 1990, 1999, and 2011 for the per capita GVA values are respectively 0.202, 0.283, and 0.346 and highly significant (all results have p-values less than 0.001).[14] Therefore, significant positive global spatial dependence is suggested; regions with similar GVA per capita tend to be clustered around each other. In order to identify how individual regions behave in this context, the Moran scatterplots (Anselin, 1996; LeSage and Pace, 2009) are presented in Figures A.1 to A.3.[15] These scatterplots suggest that richer regions are close to richer ones, and poorer regions to poorer ones. A non-surprising result considering the long history of regional inequalities in Turkey.[16,17]

In order to identify local spatial clusters or "hot spots" as labeled by Anselin (1995), we calculate the Local Moran's I results for all 26 regions. Local Moran's I shows the extent of significant local spatial clustering around individual regions (Anselin, 1995). Using the Local Moran's

[11] On the other hand, Celbis et al. (2014a) show that in Turkey, the regional allocation of public investments in transportation and communication have been subject to political bias (created due to a preference towards regions that are politically affiliated to the government) during the period 1999-2011.

[12] The Global Moran's I statistic is calculated as $I = \left(\frac{n}{\sum_i \sum_j w_{ij}}\right) \sum_i \sum_j w_{ij} z_i z_j / \sum_i z_i^2$ while local Moran's I statistic is $I_i = z_i \sum_j w_{ij} z_j$ where z_i are deviations from the mean GVA per capita, and w_{ij} measures the regional connectivity between i and j, usually in the form of contiguity or distance (could be either row-normalized or not) of the regions i and j (Anselin, 1995). The above given calculation of the Global Moran statistic is for a non-standardized spatial weight matrix W of which w_{ij} is its element.

[13] See also Varga (1998) for a comprehensive review of global and local Moran's I.

[14] 1990 is the first year in our sample where we can calculate regional GVA per capita. 1999 is the first year where we have observations for all explanatory variables and therefore is the starting year for our estimations. 2011 is the final year in our data set.

[15] The calculations of the Moran's I values and scatterplots were done using the SPATLSA and SPATGSA commands in Stata developed by Pisati (2012).

[16] See Gezici and Hewings (2004), who do not find evidence for convergence in Turkey for the period 1990-1997, for a comprehensive review of convergence studies on Turkey.

[17] In the rest of this study, we use the term "rich" for regions with higher than average per capita income, and the term "poor" for those that have a lower per capita income than the country average.

I statistics for each region, and the distribution of the regions among the four quadrants of the associated Moran scatterplot, a "Moran significance map" can be drawn (Anselin et al., 2006; LeSage and Pace, 2009).

The Moran significance maps are presented for the years 1990, 1999, and 2011 in Figures 2a to 2c. In building the Moran significance map, we define categories of regions based on the quadrants of the Moran scatterplot as in Le Gallo and Ertur (2003): regions labelled "High-High" are those that have higher than average GVA per capita and are surrounded by regions with also higher values. "Low-Low" stands for regions with lower than average income per capita surrounded by similarly poor regions. Regions with lower than average per capita income surrounded by rich regions are labelled "Low-High" while "High-Low" stands for regions that have the opposite kind of spatial association to their surrounding regions. We also include a fifth category labeled "not significant" for regions with Moran's I p-values of greater than 0.10, such that only *significant local clusters* are colored (Le Gallo and Ertur, 2003).

Based on these figures, for all three years we observe significant patterns of spatial clustering around the largest regional economy of the country, Istanbul (TR10), in the north-west, which may be considered to include the capital Ankara in its extremity. Istanbul is a natural trade hub, connecting the maritime trade routes of the Black Sea and the Mediterranean Sea, the land trade routes from the rest of the country and the EU, and is also the commercial and financial center of Turkey. This clustering around Istanbul could also be interpreted from a *core-periphery* point of view (Krugman, 1991): a core economy exists in the North-West, with peripheral economies located around it.

The Moran significance maps also identify a High-High type of clustering in the south-west of the country. This is most probably due to the area being the tourism core of Turkey. Therefore, another spatially relevant observation could be regarding the clustering of specific industries.

An alarming and crucial suggestion of the Moran significance maps is the spatial clustering of poor regions in the east, underlining a strong spatial distinction from the rest of the country: this area, which is about one-third of Turkey, falls into the Low-Low category. To exacerbate the situation, regions that can be considered as core economies do not exist in the vicinity which can help reversing the trend of poor-poor spatial clustering, including beyond the international borders to the east and the south of this area.[18] The opposite is true for the regions in the west, which share either land or maritime borders with the EU.

There are only two regions that fall into the remaining categories of High-Low and Low-High: the region of Ankara, named after the capital of the country in which it is located, is a rich economy surrounded generally by poorer ones (High-Low). This type of economy is referred to as "diamond in the rough" by Le Gallo and Ertur (2003). Ankara used to be a small village when

[18] Areas under varying degrees of conflict exist outside of Turkey's borders to the east such as Northern Syria, Northern Iraq, Nagorno-Karabakh, and Chechnya. Moreover, the eastern region of Turkey itself was under conflict during the recent decades.

it replaced Istanbul as the capital in 1923, suggesting a significant exogenous intervention to its regional economy that might have caused this outcome.[19] On the other hand, by 2011, Ankara had moved into the category of High-High regional economies, leaving the "diamond" category. The other regional economy that is in a similar situation in terms of its dissimilarity to its surroundings, is TR71, a neighbor of Ankara.[20] This region falls into the category Low-High, a poor region close to richer regions, a type of regional economy which is referred by Le Gallo and Ertur (2003) as a "doughnut." On the other hand, the rest of the regions that are colored in white are those that do not yield significant local Moran's I statistics on the 10% level, and therefore are not subject to a significant spatial clustering.[21,22]

Since σ-convergence, and significant spatial clusters are apparent for Turkey, two questions that relate to these two findings can be asked: (1) how fast are poor regions catching up to the rich regions? and (2) what does the spatial distribution of income per capita look like? Figures 3 and 4 compare the per capita income levels of the regions to the growth rates of their per capita incomes for the years 1999 and 2011 respectively where darker colors represent higher per capita income. Clear correspondences of high incomes to low rates of growth can be seen for the earlier defined North-Western and South-Western clusters and the region TR31 in the West for the year 1999. Poorer regions who had high growth rates in this year are mainly grouped in the North-East, North, and Center-East. We can also observe that the region TR 71, consistent with the Moran Significance Maps, did not grow fast despite being a low income region. In the maps for 2011, it can be seen that certain poorer South-Eastern regions experienced higher growth. Region TR 71 which fell into the "doughnut" definition based on the Moran significance map also had high growth in this year. It is possible that if this region continued to experience high growth, it may have moved out (or moving out) from the Low-High category in the period after 2011. We also see that the rich regions in the South-Western cluster together with some regions from the North-Western cluster have behaved according to the high-income low-growth hypothesis.

To conclude this section, we suggest the existence of several stylized facts for Turkey for the period in focus: (1) an increasing trend in public investments in transportation and communication corresponds to a decreasing trend in regional per capita income disparities, (2) despite the decreasing trend in regional disparities, the spatial clustering of poor and rich regions is persistent. On the other hand, it should be noted that these maps are merely snapshots in time and are solely for giving preliminary descriptive information. Nevertheless, these two stylized facts set the stage for absolute and conditional β-convergence analyses which we present in the next section.

[19] This change in capital city is due to the replacement of the Ottoman state by the Republic of Turkey.
[20] Region TR 71 consists of the following provinces: Kirikkale, Aksaray, Nigde, Nevsehir, and Kirsehir.
[21] All maps are drawn using the Stata command SPMAP by (Pisati, 2007).
[22] The Stata command MERGEPOLY by Picard and Stepner (2012) for aggregating smaller scale spatial units to larger units were used to construct all maps as the original source map was in NUTS-3 level.

Figure 1.
Sigma convergence represented by the coefficient of variation, and TPI (millions), 1990-2011

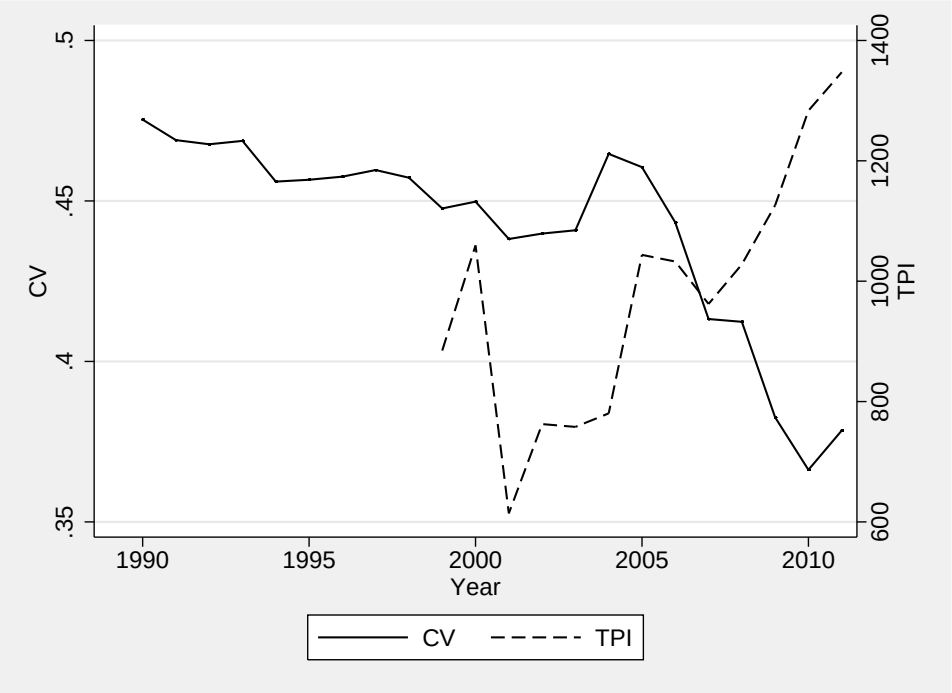
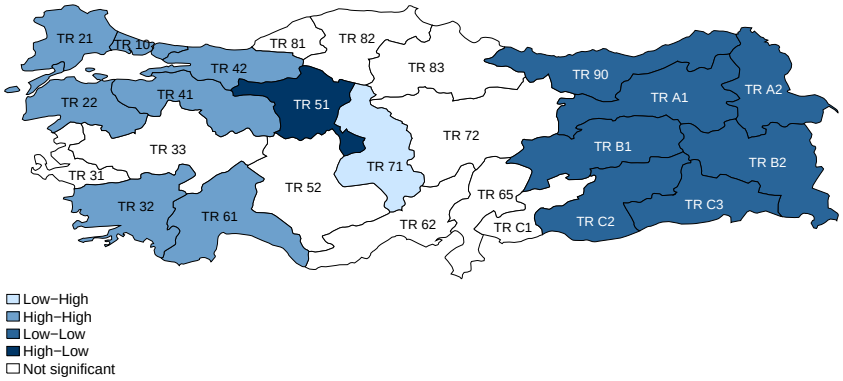
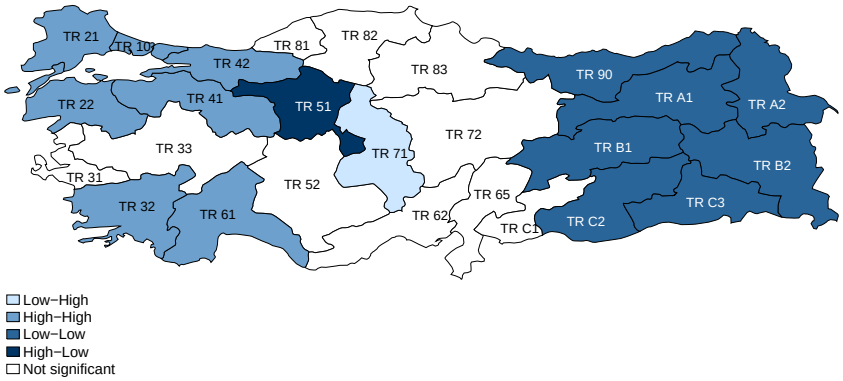


Figure 2.
Moran significance map

(a) 1990



(b) 1999



(c) 2011

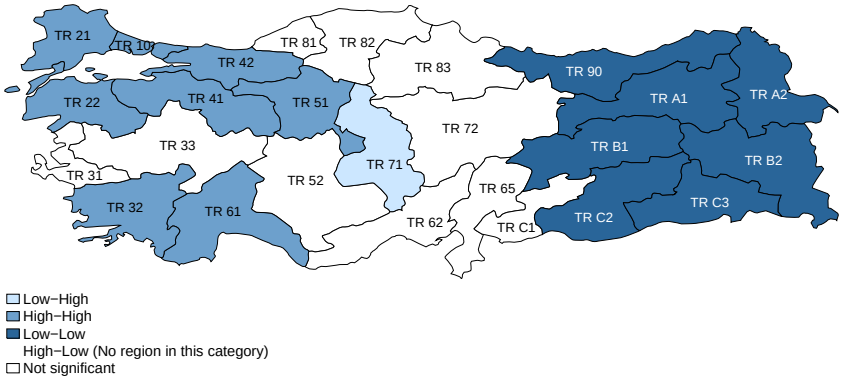
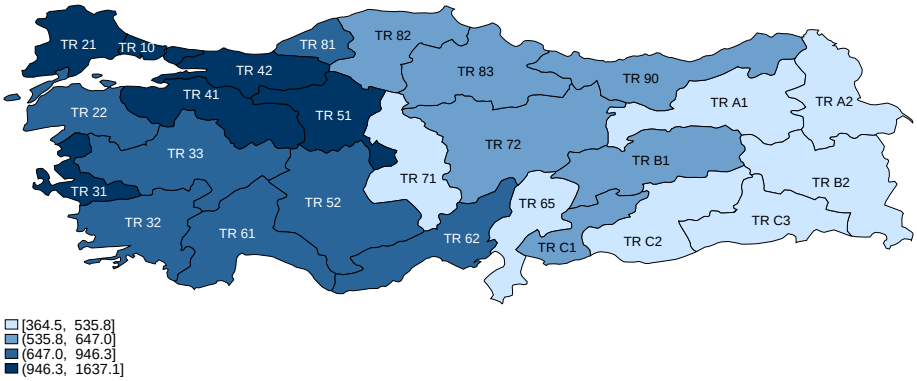


Figure 3.
GVA per capita and the growth rate of GVA per capita, 1999

(a) GVA per capita



(b) Growth rate

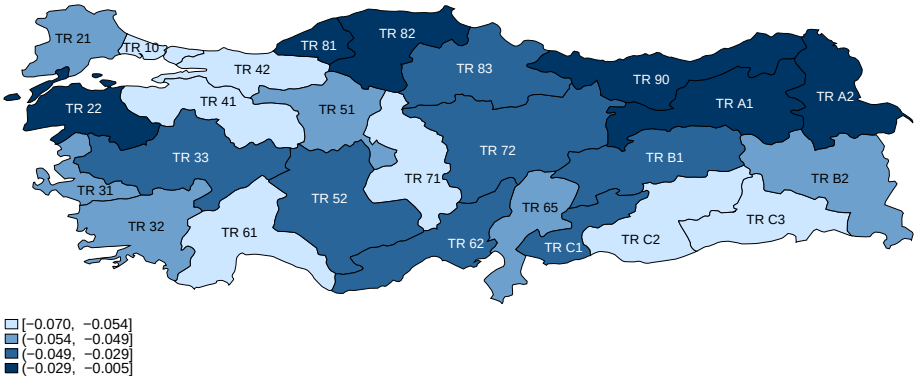
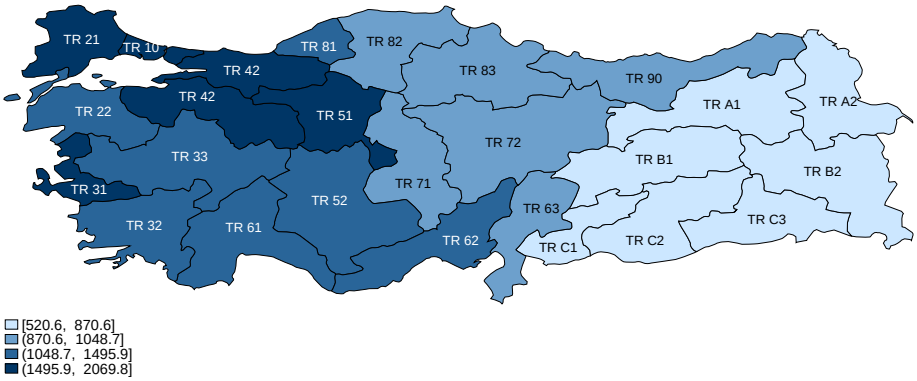
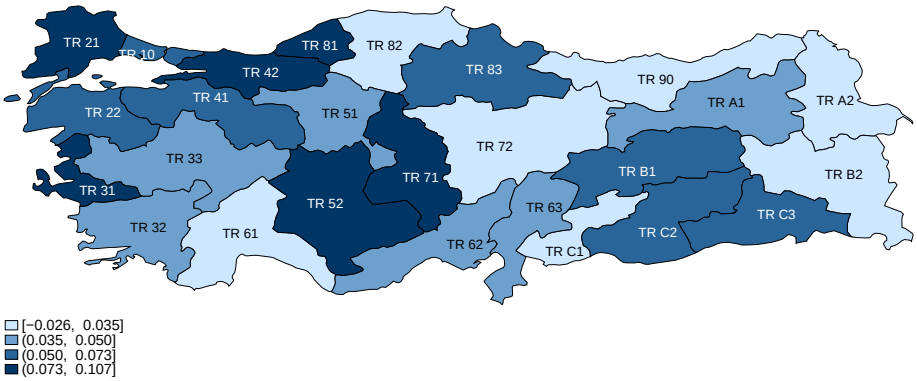


Figure 4.
GVA per capita and the growth rate of GVA per capita, 2011

(a) GVA per capita



(b) Growth rate



4 Empirical approach

As discussed in section 2.3, even though communication reduces the effect of the spatial barriers to the diffusion of information, space and location remain relevant. *Spatial effects*[23] are commonly taken into account in convergence research as can be seen in Table A.1 which lists a sample of 18 convergence studies and the explanatory factors they consider. The table shows that there is a large diversity in the literature regarding the explanatory variables considered in convergence equations. Among these factors, spatial effects are commonly formalized as "spatial dependence" (Anselin, 1988) which is defined as representing "the continuity of economic phenomena in space" (Arbia, 2006, p. 16). In this perspective, Ertur and Koch (2007) argue that technological interdependence between economies exist and that the mechanism of these interdependencies is through spatial externalities and find evidence that these spatial externalities are important determinants of conditional convergence among countries. This type of dependence between economies is also highlighted by Armstrong and Taylor (2000) who point out that small economies can benefit from technical progress that takes place outside their borders due to diffusion across space.[24]

In the light of these views, and the suggestion of possible spatial dependence by our descriptive analyses, we begin by testing the absolute convergence hypothesis with estimating the cross-sectional equation (2) which does not take into account region specific characteristics. In order to see if our results are robust to the inclusion of the earlier discussed spatial effects, we augment equation (2) to account for spatial dependence. The *spatial autoregressive model* (SAR) (Anselin, 1988) adaptation of equation (2) takes the form

$$ln(y_{i,t_0+T}) = \alpha + \rho \sum_{j=1}^{N} w_{ij} ln(y_{j,t_0+T}) + (1+\beta) ln(y_{i,t_0}) + \nu_i \tag{5}$$

where w_{ij} is the element of the weight matrix W of inverse distances between regions with zeros in the diagonal ($w_{ii} = 0$), and N is the number of spatial units. Therefore, the SAR model hypothesizes that the per capita income of region i is partly determined by the weighted average of the per capita incomes of the other regions, where the weight of a region is defined by its proximity to i. The additional parameter ρ measures the magnitude of this spatial dependence. All other terms are the same as in equation (1).

An alternative augmentation to equation (2) is the *spatial error model* (SEM) (LeSage and Pace, 2009) where the spatial dependence is hypothesized to exist through the disturbances ν_i:

[23] Florax and Van der Vlist (2003) define spatial effects as a "catchall term referring to both spatial dependence and spatial heterogeneity".

[24] See Ertur and Koch (2007); Pfaffermayr (2012) for discussions on the integration of spatial effects to the underlying theoretical growth model.

$$ln(y_{i,t_0+T}) = \alpha + (1+\beta)ln(y_{i,t_0}) + \nu_i$$
$$\text{where} \quad \nu_i = \lambda \sum_{j=1}^{N} w_{ij}\nu_j + \zeta_i \tag{6}$$

where $\zeta_i \sim N(0, \sigma_\zeta^2)$ and the parameter λ captures the spatial error dependence: a significant λ could mean that there are spatially clustered relevant variables that are omitted in the model, resulting in error terms are not independent from each other (Ward and Gleditsch, 2008). A third form is the General Spatial Model (GSM)[25] and is a combination of the above SAR and SEM specifications Kelejian and Prucha (1998):

$$ln(y_{i,t_0+T}) = \alpha + \rho \sum_{j=1}^{N} w_{ij} ln(y_{j,t_0+T}) + (1+\beta)ln(y_{i,t_0}) + \nu_i$$
$$\text{where} \quad \nu_i = \lambda \sum_{j=1}^{N} c_{ij}\nu_j + \zeta_i \tag{7}$$

where we assume $w_{ij} = c_{ij}$ (i.e. the same spatial weight matrix W defines the connectivity between regions both in terms of their per capita incomes and their disturbances). The conditional convergence counterparts of the absolute convergence equations (5), (6), and (7), condition the convergence process on three regional connectivity-enhancing attributes: internet infrastructure together with air, and land transport infrastructure. Our variable of interest, internet infrastructure, is measured as the number of ADSL lines in regional post offices per capita and is denoted by c_i. As discussed in Section 1, the connectivity between regions is not established only through communication, but also through transportation. Thus, we include two other variables that are expected to enhance inter-regional connectivity: air transport capacity per capita (a_i), and an index of land transportation infrastructure density (r_i). This set of explanatory variables correspond to the term $\sum_{k=1}^{m} \gamma_k x_{k,it}$ in the panel conditional convergence equation (3) such that: $\sum_{k=1}^{m} \gamma_k x_{k,it} = \gamma_1 lnc_{it} + \gamma_2 lna_{it} + \gamma_3 r_{it}$.[26]

In order to explore how the rate in which a region approaches its steady-state depends on its internet infrastructure, we introduce an interaction term $ln\ y_{i,t-1} \times ln\ c_{it}$ so that $\sum_{k=1}^{m} \gamma_k x_{k,it}$ is now defined as $\sum_{k=1}^{m} \gamma_k x_{k,it} = \gamma_1 lnc_{it} + \gamma_2 ln\ y_{i,t-1} \times ln\ c_{it} + \gamma_3 lna_{it} + \gamma_4 r_{it}$. This implies that e^{-bT}, which is the marginal effect of $ln\ y_{i,t-1}$ is now defined as $e^{-b(ln\ c_{it})T}$ (i.e the speed of convergence is a function of $ln\ c_{it}$) and equals $(1+\beta) + \gamma_2 ln\ c_{it}$ where $(1+\beta)$ is the estimated coefficient on

[25] This model is also labeled as SAC (LeSage and Pace, 2009).

[26] The land infrastructure index r_{it} does not appear in natural logarithms because, as will be detailed in Section 5, the components of this index are in natural logarithms.

$ln\ y_{i,t-1}$.

The specifications corresponding to equations (5), (6), and (7) which include individual region and year effects, and the set of explanatory variables x_k are respectively:

$$ln(y_{it}) = \alpha + \rho \sum_{j=1}^{N} w_{ij} ln(y_{jt}) + (1+\beta) ln(y_{i,t-1}) + \sum_{k=1}^{m} \gamma_k x_{k,it} + \mu_i + \eta_t + \xi_{it} \qquad \text{(SAR)} \qquad (8)$$

$$\begin{aligned} & ln(y_{it}) = \alpha + (1+\beta) ln(y_{i,t-1}) + \sum_{k=1}^{m} \gamma_k x_{k,it} + \mu_i + \eta_t + \xi_{it} \\ & \text{where} \quad \xi_{it} = \lambda \sum_{j=1}^{N} w_{ij} \xi_{jt} + \vartheta_{it} \qquad \text{(SEM)} \qquad (9) \end{aligned}$$

$$\begin{aligned} & ln(y_{it}) = \alpha + \rho \sum_{j=1}^{N} w_{ij} ln(y_{jt}) + (1+\beta) ln(y_{i,t-1}) + \sum_{k=1}^{m} \gamma_k x_{k,it} + \mu_i + \eta_t + \xi_{it} \\ & \text{where} \quad \xi_{it} = \lambda \sum_{j=1}^{N} w_{ij} \xi_{jt} + \vartheta_{it} \qquad \text{(GSM)} \qquad (10) \end{aligned}$$

where $\vartheta_{it} \sim N(0, \sigma^2_{\vartheta})$. The estimation results for each model are presented in Section 6 where the absolute convergence counterparts of all panel equations are also presented.

The growth-convergence panel equations (3), (4), (8), (9), and (10) are subject to the Nickell (1981) bias induced by the de-meaning of the data for each unit of observation for fixed effects estimation. This bias is of order $1/T$ and therefore decreasing with larger time periods. Since our data is over a period of 13 years, we can expect a moderate degree of Nickell bias in our estimations. As will be presented in our results, since our estimates of $(1+\beta)$ are positive in all models, this bias would be negative (Nickell, 1981).

Common approaches as a remedy for this bias are the Arellano and Bond (1991) estimator and the Arellano and Bover (1995)/Blundell and Bond (1998) GMM estimators. However, in the context of dynamic panel models with spatial effects, Elhorst et al. (2010) conduct a Monte Carlo simulation which implies that while an Arellano and Bond (1991) GMM approach would reduce the bias in the estimate of $(1+\beta)$, it would yield an estimate of the spatial autoregressive parameter ρ with a larger bias compared to maximum likelihood estimation (MLE).[27] Given that the time span in our study corresponds to 13 years, and the above implication regarding the trade-off between MLE and GMM approaches, a MLE approach is taken in estimating the SAR, SEM, and GSM based

[27] Elhorst et al. (2010) suggest the use of a combination of GMM and MLE based on their simulation results.

specifications under the assumption that the data is distributed normally.[28] While being a commonly employed method for dealing with bias and inconsistency issues in spatial models (Elhorst, 2003), MLE is also among the common approaches used to estimate growth-convergence equations (Islam, 2003). In addition, MLE provides advantages in terms of asymptotic efficiency, but on the other hand may not be robust to violations of assumptions regarding the distribution of the data. Recent studies using a MLE approach for estimating spatial panel models include Pfaffermayr (2012) who examines European regional convergence from 1980 through 2005, Baltagi and Bresson (2011) who use a panel of eighty districts of Paris from 1990-2003, Ertur and Musolesi (2012) who use a panel of 21 OECD economies and Israel over the years 1971-90, Elhorst and Freret (2009) who estimate a spatial Durbin panel model using data from ninety-three local government departments in France over the period 1992-2000, and by Lee and Yu (2010a), Lee and Yu (2010b), and Debarsy and Ertur (2010) in Monte-Carlo analyses.

5 Data

The variables used and their sources are defined as follows: we use the regional GVA series in constant 1998 national currency compiled by Celbis et al. (2014a). This GVA series is based on the Turkish Statistics office (TURKSTAT) data[29] and it is corrected for changes in spatial scale and output collection methods of TURKSTAT that took place in the 2000's. Additionally, two missing years in the data were imputed as the original data was available as NUTS-3 level GDP for the years 1987-2001 and NUTS-2 level GVA for 2004-2011.[30] The regional population data is from OECDstat.[31] The variable c_{it} is measured as the number of ADSL lines in regional post offices per capita[32] and is collected from the publications of the General Directorate of PTT.[33] The missing values for the number of ADSL lines for the years 1999-2002 and 2005 are predicted using the regional public investment in transportation and communication made in these years. Air transport capacity data is obtained from the interactive web-tool of the Republic of Turkey: Ministry of Transport, Maritime Affairs and Communication,[34] and measured as the total passenger capacity in airports as reported after the establishment date of the specific airport(s) within a region, divided by regional population. The three components that are used to construct the land infrastructure density index are from TURKSTAT. The index is constructed using the first principal components

[28] All models with spatial terms are estimated using the Stata command SPAUTOREG written by Shehata (2011) for the cross-sectional models, and the command XSMLE developed by Belotti et al. (2013) for the panel models. The generation of the weight matrix from coordinates is done using the Stata command SPMAT developed by Drukker et al. (2011).

[29] www.turkstat.gov.tr

[30] See appendix A1 of Celbis et al. (2014a) for the details of these adjustments.

[31] http://stats.oecd.org/

[32] For our estimations we have scaled this density by dividing population by 1,000,000,000.

[33] Retrieved from http://www.ptt.gov.tr/?wapp=statistics_tr on 10 April, 2014.

[34] Retrieved from http://web.shgm.gov.tr/tr/havaalanlari/381-havaalanlari on 15 April, 2014.

of the natural logarithms of road length, highway length, and railway length in kilometers per 1000 km^2. The distance weight matrix used in the spatial analyses is constructed as follows: the coordinates in decimal degrees of the city in a region with the highest population is taken as the "regional center." This is done so that a more sensitive measure of regional connectivity, compared to using polygon centroids, can be achieved. The euclidean distances between regions are generated from these coordinates. The descriptive statistics of all variables used in the construction of model covariates are reported in Table 1.

Table 1.
Descriptive Statistics

Variable	Mean	Std. Dev.	Min.	Q1	Q3	Max.
GVA (Billion TL)	3.03	4.08	0.44	1.12	3.27	27.44
ADSL	113.56	100.88	2	44	160	665
Population	2,707,646.58	1,981,422.14	732,790	1,617,820	3,048,651	13,255,685
Air capacity	1	1.12	0	0.18	1.44	5.18
Land infrastructure index	3.93	1.12	1.86	3.18	4.83	6.95

Observations: 26 regions, 13 years.

6 Estimation results

6.1 Cross-sectional estimation

Table 2 presents the estimation results for the absolute convergence equations (2), (5), (6), and (7). All models suggest the existence of absolute convergence of Turkish regions over the period 1999-2011, including those that take spatial effects into account. However, the estimated speeds of convergence range from about 0.8% to about 2.5%, which imply a very long half-life of at least about thirty years.

Estimates of ρ in the SAR and GSM models suggest the existence of positive spatial externalities: the current per capita income level of regions, $ln(y_{i,t_0})$ are positively impacted by the levels of $ln(y_{i,t_0})$ of the regions in their surroundings, implying that spatial proximity plays role in the growth and convergence of regions. The fastest rates of convergence are estimated by these two models (SAR: 2.46% with a half-life of about 28 years, and GSM: 2.19% with a half life of about 32 years). The GSM estimation does not find spatial correlation between model residuals but similar to SAR results, finds positive spatial dependence in $ln(y_{i,t_0})$.

On the other hand, the estimate of λ in the SEM suggests that the errors of the model are

negatively correlated in space, which could bias the estimates on the exogenous variables if this correlation is not taken into account. Additionally, the SEM estimates a lower (in absolute value) convergence factor β, a lower convergence rate of about 0.82%, and a much longer half-life of about 85 years compared to the results of the Base, SAR, and GSM results. The significant estimate of λ in SEM becomes insignificant when the spatial autoregressive term ρ is taken into account in the GSM estimation. In other words, spatially correlated error terms are only observed when the spatial lag of $ln(y_{i,t_0})$ is omitted. Finally, the base model, where spatial effects are not taken into account, estimate the convergence speed and half-life to be higher than those reported by the SAR and GSM, but lower than the SEM results.

In order to identify the specification with higher adequacy, aside of the log-likelihood values, we report Akaike's Information Criterion (AIC), and the Bayesian Information Criterion (BIC) at the bottom of Table 2. While SAR and GSM models yield the highest log-likelihood values, the AIC and BIC results suggest that the SAR model fits our data better compared to the GSM specification.[35] We also report separately the likelihood ratio (LR) and Wald test p-values where the GSM is the unrestricted model in part (a) of Table 6. In accordance with above results, the p-values of both tests suggest that while the GSM can be reduced to the SAR model (i.e. $\lambda = 0$), neither the base model or the SEM model are adequate, as $\rho \neq 0$.

Therefore, the SAR model is preferred regarding the cross-sectional results. The results of the SAR model suggest positive spatial dependence in $ln\ y_{i,t_0+T}$, implying that regional per capita incomes are positively affected by the per capita incomes of the other regions in proximity. This result is in line with our earlier observations of spatial clustering of similar economies in Turkey and affirms the earlier hinted existence of spatial effects.

6.2 Panel estimation

We extend the cross-sectional approach to a panel form and present the results of the absolute convergence models in Table 3. Regional fixed effects are included in all estimations except in the first column. When fixed effects are not included, the estimated convergence speed is about 1.3%, a result similar to those of the cross-sectional base model. This result, while in principle suggesting convergence, implies that this convergence is very slow with a half-life of around 55 years which can be seen as the non-existence of convergence. This slow convergence speed is observed even though the estimated coefficient on $ln\ y_{i,t-1}$ is 0.987 which is only about 0.17 percentage points higher than the corresponding elasticity estimated by the fixed effects base model in column 2.

A possible explanation to this result can be found in Arestis et al. who show that in the calculation of the speed of convergence is "extremely sensitive to small changes in the estimated regression coefficients and hence may be greatly influenced by a relatively small bias on these

[35] The base model is a restricted specification of SAR, SEM and, GSM as follows: if $\rho = 0$ SAR reduces to the base model, if $\lambda = 0$ SEM reduces to the base model, and if $\rho = \lambda = 0$ GSM reduces to the base model (Elhorst, 2010).

estimates Arestis et al. (2007, p.214). It is likely that the omission of region-specific fixed effects resulted in the estimation of such a slow speed of convergence in column 1 which is more similar to its cross-section counterpart in the first column of Table 2 rather than the specification with fixed effects. Moreover, as ordinary least squares estimation (OLS) may lead to biased and inconsistent results if spatial effects exist but are not included (Anselin, 1988; Elhorst, 2003; Debarsy and Ertur, 2010), it is also likely that the omission of spatial effects may have played a role.

The estimated speed of convergence becomes much higher when region-specific fixed effects are taken into account as reported in the second column of Table 3. This high convergence speed of 20% corresponds to a half life of only about 3.5 years. Therefore, when conditioned on time-invariant region specific factors, we observe a conditional convergence speed that is hugely different than the earlier estimated absolute convergence speeds.

The remaining columns of Table 3 report the estimation results with spatial effects. For a better understanding of the results of these models, we draw attention to part (b) of Table 6, where the LR and Wald test p-values for the Base (FE), SAR, and SEM models (with the unrestricted model being the GSM) are presented. The test results suggest that the spatial lag parameter ρ is not significantly different than zero in the GSM, and that a SEM specification is valid. In other words, test results suggest, that the GSM cannot collapse to a SAR specification where $\lambda \neq 0$, or to the base model where both ρ and λ are zero.

The preferred SEM model, which controls for the region specific constant effects, finds evidence for conditional convergence (a negative and significant β). This model also yields a convergence speed of almost 20% and a half life of 3.5 years, similar to the base model results. These estimates of convergence speeds are much higher than the "legendary 2%" reported in the literature which is mostly based on national economies (Durlauf et al., 2005; De Groot and Florax, 2005). We also observe in the SEM results a significant λ which suggests that spatial correlation exists among omitted terms.

Table 4 presents the estimation results when the term including the explanatory variables ($\sum_{k=1}^{m} \gamma_k x_{k,it}$) is included. The results are very similar in all models: all four specifications find conditional convergence, and estimate that internet infrastructure has a positive and significant effect on regional per capita income. Regarding how fast this convergence process is, the interaction term $ln\ y_{i,t-1} \times ln\ c_{it}$ necessitates that different values for the convergence factor β, the convergence speed, and the half-life should be estimated based on the level of internet infrastructure region i has. As the P-values of LR and Wald tests (where the GSM is the unrestricted model) reported in part (c) of Table 6, suggest that spatial effects do not play a significant role when the set of explanatory variables is included, we use the results of the base model for elaborating on how fast the convergence process is. The implied values by the base model are presented for several percentiles of c_{it} in Table 5.

The speed of convergence increases in c_{it}: for instance, regions with internet infrastructure in

the fifth and ninety-fifth percentiles have about 10 percentage points of difference in the speed of convergence. This corresponds to a decrease of about one-thirds in the estimated half-life (from around four years to around 2.5 years). Therefore a regional economy benefits from internet infrastructure not only in terms of growth in per capita income, but also through a higher speed of convergence towards its steady state. Moreover, considering that the half-lives in the interquartile range reported in the third column of Table 5 are below the half-life estimated by the base model without the set of explanatory variables (about 3.5 in Table 3), we suggest that regional infrastructure including internet infrastructure, helps the individual steady-states of different regions to become more homogeneous, allowing for convergence towards similar per capita income levels. As a result, internet infrastructure can be seen as providing benefits to a regional economy through three different mechanisms: growth, faster convergence to the steady state, and the homogenization of region-specific steady-states.

Another important result is the additional finding in our study is that air transport capacity is also an important regional attribute that contributes to a regional economy: all models in Table 4 find a positive and significant effect of air transport infrastructure ($ln\ a_{it}$) on $ln\ y_{it}$. In relation to this result, Celbis et al. (2014b) found in a study on Turkey for the period 2002-2010, that regional air transport capacity enhances the international export performances of regions. Therefore, it may be possible that the observed effect of this variable is due to better trade connections with the international markets.

Finally, we do not observe any significant result for the land infrastructure index, r_{it}. One interpretation could be that regions rely more on other means of transportation rather than land routes. It is also possible that this variable simply does not provide enough variation. Moreover, as pointed out by (Celbis et al., 2014a), it common to observe decreases in road lengths within Turkish regions which correspond to *improvements* in road infrastructure and travel times. This is a general problem whenever road stock is used as an indicator of land infrastructure in empirical research. However, measures on the quality and efficiency of roads in a regional scale do not exist for Turkey.

Table 2.
Cross-sectional estimation results

	(1) Base Model	(2) SAR	(3) SEM	(4) GSM
$ln\ y_0$	0.865***	0.744***	0.907***	0.769***
	(0.0472)	(0.0695)	(0.0253)	(0.0714)
α	1.322***	-0.563	1.047***	-0.334
	(0.318)	(0.890)	(0.167)	(0.741)
β	-0.135***	-0.256***	-0.0934***	-0.231***
	(0.0472)	(0.0695)	(0.0253)	(0.0714)
ρ		0.381**		0.325**
		(0.174)		(0.164)
λ			-1.403**	-0.856
			(0.596)	(0.757)
Convergence speed	0.0121	0.0246	0.00817	0.0219
Half-life	57.23	28.16	84.87	31.62
Observations	26	26	26	26
Log-likelihood	25.55	28.41	27.38	29.06
AIC	-47.11	-48.83	-46.76	-48.11
BIC	-44.59	-43.79	-41.73	-41.82

Stata module for spatial models: SPAUTOREG (see footnote 28).
SAR: Spatial Autoregressive Model.
SEM: Spatial Error Model.
GSM: General Spatial Model.
Standard errors in parentheses: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.
Panel estimation results

	(1) Base Model	(2) Base Model	(3) SAR	(4) SEM	(5) GSM
$ln\ y_{i,t\text{-}1}$	0.987***	0.819***	0.819***	0.822***	0.821***
	(0.00503)	(0.0397)	(0.0325)	(0.0322)	(0.0325)
β	-0.0126***	-0.181***	-0.181***	-0.178***	-0.179***
	(0.00503)	(0.0397)	(0.0325)	(0.0322)	(0.0325)
ρ			0.141		-0.0288
			(0.103)		(0.140)
λ				0.323**	0.343**
				(0.128)	(0.157)
Convergence speed	0.0127	0.200	0.199	0.196	0.197
Half-life (years)	54.79	3.467	3.482	3.541	3.520
Observations	338	338	338	338	338
Observations per region	13	13	13	13	13
Log-likelihood	641.8	662.2	663.1	665.0	665.0
Fixed effects	No	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes

Stata module for spatial models: XSMLE (see footnote 28).
SAR: Spatial Autoregressive Model.
SEM: Spatial Error Model.
GSM: General Spatial Model.
Standard errors in parentheses: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4.
Panel estimation results

	(1) Base Model	(2) SAR	(3) SEM	(4) GSM
$ln\ y_{i,t\text{-}1}$	1.002***	0.997***	1.001***	0.999***
	(0.0702)	(0.0599)	(0.0601)	(0.0606)
$ln\ y_{i,t\text{-}1} \times ln\ c_{it}$	-0.0204***	-0.0199***	-0.0201***	-0.0200***
	(0.00565)	(0.00472)	(0.00476)	(0.00482)
$ln\ c_{it}$	0.145***	0.142***	0.143***	0.142***
	(0.0377)	(0.0312)	(0.0316)	(0.0319)
$ln\ a_{it}$	0.0795**	0.0784**	0.0767**	0.0768**
	(0.0343)	(0.0306)	(0.0308)	(0.0308)
r_{it}	-0.0178	-0.0172	-0.0177	-0.0175
	(0.0126)	(0.0129)	(0.0128)	(0.0129)
ρ		0.0538		0.0243
		(0.104)		(0.126)
λ			0.100	0.0808
			(0.154)	(0.185)
Observations	338	338	338	338
Observations per region	13	13	13	13
Log-likelihood	681.3	681.4	681.5	681.5
Fixed effects	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes

Stata module for spatial models: XSMLE (see footnote 28).
SAR: Spatial Autoregressive Model.
SEM: Spatial Error Model.
GSM: General Spatial Model.
Standard errors in parentheses: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.
Convergence factors, speeds, and associated half-lives (Base model)

Percentile of c	Convergence factor	Convergence speed	Half-life (years)
1%	-0.138	0.148	4.671
5%	-0.158	0.172	4.019
25%	-0.199	0.222	3.126
50%	-0.213	0.240	2.893
75%	-0.224	0.254	2.734
95%	-0.235	0.268	2.588
99%	-0.241	0.276	2.510

Table 6.
Model comparison versus GSM

	Base model (FE)	SAR	SEM
(a) Absolute convergence cross-sectional models			
LR test p-value	0.030	0.256	0.067
Wald test p-value	0.020	0.258	0.047
(b) Absolute convergence panel models			
LR test p-value	0.059	0.049	0.836
Wald test p-value	0.035	0.029	0.837
(c) Conditional convergence panel models			
LR test p-value	0.799	0.667	0.848
Wald test p-value	0.797	0.662	0.847

SAR: Spatial Autoregressive Model.
SEM: Spatial Error Model.

7 Concluding Remarks

Internet infrastructure is arguably a component which has become more important than the other types of telecommunication infrastructure in the last two decades. The purpose of this study was to examine its role in regional per capita income convergence. Our approach brings together the convergence theories and the theories regarding the diffusion of information in the context of economic geography. We have examined the process of σ-convergence, the spatial differences in regional per capita income and their growth rates in Turkey.

We have observed different results regarding absolute convergence and conditional convergence: when convergence was conditioned on region specific characteristics, the convergence speeds were estimated to be much higher, and the half-lives to be much shorter compared to when these factors were not taken into account. As a result, we have observed evidence for conditional β-convergence with reasonable speed among Turkish regions during the period 1999-2011.

As the descriptive analysis suggested that spatial effects may play a role in the convergence of Turkish regions, we modeled spatial dependence with alternative SAR, SEM, and GSM specifications. We found that internet infrastructure contributes to a regional economy in three ways: (1) by positively impacting on per capita income, (2) by increasing the speed of convergence of a region to its steady-state, and (3) by contributing to make region-specific steady-states more alike. Therefore, as internet infrastructure can reduce the time needed for regions to converge to their steady-states, we suggest that investing in this type of infrastructure in lagging regions is important for regional convergence.

While regional time-invariant structural characteristics are controlled through the use of fixed effects, two other connectivity-enhancing variables aside of internet infrastructure were considered (air and land infrastructure). Air transport capacity was also found to play a contributing role to a regional economy.

Finally, our analysis suggests that the economic geography of Turkey is defined by a strong core-periphery pattern and a significant clustering of regions that have lower than average income per capita levels. However, it is therefore remarkable that controlling for spatial effects did not change any of our main findings regarding the convergence process.

A Appendix

Table A.1.
Examples of variable used in the analysis of convergence

Author	Title	Sample	Period	Explanatory factors
Barro et al. (1991)	Convergence across states and regions	US states and regions, European regions	1880-1988 for US, 1950-1985 for Europe	Regional or country dummies, Sectoral dummies.
Barro and Sala-i Martin (1992)	Convergence	48 US states	1840-1988	Regional dummies, sectoral composition, education, Gov't expenditure, revolutions and coups, assasinations, market distortions.
Mankiw et al. (1992)	A Contribution to the Empirics of Economic Growth	98 countries	1960-1985	Population, investment, education.
Sala-i Martin (1996b)	Regional cohesion: evidence and theories of regional growth and convergence	US, Canada, Japan, 5 European nations	1880-1991	Regional dummies, sectoral variables.
Persson (1997)	Convergence across the Swedish counties, 19111993	Swedish counties	1911-1993	Size of the agricultural sector, migration, housing rent.
Lall and Yilmaz (2001)	Regional economic convergence: Do policy instruments make a difference?	US states	1969-1995	Spatial effects, public capital, education, time dummies, state dummies.
Badinger et al. (2004)	Regional Convergence in the European Union, 1985-1999: A Spatial Dynamic Panel Analysis	196 European regions	1985-1999	Spatial effects, investments, population, regional dummies, time dummies.

Table A.1.
Examples of variable used in the analysis of convergence (cont'd)

Author	Title	Sample	Period	Explanatory factors factors
Leon-Gonzalez and Montolio (2004)	Growth, convergence and public investment. A Bayesian model averaging approach	Spanish provinces	1965-1995	Private investments, public investments, education, sectoral structure, area, localization, fertility, fixed regional effects.
Arbia (2006)	Spatial econometrics: statistical foundations and applications to regional convergence	92 Italian provinces	1950-1999	Spatial effects.
Arbia (2006)	Spatial econometrics: statistical foundations and applications to regional convergence	129 European regions	1950-1999	Spatial effects.
Ertur and Koch (2007)	Growth, technological interdependence and spatial externalities: theory and evidence	91 Countries	1960-1995	Spatial effects, population, investments.
Kirdar and Saracoglu (2007)	Migration and regional convergence: an empirical investigation for Turkey	67 Turkish provinces	1975-2000	Migration, population, state of emergency status.
Battisti and De Vaio (2008)	A spatially filtered mixture of β-convergence regressions for EU regions, 1980–2002	190 and 242 EU regions	1980-2002	Spatial effects.

Table A.1.
Examples of variable used in the analysis of convergence (cont'd)

Author	Title	Sample	Period	Explanatory factors factors
Ding et al. (2008)	Telecommunications infrastructure and regional income convergence in China: panel data approaches	29 Chinese regions	1986-2002	Spatial effects, lagged dependent variable, investments, population, employment, telecommunication, urbanization, public industrial output ratio, transportation infrastructure, region and time dummies.
Yildirim et al. (2009)	Income Inequality and Economic Convergence in Turkey: A Spatial Effect Analysis	67 Turkish provinces	1987-2001	Spatial effects, education, fertility, gov't expenditure, unemployment.
Del Bo et al. (2010)	Regional Infrastructure and Convergence: Growth Implications in a Spatial Framework	EU regions	1995-2006	Spatial effects, transportation infrastructure, communication infrastructure, capital stock, employment, human capital, regional and time fixed effects.
Onder et al. (2010)	The Impact of Public Capital Stock on Regional Convergence in Turkey	26 Turkish regions	1980-2001	Transportation public capital stock.
Pfaffermayr (2012)	Spatial convergence of regions revisited: a spatial maximum likelihood panel approach	European regions	1980-2005	Spatial effects, country and time dummies.

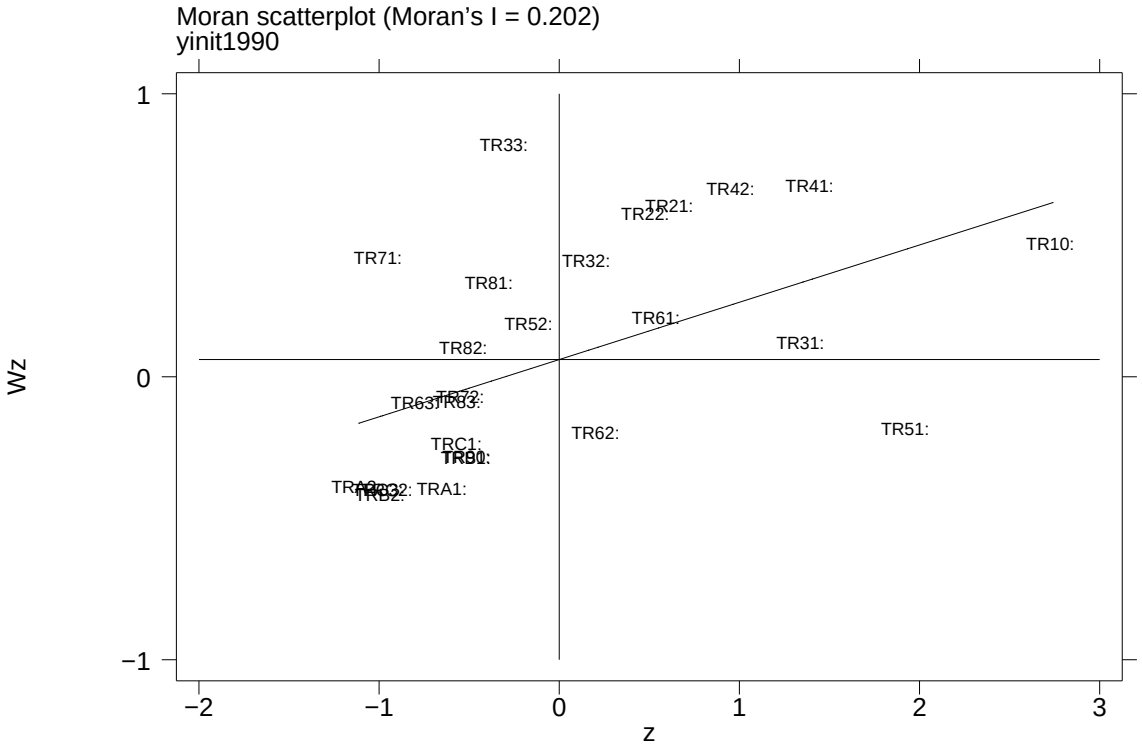


Figure A.1.
Moran scatterplot: Per capita GVA, 1990 (Moran's I: 0.249).

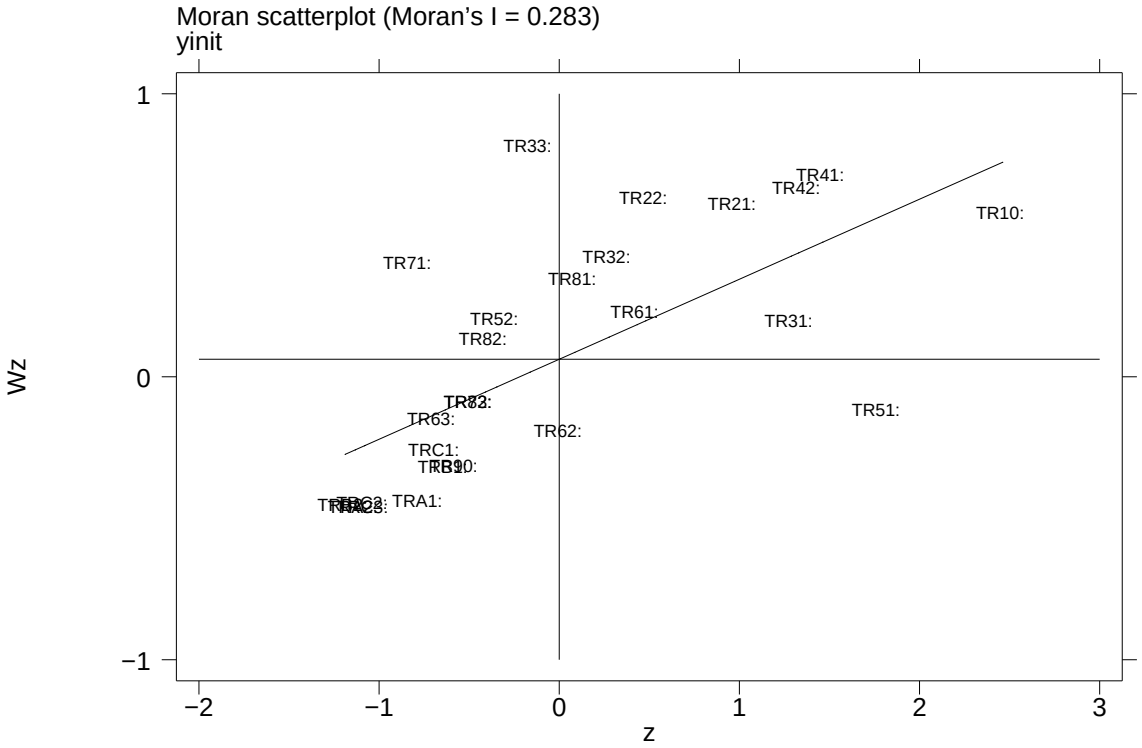


Figure A.2.
Moran scatterplot: Per capita GVA, 1999 (Moran's I: 0.332).

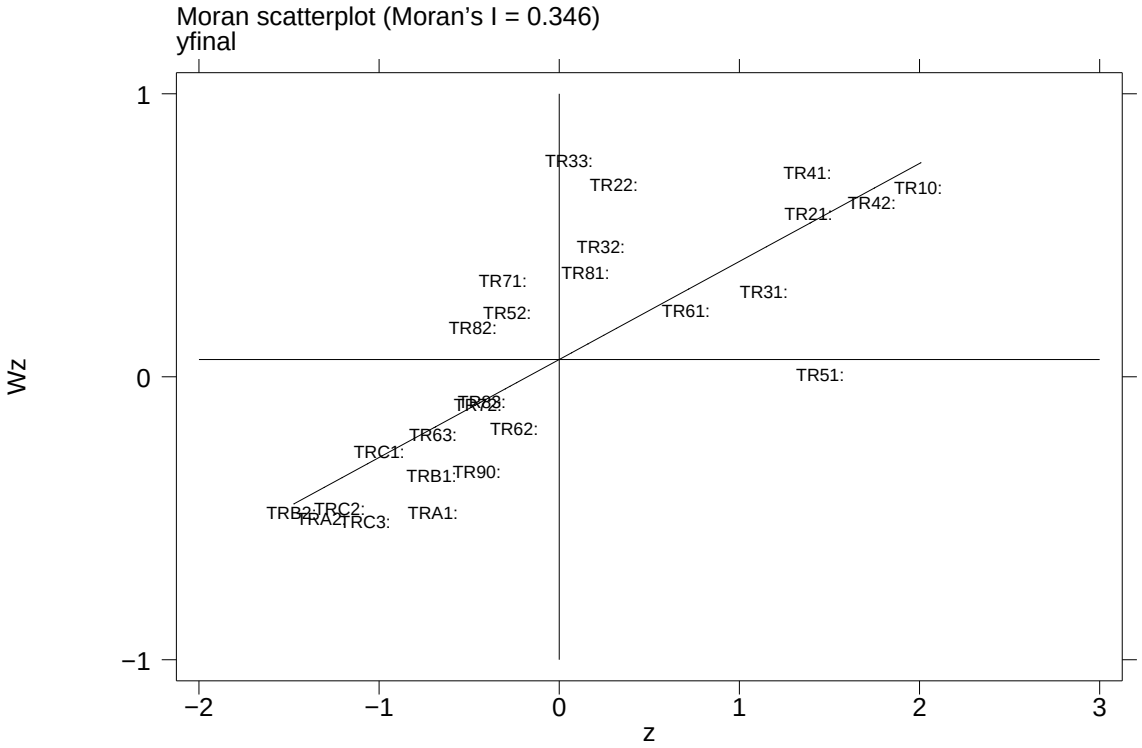


Figure A.3.
Moran scatterplot: Per capita GVA, 2011 (Moran's I: 0.353).

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